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Comprehensive Studies of Seismic Forecast and Seismic Hazard Assessment in Armenia, Current State and Prospects

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The study of geophysical processes in different layers of the Earth, seismic hazard assessment, earthquake prediction, etc. are topical fundamental and applied problems. The development of a modern adequate methodology for assessing seismic hazards, operational forecasting of earthquakes, and the study of the geodynamic regime of the region are important and interrelated tasks of one common problem: protecting people's lives and their property from destructive earthquakes. It is obvious that this problem is of great socio-economic importance for the Republic of Armenia and other countries located in seismically active regions (Dzeboev et al., 2019; Li et al., 2019; Ismail-Zadeh et al., 2020; Karapetyan et al., 2020).

The territory of the Republic of Armenia belongs to the tectonically active and earthquake prone zone of the Caucasus. This is expressed in modern slow creep movements of the earth's surface and fast seismogenic movements along faults and in their intersection nodes. Throughout history, several catastrophic earthquakes occurred in Armenia, including historical ones - Garni, 1679; Cilicia, 1268, etc. On 7 December 1988, near the city of Spitak, an earthquake occurred (M = 7.0, J = 9−10 points), which killed about 25 thousand people. Tectonics is probably the most multifaceted and hard access for geophysicists and geologists of all the existing fields of Earth Sciences. Most likely, this is the reason for the enormous scientific interest that has existed in this science for decades. The relevance of explorations in the field of tectonics and seismicity is especially growing when it comes to geodynamically active regions of the Earth. One of such territories is Armenia, occupying the southern part of the Lesser Caucasus, located on the north-eastern peripheral zone of the Armenian Highlands. The territory of Armenia is located in the collision zone between the Arabian (from the south) and Eurasian (from the north) lithospheric plates. This territory for millions of years experiences the full power of this phenomenon in the form of dynamic crustal movements and frequent strong earthquakes. This is the reason for the great scientific interest in tectonics and seismotectonics in this region (Karapetyan et al., 2020).

A substantial number of studies conducted by Paffengoltz, Vardanyants, Milanovsky, Gabrielyan, Aslanyan, Sargsyan, Simonyan and others is devoted to this problem. As a result, tectonic schemes of Armenia with the identification of the main fault formations were developed, tectonic units of the territory were identified, geotectonic zoning was conducted, etc. The geotectonic zoning scheme of Armenia (Gabrielyan, 1974) was widely used at that time and a large number of seismotectonic problems were solved on its basis. A review (Gabrielyan et al., 1981) of strong historical earthquakes from a structural -tectonic position is made. However, it is known that each geotectonic zone of Armenia has its own internal complex block structure, and, therefore, the interpretation of seismic activity at this level is largely generalized, which makes it impossible to examine in more detail the patterns of seismic activity within the geotectonic zones themselves. The research results were subsequently systematized in Gabrielyan et al. (1981). Based on this map in 2015, the first large-scale (1:200 000) tectonic map of the territory of Armenia was compiled (Sarkisyan and Shakhbekyan, 2015).

Taking into account the above-mentioned this circumstance determines the urgency of the tasks regarding the establishment of possible seismic sources (hereinafter referred to as PSS) of strong earthquakes and the assessment of the seismotectonic potential of the main seismogenic zones of Armenia. Despite the high seismic activity in Armenia, there is a limited number of works devoted to the identification of strong earthquakes PSS. Superiority among them belongs to the work (Gabrielyan and Piruzyan, 1972), where the authors first put forward the most important idea of the spatial confinement of strong and weak earthquakes to certain structural-tectonic zones.

A number of works on the establishment of PSS and the seismotectonic potential assessment were carried out in the Institute of Geophysics and Engineering Seismology of the National Academy of Sciences of Armenia Republic of Armenia. Among them, one can note the work (Hovhannisyan et al., 2008; Gasparyan et al., 2019). In these works, the concept of a seismically active stratum and its block structure was first put forward. According to this study, the seismically active stratum includes the top most part of the earth's crust in the territory of Armenia, with an average thickness of 20 km, in which the main part of the recorded earthquakes sources are concentrated.

