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Geophysics

Primary Analysis of Acoustic Emission Events of Stick-Slip Process under External Influence

Tamaz Chelidze*, Ekaterine Mepharidze, Aleksandre Sborshchikovi**, Natalia Zhukova**, Irma Davitashvili§, Dimitri Tephnadze**, Levan Laliashvili****

**Academy Member, M. Nodia Institute of Geophysics, Ivane Javaskhishvili Tbilisi State University, Tbilisi, Georgia*
***M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
§Georgian Technical University, Tbilisi, Georgia

ABSTRACT. In the present paper we investigated nonlinear features of interevents (time interval sequences) of Acoustic Emission (AE) recorded by spring – slider laboratory system, under periodic mechanical forcing. AE laboratory stick-slip experiments were carried out for three types of stiffness of driving spring (78.4 N/m, 235.2 N/m, 1705.2 N/m). Frequencies in the range 5-120 Hz for different voltages was applied to a vibrator. AE interevent time series were analyzed by the methods of Detrended Fluctuation Analysis (DFA) and Recurrence plot (RP) analysis. *© 2019 Bull. Georg. Natl. Acad. Sci.*

Key words: forced stick-slip, waiting times, nonlinear analysis

We investigated dynamical characteristics of nonlinear stick-slip process of basalt plate samples under a weak external forcing. Research was motivated by the fact that stick-slip process of rock samples represents a model for the seismic process [1]. It is also known that natural seismic activity may be influenced by different external, including periodic, impacts. One of the ways to investigate the phenomenon of anomalously high sensitivity to small external changes is nonlinear analysis of interevents sequences derived from AE records. Analysis of the dynamics of interevent time interval sequences is often thesubject of researches in geosciences and especially in geocomplexity [2,3].

Methods

In the present paper we used laboratory set up, which represents a system of two horizontally oriented saw-cut basalt plates. The height of the surface asperities was about 0.1-0.2 mm. A constant pulling force was applied to the upper (sliding) plate on 20 Hz vibrator. The weight of the sliding plate was 700 gr. In our experiments we have varied: i) the frequency of periodical mechanical perturbation; ii) the amplitude of the external mechanical forcing [4].

Stick-slip events in experiments were registered as acoustic bursts by the sound card of PC. In the first stage three types of springs were chosen for testing: 78.4 N/m, 235.2 N/m and

1705.2 N/m. The forcing frequency range was 0.5-120 Hz for different voltages, applied to 20 Hz vibrator which in this case is a proxy of mechanical forcing intensity. The experimental records on computer were displayed by 100 Hz Piezo-Transmitter.

