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Azerbaijan-Turkmen seismic-acoustic smart system for noise monitoring of the beginning of earthquake preparation and warning of its focus area

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A B S T R A C T

One of the possible solutions to the problem of monitoring the beginning of the initiation of anomalous seismic processes by noise analysis of seismic-acoustic signals received from earth's deep strata is considered. The diagram of the station for noise monitoring of the beginning of seismic processes is proposed in which bores of suspended oil wells (1500-5000 m) are used as communication channels to receive seismic information from earth's deep strata. Experiments on shallow wells (40-200 m) have shown that they also reliably receive seismic-acoustic information, although within a shorter radius of reception of seismic-acoustic signals. The chapter analyzes the results of the experiments with the intelligent seismic-acoustic system for identifying the area of the focus of an expected earthquake based on the network consisting of seismic-acoustic stations built on six deep and four shallow wells. It has been established that only with the application of the noise technology, the beginning of seismic processes is reliably detected based on the estimates of the correlation function between the useful seismic-acoustic signal and its noise. The combinations of seismic-acoustic stations vary depending on their location and direction. If seismic processes from one direction are recorded by 3-5 stations, then completely different combinations of stations respond to them from the opposite direction. Due to this, the system can be used by seismologists as a tool for identifying the area of the focus of an expected earthquake based on the combinations of stations that respond to seismic processes.

1. Introduction

It is known that widely used seismic stations nowadays allow registering the moment of the beginning of an earthquake, determining the coordinates of its focus and magnitude. Various methods and technologies of spectral analysis are used to analyze seismic signals obtained from seismic sensors [1, 2].

It is also known that many variants of short-term earthquake forecasting have been proposed over several decades [1].

This project considers one of possible solutions to the problem of monitoring the beginning of

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earthquake preparation (BEP) by analyzing seismic-acoustic signals received from deep strata of the earth [1].

2. Problem statement

The monitoring of the beginning of earthquake preparation entails two specific problems. At BEP, both infra-low frequency seismic waves and seismic-acoustic waves with a frequency within the sound range form. Both types of wave do not reach the surface of the earth for a long time before BEP reaches the critical state, which is explained by the fact that the frequency characteristics of the upper strata of the earth do not allow seismic-acoustic waves to reach the surface of earth. Seismic waves, on the other hand, only become powerful enough when BEP is in its critical state — when an earthquake is occurring. It follows that solving the given problem first of all requires obtaining seismic-acoustic noise from the deep strata of earth, it being the primary carrier of information on the incipient earthquake.

Thus, the second key issue of the problem in question comes down to the development of a technology that takes into account the peculiarities of a heavily noisy seismic-acoustic signal in the period of formation of BEP. Here, the analysis of noise in the seismic-acoustic signal as a carrier of useful diagnostic information is of prime importance.

3. Specific features of seismic processes in Azerbaijan and Turkmenistan

The specifics of the location of Azerbaijan and Turkmenistan on opposite coasts of the Caspian Sea necessitates taking into account seismic information from both coasts when solving the problem of determining the area of the focus of an earthquake expected in the Caspian region. At the same time, it is also necessary to take into account the information accumulated by ground-based seismological services on both coasts.

An experimental analysis of seismic processes occurring in deep strata of the earth during the preparation of earthquakes in the Caspian region over the past 10-15 years has shown that a systematic recording of seismological data in the territories of Azerbaijan and Turkmenistan is necessary to monitor the beginning of an earthquake and determine its focus area. This problem is impossible to solve in the absence of BEP data from both coasts of the Caspian Sea.

