Method of Early Prediction of the Moment of Earthquake According to the Noise of Seismic Stations

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Abstract. The proposed study is interdisciplinary and is based on the use of methods of technical diagnostics in relation to non-man-made objects. Previously developed method of indirect assessment of the degree of the stress state of rocks according to seismic data allowed us to offer two earthquake’s short-term precursors that have been applied for the purposes of the operative forecast. For this purpose, the wave forms of noise measured by seismic stations before the earthquake during and after the anomalous values of the precursors were used. Post-monitoring of preparation of five earthquakes is carried out.

1. Introduction
Each earthquake is preceded by increasing stresses in the earth's rocks. These changes lead to the appearance of anomalies of various geophysical fields, which can be used as precursors of earthquakes [1]. Currently, there are many geological, geophysical, hydro-geochemical, biological, mechanical, seismological, biophysical precursors of earthquakes, but the problem of reliable short-term (days, weeks) and operational (minutes, hours) earthquake prediction is still not solved [2].

In the work [3] two criteria of an indirect estimation of a stress state of rocks based on the data of wave forms of the previous (diagnosing) earthquakes are offered, and these criteria can be used as short-term precursors of earthquakes. The basis of the work is the transfer of well-developed methods of technical diagnostics to non-man-made objects. The use of external to the object under study diagnosing earthquakes does not allow to carry out an operational forecast, because it may be no diagnosing earthquakes at the right time. Therefore, an attempt was made to use wave forms of noise, which can be measured by recording seismic stations at any time. This paper presents the results of post-monitoring of earthquake preparation by wave forms of the noise measured by seismic stations.

2. Method of calculation
In the automated control theory, the ratio between the form of input and output signals is determined by the transfer function of the object, which characterizes the object and is expressed through its internal parameters. The task of technical diagnostics is to determine the known input and output signals of the internal characteristics of the object – its transfer function [4]. If we will consider the area of earth's rocks as a non-man-made object for which the input and output signals are known, then the transfer function, which is characteristic of its internal properties, can be calculated.

Let two seismic stations – input and output for the studied area be chosen. Three waveforms are taken from each station – BHE (BH1), BHN (BH2) and BHZ. Denote them as $x_{BHE}^{i}(t_i), x_{BHN}^{i}(t_i), x_{BHZ}^{i}(t_i), i=(1,2,...,N)$ for the input station and as $y_{BHE}^{i}(t_i), y_{BHN}^{i}(t_i), y_{BHZ}^{i}(t_i),$. 

...
for the output. Here \( t \) is the time, \( i \) is the current count, \( N \) is the number of points in the wave form. The spectrum of each curve is obtained using the fast Fourier transform \([5]\). It imposed additional requirements on the wave forms. All of them must have the same sampling rate and the same number of points \( N \). Denote as \( X_{BHZ}^i(\omega), X_{BHN}^i(\omega), X_{BHE}^i(\omega), i=(1, 2, ..., N) \) the spectra of the channels of the input station and as \( Y_{BHZ}^i(\omega), Y_{BHN}^i(\omega), Y_{BHE}^i(\omega), i=(1, 2, ..., N) \) the spectra of the channels of the output station. There's a circular frequency here \( \omega_j = 2\pi f_j \). Further, only \( M=N/2 \) spectrum points were used in the calculations, since the second half of the spectrum is a mirror image of the first. The spectrum of each station was averaged as follows:

\[
X_{TOT}^i(\omega) = \sqrt{\frac{1}{n} \sum_{m=1}^{n} |X_m^i(\omega)|^2}, \quad i=(1, 2, ..., M) \text{ for input station and}
\]

\[
Y_{TOT}^i(\omega) = \sqrt{\frac{1}{n} \sum_{m=1}^{n} |Y_m^i(\omega)|^2}, \quad i=(1, 2, ..., M) \text{ for output station.}
\]

Here \( m \) is the current channel of the station, \( n \leq 3 \) – the total number of channels exposed by the station for a particular earthquake. The fact is that for some earthquakes, the station does not expose the entire set of channels BHE, BHN, BHZ, but only some of them and averaging is performed only on those channels that are exposed by the station.

