Improving the Efficiency of Searching for a Short-Term Operational Earthquake Precursor Based on Vector Identification Measurements

Bibigul, Koshekova
The North-Kazakhstan State University n.a. M.Kozybayev (NKSU)
Petropavlovsk, Republic of Kazakhstan
e-mail: kbv.petr@gmail.com

Oleg, Belosludtsev
Institute of Seismology (IS)
Almaty, Republic of Kazakhstan
e-mail: seismology@seismology.kz

Yuriy, Klikushin
Omsk State Technical University (OmGTU)
Omsk, Russian Federation
e-mail: iit@omgtu.ru

ABSTRACT
The results of research on the search for operational precursors of earthquakes based on identification measurements of only the seismogram were presented in [1]. However, the possibility of increasing the efficiency of the search procedure for operational earthquake precursors based on vector identification measurements of the seismogram and the characteristics of its increments is shown in this paper. It is established that for both characteristics the seismic monitoring process corresponds to the movement of the pointer arrows on the identification S-scale. Complex in the mathematical description of the seismogram is a cluster of deviations from the reference marks of two scales. The most optimal threshold value is determined, which is the same for both characteristics and acts as a short-term operational earthquake precursor, as well as the corresponding prediction intervals. It is established that when using the characteristic of seismogram increments, operational precursors for a short-term forecast appear 60 times earlier by times. A complex computer intelligent device is developed that measures the statistical parameters and the seismogram shape and its characteristics, and also realizes the search for possible operational earthquake precursors. A new method for determining earthquake precursors is proposed, based on a successive comparison of the identification S-parameter with a threshold value that changes as the earthquake approaches the moment of the earthquake.

Keywords
Operational forecast of earthquakes; identification measurements.

1. INTRODUCTION
At present, despite the presence of a large number of various earthquake precursors [2-5], from ground to air and space, earthquake prediction remains an urgent scientific problem, since it is impossible to find satisfactory theoretical and experimental solutions [6] for determining the information for predictions.

In connection with the rapid development of computer technology, methods and tools based on the statistical processing of seismograms have become a promising direction for the definition of earthquake precursors [5-8], but the probability of the forecast remains low for a number of reasons. In particular, it is difficult to establish informative patterns for the prediction of casual seismograms shapes in a mathematical description by deterministic functions. The situation is complicated by the presence of noise and interference caused by various phenomena: wind, atmospheric pressure differences, temperature variations, anthropogenic factor, etc. At the same time noise [7] hides in itself some manifestations of the preparation processes of destruction, which contain great interest in the issue of forecasting earthquakes.

Therefore, in order to increase the efficiency of searching operational and information earthquake precursors, it is necessary to use more accurate technologies for identifying a noisy seismogram [8, 9].

In research [1] the authors of the article showed that the theory of identification measurements is applicable for the analysis of seismograms using the S-type scale with reference marks in the form of points with symmetrical laws of instantaneous values distribution. It is established that the seismic monitoring process corresponds to the movement of the pointer of the scale within the standards from the arcsine distribution (ASIN, S = 92) to the Cauchy distribution (KOSH, S = 0), and the seismogram that is complex in description can be represented by a cluster of deviations from the reference marks. This approach made it possible to reveal regularities in the seismograms change: 1) immediately at the time of the earthquake, the distribution of the instantaneous values of the seismogram becomes equal to the distribution of KOSH; 2) if we establish intermediate threshold values of the S-parameter, then they can be used as operational precursors (OEP) for prediction of earthquakes.

As a result of the research, an intelligent algorithm was proposed and a computer device realizing the method of processing real seismograms and searching for OEP, which showed sufficient effectiveness. However, its hardware implementation required further improvement of the method and the computer device for the following reasons: 1) the need to reduce the error in identifying seismograms due to ambiguous transformations of the set into a number, 2) the elimination of false OEP and short time prediction for low values of the S-parameter; 3) improving the accuracy and quality of forecasting by proposing new, earlier OEP.

