UTILIZING OF ULTRASONIC EMISSION TO THE PREDICTION OF ROCK SAMPLE INSTABILITY

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ABSTRACT
The evaluation of stress-deformation stage of rocks, mainly time prediction of the origin of extensive brittle fracturing, belongs to the present important tasks of geomechanics. Laboratory results obtained are very important for the assessment of the origin of natural earthquakes as well as induced seismic events.
Laboratory experiments were oriented to the evaluation of the possibility to predict the time of the total fracturing of the rock samples subjected to the uniaxial loading. The sandstone samples were studied. In all experiments the ultrasonic emission was recorded. Time series of ultrasonic emission were analyzed by autocorrelation method.
It was found that during the fast rock sample loading the ultrasonic emission could be observed when 65% of total strength of the material is exceeded. Following parameters of the course of autocorrelation function were used:
- the first value of autocorrelation coefficient R(1)
- the number of positive autocorrelation coefficients (correlation radius)
- the trend of autocorrelation function according to linear time dependence.
For the short term rock sample loading, after the crossing of the 90% of the total strength of the material, the significant increase the value of correlation coefficient of linear approximation are observed. The dependence of the autocorrelation function is nearly linear. It means that the value of the first autocorrelation coefficient R(1) increase as well. The correlation radius at different values of acting load (starting from the 90% of strength limit) however is nearly the same.
For the cyclic loading, in the case of second cycle, the autocorrelation methods can be applied, due to the Kaiser effect, after the maximum acting stress of the first loading cycle is exceeded.
The nature of the ultrasonic emission originating during short-term test is influenced mainly by the response of the sample to acting force. During long-term test the parameters of ultrasonic emission reflect rheological properties of rocks sample.
Results obtained under laboratory conditions could be applied to seismoacoustic investigation of rock burst occurrence.

KEYWORDS: Ultrasonic emission, loaded rock samples, prediction of total rupture, autocorrelation analysis, stress- strain state of rocks.

INTRODUCTION

One of the present significant tasks of geomechanics is the assessment of the stress-strain state of rocks, and especially forecasting the occurrence of extensive brittle fractures.

A number of methods and procedures are used to study deformation processes in rock massifs and in forecasting sudden releases of seismic energy. In this paper, we deal with a laboratory method of assessing the instability of rock samples based on monitoring and interpreting ultrasonic emissions from loaded rock samples.

Deformation processes, taking place in-situ, can be modelled by laboratory methods under simplified conditions. To be specific, the system of loading can be chosen, and the reaction of various types of rocks to the loading can be studied. Although a considerable simplification of actual deformation processes is involved, nevertheless, significant similarity between laboratory experiments and phenomena occurring in the natural environment can be observed. This similarity is in the same manner of seismic energy release, and also in the same form of the distribution functions, e.g., energy-frequency function, time distribution of the after-shock sequence, etc. (Shibazaki & Matsu'ura, 1988). The parameters of these distribution functions are not random, but depend on the physical (material) properties of rocks (e.g., granularity, primary degree of failure) and on the level of stress. The problem of similarity between the sample and natural conditions is in substantially faster changes of the state of stress under laboratory conditions, and also in the finite dimensions of the samples.

The methods of forecasting total failure of rock samples are based on analyzing the distribution of the acoustic emission, and mostly require comparing these distributions under various loads. The results of the experiments we conducted and the study of time series, based on the application of autocorrelation analysis, indicate, however, that the changes in the autocorrelation coefficients provide absolute criteria for determining the warning state of sudden failure without comparison with the preceding state.

CORRELATION ANALYSIS OF UE SEQUENCES

In assessing the UE from a loaded sample using correlation analysis, it is possible to select the time series of the number of UE events, occurring per unit time (acoustic rate). We shall start with the simple hypothesis of a loaded rock sample under uniformly increasing load as the model of the failure process of a rock massif. If we then wish to compare the processes of sample failure under various loads, we can chose equal long time intervals, corresponding to such loads, and perform the autocorrelation analysis within them independently. To be able to compare the results of the autocorrelation analysis in different intervals, it is necessary to compute the frequency sequence of UE events so that the average value of the number of events of all series being compared is the same. This can be done by choosing different lengths of the elementary time steps, with respect to which the frequency of the events is being computed in the individual loading intervals.