Then the ratio was calculated:

\[
A_{TOT}^i(\omega) = Y_{TOT}^i(\omega) \cdot \left( X_{TOT}^i(\omega) \right)^{-1}, \quad i=(1, 2, ..., M).
\]

It is called quasi-amplitude-frequency characteristic (QAF) of the medium at the location of the output station. Each QAF \((1)\) was smoothed by the filter \([3]\) using an approximating power polynomial of the third degree at forty points of the floating window.

Further, the integral criterion of the quasi-amplitude-frequency characteristic (IQAF) was calculated:

\[
R_{TOT}^i = \left( \sum_{i=1}^{M} A_{TOT}^{i-1}_{SM}(\omega_i) \cdot \Delta \omega_i / M, \quad i=(1, 2, ..., M), \right)
\]

where \( \Delta \omega_i \) - is the sampling step of the circular frequency, and the expression

\[
\sum_{i=1}^{M} A_{TOT}^{i-1}_{SM}(\omega_i)
\]

is smoothed QAF \((1)\). In addition another criterion was formulated, called the fractional integral criterion of quasi-amplitude-frequency characteristic (FIQAF), which was recorded as:

\[
D_{TOT}^{i-1} = \sum_{j=1}^{K} A_{TOT}^{i-1}_{SM}(\omega_j) \cdot \left( \sum_{i=1}^{M} A_{TOT}^{i-1}_{SM}(\omega_i) \right)^{-1}, \quad i=(1, 2, ..., M), j=(1, 2, ..., K),
\]

where \( K<M \). The choice of the \( K \) value was based on the shape of the QAF, and remained constant for the whole series of post-monitoring of the stress state of the medium.

3. Post-monitoring of earthquake preparation

Five earthquakes, the characteristics of which are presented in table 1, are randomly selected. Each of these earthquakes was preceded by diagnostic earthquakes, the wave forms of which, lasting thirty minutes, began thirty minutes before the arrival of the \( p \) – waves of these earthquakes. Thus, the background was measured. Since diagnostic earthquakes determined only the moments of the beginning of the background measurement, their characteristics are not significant and are not given. The value of \( K \) in criteria \((3)\) corresponded to 1.5 Hz.
Table 1. Characteristics of investigated earthquakes.

| №  | Date (y.m.d)  | Date and time (h:m:s) | Days from the beginning of the year | Mag. | Depth (km) | Latitude (degrees) | Longitude (degrees) |
|----|--------------|------------------------|-------------------------------------|------|------------|--------------------|--------------------|
| 1  | 2017.06.12   | 12:28:38               | 163.519                             | 6.30 | 10.35      | 38.93° N           | 026.360° E         |
| 2  | 2018.12.05   | 04:18:08               | 339.176                             | 7.50 | 10.00      | 21.968° S          | 169.440° E         |
| 3  | 2018.12.29   | 03:39:09               | 363.152                             | 7.00 | 60.06      | 05.973° N          | 126.828° E         |
| 4  | 2017.05.17   | 04:42:25               | 137.196                             | 4.06 | 02.25      | 34.42° N           | 120.000° W         |
| 5  | 2018.01.10   | 02:51:31               | 010.119                             | 7.5  | 10.00      | 17.47° N           | 083.520° W         |

All wave forms of the noise in the *miniseed* format were taken at [6]. The noise, preceding earthquakes from the table 1, was measured by following seismic stations:

№1 - BFO, KIV, OBN, ANTO, ANTO1, GNI, GNI1, **GRFO**;
№2 - MSVF, MSVF1, AFI, AFI1, CTAO, CTAO1, FUNA, FUNA1, HNR, HNR1, RAO, RAO1, SNZO, SNZO1, TARA1, HRV, HRV1, HRV11, PMG, PMG1, **TARA**;
№3 – HKPS, HKPS1, QIZ, KAPI, KAPI1, DAV, DAV1, GUMO, GUMO1, PMG, PMG1, TATO, TATO1, BTDF, **PMG**;
№4 – CMB, PASC, PASC1, PFO, PFO1, NV31, ANMO1, COR, COR1, COR11, TUC, TUC1, TUC11, **ANMO**;
№5 – BCIP, GTBY, MTDJ, TGUH, JTS, DWPFI, TEIG, TEIG1, TEIG11, **DWPF**.