In view of the above, Azerbaijani scientists Academician Telman Aliev, Dr. Gambar Guluyev (DSc in Engineering), Dr. Farhad Pashayev (DSc in Engineering) were invited to Turkmenistan several times. At the meeting with Turkmen scientists Prof. G. Sariyeva, Prof. M. Chariyev and others at the Institute of Seismology of the Academy of Sciences of Turkmenistan, the appropriate technologies for obtaining and analyzing seismic-acoustic signals from deep strata of the earth were discussed. Possible options for using suspended oil wells to build seismic-acoustic stations for noise monitoring the beginning of earthquake preparation were considered. The possibilities were also considered of applying the technology of analysis of seismic-acoustic noise, which at the beginning of earthquake preparation becomes a carrier of information about the beginning of changes in the seismic situation.

In September 2012, Turkmen scientists Prof. G. Sariyeva, Prof. M. Chariyev (DSc in Engineering), arrived in Azerbaijan at the invitation of the Azerbaijan National Academy of Sciences. An familiarization expedition was organized to demonstrate the experimental versions of the five seismic-acoustic stations built on Gum Island in the Caspian Sea, in Shirvan region, in Neftchala region, in Siyazan region and in the resort town of Naftalan. A joint examination of the results of the analysis of a seismogram (a recording of seismic-acoustic signals) with the use of various technologies showed that the Noise technology allows recording estimates of their characteristics related to the beginning of earthquake preparation with sufficient reliability 10-25 hours in advance.

In this regard, a joint decision was made on the feasibility of creating an experimental version of a seismic-acoustic station for noise monitoring of the beginning of earthquake preparation based on the analysis of seismic-acoustic signals received from deep strata of the earth through suspended oil wells.

In order to verify the effectiveness of the operation of similar stations built on the territory of Turkmenistan, it was obvious that similar experiments should be conducted at the Institute of Seismology of the AST. For this purpose, Azerbaijani scientists delivered the main units of one set of seismic-acoustic station to Turkmenistan. As a result, a Turkmen experimental seismic-acoustic station was built 120 km from Ashgabat, at the foot of Kopetdag. From the very beginning of operation, the station recorded the beginning of the earthquake preparation 10-25 hours earlier than ground-based seismic stations. However, due to the lack of relevant decision-making from superior organizations of Azerbaijan and Turkmenistan, these experiments did not last long.

These experiments have once again shown that to solve the problem of monitoring the earthquake preparation during its beginning, it is advisable to use noise technology for analyzing the noise of a seismic-acoustic signal. It was also established that to determine the area of the focus of an expected earthquake, it is advisable to use modern intelligent technologies for analyzing the results of monitoring of BEP by stations located on both coasts of the Caspian Sea.

These experiments have also shown that the reliability and validity of the obtained results can be achieved by integrating Azerbaijan seismic-acoustic stations with Turkmen seismic-acoustic stations. Thus, the conducted work made it obvious that it is necessary to create an Azerbaijan-Turkmen seismic-acoustic smart (intelligent) system for Noise monitoring the beginning of earthquake preparation and warning of its focus area.

4. Block diagram of the Azerbaijan-Turkmen seismic-acoustic smart system for noise monitoring of the beginning of earthquake preparation and warning of its focus area

As can be seen from the block diagram in Fig. 1 the proposed system consists of the following parts:

1. Seismic-acoustic stations for Noise monitoring of the beginning of earthquake preparation on the Azerbaijani side AS_1-AS_n and stations TS_1-TSm on the Turkmen side.

2. Equipment for transmitting the Noise monitoring results from Noise monitoring stations to monitoring centers AST_{1a}-AST_{na} and TST_{1T}-TST_{mT}.

3. Monitoring Center of Azerbaijan MCA and Monitoring Center of Turkmenistan TMC.

4. Equipment for transmitting and receiving information between the Azerbaijan and Turkmen smart systems STRA, STRT.

5. Unit of archiving seismic-acoustic signals U'AS (sam).

6. Azerbaijan and Turkmen centers of decision making on the warning of the beginning and the area of expected earthquake ADM and TDM.