Under low stress, inhomogeneities of the stress field at pre-existing fractures and at the edges of grains are generated only gradually. In these source regions, isolated at the beginning, the strength of the material is exceeded locally and through UE the expansion of existing fractures can be observed, as well as the generation of new micro-fractures. Low values of autocorrelation coefficients are usually observed, indicating a more or less random occurrence of UE events. As the stress increases, also the number of places where the strength has been exceeded grows locally, and the separate fractures or source regions of failure may affect one another. The values of the initial autocorrelation coefficients increase, the interval of correlation increases, and a tendency to order the autocorrelation coefficients along a straight line is usually observed.

EXPERIMENT

The sandstone samples were collected in the region of the Kladno coal mines and come from a depth of 400 m below the surface, i.e. from a sandstone bank overlying the main coal seam. The Kladno coal basin belongs to the Central Bohemian region of the limnic carbon formation of the Bohemian Massif. The sandstone samples displayed clastic components, 0.25 – 0.50 mm in size, with sporadic occurrence of millimeter size grains. A minor feldspar component occurs in trace quantities, as do fragments of slate, lydite and spilite rocks. The rock structure is psamitic of a basal nature and with a fine-grained matrix: the individual grains are dispersed in the matrix and are not in mutual contact. Prism-shaped samples, 100 x 100 x 200 mm in size, were measured.

The rock samples were loaded uni-axially. The basic deformation parameters of the studied sample were measured in the course of the loading: the acting load, and locally, at two measuring points (at half the height) the longitudinal and transverse deformations were measured by two cross strain gauges. The data from the gauges were processed by a Hottinger Baldwin digital multi-channel tensometric bridge. Ultrasonic activity was monitored by 4 broadband ultrasonic emission pick-ups, type WD, produced by the firm PAC. A broadband amplifier, amplification 40 dB, amplified the signals. A special PC interface card SF 41 recorded the ultrasonic emission. The card enables independent and continuous recording of the ultrasonic emission in the frequency range of 5 kHz to 1.5 MHz. The SF41 device can record the arrival time of the signal in the separate channels with accuracy as high as 125 nanoseconds, the integral value of the rectified signal (this value is proportional to the energy) and other parameters (Lokajíček & Vlk 1996).

The sandstone samples were loaded in two loading cycles. During the first, the samples were loaded to about 85% of their compressive strength at a rate of 0.5 MPa/min. During the second loading cycle, the load close to that in the first cycle was quickly achieved by applying a quadruple loading rate, i.e. 2 MPa/min, and the sample was then loaded at the rate of 0.5 MPa/min as in the first loading cycle. During the second cycle the activity of the ultrasonic emission confirmed the Kaiser effect. Until the previous value of the acting load had been achieved, only minimum activity of the acoustic emission was observed.

ASSESSMENT OF THE STATE OF STRESS BY AUTOCORRELATION ANALYSIS

The state of stress of the rock samples were assessed and namely the time of the future total failure was estimated by determining the changes in the parameters of the autocorrelation function of the sequence of emitted ultrasonic signals.

The experiment was conducted under rapid loading of the sample. Previous experience (Rudajev et al. 1998) showed that the results of the auto-correlation analysis under rapid loading do not display the unique trends observed in the slow tests. The reason is that the short-term loading experiment involves the immediate reaction of the samples' material to the acting force without the effect of the structure and especially the rheological properties of the rock being manifest.