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Further, the authors conducted gravity modeling in order to identify the block structure of the seismically active stratum. For this purpose, in relation to a conventionally accepted surface (20 km deep), the authors distinguish a number of blocks, some of which are downthrown, and the other part is up thrown (Fig. 1).This map reflects the main tectonic structures (Fig. 1).

Summing up the above, it should be noted that there are many contradictions in the results of tectonic studies in Armenia. In this regard, the first priority should be the compilation of a reasonable and accurate map of the tectonic structure of the territory, with the identification of block structures and active faults. When drawing up this scheme, all existing geological and geophysical materials and tectonic schemes should be taken into account, as well as modern geographic information technologies and Earth remote sensing materials should be applied.

In the field of seismological research, it is necessary to emphasize the importance of applying the most accurate seismological data to obtain reliable results in connection with the study of the confinement of earthquake focuses to certain tectonic structures and the study of the deep structure.

Based on the solution of the aforementioned problems in the fields of tectonics and seismology, which are essentially of primary importance, new prospects will open up for studying the seismotectonic problems of Armenia using a modern methodological approach and reliable data.

Thus, the most urgent tasks are the following - the study of spatial seismicity patterns, a comprehensive assessment of the tectonic activity of blocks, the identification of focal zones of strong earthquakes, the study of the stress-strain state of the earth's crust, assessment of the seismotectonic potential and seismic hazard.

To solve the above problems, it is necessary to improve the quality and quantity of mass observations by equipping observational seismometric and geodynamic stations with new-generation devices, as well as the need for monitoring (registration and analysis of earthquakes, micro-earthquakes, etc.) in urbanized territories, especially critical facilities, buildings and structures new knowledge in the field of physics of the Earth, as well as the transition to the use of modern methods and approaches of mathematical geophysics (including discrete mathematical analysis, modern methods and algorithms for image recognition, modern artificial intelligence tools, geoinformatics) (Dzeboev et al., 2020; Karapetyan et al., 2020).

For the implementation of the outlined promising, fundamental, scientific programs on the basis of the intergovernmental memorandum of cooperation between the People's Republic of China and the Republic of Armenia (China Earthquake Administration and Science Committee, Ministry of Education, Science, Culture and Sports RA) in the field of earthquake monitoring, a Chinese-Armenian international laboratory was established "Earthquake Monitoring and Simulation".

At the first stage of joint work throughout Armenia in 2019 by the Institute of Geophysics, China Earthquake Administration and the Institute of Geophysics and Engineering Seismology named after A. Nazarov National Academy of Sciences of the Republic of Armenia, a study of the level of seismic and geodynamic interference was carried out in order to identify the most favorable areas for the organization of joint complex (seismic, geodynamic, geophysical) seismic forecast stationary observation stations (Li et al., 2019).

The field survey work mainly includes two parts: the field survey on the candidate sites and the field test of the background noise of ground motion and GNSS signal strength, of which the field survey is to be conducted to understand the factors of vehicle accessibility, weather