Possible solutions of these problems are associated with the use of identification measurements, processing and signals analysis using vector scales. The authors of the article successfully solved similar problems by simultaneously measuring several characteristics in the technical diagnostics of hydrogen fuel cells [9].

The purpose of this research is to improve the quality and accuracy of OEP search by using vector identification measurements of seismograms and the development of a new, more effective and easy-to-implement method for the computer determination of OEP for forecasting. The real seismograms were used to conduct research to find the predictive signs.

2. METHODOLOGY AND RESEARCH TOOLS

Vector identification measurements allow for a deeper analysis of casual signals. The methods for constructing recognition tools are determined by the types of measured characteristics:

1) homogeneous, for example, temporal: waveform, its speed (increment characteristic) or acceleration;
2) heterogeneous, for example, temporal and spectral, temporal and correlation, etc.;
3) combined (homogeneous and heterogeneous): the waveform and its spectrum, the signal speed and its spectrum.

To construct a computer intelligent device measuring seismograms, was used the first method with a vector identification equation

$$\vec{S} = ReS + jImS = \sqrt{(ReS)^2 + (ImS)^2} exp\left[jarctg\left(\frac{ImS}{ReS}\right)\right], \quad (1)$$

where $ReS = IdP[X(t)]$ - identification parameter of the seismogram shape;
$ImS = IdP[\Delta X(t)] = IdP[X_i - X_{i-1}]$ - identification parameter of the signal increment characteristic;
IdP[...] - Operator of the identification transformation function by the S- method implemented by the following steps:
the studied sample of the instantaneous values of the $X(t) = \{X_1, ..., X_i, ... X_N\}$ seismogram is ranked in ascending order;
from the ranked function 9 values are selected by means of uniform sampling, and the fifth value has to be the same as the median of the studied sample;
the S-parameter is calculated as

$$S = \frac{C(8) - C(2)}{C(9) - C(1)} 100, \quad (2)$$

where C(J) – j-value of the ranked function of the studied sample.

The form of the ranked functions does not depend on the parameters of the shift and scale, and the average steepness in the central section gradually increases and is related to the distribution of the random signals, as shown in Table 1, which is called a S-type identification scale.

The identification ImS - parameter of the X'(t) - seismogram increment is also determined by the S-method.

The tabular representation of an identification scale includes the serial numbers (Rank) of defined points, their names which are compactly designating symmetric distributions of casual signals: two-modal (2MOD), arksine (ASIN), even (EVEN), trapezoidal (TRAP), triangular (SIMP), normal (GAUS), bilateral exponential (LAPL) and Cauchy (KOSH), and also numerical estimates of their identification S-parameter defined according to (2). In addition to the values of the reference (S) points of the identification S-scale, the possible values of the identification number (Sx), which can be used as operational precursors for earthquake prediction (OEP-1 - short-term, OEP-2 - average-term, OEP-3 - long-term).

Further research is related to improving the efficiency of the OEP-1 search. To carry out the research, the authors proposed a new structure of the developed computer device, which realizes the intellectual analysis of seismograms by the S - method of vector identification measurements [10].

TABLE I. THE S- TYPE IDENTIFICATION SCALE

Type of distribution	**2MOD**	**ASIN**	**EVEN**	**TRAP**	**SIMP**	**GAUS**	**LAPL**	**KOSH**
Rank	1	2	3	4	5	6	7	8
S-values of defined points of a scale	100	92	75	67	51	32	12	0÷5
Sx-possible indications of an identification seismograph						OEP-1		
					OEP-2			
				OEP-3				

The block diagram of the device is shown in Figure 1, where DF is a formation block of the seismogram increment form, S1-tester is a seismic-trace identification tool, S2-tester is a tool for identification transformation of the seismogram increment form, IBOS is a block formation of $\vec{S}$ – vector and intelligent processing of the seismogram shape and the characteristics of the increment, SDTVIP - the setting device of the threshold values of the identification parameters.

