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SEISMIC MONITORING SYSTEM, METHODS AND TECHNOLOGIES

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ANNOTATION

The article describes the seismic monitoring system in Azerbaijan and surrounding regions, using BRTT Antelope software. In the period from 2003 to 2023, the main attention of the Republican Seismic Survey Center (RSSC), along with monitoring geodynamic processes on the territory of the republic and adjacent regions, was aimed at expanding the network, as well as developing and modernizing methods and means for organizing observations, collecting, data processing and analysis.

As a result, a wide network of telemetry stations was created, equipped with the most modern instruments for recording earth vibrations in real time. A storage system for seismological and geodetic (GPS) data was organized, high-speed access to the data archive was provided, high-performance computing clusters were deployed, and all seismic stations were connected into a single network. Work is being carried out and continues to introduce innovative technologies and master world experience in monitoring the parameters of the seismic regime on the territory of the republic.

In 2003–2023 the seismic monitoring system in Azerbaijan allowed to process and analyze all recorded local, regional, remote tectonic earthquakes, industrial explosions, volcanic eruptions, as well as conduct comprehensive studies for seismic records.

Key words: seismic monitoring, software, magnitude, trigger.

SEYSMIK MONITORINQ SISTEMI, ÜSULLARI VƏ TEXNOLOGIYALARI

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ANNOTASIYA

Məqalədə Azərbaycanda və ətraf bölgələrdə BRTT Antelope proqram təminatından istifadə edərək seysmik monitorinq sistemi təsvir edilmişdir.

2003-cü ildən 2023-cü ilə qədər Respublika Seysmik Xidmət Mərkəzinin (RSXM) əsas diqqəti respublika ərazisində və qonşu bölgələrdə geodinamik proseslərin monitorinqi ilə yanaşı, şəbəkənin genişləndirilməsinə, məlumatların toplanması, emalı və təhlili, müşahidələrin təşkili üsul və vasitələrinin hazırlanması və modernləşdirilməsinə diqqət yönəldilmişdir.

Nəticədə real vaxtda yer titrəmələri qeydə alınması üçün ən müasir cihazlarla təchiz olunmuş geniş telemetrik stansiyalar şəbəkəsi yaradılmışdır. Seysmoloji və geodeziya (GPS) məlumatlarının saxlanması sistemi təşkil olunub, məlumatlar arxivinə yüksək sürətli giriş təmin edilib, yüksək məhsuldar hesablama klasterləri yerləşdirilib, bütün seysmik stansiyalar vahid şəbəkəyə birləşdirilib. Innovativ texnologiyaların tətbiqi və dünya təcrübəsinin mənimsənilməsi istiqamətində işlər aparılir və davam etdirilir.

2003-2023-cü illərdə Azərbaycanda yaranmış seysmik monitorinq sistemi qeydə alınmış bütün yerli, regional, uzaq tektonik zəlzələləri, sənaye partlayışlarını, vulkan püskürmələrini emal və təhlil etməyə, habelə seysmik qeydlər üzrə kompleks tədqiqatlar aparmağa imkan vermişdir.

Açar sözlər: seysmik monitorinq, proqram təminatı, miqyas, triqqer.

СИСТЕМА СЕЙСМИЧЕСКОГО МОНИТОРИНГА, МЕТОДЫ И ТЕХНОЛОГИИ

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АННОТАЦИЯ

В статье описана система сейсмического мониторинга в Азербайджане и прилегающих регионах с использованием программного обеспечения BRTT Antelope. В период с 2003 по 2023 год основное внимание Республиканского Центра Сейсмической Службы (РЦСС), наряду с мониторингом геодинамических процессов на территории республики и сопредельных регионов,

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было направлено на расширение сети, а также разработку и модернизацию методов и средств организации наблюдений, сбора, обработки и анализа данных.

