

THE ROLE OF GEODESY MEASUREMENTS IN THE FORECAST OF EARTHQUAKES

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Abstract. Earthquakes take one of the first place among other natural disasters for destructive results, the number of victims, material damage and human environment. The sudden revelation of earthquakes increases their destructive effects. The death of people is caused not only by the earthquake, but also by various secondary natural phenomena activated by the earthquake (creeping, subsidence, volcanoes, avalanches, etc.). Secondary man-made effects create great dangers (release of fires, explosions, radioactive and toxic materials). Very often, the primary damage and loss during the earthquakes is associated with secondary events. Properly organized precision geodetic work can greatly contribute to the complex solution of earthquake planning by providing information about the tectonic deformations of large areas of land resources without planning. At present, such information can be obtained both from the analysis of repeated measurements in the astronomical geodetic network, and based on the high-precision level network available in the territory of Azerbaijan, as well as from repeated measurement cycles in geodynamic polygons.

Keywords: types of earthquake, earthquake magnitude, earthquake forecasting, geodesy measurements

Introduction. Under the influence of tectonic forces generated during mobility in the lithosphere layer, sudden movements occur along fault lines in certain periods, and the vibrations caused by these sudden movements spread throughout the lithosphere and cause destructive earthquakes. It is not possible to predict or delay the earthquake with today's technology (Allen, 2003). It is known that the temperature increases to the depths of the earth. The forces formed in the asthenosphere, especially in the expense of convection currents, the stone peel is broken and divided into many "plates".

There are currently up to 10 large and many small plates. Together with the continents located on these plates, they move in the asthenosphere at a speed that cannot be felt by humans.

The borders where the plates rubbed each other, crossed each other and they go under each other are the places where the earthquakes occur in the world. The movement occurs when the fracture force is exceeded between the pushing slab and another plate. This action occurs in a very short time and is shocking. Finally, the earthquake waves are emerging until distances. At this time, territorial cracks, sometimes visible to the naked eye, stretching for kilometers and called faults are formed on the earth. These fractures are sometimes not visible on the ground and can be hidden by surface layers. It can also be noted that the two separate blocks formed as a result of breaking move to the right or left relative to each other which is an example of right- or left-lateral strike-slip faults. Sliding breaks have the potential to create high intensity (destructive) earthquakes (Balkaransingh 2001, Dempsey 2012). Most breakings may have both horizontal and vertical motion.

Types of earthquakes. There may be different types of reasons for earthquakes. Although most earthquakes (90% of the earthquakes) occur above (tectonic earthquakes), there are types of earthquakes that occur in small amounts of other natural reasons. Earthquakes resulting from the movement of the plates are usually described as tectonic earthquakes, and these earthquakes occur in the boundaries of more tiles (Fabrizio 2022).

Second type earthquakes are volcanic earthquakes. These are formed as a result of the eruption of volcanoes. It is known that such earthquakes occur by the explosion of gases formed as a result of physical and chemical events during the eruption of melted material in the depths of the earth. These earthquakes do not seriously damage because they are related to volcanoes. Some of the earthquakes in Japan and Italy belong to this group. Such earthquakes do not occur in Turkey, because there are no active volcanoes there (Bouchon 2002). In Azerbaijan, mainly mud volcanoes are the majority (more than 220 mud volcanoes). The biggest of them are Galmas, Toragay, Beyuk Kenizdag, etc. volcanoes. As a result of scientific research and studies, it has been learned that strong earthquakes with a magnitude of 4-5 or more cause the eruption of mud volcanoes, that means, if the center of the volcano is located in the same fault zone as the hypocenter of the earthquake or the distance between the earthquake and the volcano is within a radius of 70-80 km, then the earthquake will cause the volcano eruption (Kahraman 2017). In addition, during the "preparation" period of the earthquake, the activation of volcanoes and the high percentage of some chemical elements in the gas and mineral water that they release to the surface are monitored. This can tell us about the occurrence of the earthquake [1].

