Change in the elastic and rheological properties of structurally heterogeneous geomaterials under multiple weak impacts

VP Kosykh
Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
E-mail: v-kosykh@yandex.ru

Abstract. The paper discusses the lab-scale studies of the effect exerted by multiple weak impacts on creep in a sample of an equivalent geomaterial additionally subjected to static compression. It is found that under weak impacts for a long time, the creep strain rate first grows and then lowers down to a stationary value. Weak impacts initiate P-waves in the sample. The P-wave velocity increases non-monotonously with growing number of impacts. The change in the elastic and rheological properties of the material is connected with the change in its internal structure under the influence of external loading.

1. Introduction
Mechanical behavior of geomaterials depends on the loading conditions and can vary in deformation. An illustration of this statement is creep strain in rocks and rock relaxation from stresses under long-term effect of static loads [1–3]. Cyclic loading in the course of time lead to fatigue failure of geomaterials, and blasting induces alternating response of rocks, which means the change of sign of effective stresses in rock mass after blasts [4–6]. As a result of blasting, the internal structure of rock mass (blocks, grains) undergoes re-packing and comes to a new balance of equilibrium different from the previous conditions. Behavior of deformation in geomaterials can also vary under the action of weak impacts, for instance, vibrations. The latter can promote stress concentration and relaxation at discontinuities, which predetermines fracture [7, 8]. Microseismicity can trigger and initiate earthquakes [9, 10].

Geomaterials composed of elastic blocks and grains capable to sleep along their boundaries and possessing internal friction can accumulate and release the elastic energy in certain conditions of loading [11–14]. For examples, long-term and weak impacting on the background of static loading can induce periods of energy accumulation and liberation in samples of geomaterials [15, 16]. The medium evolves from equilibrium to equilibrium, and the properties of the medium change as well.

This paper describes the experimental studies into multiple weak impacts on the development of creep strains and on the P-wave velocities in a cylindrical sample of an equivalent geomaterial.

2. Experimental procedure
The tests were carried out with a tube-shaped sample made of a mixture of water, eco-rubber and quartz sand 0.3 mm in size at a ratio of 28:100:100. The sample had a total length of 120 mm, and the effective length was 100 mm. The external and internal diameters were 37 and 15.4 mm, respectively.
The longitudinal static deformation of the sample was measured using foil strain gauges BF100-3AA with a spacing of 3 mm and resistance of 10 Ohm. The dynamic distortion was determined by semiconductor strain gauges HU-101B-350 with a spacing of 5 mm and resistance of 350 Ohm. The pacing of the gauges glued on the sample was 24 mm as in Figure 1.

![Figure 1. Arrangement of strain gauges on the sample.](image)

The complex loading testing machine enables examining evolution of strength and deformation characteristics in samples of geomaterials subjected to static compression and/or twisting with simultaneous weak impacting. The loading assembly of the testing machine is schematically shown in Figure 2. Sample 3 is fixated in clamps 1 and 4. Left-hand clamp 1 is mounted on the vertical plate, via membrane 2, and is centered using a fluoroplastic sleeve. Right-hand clamp 4 is also centered using a fluoroplastic sleeve, and transmits the compressive load from screw 5 via a ball to sample 3. The vertical plates are rigidly set on massive mase support 6. In the tests, the sample is subjected to impacts delivered at a preset energy to the shank of clamp 1. The measurement is performed by L-Card LTR-EU-8-2 crate equipment. The testing machine is in detail described in [17].

The testing machine and the sample were placed in a thermostat with a maintained temperature of 25±0.1°C and were cured for two days. Then, the sample was loaded using screw 5, and the compressive force and induced longitudinal deformation were recorded as functions of time. From the obtained evidence, the stress–compressional strain $\varepsilon_0$ curves were plotted (Figure 3). The value of $\varepsilon_0$ was determined as a mean average of deformation data from 4 foil strain gauges (Figure 1).

The maximum stress in the loading tests was 18.4 MPa. The loaded sample was aged for 1100 hours and, then, was exposed to impacting for 1100 hours more. During the testing, the static deformation and the effective stresses were continuously recorded. The impact frequency was 1.2 Hz and the impact energy was 0.08 J.
3. Results and discussion

The total strain of the sample, after averaging of readings from 4 gauges is composed of the initial strain $\varepsilon_0$, which arises immediately upon application of the compressing force, and the slowly
growing creep strain. The value of $\varepsilon_0$ at the maximum stress is constantly $1.8 \times 10^{-3}$ (Figure 3), and the time variation in the creep strain $\varepsilon_t$ and the creep strain rate $\dot{\varepsilon}_t$ is shown in Figures 4a and 4b.

It is seen in Figures 4a and 4b that the strain $\varepsilon_t$ increases at a varied rate. The maximum rate is observed in the beginning of the test, then, with time, the strain rate decreases to $5.8 \times 10^{-12}$ l/s in 600 hours. In next 500 hours (from the point A in Figures 4a and 4b), the creep strain rate fluctuates in a range of $\dot{\varepsilon}_t$ l/s.

The loading tool possesses finite stiffness, and the change in the strains goes with the appropriate change in the stresses (Figure 4c). As the strains increase, the stresses decrease. The stress curve exhibits some waviness as per the creep rate fluctuations.

After holding the sample under compressive loading for 1100 hours, weak impact were inflicted again on the left-hand clamp. This moment is marked by A in Figure 4. The impact induce elastic vibrations in the sample–testing machine system. The sample experiences alternating decaying dynamic deformation as a result. The values and shapes of these strains, measured by a semiconductor strain gauge glued on the sample are shown in Figure 5.

The dynamic impacts together with static compression change the behavior of the creep strain in the sample. It is seen in Figure 4a and 4b that the first impacts (point A) cause a jump of the strains by a value of the order of $10^{-6}$. Then the creep strain grows at a varied rate. First, within 300 hours of impacting (time range from 1100 to 1400 hours in Figure 4a and 4b), the strain rate grows, then passes the maximum, decreases and gradually stabilizes. In the time interval from 1700 to 2100 hours, the average creep strain rate is $5.8 \times 10^{-12}$ l/s, which is similar to its value obtained without impacting, while the compressive stress decrease from 14 to 13 MPa (Figure 14c).

Gradual accumulation of creep strains is reflective of transformation of the internal structure of the sample as a consequence of damage accumulation. Such transformation can change the mechanical properties of the material, for instance, its elasticity modulus and, consequently, the P-wave velocity.

At the second stage of the tests, we analyzed the P-wave velocities in the sample. Under every impact, an impulse of elastic deformation propagates in the sample (Figure 5). This value was measured by 4 semiconductor strain gauges (Figure 1) distributed along the sample length. The oscillograms recorded by the gauges were shifted in time. By the values of these shifts and using the known spacing of the gauges, we calculated the P-wave velocities in the sample by the procedure described in [15].

The P-wave velocities versus time are demonstrated in Figure 6. The zero time in the plot agrees with the beginning of impacting (point A in Figure 4).

Apparently, the P-wave velocity changes with increasing time of holding the sample under loading and with growing number of impacts. In the first 700 hours, the P-wave velocity increase by 10%, then drops and starts growing again.
4. Conclusions
1. The creep deformation behavior in the sample of an equivalent geomaterial subjected to static compressive stresses changes under the influence of weak impacts. The creep strain rate first increases, passes the maximum and drops to a stationary value.
2. The P-wave velocity in the sample exposed to static compressive stress and multiple weak impacts grows non-monotonously with increasing time of the test.

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