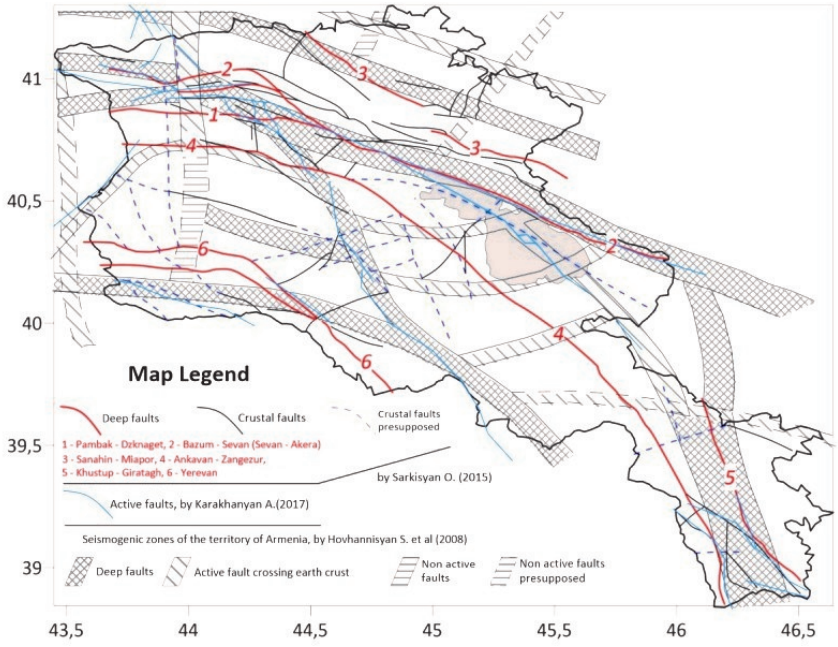

Fig. 1. Fault scheme in the territory of Armenia according to the data of geological and geophysical explorations (Karapetyan et al., 2020).

conditions, power supply conditions, and safety of the candidate sites and the field test through the equipment is to be performed to quantitatively measure the background noise level of ground motion and the blind spots of GNSS signals caused by terrain, based on which the feasibility of candidate sites as the actual sites is to be comprehensively assessed.

The site survey of the seismic network was conducted by the Institute of Geophysics, CEA and the Institute of Geophysics and Engineering Seismology after A. Nazarov (IGES) during Dec. 2–23, 2019.Finally, both Chinese and Armenian sides determined to set up 8 stations in the territory of Armenia, listed as following.

According to the project design of the "Belt & Road" Seismic Monitoring Networks, 8 observation stations are planned to be built within the territory of Armenia, for which the site survey was performed at 13 point locations, of which the instrument test was conducted at 9 point locations (Table 1).

The test data from the background ambient noise of ground motion was processed by Cal79_20170308C_ win64_user software provided by Beijing Gangzhen Mechanical & Electrical Technology Co., Ltd. to calculate the power spectral density (PSD) and root mean square (RMS) of the station-based environmental noise. The average ambient and ground -motion noise levels (1-20Hz, RMS value) within 24 hours of each survey point tested by the instrument are as follows (Table 2):

The Convert To Rinex software was first used to process the GNSS test data to convert the original GNSS data into the data in Rinex2.11 format, and then the TEQC software was used to perform statistical calculations on the observation data at an altitude angle more than10°, that is, to calculate the effective data size of the data, mp1 and mp2 (which are L1 and L2 pseudo-range multipath effects, respectively. The key parameters of each survey site for 24 hours are as follows (Table 1).

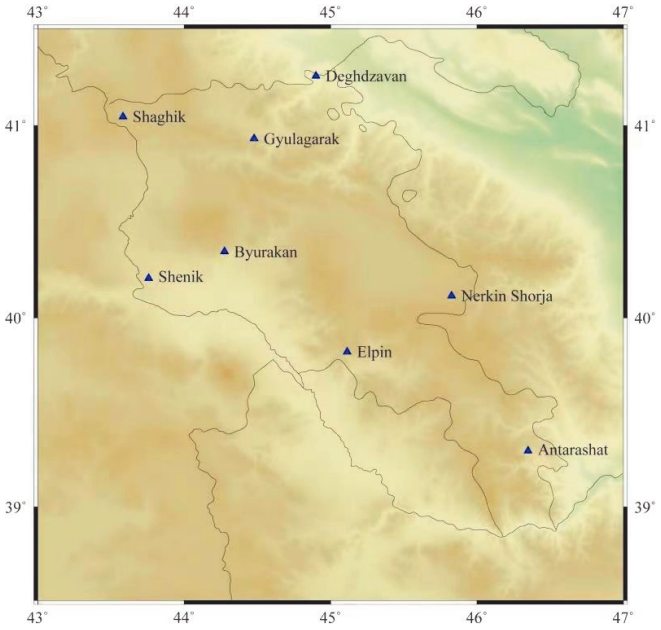

Fig. 2. Geographical map of the point locations of site survey.

The network contains 8stations and 1 datacenter (Fig. 2), which will provide real-time earthquake recordings and fast location information after a M2.5 earthquake in Armenia (Fig. 3).