Another type of earthquakes are earthquakes caused by subsidence. They are formed as a result of the collapse of the ceiling block caused by melting in underground cavities (caves), coal mines, salt and gypsum areas. Meteorites from large shifts and meteorites falling from the sky are also known to cause small boosts (Shishikura 2003).

When an earthquake occurs, the following earthquake parameters can be viewed for its description and characteristics:

- Focus point (Hiposantr): The earthquake is the point where the energy is on the ground. This point is also called the centerpiece or the internal center. In fact, this is not the point, but an area where the energy has occurred, but is regarded as a point in practical applications.

- Foreign center (Episantr): It is the area where an earthquake causes the most damage and loss or is felt most strongly.

- Focus depth: The shortest distance from the ground to the point where the energy was separated from the ground is called the depth of the earthquake. Earthquakes can be classified according to the depth of focus. This classification is valid for tectonic earthquakes. Earthquakes occurring at a depth of 0-60 km are characterized as shallow earthquakes. Earthquakes at a depth of 70-300 km from the ground are earthquakes in medium-depth. Deep earthquakes are earthquakes at a depth of 300 km. Shallow earthquakes cause greater damage and loss.

- Farifier earthquake (Foreshock): They are small tremors (waves) that occur seconds, hours, or weeks before a larger earthquake or mainshock and occur at or near the rupture zone of a larger earthquake.

2.1. Wave types. "P" Wave: This is the first seismic wave to reach the receivers. Its speed varies between 1.5 and 8 km/s depending on the structure of the earth's crust. Movements of particles are in the direction of spreading (longitudinal wave) and destructive effects. Paves are pressure / initial waves (Pressure / Primary Waves), longitudinal or compression waves. Earthquake waves are mechanical waves and are the same as sound waves. Sound wave speed: in the air-330 m / s, in water-1450 m / s, iron-5000 m / s, granite-5000 m / s (5 kilometers per second) [2,3].

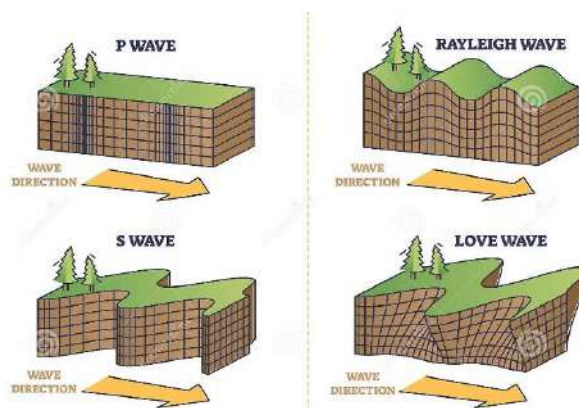


Figure 1. Wave Types [3]

"S" wave: Seismic wave that reaches the second to receivers. Its speed is from 60% to 70% of the speed of the "P" wave. The movement of particles is perpendicular or transverse (transverse wave) and destructive effects. The waves of waves consist of from the transverse waves (Shear Waves, Transverse Waves) and Surface Waves (Surface Waves, Rayleigh-Love) and are also known as secondary waves (Secondary Waves). Saves occur in solid environments. The amplitude of the waves of waves is much larger than the amplitudes of p waves. Surface waves are slower and longer term destructive waves in large amplitude. As Rayleigh and Love waves are divided into two places. Love waves move back and forth in the direction they travel (fig. 1). Rayleigh waves, on the other hand, are in circular motion, meaning that they move backward as the waves move forward (Ying Zhou 2022) [4,5].

2.2. Earthquake Severity and Magnitude.

The difference between magnitude and intensity is that magnitude is a measure of the energy released at the source of the earthquake; intensity is the measure of the impact of this earthquake on buildings and people.

