Evolution of microseismicity parameters depending on geomaterial deformation stages

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Abstract. The paper describes the laboratory tests on deformation of specimens made of artificial geomaterials simulating rock mass composed of two alternating beds of different hardness and different bedding angles. In the course of loading, stresses, strains and microseismic emission signals are continuously and concurrently recorded. The analysis of the time–deformation curve is reflective of the step-wise behavior of deformation and allows determining features of change in parameters of microseismic signals at various deformation stages.

Propagation of deformation and failure in loaded rock mass initiates various nature fields: deformation, microseismicity and electromagnetic emission, temperature. Some recent researches focus on the analysis of deformation and strength characteristics of rocks in integration with signals of microseismic emission that is assumed an analog to seismicity in lab tests [1–5].

It is of the current concern to find deterministic connection between the parameters of different physical nature fields as it is helpful in prediction of rock mass damage (rock falls, rock bursts, earthquakes).

This study was aimed to analyze interaction and cross-effect of parameters of different nature fields: deformation, stresses and signals of microseismic emission (MSE) in specimens under loading of two types: uniaxial loading of geomaterial to failure; fluid-fracturing of equivalent geomaterial for prediction of initiation and growth of main fracture.

Figure 1. Specimens before the tests, bedding angle $\Psi = 0, 15, 30, 0, 45, 60, 75, 90^\circ$ (on the left); specimen with sensors to record signals of MSE (on the right).

I. In the first case, the test specimens were made of an artificial material to simulate layered rock mass composed of two alternate layers having different strengths and made of a mix of cement, sand, glue Neolit and water at varied ratios. The specimens were made as cylinders with the length of...
60 mm and the diameter of 30 mm. The bedding angle (angle between the axis of the cylinder and the normal drawn to the plane of beds (isotropy) was $\Psi = 0, 15, 30, 45, 60, 75, 90^\circ$. Figure 1 shows the pictures of specimens before the tests and a picture of a specimen with MSE sensors mounted.

The uniaxial compression of the specimens was applied up to failure at the movable jaw rate of 0.1 mm/min. During the tests, axial load and longitudinal and transversal deformation (change in the length and diameter, respectively) were continuously measured and filed using Instron sensors. Each tests series took not less than 3 specimens. The curves of the limit strength $\sigma_{\text{lim}}$, elasticity modulus $E_{\text{st}}$ and bedding angle $\Psi$ were plotted for each type of geomaterial (Figure 2).

![Figure 2](image-url)

**Figure 2.** (a) Limit strength and (b) elasticity modulus of geomaterial under uniaxial compression versus bedding angle $\Psi$.

It follows from the test data analysis that the degree of anisotropy essentially influences deformation and strength characteristics of the specimens made of an artificial geomaterial with a layered structure. When $\Psi = 0$ and $90^\circ$, the limit strengths differ not more than by 3% and the elasticity modulus not more than by 4%, and the both values are higher at $\Psi = 0$ than at $\Psi = 90^\circ$. The limit strength and elasticity modulus assume the lowest values when $\Psi = 45^\circ$. In the range between 0 and 45 deg, the values of the discussed characteristics gradually decrease at the ratios of maximum/minimum strength limit and elasticity modulus of 2.8 and 1.8, respectively.

Concurrently with the measurement of stresses and deformation, MSE signals were recorded in the test. Below, the authors analyze MSE signals in the specimens with the highest difference in the strength and deformation characteristics, i.e. the specimens with the bedding angles of 45 and 90 deg.

Figures 3a and 3b present $\sigma$-$\sigma_{\text{lim}}$-$t$ curves for specimens nos. 4 and 9 with the bedding angles of 90 and 45 deg, respectively, where $\sigma$ is the current stress, $\sigma_{\text{lim}}$ is the uniaxial compression strength limit, $t$ is the time, s. Specimens nos. 4 and 9 have $\sigma_{\text{lim}} = 17.3$ and 6.2 MPa, respectively. The stress and time curve is reflective of the step-wise behavior of deformation.

Figures 3c and 3d show $\sigma$-$\sigma_{\text{lim}}$-$t$ curves for specimens nos. 4 and 9 from Figures 3a and 3b in more detail, at deformation stage 3. The dashed lines and figures point at the moments of MSE recording. Figures 3e and 3f give $\sigma$-$\sigma_{\text{lim}}$-$t$ curves for the specimen with the bedding angle of 45 deg for the time intervals 0–350 s and 350–500 s, respectively, for the better observability.