В результате была создана широкая сеть телеметрических станций, оснащенных самыми современными приборами для регистрации колебаний земли в реальном времени. Была организована система хранения сейсмолого-геодезических (GPS) данных, обеспечен высокоскоростной доступ к архиву данных, развернуты высокопроизводительные вычислительные кластеры, все сейсмические станции объединены в единую сеть. Ведутся и продолжаются работы по внедрению инновационных технологий и освоению мирового опыта мониторинга параметров сейсмического режима на территории республики.

В 2003–2023 годах система сейсмического мониторинга в Азербайджане позволила обработать и проанализировать все зафиксированные локальные, региональные, отдаленные тектонические землетрясения, промышленные взрывы, извержения вулканов, а также провести комплексные исследования сейсмических записей.

Ключевые слова: сейсмический мониторинг, программное обеспечение, магнитуда, триггер.

Introduction

The ability to reduce the impact of earthquakes on society depends on the availability of large quantities of high-quality observational data. The development of the seismic network and advanced data acquisition system over the past few years is essential to achieving this goal. Modernization of the system for collecting, processing and storing seismological information in Azerbaijan began in 2003 and was carried out simultaneously with the expansion of the network of seismic stations. In this case, the main attention was paid to telecommunications and storage of data at the stations themselves in case of accidental loss of communication with the Earthquake Research Center located in Baku, with the possibility of subsequent reading of information upon request from the information processing center. Work was carried out to clarify the velocity characteristics of the earth's crust and upper mantle on the territory of Azerbaijan and adjacent regions with the assistance of specialists from the relevant services. Since 2003, digital recording of seismic information has been introduced and since that time, processing of seismological data has become possible in real time. Digital recording of seismological data has made it possible to put into practice the processing and interpretation of this data, using the capabilities of the latest computer systems. This in turn led to the development and implementation of methodological and software tools for processing information in an automated manner. As a result, a system for monitoring seismicity on the territory of the republic was created on-line, meeting all the necessary requirements for uninterrupted and efficient operation.

Seismic network expansion, data transmission

In 2003, the Republican Seismic Survey Center (RSSC) of the Azerbaijan National Academy of Sciences (ANAS) began reconstruction of the seismic monitoring system in the republic. The first 14 seismic telemetry stations were purchased from Kinemetrics (USA), which were installed in seismically active zones. To expand complex seismological and geophysical research, from 2008 to 2013, under the leadership of the General Director of the RSSC, corresponding member of ANAS, Honoured Scientist, Doctor of Geological and Mineralogical Sciences, Professor Gurban Jalal oglu Yetirmishli, the seismic network of the republic was expanded, the total number of digital seismic stations reached 35. Then work continued to expand the seismic network. To study the deep processes of the Absheron Peninsula, a network of ten Kinemetrics Basalt accelerographs was installed, recording strong ground vibrations. In 2017, as part of the international project “Caucasian Transect”, together with the University of Missouri (USA) and the Science and Technology Center in Ukraine, 17 new seismic stations were installed in the transition zone of the Kura Basin and the Greater Caucasus. In 2021, as part of another international project “Expansion of the seismic network in the Caucasus and Central Asia”, another 22 new seismic stations produced by Nanometrics (Canada) were installed on the territory of Azerbaijan. Of these, 12 stations are located near volcanoes, which allows continuous monitoring of volcanic activity in real time.

Currently, the seismic network of Azerbaijan consists of 84 seismic stations (Fig.1).