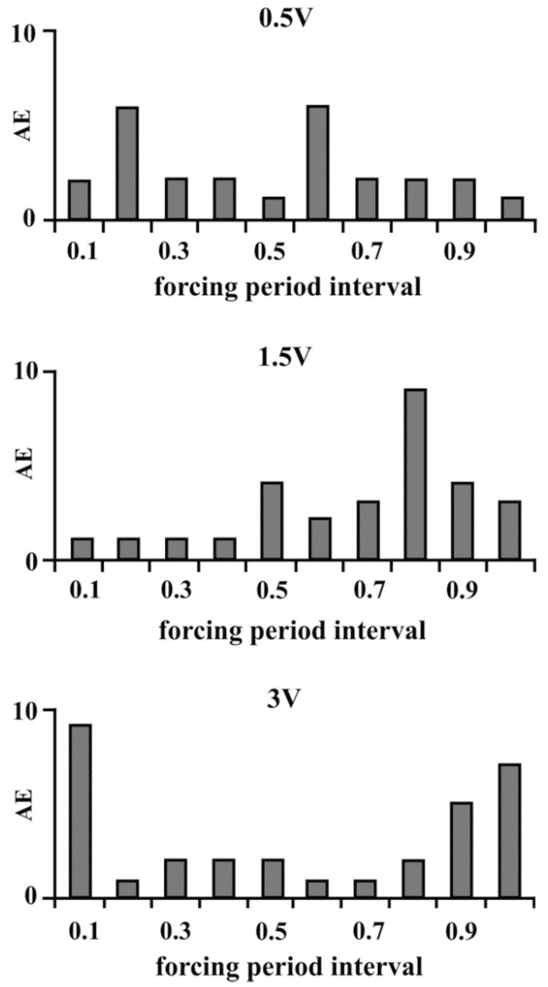

Fig.1. The distribution of AE onsets' number (under external forcing) at different mechanical forcing period's phases (in decimals). Here we take the forcing frequency 20 Hz and applied voltage 0.5V, 1.5V, 3V on 20Hz vibrator.

For the dynamical analysis we used time intervals between the bursts of laboratory Acoustic Emission of stick-slip processes: $\Delta t = t(i+1) - t(i)$.

Long-term correlation and scaling features of the bursts between time intervals of AE were assessed by DFA method [5-7]. The DFA method is used in many research fields: geophysics, dynamics, meteorology, biology, bioinformatics, economics, etc.

This scaling analysis method provides a simple quantitative parameter and represents the correlation properties of a signal. Comparing to various well- known methods DFA has an advantage. It finds long-range correlations embedded in non-stationary time series.

For further analysis of dynamic features of interevents sequences of Acoustic Emission of stick-slip process, we used Recurrence Plot (RP) analysis method, which is often used for qualitative analysis of complex time series of different origin [8]. RP plots represent graphs with horizontal and vertical lines/clusters, which correspond to different states of stick-slip process. From this plots we got information about occurred qualitative changes in the considered process, here, in the stick-slip acoustic emission under different external influences.

Results and Discussion

Under higher velocity of movement the transition to inertial periodic oscillations occurs, that corresponds to a stable sliding of basalt plate with small fluctuations. In Fig.1, we can see the distributions of the AE burst onset for the external forcing. From the results of our analysis we can say that at low voltages (up to 1V) the onsets are more or less randomly distributed in the decimals of the forcing period. Also we see that while we increase the voltage at first and last decimals of forcing phase the concentration of the offsets increases significantly. So, when we increase voltage applied to vibrator, we can see synchronization of AE offsets with external forcing.

From the results of DFA analysis of time intervals between consecutive AE bursts, we can see that long-range correlation and scaling features of AE undergo clear changes under