Let us now consider the main functions performed by these units (1-5):

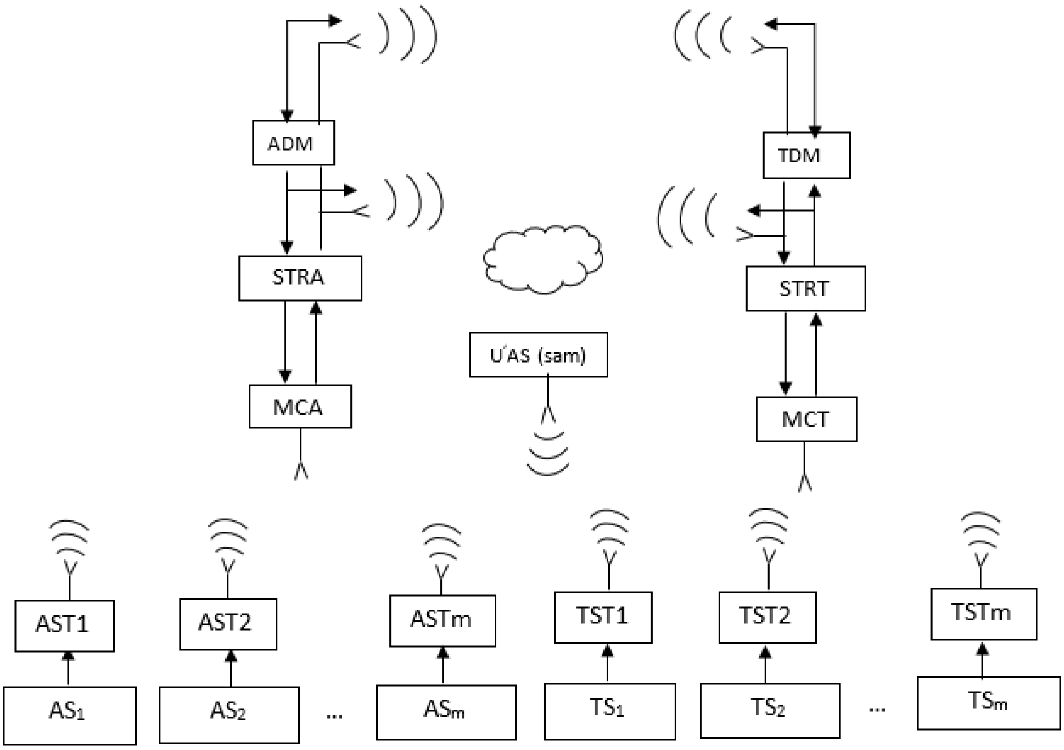

Fig.1. Block diagram of the Azerbaijan-Turkmen smart system

The Azerbaijan-Turkmen seismic-acoustic smart system consists of the following part:

1. AS_1-AS_m; TS_1-TS_m – Azerbaijan and Turkmen seismic-acoustic stations for Noise monitoring of the beginning of earthquake preparation;

2. AST1- ASTm; TST1- TSTm – systems for transmitting the seismic-acoustic information from seismic-acoustic stations to respective monitoring centers;

3. MCA-MCT – centers of Noise monitoring of the beginning of earthquake preparation in Azerbaijan and Turkmenistan;

4. STRA-STRT – systems for transmitting and receiving information on the results of Noise monitoring of the beginning of earthquake preparation in Azerbaijan and Turkmenistan;

5. U'AS (sam) – unit of archiving samples of seismic-acoustic signals during earthquake preparation by means of cloud technology.

6. ADM-TDM – Azerbaijani and Turkmen decision-making systems about the beginning of the earthquake preparation time, its focus area and possible intensity.

$ST1_a$-STN_a and ST_{1T}-ST_{mT} transmit recorded information about the start of earthquake preparation as a result of Noise monitoring of the noise of the seismic process. The information is transmitted in the form of an estimate of noise characteristics to the monitoring center in two versions. In the first version, the information is transmitted via the “Internet channel”. In the second version, information is transmitted via satellite communication.