In the first loading cycle, a constant loading rate, corresponding to 85% of the compressive strength, was achieved by applying additional load during approx. 2200 s. The sample was kept at this level of the state of stress for 800 s. Thereafter the sample was rapidly unloaded in the course of 600 s. The loading, corresponding to the strain and increase of the cumulative number of events in the course of the

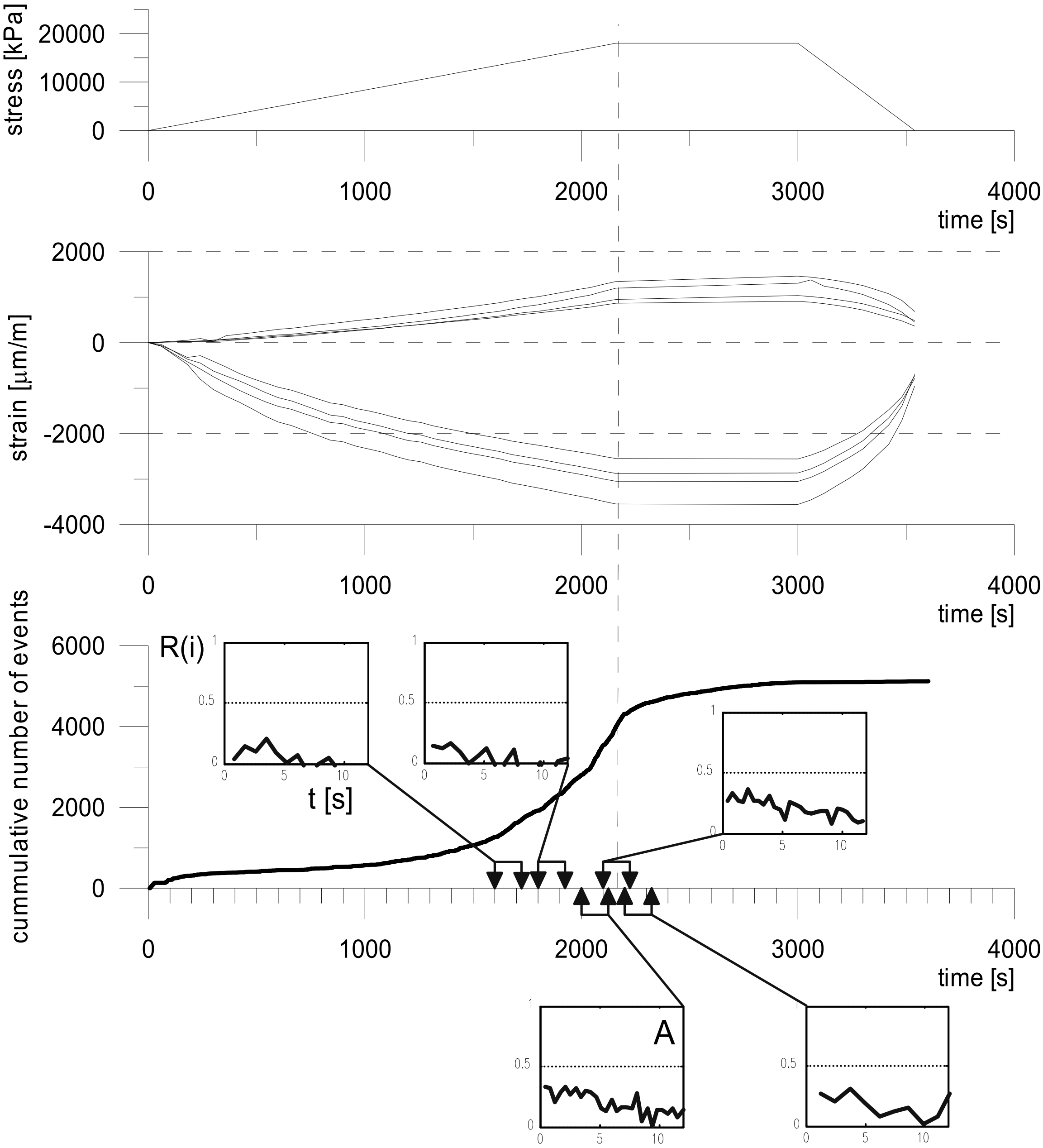

Fig. 1 Cyclic loading test – first cycle, sandstone. Upper graph – loading, middle graph – longitudinal and transverse relative deformations. Lower graph – increase of cumulative frequency of relative deformations with time (load). The autocorrelation function is shown for selected sub-intervals.