The magnitude of the earthquake characterizes the intensity of the land shaking during the earthquake (sometimes the intensity of the earthquake"). The magnitude of the earthquake characterizes the overall energy

of the seismic vibrations of the earth's surface. The magnitude is defined as the logarithm of the maximum amplitude of the waves of the defined earthquake (Andrzej 2004).

The impact of the earthquake to the earth is determined as the severity of the earthquake. In other words, the violence of the earthquake is the size of its effects, nature and people.

Earthquake prediction by geodetic methods. Natural events, including earthquakes are also inevitable. They cannot be avoided, but it is possible and important to reduce their destructive effect. For this, it is necessary to know the causes of earthquakes, to study the processes related to their formation and occurrence, and to develop methods for predicting these events. The forecast of the earthquake is understood to determine the location, time and strength of the earthquake. According to the time, the forecast is divided into long-term (for decades ahead), medium-term (years ahead), short-term (months-months ahead) and operational (minutes-hours ahead). It should be noted that this division is quite conditional. Each stage of the forecast is based on a certain set of data, that is, geophysical phenomena that precede and inform the earthquake [6-8].

We can list the contribution and responsibilities to earthquake research as follows (Prawirodirdjo 2010, Riguzzi 2012): In previous research:

- Collection of three-dimensional (3D) territorial information with high-precision and detection of changes in the area over time;
- Development and update of breaking (Fay) maps;
- Determination of geodynamic events (polar mobility, the speed of rotation of the earth);
- Determination of the gravitational area of the earth;
- Study of volcanic activities, tiles tectonics and movements of the earth crust;
- Connection of various sources (geodetic, geological, geophysical, seismic, etc.) in the geographical information system. This research is determined and necessary to implement the correct solutions in long-term research (shelter, repair, etc.) to provide effective and rapid intervention (transport, communications, rescue, etc.), immediately after the earthquake.
- In post- earthquake research:
- research on damage and damage;
- Determination of deformations of engineering structures such as roads, bridges, dams and buildings;
- repair and strengthening damaged structures, restructuring if necessary;
- Repair of damaged geodetic infrastructure;
- The use of this model in possible cadastral work to create a deformation model of Earth and earthquake.

The exact concern is the important practical problem, as well as the establishment of a number of scientific tasks in the whole area of the country, as well as the identification of the earth's figure with the gravimetric data, determining the differences between the seas and the oceans.

Recurring high-precision geodetic measurements allow the movement of continental slabs in the upper mantle of the Earth, the movements of the ground crust, the global and regional tectonic processes expressed in large-scale dimensions of the earth. According to the results of re-geodetic measurements, the Earth's crust has always been exposed to deformation processes (Feigl 2006, Okamoto 2002). Geodesy measurements help determine the degree of activity of separate tectonic breakers, which is important for seismic zoning of the regions.

The analysis of the results of repeated geodetic measurements allows to study the nature of the deformation of the earth's surface, which is the extraction of minerals from the depths of the Earth or the construction of complex engineering structures, the creation of water reservoirs, canals, etc. It occurs as a result of tectonic and man-made activity as a result of human intervention [8].

At present, the method of high-precision geometric leveling, based on the results of systematic repeated measurements, is widely used to detect vertical movements of the Earth's crust. The high-precision geodetic base of our country consists of I, II, III and IV classrooms. The length of the first-scale nuclear lines, which organized a high-precision speech network of polygons, about 600-800 km, and the length of the II classrooms is about 500-600 km. The network of warehouses complies with the requirements and recommendations of the International Geodetic Association in terms of measurement, uniformity and violence. The forecast of earthquakes with the geodetic measurement method has been repeatedly confirmed. For example, before the earthquake, I leveling was carried out on the line for 2 months, immediately after the earthquake, re-leveling was carried out and it was found that the earthquake process raised the area by 1.2 m. Modern vertical movement rates of the Earth's crust (mm/year) are calculated by the following formula:

$$\Delta V = (h_1 - h_2) / \Delta T, \quad (1)$$

$$\Delta T = T_2 - T_1$$

Here, in h_2 and h_1 - in T_2 and T_1 (years) are excessive between adjacent level signs (mm/year). ΔT is the time interval between repeated measurements (for years).