The monitoring centers of Azerbaijan and Turkmenistan MCA, MCT form the sets of corresponding reference informative attributes only in the periods of the beginning and preparation of the earthquake on the basis of the results obtained from the respective Noise monitoring stations. Subsequently, knowledge bases are formed on their basis, by means of which the the process of registration of the beginning of earthquake preparation is studied. Ultimately, in the future they are used to determine possible focus areas and the beginning of the time of the expected earthquake.

The system for transmitting and receiving information STRA, STRT, when registering the start of earthquake preparation by the respective stations, transmits and receives information between monitoring centers. This information is also transmitted to ADMS and TDMS decision-making systems.

The unit of archiving seismic-acoustic signals by means of cloud technology is included in the smart system to ensure the further development of a smart system for monitoring the beginning of earthquake preparation and warning of its focus area. Studies devoted to this problem in recent years have shown that with the advent of a new, more efficient technology for the analysis of noisy signals, more accurate methods for their identification and more advanced methods for determining the location of the earthquake focus, their application it requires the availability of experimental data obtained at seismic-acoustic stations and recorded during earthquake preparation. Unfortunately, in the monitoring centers of the above-described seismic stations, only estimates of the noise characteristics obtained as a result of Noise analysis of seismic-acoustic noise are saved. This was due to the fact that storing all data consisting of samples of seismic-acoustic signals, even with one earthquake, requires an enormous amount of memory. Storing it for several years even for one station requires even a much larger amount of memory. At the same time, storing, i.e. archiving relevant data from all stations AS_1-AS_m; TS_1-TS_m is very important. Our analysis of achievements and opportunities related to this problem has shown that using cloud technology it is possible to create a unit for archiving samples of seismic-acoustic signals received by Noise monitoring stations during earthquake preparation periods.

Decision-making systems operate as follows: at the beginning of earthquake preparation, estimates of Noise characteristics obtained as a result of analysis of seismic-acoustic noise by respective stations via the communication channel are synchronously transmitted to the server of the respective monitoring center MC. Based on the obtained monitoring results, the combinations of the sequence of indication times T_{1i},T_{1j} and the combinations of their difference $\Delta\tau_{ij}$ are formed, which can be used as source data to determine the location of the expected earthquake.

The experiments have demonstrated that the combinations of the sequence of the times of indication by the stations practically repeat themselves for each earthquake focus area. Our analysis of the recorded charts has demonstrated that each sequence combination of time of indication of current BEP corresponds to one of the concrete earthquake areas. Employees of the laboratories studying the problem of interpretation of the experimental materials for over 2 years have learned to identify the location of the area of an expected earthquake intuitively and practically error-free, using these time combinations. It then became obvious that the problem of identifying the location of an expected earthquake should be solved by using expert systems (ES). This, in its turn, demonstrated the possibility of creating an ES which in the future will allow seismologists to use the network of the proposed stations as a toolkit to determine the location of the area of an expected earthquake.

The proposed experimental version of the expert system for identifying the location of the BEP focus area will be based on a knowledge base (KB) formed from the totality of corresponding sets consisting of the combination of sequence of times of BEP indication by the stations T_{1i}, T_{1j}, the combination of the differences in times of their indication T_{1i}, T_{1j}, and the combination of the estimates of the noise characteristics of the noise of the seismic-acoustic signal. The value of magnitude M_i determined during the corresponding earthquakes by ground seismic stations can also be entered in the KB.

Thus, the identification of the location of earthquake areas by the decision-making system after training is carried out as follows. The current combination is formed on the basis of the results of monitoring carried out by the network of Azerbaijan and Turkmen stations. After that, the current element is compared with all elements of the indicated sets. If it matches any element of any set, the location of the area of an expected earthquake is identified based on the number of that set. At the same time, the current combination is entered into that set of the KB. New combinations of informative attributes of seismic-acoustic signals are continuously written into the KB during the operation of the system. Thus, the network of stations, the monitoring center and the decision-making system operate as a whole.