Based on the data received from the stations, continuous monitoring of seismic and geophysical fields will be carried out in order to identify various anomalous manifestations of geophysical fields which might precede the preparation and implementation of possible strong earthquakes in the territory of Armenia.

In the field of seismic hazard assessment of the territory of Armenia, a three-dimensional structurally dynamic model of the Earth crust is being developed. Assessment of the seismic potentials of individual elements of this structural model is envisaged. On the basis of instrumental data of strong movements registered in the territory of Armenia, we consider the possibility of developing a real model of seismic impacts.

On the basis of the scientific program formed in the scientific laboratory for the implementation of joint research, fundamentally new physical and mathematical models will be developed and tested, mathematical algorithms for operational earthquake prediction and seismic hazard assessment will be built using image recognition methods and modern artificial intelligence tools.

The solution will allow us to develop physical bases for

Table 1 Results of the key parameters within 24 hours for GNSS observation at the survey site

Code of survey point	Effective data size	mp1 (m)	mp2 (m)
SHA	100%	0.25	0.24
BYUR	100%	0.26	0.24
SHNK	100%	0.23	0.22
ELP	95%	0.32	0.32
ELPN	99%	0.26	0.24
NRSH	96%	0.26	0.23
ATSH	95%	0.26	0.24
DZVN	99%	0.29	0.25
GYRK	84%	0.63	0.64

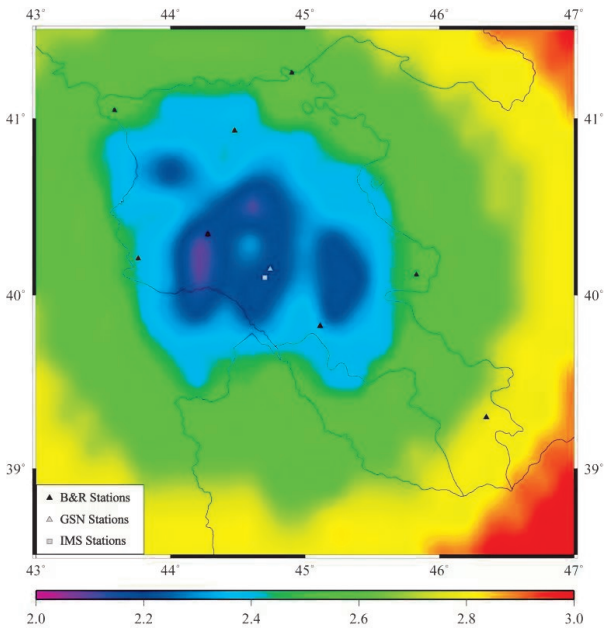

Fig. 3. The assessment of significance of minimum magnitude earthquakes for different regions of the territory of Armenia.

Table 2 The average ambient and ground-motion noise levels within 24 hours of survey points

Code of survey point	Noise level in U-D direction (m/s)	Noise level in N–S direction (m/s)	Noise level in E–W direction (m/s)	Noise level evaluation （GB/T 19531.1-2004）
Shaghik (SHA)	3.39E-08	8.35E-08	7.30E-08	Class II station base
Byurakan (BUR)	6.61E-08	9.97E-08	8.44E-08	Class II station base
Shenik (SNK)	7.99E-08	3.67E-08	4.69E-08	Class II station base
Elpin (ELP)	1.90E-08	4.75E-08	6.93E-08	Class I station base
Elpin (ELPN)	1.21E-07	2.52E-07	2.38E-07	Class III station base
Nerkin Shorja (NRS)	2.47E-08	5.07E-08	6.90E-08	ClassIstation base
Antarashat (ATS)	2.06E-08	3.43E-08	5.95E-08	Class I station base
Deghdzavan (DVN)	5.20E-08	6.77E-08	6.65E-08	Clas II station base
Gyulagarak (GRK)	2.16E-08	4.19E-08	3.99E-08	Class I station base

the creation of technologies and systems to prevent extreme and emergency situations both natural and man-made.

Key words: seismic hazard assessment, earthquake prediction, earthquake monitoring, Earth crust

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