Some stations exhibited several sets (BHE, BHN, BHZ). For example, TEIG station exhibited three sets: TEIG, TEIG1, TEIG11. The calculations involved only one, the one that followed the first in the *miniseed* file. Bold italics highlighted the station, which was the input in the calculations.

Figure 1 presents the values of the criterion (2) (IQAF) and (3) (DIQAF) prior to the earthquake No. 5.

**Figure 1.** Values of criteria (2) and (3) at time 2018.01.09 22:15:0, preceding the earthquake No. 5 (see table 1).
Figure 1 shows the surfaces of criteria (2) and (3), the contours of the criteria values, the coastline and the location of seismic stations, the data of which are used in the calculations.

On the figure (2) the values of criteria (2) and (3) calculated in the process of post-monitoring of earthquake No. 5 preparation are given.

On the figure 2 the bold dashed line and oval indicate the estimated time of the earthquake. For each station, the first (and only) section of the curve with a slope tangent less than -0.3 (~ -19 degrees) was selected. For him, the moment of time taken for the estimated time of the earthquake was determined by extrapolation to the time axis. Then the average for all stations (T = 10.0786) and the mean square sample (dT = 0.15286) for the earthquake were calculated (the given values - for earthquake No.5). The value Tmax = 10.0631 (numerical value – for earthquake No.5) means the end time of the latest selected section of curves (the end time of forecasting).

**Figure 2.** Data of the post-monitoring of the earthquake No.5 preparation.

For figures 3 and 4 data of post-monitoring of preparation of earthquake No. 3 are given (see table 1).
Figure 3. Values of criteria (2) and (3) at time 2018.12.29 01:0:0 preceding earthquake No. 3 (see table 1).

Figure 4. Data of the post-monitoring of the earthquake No.3 preparation.

A summary of the calculations for all earthquakes is given in table 2.
When conducting a post-monitoring using wave forms of diagnosing earthquakes [3, 7], the signals of the input and output stations are more likely to belong to the same event than when using noise. Therefore, the behavior of criteria (2) and (3) before the earthquake (the growth of criterion (2) and the simultaneous fall of criterion (3)) in this case is more obvious. However, in the case of noise, this pattern is also present. For figure 1 the nearest “TGUH” station to the future earthquake No.5 has a relative maximum of criterion (2) with a simultaneous minimum of criterion (3). In figure 3, the nearest “DAV” station to earthquake No. 3 also repeats this pattern.

The calculated and real moments of earthquakes are within the standard deviation for all earthquakes (exception – earthquake No.4). This is due to the relatively small number of measurements for this earthquake. If we measure the wave functions of noise, without being tied to diagnostic earthquakes, as it is done now, and continuously, the results can be better.

4. Conclusion
The use of the identified earthquake precursors allows for short-term (days, weeks) prediction of the earthquake moment when using diagnostic earthquakes and operational (minutes, hours) when using noise. The obtained numerical values of the predicted moments of earthquakes fit into this time frame. The end of the prediction process always precedes the moment of the real earthquake, which leaves room for the involvement of other methods to clarify the parameters of the predicted earthquake.

5. References
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Table 2. Summary of calculations of the post-monitoring of the preparation of five earthquakes.

| № | Date, time (UTC) | Days | Date, time (UTC) | Days | Mean | Date, time (UTC) | Days |
|---|-----------------|------|-----------------|------|------|-----------------|------|
| 1 | 2017.06.12 12:28:38 | 163.519 | 2017.6.11 16:01:55 | 162.668 | 0.917 | 2017.6.12 11:57:07 | 163.498 |
| 2 | 2018.12.05 04:18:08 | 339.176 | 2018.12.05 07:43:40 | 339.322 | 0.901 | 2018.12.04 23:08:09 | 338.964 |
| 3 | 2018.12.29 03:39:09 | 363.152 | 2018.12.29 06:08:38 | 363.256 | 0.188 | 2018.12.29 02:47:02 | 363.116 |
| 4 | 2017.05.17 04:42:25 | 137.196 | 2017.05.17 08:13:55 | 137.343 | 0.069 | 2017.05.17 04:14:52 | 137.177 |
| 5 | 2019.01.10 02:51:31 | 101.119 | 2017.01.10 01:52:19 | 101.078 | 0.152 | 2018.01.10 01:30:51 | 10.0631 |