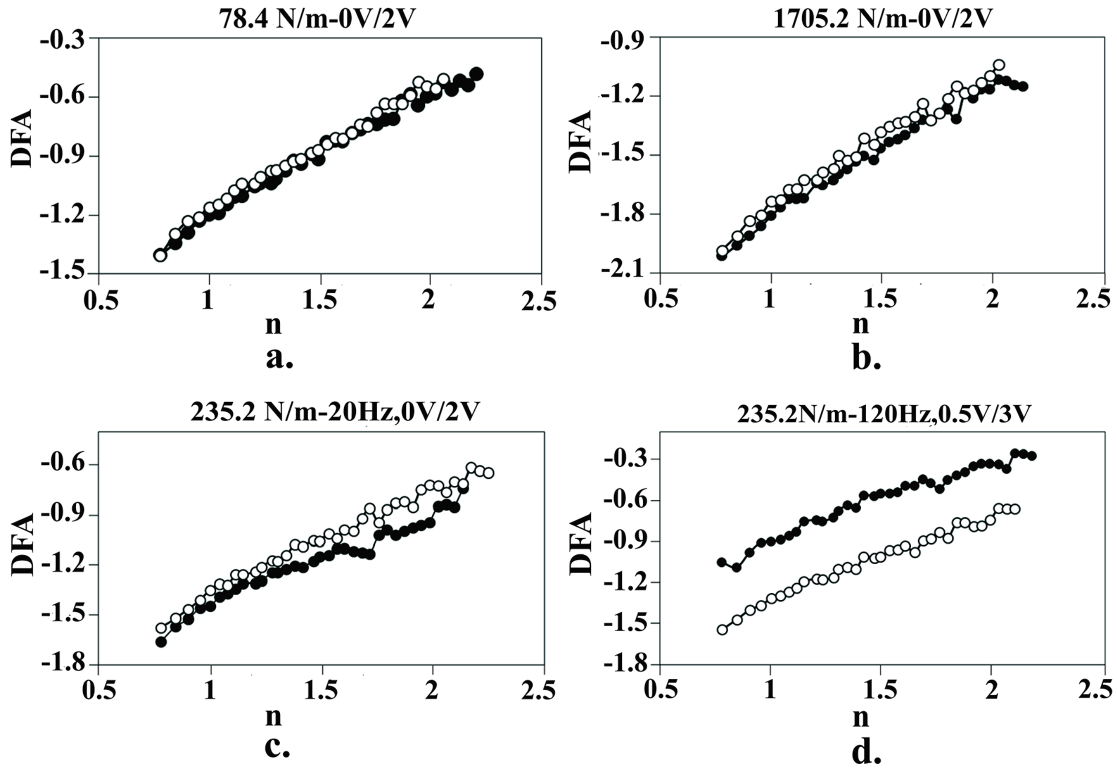

Fig.2. DFA analysis of interevent times of AE events: white circles –natural conditions 0V, black circles – applied voltage 2V on 20Hz vibrator; a) spring stiffness 78.4 N/m, b) spring stiffness 1705.2 N/m; spring stiffness 235.2 N/m: c) white circles –natural conditions 0V, black circles – at applied voltage 3V and frequency 20Hz on 20Hz vibrator; d) applied frequency 120Hz on 20Hz vibrator: white circles – voltage 0.5V, black circles – voltage 3V.

external influences (applied different voltage and frequency). In the present research DFA was accomplished at a polynomial fitting p=2 (Fig. 2).

Results of RP analysis show qualitative changes in the extent of regularity of AE emission. From RP plots we can see recurrence structures at frequencies of 20-40 Hz (at spring stiffness 235.2N/m and forcing intensity 0.5V, 1.5V, 2V). The recurrence structures are not clear for spring stiffness 78.4 N/m and 1705 N/m and the plots are similar to RP of random sequences. Exactly, we observe changes caused by mentioned above factors (Fig. 3).

Conclusions

Data sets of AE interevent times recorded in laboratory stick-slip experiments analyzed. Data sets were collected at different applied to vibrator voltage and frequency. It was found that stick-slip regime takes place at relatively low velocities of movement and at low stiffness. Results of DFA and RP analysis indicate both quantitative and qualitative changes occurred in the extent of regularity of stick slip process under different external influences. This experimental data can model synchronization of micro-seismicity under weak external forcing (tides, reservoir load-unload).