whole cycle, is shown in Fig. 1. Correlation functions of the recorded sequences of UE events were computed in select intervals. These curves indicate that the parameters of the autocorrelation function display no pronounced trend. The parameters of the autocorrelation function, corresponding to the interval before maximum state of stress was reached in the first cycle, i.e. 18 MPa (87.5% of compressive strength) are given in Table1. The curve of this autocorrelation function is marked A in Fig. 1.

The second loading cycle lasted 1100 s and ended with total failure of the sample. At the beginning of this cycle, a loading rate of 2 MPa/min was applied up to a load of 16 MPa (480 s from the beginning of loading). Further load was added until total failure at the rate of 0.5 MPa/min. The maximum load in the first cycle (18 MPa) was achieved after 720 s from the beginning of loading. The loading, corresponding strain and the autocorrelation functions in selected intervals are shown in Fig. 2. The intervals relating to the loading from the first cycle are marked B, C and D.

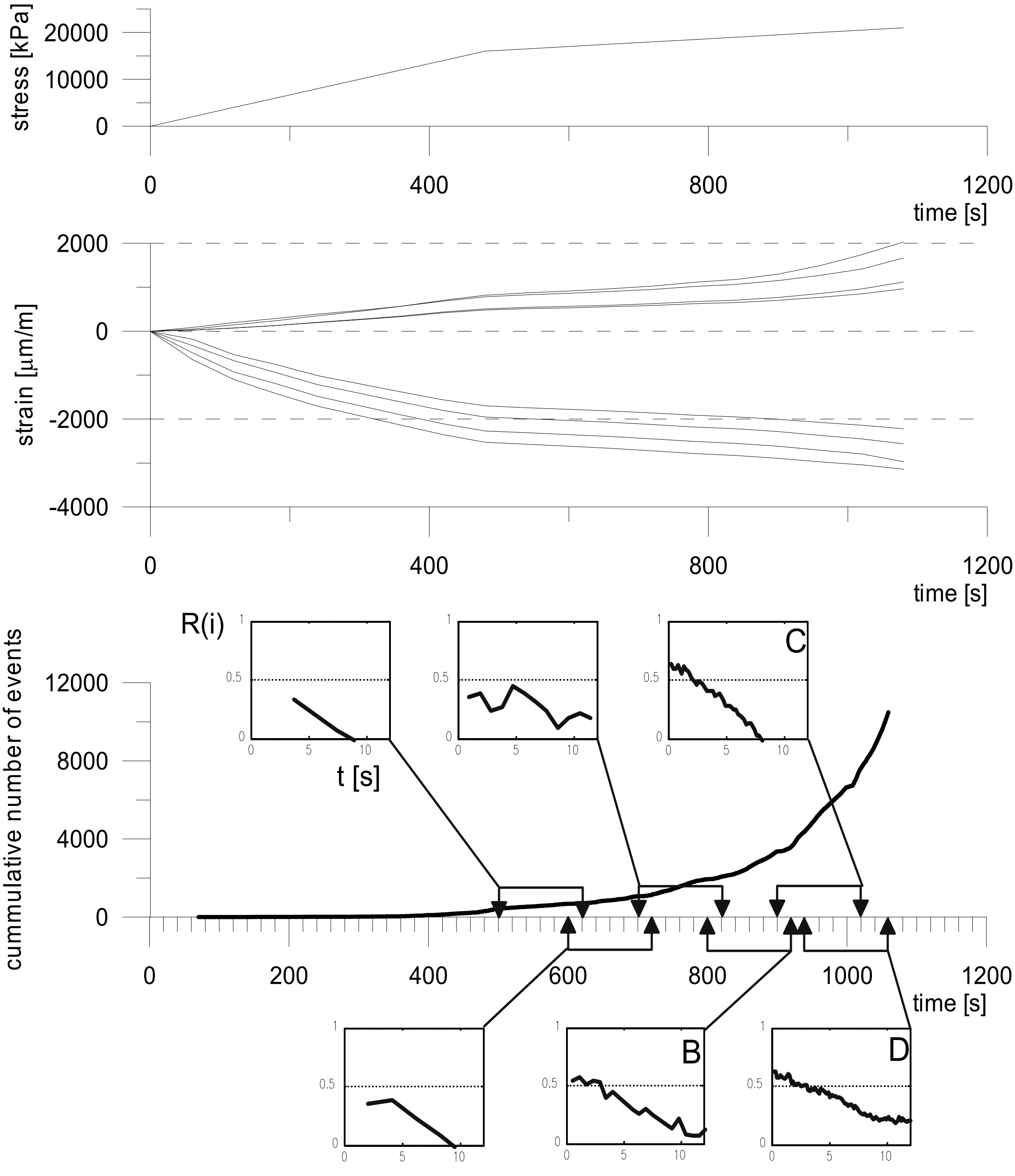

Fig. 2 Cyclic loading test – second cycle, sandstone. Upper graph – loading, middle graph – longitudinal and transverse relative deformations. Lower graph – increase of cumulative frequency of relative deformations with time (load). The autocorrelation function is shown for selected intervals.

The loading interval, from the beginning of the second cycle to time 750 s, is affected by the Kaiser effect, i.e. the number of UE events is relatively small and the autocorrelation functions do not provide information about the relation between the load and the UE. Table 1 gives the parameters of the autocorrelation functions for intervals B, C and D. The results indicate that the values of the correlation coefficient of the approximation line and the first values of autocorrelation coefficients R(1) in sub-interval A are significantly smaller than in the intervals close to total failure. Hence, these two parameters are of a precursory nature even under rapid loading.

Table 1 Parameters of the autocorrelation analysis for the sample of cyclically loaded sandstone (Figs 1, 2)