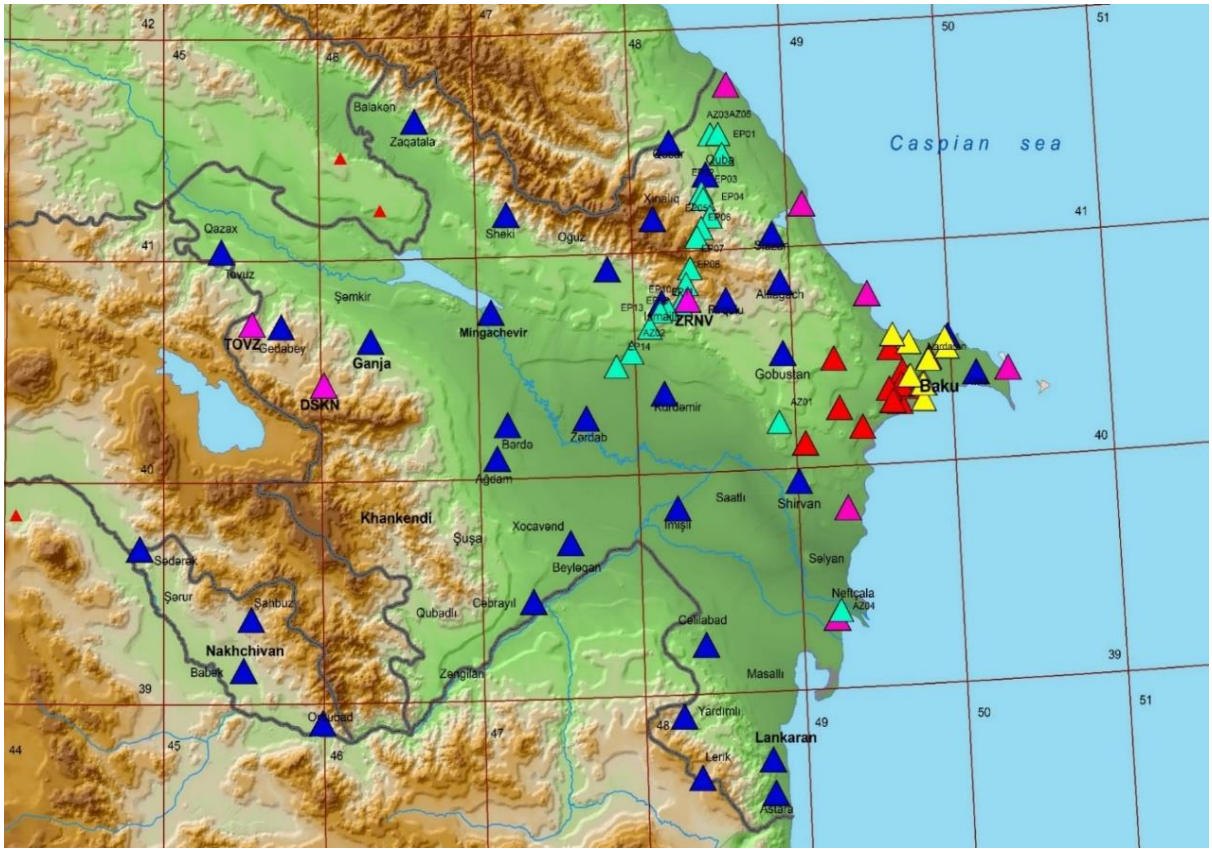

Figure 1. Seismic station location map.

▲ *- the Kinemetric's stations* ; ▲ *-"Caucasian Transect" project stations*;

▲ *- accelerometer "Basalt"* ; ▲▲ *- "Expansion of the seismic network in the Caucasus and Central Asia" project stations.*

All data from seismic stations is transmitted via satellite in real time and integrated into a system using BRTT Antelope software from Boulder Real-Time Technologies (BRTT), which provides data acquisition, automatic location determination, data archiving and a warning system through a short-wave service. messages (SMS), e-mail, fax and Internet. The main purpose of the real-time seismic network is to provide earthquake parameters from broadband stations with a large dynamic range for faster and more accurate determination of earthquake location and magnitude. And also, in case of strong earthquakes, quickly report the parameters of the event to the necessary decision-making bodies. Research conducted on the basis of earthquake catalogues and bulletins makes it possible to identify seismic active zones.