Figures 4a and 4b depict MSE signal recorded at point 1 in Figure 3e, and Figure 5—at point 2 in Figure 3f.

At the first deformation stage between zero load and $\sigma$-$\sigma_{\text{lim}} = 0.2–0.25$, the specimens undergo compaction and the elasticity moduli have lower values than in the subsequent stage, probably, due to damage of small heterogeneities at the faces of the specimens, or owing to closure of pores, micro-joints etc. At deformation stage 2 (elastic deformation) between $\sigma$-$\sigma_{\text{lim}} = 0.2–0.25$ and $\sigma$-$\sigma_{\text{lim}} = 0.55–0.65$, the elasticity moduli grow and become steady-state. MSE generated at this time has the acceleration of 7.0 m/s$^2$ (Figure 4a) and a wide frequency band (Figure 4b).

Deformation stage 3, from $\sigma$-$\sigma_{\text{lim}} = 0.55–0.65$ to $\sigma$-$\sigma_{\text{lim}} = 1$, features an essential reduction in values of the elasticity moduli, the material undergoes restructuring and micro-defects appear. The stress–time curve has horizontal segments and segments where the stresses somewhat decrease though the specimens are subjected to “stiff” uniaxial compression at the jaw rate of 0.1 mm/min. according to [6], when $\sigma$-$\sigma_{\text{lim}} = 0.5$, deformation is essentially nonuniform, with localization zones that
shape a main fracture under the continued increase in the loading up to the limit strength value. At \( \sigma = \sigma_{\text{lim}} \) the stress–time curve is flattened, the values of \( \sigma \) decrease later on, and the main fracture is generated in the specimen.

\[
\sigma / \sigma_{\text{lim}}, \text{MPa} \\
\sigma / \sigma_{\text{вр}}, \text{МПа} \\
\sigma / \sigma_{\text{lim}}, \text{MPa} \\

t, \mu\text{s} \\
\sigma / \sigma_{\text{lim}}, \text{MPa} \\

t, \text{s} \\
F, \text{kHz} \\
\text{Acceleration, m/s}^2 \\
\text{Spectral density, m/s}^2/\text{Hz} \\
\text{Frequency, kHz} \\
\text{Frequencies shift to lower values of the frequency spectrum, and the spectrum becomes narrower (Figure 5b).}
\]

Figure 3. Stress–time curves for specimens (a) no. 4 and (b) no. 9; the same for specimens (c) no. 4 and (d) no. 9 at deformation stage 3 with MSE recording (figures and dashed lines); the stress–time curve for the specimen with the bedding angle of 45 deg in the time intervals of (e) 0–350 s and (f) 350–500 s. Squared 1 and 2 mark the times of MSE recording.

Figure 4. (a) and (b) MSE signal recorded at point 1 in Figure 3a.

Later on the MSE signal amplitude grows (Figure 5a) and its acceleration reaches 46.0 m/s\(^3\). Frequencies shift to lower values of the frequency spectrum, and the spectrum becomes narrower (Figure 5b).
The revealed mechanisms are most pronounced in the specimens with the bedding angle of 45 deg, probably, due to stronger deformation of these specimens, and re-structure of the geomaterial and initiation of new defects is more intensive in this case.

II. Oparin et al [6] studied the processes of deformation and failure in a material during its fluid-driven fracturing using three methods: speckle measurement of microstrains, acoustic emission and high-speed filming. The physical model was a parallelepiped 200×167×145 mm with an internal hole for fluid fracturing. During the tests, viscous fluid (plasticine) was fed in the hole at a constant flow rate.

The researcher analyzed the test results from various standpoints and drawn some conclusions:

— from the standpoint of time evolution of microstrains on the side surface of the specimen, in the area where the fluid-drive fracture reaches the surface. It was found that the field of microstrains of the material changed as the fracture grew. This means feasibility of studying internal destructive processes in a material by recording microstrains on its surface;

— from the viewpoint of time change in acoustic emission. It was found that MSE signal of the largest amplitude and frequency was recorded at the moment of the fracture initiation. The fracture propagated step-wise. When the fracture reached the material surface, strong low-frequency signal was recorded;

— in the context of interaction of these physical fields with the processes of the fluid fracture growth using the test video film.

Conclusion

The features revealed in the behavior of deformation and strength characteristics and MSE signals are reflective of clear inter-relation between them, which allows judging on destructive processes inside a test object. The research findings are useful for early prevention of tectonic activity and in monitoring of jointing in rock mass.

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