To check the validity and reliability of the identification of the location of the earthquake focus area, the experimental version was tested during all several earthquakes. The obtained results have demonstrated the real possibility of practical application of this version of the system to identify the location of the earthquake focus area, which creates prerequisites for using it as a toolkit for determining the location of the area of an expected earthquake. Taking this prospect into account, a function of forming and providing information to seismologists in the following form should be included in the list of key functions of the decision-making block:

1. Date of the beginning of preparation and the number of the area of the expected earthquake.

2. Results of the current monitoring performed by the stations AS_1-AS_m; TS_1-TS_m.

3. Estimated lead time at the beginning of BEP monitoring compared with the time of registration of the expected earthquake by ground seismic stations.

4. List of all elements previously registered in the corresponding set during the initiation of the previous BEP in the estimated location of the area of the expected earthquake (with dates).

5. Amount of elements matching the current elements.

6. Magnitudes of previous earthquakes.

7. Minimum magnitude of the expected earthquake.

8. If the knowledge base contains no elements matching at least some of the elements in the sets in ADM and TDM, information on the impossibility of identifying the earthquake area is formed.

Our analysis of the results of experiments to determine the location of the BEP area has shown that, knowing the current values of the estimate of the noise of the seismic-acoustic signal and the distance from the area to the stations AS_1-AS_m; TS_1-TS_m, the approximate minimum magnitude of the expected earthquake can be calculated.

At the end of the analysis of all possible options, if there is sufficient statistical data on earthquakes in the focus in the past, a mutual exchange of opinions takes place. If the opinions coincide, seismologists make the final decision on warning of the area of the focus of the expected earthquake.

5. The structural principle of a seismic acoustic Noise monitoring station

The diagram of the seismic station for noise monitoring of BEP is given in Fig. 2. Its difference from all other known prototypes is that the steel bores of suspended oil wells filled with water are used as a communication channel for receiving seismic information from the deep strata of earth.

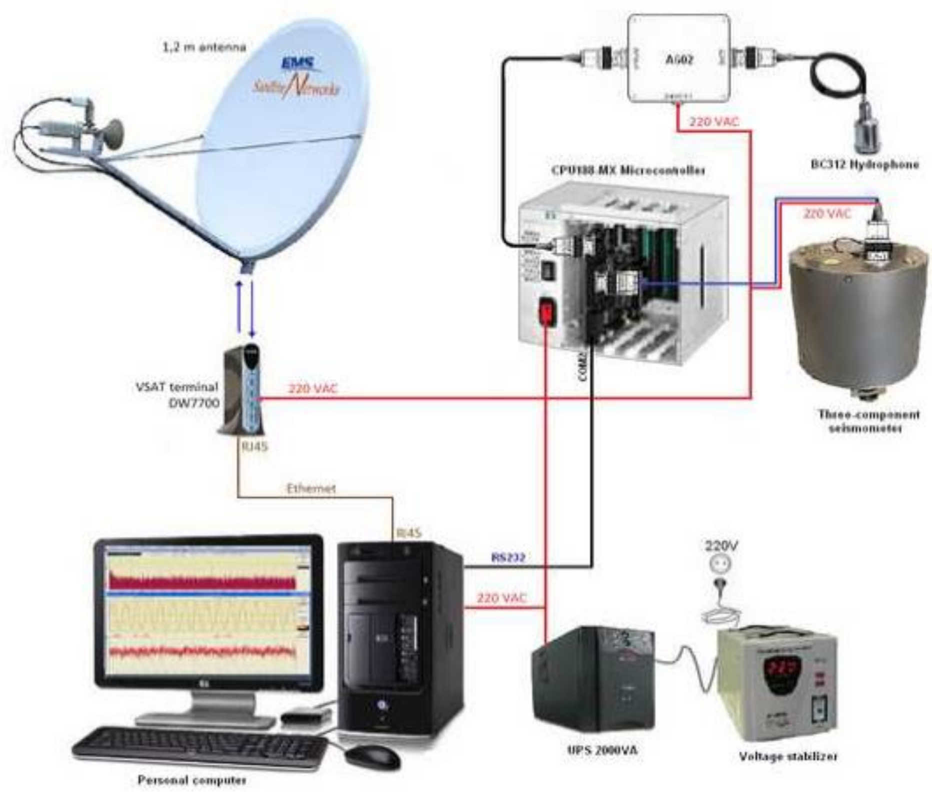

Fig. 2. Diagram of the station

The station includes the following equipment:

1. System unit;
2. Fastwell Micro PC type station controller;
3. GURALP LTD CMG 5T seismic accelerometer;
4. BC 321 hydrophone made in Zelenograd;
5. Amplifying and normalizing elements;
6. Siemens MC35i terminal forming an Internet channel via GPRS;
7. Antenna;
8. Voltage regulator;
9. UPS;
10. Monitor;
11. Connector.

An experimental version of the station was installed at the head of a 3 500 m deep suspended oil well No 5 on 01.07.2010. The well is filled with water, and for this reason a BC 312 hydrophone is used as the sensor.

Experimental research has demonstrated that in the analysis of the noise $\varepsilon(i\Delta t)$ of the seismic-acoustic signal $g(i\Delta t)$, clear identification of the time of the beginning of earthquake preparation by means of traditional technologies is impossible. At the same time, using the robust technologies for noise analysis of the estimates of the noise characteristics of the cross-correlation function between the useful signal, the noise $R_{X\varepsilon}(\Delta t)$ and the noise variance D_ε, the system detects the beginning of earthquake preparation reliably and adequately.

$$\backslash D_\varepsilon \approx \frac{1}{N}\sum_{i=1}^{N}\left[g^2(i\Delta t) + g(i\Delta t)g\big((i+2)\Delta t\big) - 2g(i\Delta t)g\big((i+1)\Delta t\big)\right]$$

$$R_{X\varepsilon}^{*}(\mu = 0) \approx \frac{1}{N}\sum_{i=1}^{N}\left[\mathrm{sgn}g(i\Delta t)g(i\Delta t) - 2\mathrm{sgn}g(i\Delta t)g\big((i+1)\Delta t\big) + \mathrm{sgn}g(i\Delta t)g\big((i+2)\Delta t\big)\right]$$

The first results of experiments show that it is possible to register the beginning of an earthquake within a radius of over 300-500 km 10-25 hours before the earthquake by means of these stations. These results have shown that the time of earthquake preparation changes depending on the location of the earthquake focus. Based on the obtained results, one can also assume that, when spreading from the earthquake focus, seismic-acoustic waves are reflected due to the resistance of certain upper strata of the earth, and for this reason they propagate horizontally. One can also assume that sufficient intensity of those waves allows them to travel to long distances (300-500 km).

6. Conclusion

The research conducted on these stations has demonstrated that to determine coordinates and magnitudes of expected earthquakes, we need to build networks consisting of at least 18-20 stations located across large areas. It was also obvious that they should be integrated with networks of similar seismic stations. To this end, another three stations were built in 2011 in addition to the station at Qum Island in the Caspian Sea: in the town of Shirvan to the south of the country, in the town of Siazan in the north, in the town of Naftalan in the west. Another four stations were built in the following years.

During the operation of all these seismic stations, as was indicated earlier, the results of noise analysis of seismic-acoustic signals at the moment of the beginning of earthquake preparation are transmitted from each station to the server at the Monitoring Center. As a result, sets of corresponding informative attributes form there.

As a result of experiments conducted at these stations since 2010.07.01, it has been established that during the initiation of ASP there is indeed a cross-correlation between the useful signal and the noise of the seismic-acoustic information.

The results of the experimental operation of these stations has shown that based on changes in the estimate of the cross-correlation function between the useful signal and the noise, each of them individually reliably indicates the start of earthquake preparation processes within a radius of 300-500 km with sufficient reliability. Using intelligent technologies, by means of a network of these stations located across large areas, it is possible to identify the location of the earthquake focus area.

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