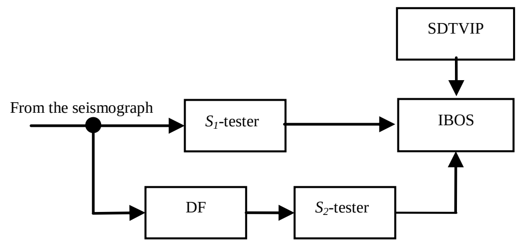

Fig. 1. Block diagram of a computer device.

The computer device, according to the block diagram presented in Figure 1, was implemented in the LabVIEW12 environment, and performs the following functional operations:

- input to the device from the seismograph (File of Signal) of the seismogram and the formation of a selective N - implementation, sequential identification measurement of samples, determination of maximum and minimum seismogram values with an earthquake with corresponding time values, screen output of the seismogram monitors and characteristics of the ReS - parameter change;
- obtaining the characteristic of the seismogram increment and the formation of the sample N - implementation, the serial identification sampling, screen output of the characteristic of the ImS - parameter change;
- allocation of the fragment of the studied seismogram before the earthquake (Portion of Signal) - the first sharp increase in the K(t) - characteristic, the determination of the statistical parameters and the earthquake characteristics;
- search for operational earthquake precursors by sequential comparison of the set thresholds entered by the operator, with

dynamic ReS- parameters changes and ImS- parameters in the monitoring process.

3. RESULTS AND DISCUSSION

A set of statistical parameters and characteristics of the studied seismograms was obtained as a result of the research. Their analysis made the following conclusions.

For the analysis of seismograms, the most effective is the use of vector identification measurements of shape characteristics - the distribution of the instantaneous values of a seismogram and its increments by the S-method with an appropriate scale, in which the points with symmetric laws of instantaneous values distribution act as reference marks. For both characteristics, the seismic monitoring process corresponds to the movement of the pointer arrows on the identification S-scales (Table 1) from ASIN (S = 92) to KOSH (0), which made it difficult to describe the seismogram as a cluster of deviations from reference marks. In this case, immediately at the time of the earthquake, the distribution of the instantaneous values of the seismogram and the increment characteristics, i.e., the values of the ReS and ImS - parameters become equal to the KOSH distribution (0≤ReS (n) ≤5 or 0≤ImS (n) ≤5).

As we approach the moment of the earthquake, the values of the identification ReS and ImS - parameters are simultaneously decreasing, but with different coefficients of slope of the characteristics. If we enter the ReSpor and ImSpor - threshold values and assume that the t1- parameter is a time interval between the instants of observation and the moment of the earthquake, t2 is a time interval between the moments of the instants of observation and the fulfillment of the condition ReS[n]=ReSpor and ImS[n]=ImSpor, then $t_3^{ReS} = t_1^{ReS} - t_2^{ReS}$ and $t_3^{ImS} = t_1^{ImS} - t_2^{ImS}$ are time intervals for the earthquake forecasting. Therefore, the ReSpor and ImSpor - threshold values established in SDTVIP will be operational earthquakes precursors (OEP). The illustrated representation of this approach for the seismogram is shown in Fig. 2.

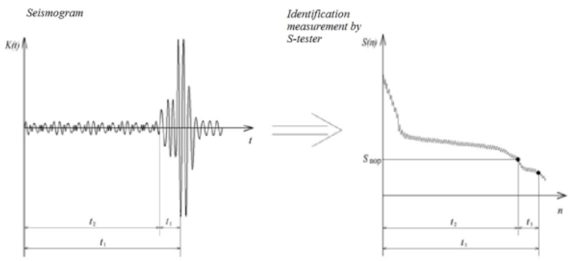

Fig. 2. Illustration of the change in the identification S-parameter as it approaches the earthquake

3. It was experimentally established that OEP-1 (Table 1) lies in the range of distributions (GAUS_LAPL) with the value 12≤Spor≤32, OEP-2 - (SIMP_GAUS) with 32≤Spor≤51 and OEP-3 - (TRAP_SIMP) from 51 to 67.