Using Antelope's Seedlink connection, data is exchanged with neighbouring countries; Türkiye (2 stations) and Georgia (3 stations). Real-time data exchange increases the number of stations, and now real-time data from all these stations is used to more accurately determine the location of regional seismic events. Seismic monitoring is carried out uninterruptedly with information transmitted via satellite communication channels (Fig. 2).

Information about earthquakes with a magnitude of 3.0 and higher is promptly posted on the website www.seismology.az and also sent to all decision-making bodies, as well as to the Ministry of Emergency Situations.

Technological capabilities of the ARTS collection and processing system

Antelope Real Time System (ARTS) is a software package running on the UNIX operating system (MacOSX, Linux). ARTS provides multi-dimensional array management, including real-time data acquisition from field digitizers (s/stations), interactive control of field equipment, system health

monitoring, automatic real-time data processing (detection, data processing, seismic event correlation, seismic event location, archiving) (Fig.3).

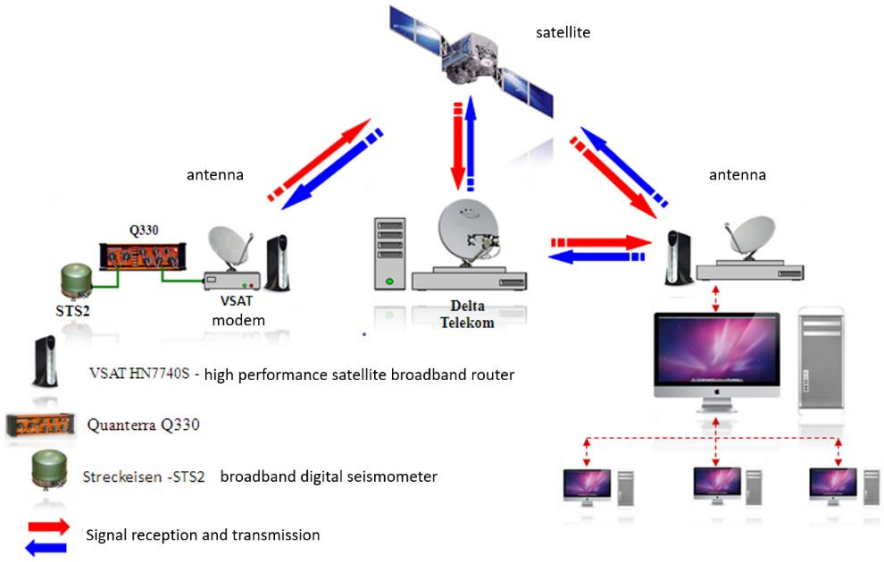

Figure 2. Scheme of data transmission via satellite channels from seismic stations in real time to the Earthquake Research Bureau of the RSSC