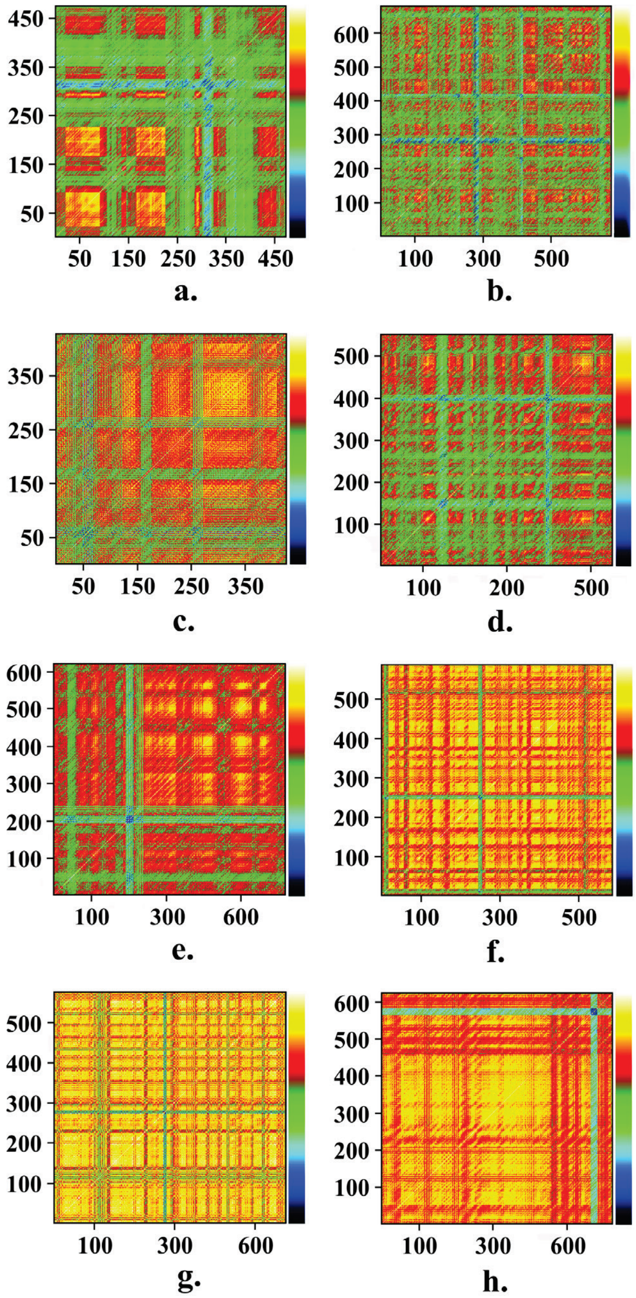

Fig. 3. RP analysis of interevent times of AE events: natural conditions – 0V, applied voltage 2V on 20 Hz vibrator; a, b) spring stiffness 78.4 N/m: c, d) spring stiffness 1705.2 N/m; spring stiffness 235.2 N/m, applied frequency 20 Hz on 20 Hz vibrator: e) voltage 0.5V, f) voltage 2V; and applied frequency 40 Hz on 20 Hz vibrator: g) voltage 0.5V, h) voltage 1.5V.

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გეოფიზიკა

სტიქ-სლიპ პროცესის აკუსტიკური ემისიის პირველადი ანალიზი გარე ზემოქმედების დროს

თ. ჭელიძე*, ე. მეფარიძე, ა. სბორშჩიკოვი**, ნ. ჟუკოვა**, ი. დავითაშვილი§, დ. ტეფნაძე**, ლ. ლალიაშვილი****

**აკადემიის წევრი, ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, მ. ნოდიას გეოფიზიკის ინსტიტუტი, თბილისი, საქართველო*
***ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, მ. ნოდიას გეოფიზიკის ინსტიტუტი, თბილისი, საქართველო*
§საქართველოს ტექნიკური უნივერსიტეტი, თბილისი, საქართველო

წარმოდგენილ ნაშრომში შესწავლილია ლაბორატორიული ზამბარა-მცოცის სისტემის მექანიკური გარე ზემოქმედების დროს აკუსტიკური ემისიის ცუგებს შორის (დროების ინტერვალების) არაწრფივი თვისებები. სტიქ-სლიპ აკუსტიკური ემისიის ექპერიმენტები ჩატარდა სამი ტიპის ზამბარის გამოყენებით (78,4 ნ/მ, 235,2 ნ/მ, 1705,2 ნ/მ). სენსორზე მიეწოდებოდა სხვადასხვა ძაბვა და 5-120 ჰც დიაპაზონის სიხშირე. აკუსტიკური ემისიის ცუგებს შორის დროის ინტერვალების ანალიზისთვის გამოყენებულ იქნა შემდეგი მეთოდები: ტრენდმოცილებული ფლუქტუაციის მეთოდი (DFA) და რეკურენტული გამოსახულების ანალიზი (RP).

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