However, with vector identification measurements, it is the most effectively recommended to use OEP-1, since ReSpor=ImSpor $t_3^{ReS} = (40 \div 100)\ t_3^{ImS}$ is an important regularity. For example, as shown in Figure 3, for ReSpor=ImSpor=27 $t_3^{ReS} = 35\ sek,\ t_3^{ImS} = 2500\ sek.$

As a result of modeling for the group of the studied seismograms, provided by the Scientific Research Institute of Seismology of the Science Committee of the Republic of Kazakhstan, the most optimal ReSpor=ImSpor=25 -threshold value for OEP-1 was determined with the $K = \{9.1, 9.2, 9.9, 10.1, 11.5, 12.5, 13.9, 14.7\}$ forces, at which prediction intervals using the seismogram were $t_3^{ReS} = (35 \div 50) sek$, and for the increment characteristic - $t_3^{ImS} = (2301 \div 2935)\ sek$. Consequently, using vector-based identification measurements and with the same threshold values, OEP-1 appears on average 60 times earlier by times.

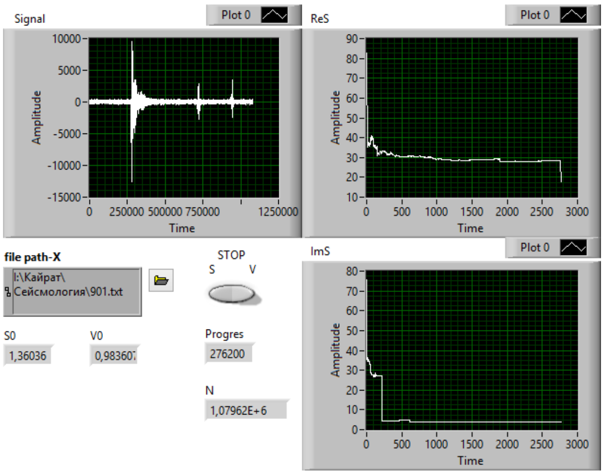

Fig. 3. The front panel of a computer device with the results of the identification measurements and the seismogram analysis with the earthquake force К=9.1 for ReSpor=ImSpor =27 $t_3^{ReS} = 35\ sek,\ t_3^{ImS} = 2500\ sek$

4. The method of operational earthquake forecasting is proposed, algorithmically realized at the following stages:

Step 1. Continuously changing the X(t) - signal of the seismogram is entered into the computer device. The characteristic of the X'(t) - increment is determined.

Step 2. The characteristics of the ReS(t) and ImS(t) - identification parameters changes from time (or number of n-sample) are cyclically determined for N = 1000 – sample of instantaneous values of the seismogram and its increments in accordance with the S-method of identification measurements.

Step 3. The cyclically determined identification ReS- and ImS-parameters are compared with the threshold values, OEP-1 is determined if the condition fulfils ReS(t)=ReSpor and ImS(t)=ImSpor equalities and a conclusion is made about the operational earthquake forecast.

5. A complex computer intelligent device is developed that measures the statistical parameters and shape (the distribution of instantaneous values) of seismograms, and also realizes the search for operational earthquakes precursors OEP-1, OEP-2 and OEP-3 by seismogram and characteristic of its increment in real time. The third node of the computer device implements the functions of determining the earthquake prediction the t3 - time between the moments of the earthquake onset and the moment of the comparator operation. The front panel of the computer device displays quantitative and qualitative indicators of the seismogram and the increment characteristics, time intervals, prediction time, etc. Also on the front panel there are information monitors for displaying fragments of characteristics forms: temporary, ranked, identification.

The authors subsequent research is aimed at solving problems in real time: a) assessing the strength and direction of the future earthquake; b) assessing the possibility of repeated shocks, their number and strength; c) the development of an intellectual seismogram database and the establishment of regularities in the change of identification parameters with the predicted force of earthquakes; d) determining the accuracy of the operational seismogram prediction using OEP.

It should be noted that identification measurements can be used to solve problems of operational prediction of not only earthquakes, but also other accidents - with automatic issuance of recommendations to an user in the form of numerical estimates and linguistic descriptions in terms accepted by experts of the given subject area.

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