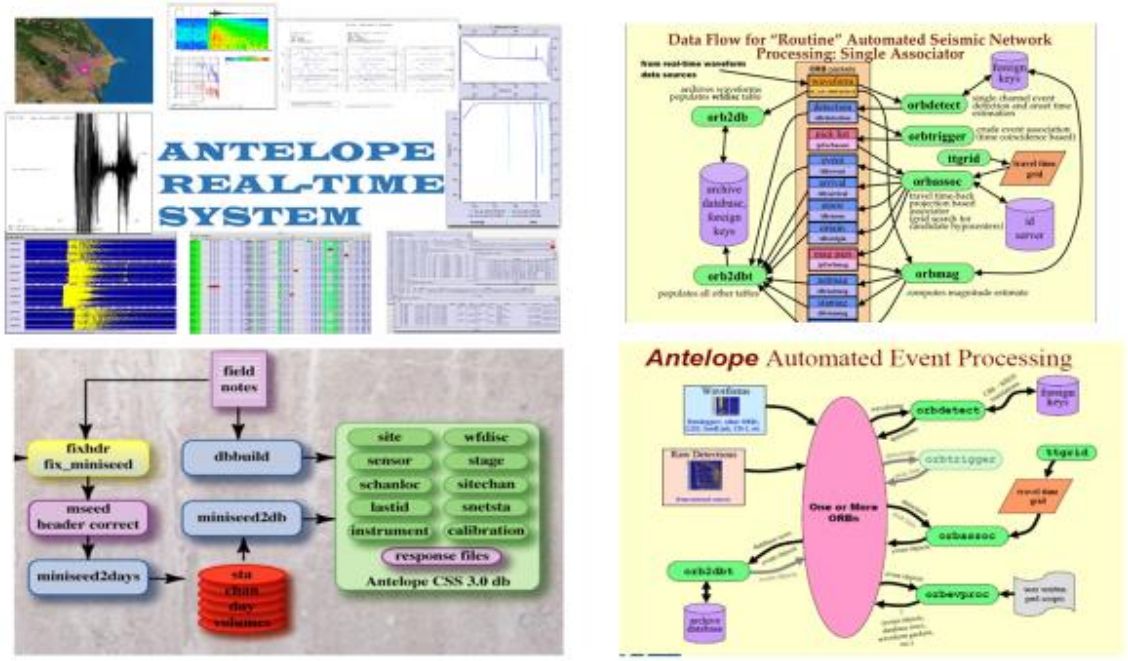

Figure 3. Functional diagram of Antelope Real-Time System

ARTS is constantly updated and we are currently using one of the newest versions, Antelope 5.6. This system supports all types of telemetry using either standard full-duplex serial interfaces or standard TCP/IP protocol over multiple physical interfaces. In addition to data acquisition, seismic network functionality includes automatic real-time event detection, phase extraction, seismic event correlation and location, archiving, system health monitoring, interactive control of remote stations, automatic distribution of raw data and processed data, processing seismic data arrays in batch mode and

powerful development tools for system configuration. It can process continuous data based on event files and uses a form of relational database management and CSS v3.0 scheme for the resulting information.

Data collection and processing

All seismic material received from seismic stations via satellite communication to the Earthquake Research Bureau of the Seismological Center located in Baku is processed on the basis of an individual program included in ARTS. This is the *dbloc2* program which is used to handle all earthquakes such as local, regional and remote earthquakes. The high sensitivity of seismometers installed at seismic stations makes it possible to record all vibrations of the earth's surface, including the weakest. These include weak earthquakes, industrial and nuclear explosions, volcanic eruptions, and landslides. Satellite communications make it possible to receive information about seismic events in real time, process them and, in a very short time (several minutes), determine all the parameters of earthquakes (coordinate, source depth, moment of wave entry, mechanism, etc.). Interactive online communication allows seismic stations located in various regions of the republic to monitor their technical condition, temperature conditions and other characteristics of the equipment, as well as, if necessary, carry out calibration and alignment of records.

In ARTS, data is buffered and transferred using a mechanism known as an Object Ring Buffer (ORB), which acts as the core of ARTS. Each ORB is controlled by one *orbserver* program, the interface of which is described in the configuration parameter library (PF). Interface modules record all data from field stations into one or more ORBs, which can also be used to send commands to field interface modules and on to remote digitizers.

Automatic processing of seismic networks is performed using ORB programs: *orbdetect, orb2db, orbtrigger, orbassoc, orbmag*. Multi-frequency *STA/LTA (Short Time Average over Long Time Average)* detection and recording start time estimation are performed using *orbdetect*, which reads real-time waveform data from the data processing ORB and writes detection status information for each channel and frequency band.

The *orb2db* program reads data from a ring buffer and creates a continuous database, *orbtrigger* implements the system's trigger algorithm, *orbassoc* is an associator/locator that determines the location of a seismic event and searches for its registration in other sources, *orbmag* calculates the magnitude of the event in real time.

All ARTS modules are started, stopped, controlled and executed by the *rtexec* script. This is the main ARTS configuration parameter file and is used to describe the entire processing network and all module parameter files and command line arguments. When started, *rtexec* reads the main configuration parameter file and runs all ARTS modules defined in the configuration.