Despite the development of technology, it is impossible to control the tectonic plate and blocks. However, through GPS stations, it is possible to identify risky areas by observing their direction of movement and changes over the years. At present, there are 32 GPS stations that observe the main tectonic blocks in Azerbaijan. However, taking into account the active fault zones and the movement of blocks, the number of GPS stations needs to be increased by 2-3 times. (Delouis 2010).

According to the results of numerous geodesy measurements, it was determined that the largest mobility in Azerbaijan is observed in the southern block (about 13 millimeters a year) (fig. 2).

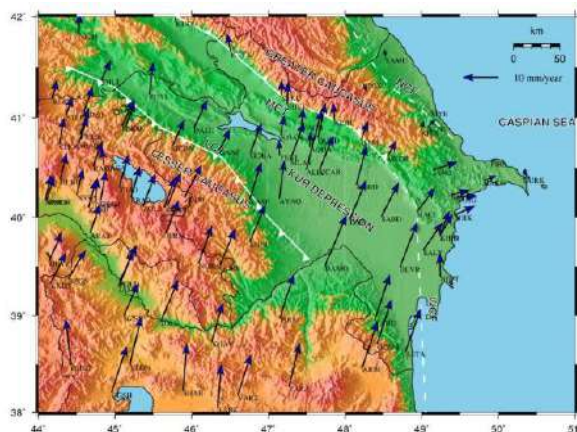


Figure 2. Mobility of tectonic blocks over the years [8]

Azerbaijan is considered as an "earthquake zone" because of a seismological point of view at the intersection of Arabia and Eurasian tectonic tiles. Earthquakes registered in Azerbaijan are mainly due to the flood of tectonic plates and blocks. However, earthquake risks also arise as an anthropological - that is the result of human activities. Anthropological impacts include deep development of oil and gas fields, drilling oil wells, as well as non-professional development of groundwater and reservoirs and other factors. There are 5 active zones in Azerbaijan (fig. 3) [9]:

- Southern slope of the Greater Caucasus Mountains (Shamakhi, Ismayilli, Gabala, Sheki, Zagatala zone)
- The northern slab of the Lesser Caucasus Mountains (Karabakh, Mingachevir, Ganja, Shamkir zone)
- Talysh mountains area
- Guba- Khachmaz region
- Caspian Sea

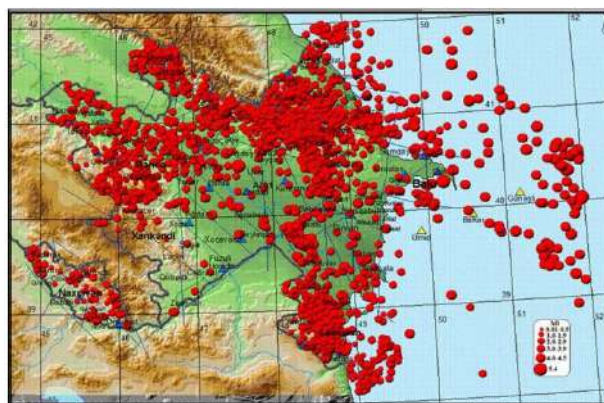


Figure 3. Seismic active areas in Azerbaijan [9]

Terrible earthquakes have happened many times in Azerbaijan at different times. The 10 largest earthquakes in Azerbaijan according to their magnitude:

1. Ganja earthquake– in 1139 magnitude of 6.3. As a result of a strong shock, the Kepaz mountain flew and blocked the Agsu river, and Goygol, Maralgol, Jeyrangol, Ordekgol, Zalugolu, Akgol, Karagol and Shamlıgol were formed. According to some sources, 230 thousand and according to another sources 300 thousand people died.
2. Shamakhi earthquake– in 1667 magnitude of 6.9. 80 thousand people died as a result of the earthquake. This earthquake is considered as the most terrible earthquake in the history of Azerbaijan.
3. Shamakhi earthquake– in 1669 magnitude of 5.7. As a result of the earthquake 7,000 people died.
4. Shamakhi earthquake– in 1828 magnitude of 5.7. There is no information about the dead and injured.
5. Shamakhi - in 1859 magnitude of 5.9. As a result of the earthquake, the city of Shamakhi was completely destroyed, so the center of Shamakhi Governorate was moved to Baku and the name of the governorate was also updated - Baku Governorate. 100 people died as a result of the earthquake. The power of this earthquake was so great that after this the expression of "As Shamakhi sank" was born.
6. Shamakhi earthquake– in 1872 magnitude of 5.7. The earthquake caused destruction in the city.
7. Shamakhi earthquake– in 1902 magnitude of 6.9. During the earthquake, more than 2,000 people were killed and thousands were injured, and up to 20,000 people were left homeless, at the same time 4,000 residential houses, 8 ancient mosques, 40 ancient eastern baths, bazaar, shops were destroyed.
8. Agdash– in 1999 magnitude of 5.4. Although there were no losses of the earthquake, more than 100 houses were destroyed, and many houses were damaged.
9. Baku– in 2000 magnitude of 6.8. As a result of the earthquake, dozens of buildings were destroyed and 30 people died.
10. Zagatala earthquake- in 2012 magnitude of 5.6. There were damage to the buildings, but no human casualties.

Conclusions. Natural events, including earthquakes, are inevitable. They cannot be avoided, but it is possible and important to reduce their destructive effect. For this, it is necessary to know the causes of earthquakes, to study the processes related to their formation and occurrence, and to develop methods for predicting these events.

It is known that since the arising of the world, earthquakes have consistently occurred in seismically active regions, resulting the death of millions of people and the destruction of buildings. As there were many devastating earthquakes in our country in the past, as a result of future earthquakes, it is a fact that we will experience large life and losses.

A practically significant forecast is a forecast that reliably answers three questions, namely, the source of the upcoming earthquake; determination of the maximum power that this earthquake source can generate; it is intended to determine the moment of the earthquake.

Accordingly, the capabilities of modern forecasting systems: the accuracy of the location of the expected earthquake is hundreds of kilometers, the possible energy is in six magnitudes, and the time is in years. It is quite clear that such a prediction has no practical significance.

The uncertainty in assessing the seismic hazard of different parts of the Earth's surface is caused by the lack of sufficient seismotectonic materials. However, the determination of the initial seismic score is possible under the conditions of seismological monitoring and topogeodetic studies. Reliable information on the seismic threat of a particular area will reduce construction costs, ensure the safety of the population and ensure the operation of enterprises and facilities and significantly reduces the costs of restoration. The study of various actions and deformations in the Earth's crust requires high-precision geodetic measurements of geodynamic landfills in monitoring regime - geodynamic landfills. Serious requirements for conducting such geodetic works include large areas covered by measurements, high level of accuracy in determining displacement and deformation values, short periods between a number of instrumental measurements, all this determines the need to use modern high-precision and productive geodetic equipment when conducting research.

In parallel with the development of technology, geodetic research for geodynamic purposes is increasing all over the world:

- Geodetic networks should be planned in the most appropriate way, allowing to study time-dependent changes and long-term movements in the earth's crust;
- There is a need for long-term information obtained from extensive areas on the ground surface with various measurements to learn more about earthquakes;

- An earthquake-oriented "geographical information system" should be created to develop right solutions after an earthquake;
- Information from multidisciplinary studies must be evaluated together in order to understand the earthquake mechanism.

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