interval	beginning of interval	load σ	coefficient of correlation	correlation radius	*R*(1)
	sec	**(% of strength)**		**sec**	
		1st cycle			
A	2000	79.4	0.78	16	0.33
		2nd cycle			
B	800	88.9	0.97	13	0.55
C	900	92.9	0.99	9	0.64
D	939	94.4	0.98	16	0.63

CONCLUSION

The experiments concentrated on assessing the possibility of predicting the time of total failure of rock samples under uni-axial pressure by the means of autocorrelation analysis of the sequences of UE events recorded.

It was found that, under rapid loading of samples, the emission of ultrasonic signals increases once the load at the level of 65% of compressive strength is exceeded. The autocorrelation analysis of UE can only be applied after this load has been achieved.

The principal parameters of the autocorrelation function considered were the first values of the autocorrelation coefficients R(1), the number of positive autocorrelation coefficients (correlation radius) and the tendency of the autocorrelation function to depend linearly on time. This trend is expressed quantitatively in terms of the correlation coefficient of the approximation line.

The value of the correlation coefficient of the approximation line increases significantly after the load has reached 90% compressive strength, i.e. the autocorrelation function is nearly linear. The value of the first autocorrelation coefficient R(1) also increases. Under cyclic loading, it was found that the autocorrelation method could be applied to a number of UE events in the second cycle only after the maximum load from the first cycle had been achieved. The actual case mentioned involved the short-term cyclic test. The time from the beginning of loading in the second cycle until final failure amounted to 20 min.

The increase in the values of the autocorrelation coefficients and the tendency to their linear decrease is evidence of increased effect the individual signals have on one another, i.e. of the redistribution of stress in the sample which occurs after stronger UE events have been generated.

The conclusion drawn from testing the samples may be useful in field measurements connected with research into rockbursts, in which the seismoacoustic method is used.

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