Determining the hypocentre of an earthquake depends on the correct determination of the P and S phases. It can sometimes be difficult to recognize the correct start of the phase because the signal may be blurred for various reasons, such as the complexity of the fault mechanism and the presence of natural or artificial noise. For this reason, we study, analyse and compare different phase selection and location methods. The more phases (P- and S-waves) are involved in determining the hypocentre, and the more accurate the velocity model of the lithosphere used in the calculations, the more accurately the parameters of the earthquake hypocentre are determined. In interactive mode, the clarification of the parameters of the hypocentres includes two stages: the first - the time of arrival of the P-wave is specified and the time of arrival of the S-wave at the station is determined; the second is recalculation of the hypocentre parameters based on the data obtained. The first stage uses the *dbpick* program, the second uses *dbloc2*, included in the Antelope package. The *dbpick* program uses waveforms (*MINISEED* format) and database tables *(wfdisc*, *arrival*, etc.) generated by the automatic processing mode as input data. When exiting, the program edits existing and adds new records about S-wave arrival times to the arrival table of the database. The *dbloc2* program uses the edited arrival table as input, calculates new values for the event hypocentre parameters, and also edits entries in the origin table. Antelope's procedure for locating an earthquake is called *orbassoc*. This methodology reads picks determined using the STA/LTA method and associates the location of the event along three possible grids: teleseismic,

regional and local. The solution that produces a set of minimum travel time residuals (the difference between the synthetic travel time and the observed travel time) is considered to be the best.

Data interpretation

After the final processing of the earthquake, all data is recorded in the corresponding database tables, using which earthquake catalogues and bulletins are compiled. By examining and analysing the data obtained, maps of earthquake epicentres are constructed for each quarter and for the entire year, graphs, an activity map, the mechanism of earthquake source is determined, spectral analysis is determined, the current seismicity of seismically active zones is analysed, and calm zones are identified, the migration of foci is traced, and the seismic situation is assessed in the republic, the deep distribution of earthquake sources and their connections with faults is studied, distributed seismic energy is analysed by year, and research work is carried out to study statistical and dynamic parameters.

Data obtained as a result of processing earthquakes with a magnitude of 3.0 and above are promptly transmitted to policymakers and other relevant authorities.

Archiving of received data and processing results

Creating the necessary conditions for the security of the archive is one of the main tasks of the Seismological Center. We have collected an electronic archive of data on strong and weak earthquakes, explosions, and volcanic eruptions for 20 years, from 2003 to 2023. Data is stored on disks in several copies. One copy is located on a server allocated for the RSSC by the Institute of Information and Technology. The server also stores copies of data from all divisions of the RSSC, as well as an archive of annual records of GPS stations.

The data is stored in a closed box at a certain temperature.

The entire archive is periodically checked for integrity and, if necessary, updated. The compiled catalogues are reviewed again, additional research and updates are carried out.

Discussions

The study of modern geodynamics in regions with high seismic activity makes it possible to identify the connection between seismicity and physical processes in the earth's crust and mantle, as well as to quantify the natural hazard of these phenomena. These problems can be solved using a digital recording system for seismic signals based on modern broadband seismic stations. This requires stable, continuous operation of equipment to compile a standard data archive and automate the process of their collection, transmission and storage.

At RSSC we maintain and continuously improve a seismological system that covers basic requirements such as data acquisition, automatic processing and real-time analysis. The system is based on Antelope software, which is also used to exchange real-time data with neighbouring countries.

In the process of processing and analysing seismic data from the network, it was found that the system used makes it possible to well record not only local seismicity, but also remote large seismic events, as well as explosions, landslides, and volcanic eruptions. A comparison of the results of processing seismic events recorded by our system with data from the global seismic network showed their good compatibility. The results obtained led to the conclusion that this network is a unique tool for conducting various seismological studies.

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