ELECTROMAGNETIC EFFECTS IN LOADED MARBLE

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Introduction

This work is devoted to experimental studying of rocks deformation and destruction processes under conditions of uniaxial compressive loading and source of electromagnetic field. Numerous works on induced seismicity have become a base for such experiments arrangement. In these works changes of seismic field due to the underground nuclear explosions, fluid industrial waste injection to borehole located in seismic area, variation of water level in large water storage, mining operations etc. have been considered. At the end of last century first mentions about induced seismicity from sources of powerful electromagnetic field have appeared. Pioneer results on the effect of power electromagnetic pulses produced by magnetohydrodynamic (MHD) generators to test the seismic activity in regions of Bishkek and Gharm testing fields were obtained in Russia and Kyrgyzstan (UIPE, OIVTRAN) [Tarasov & Tarasova, 2004]. It is very important that such external impacts always trigger the seismic events of minor magnitude ($M<5$). Such power actions are adequate for civil and scientific purposes only. At the present time the results of Tarasov have been confirmed by other works, which involve new approach to the experiment with MHD generator as well as the fresh data on powerful electromagnetic soundings [Sychev et al, 2008]. It is evident that the similar effect must occur in loaded rock specimens, when the pulses of electromagnetic fields act on them in addition to the main mechanical loading. The method of acoustic emission (AE) measurements allows getting information about aforementioned effect during laboratory experiments. This work is devoted to the simulation of phenomenon of weak seismicity triggering by actions of impulsive physical fields (so-called energy influence, EI). It should be noted, concerning terminology, that the signatures of the electromagnetic influence on defects accumulation in the loaded geological medium are described as seismic, seismic-acoustic or acoustic emission response, depending on the scale. It is well-known that strong enough electric and magnetic fields have an influence on plastic straining of nonmetallic solids (particularly on the plasticity of alkali-halogen crystals [Urusovskaya, 2000]. Effects such as changes in internal friction and conductivity under electric fields were in a focus of the quoted works. A relationship between these effects and dislocation motion has been revealed. According to the previous works some increment of plasticity occurs when the strength, E, of the electric field is of the order of 10-100 kV/m at least [Urusovskaya, 2000], or when the magnetic inductance, B, exceeds 0,1 T. One can assume that EM fields of such minor values of E or B components may contribute to inelastic straining (microfracture) which can evolve in micro- and meso-scales of length. So, temporal variations of AE activity may be considered as a signature of the effect of physical fields applied externally, i.e. as induced (or triggered) changes in a rate of accumulation of structural defects, microcracks in particular. In our previous experiments [Zakupin et al., 2006, 2009; Bogomolov & Zakupin, 2008] we have revealed the effect of AE activity increment stimulated by external electromagnetic fields, which indicates medium's factors effect on crack formation. AE activity due to EM field pulses occurs, provided by the fixed compressive loading over tested rock specimens, that is from 0,75 to 0,95 of the maximal value (fracture stress). We have tested a number of specimens, made of materials with different elastic and piezoelectric properties: granodiorite, quartzite, granite, halite, and zirconium oxide ceramic. Our previous laboratory works were relied on experiments in the conditions of quasi-static compressive loading influence on a specimen. It was conditioned by work specificity on the spring press UDI [Stavrogin, 1979]. In addition tensometric measurements either have not been conducted, or they have been too coarse, stress has been laid on AE. Since 2009 year we have been expanding the ideas about responses to EI by the arrangement of experiment in new conditions. Measuring of tensometric parameters (loading, longitudinal and lateral deformations) is integral part of laboratory experiments, so long as specified parameters characterize deflected mode of a test specimen. Note, that the system of AE data gathering has passed upgrade both by quality of record signals, and by registration speed (several hundreds of acts per second) and system sensitivity. Using the new system of loading (lever press) and material (marble versus granitoids has apparent semibrittle properties) is a logical development of the experiments we have conducted earlier. The experiments have been held at Bishkek Geodynamic Research Center - RS RAS.

Experimental technique. At the present time tests in the RS RAS are conducted with the lever press UDI-L (fig.1), providing a loading up to 35 tonnes and noiseless conditions of experiment implementation, including experimental sessions with constant uniaxial compressive loading and with loading, increasing by addition of weight on the long lever arm.

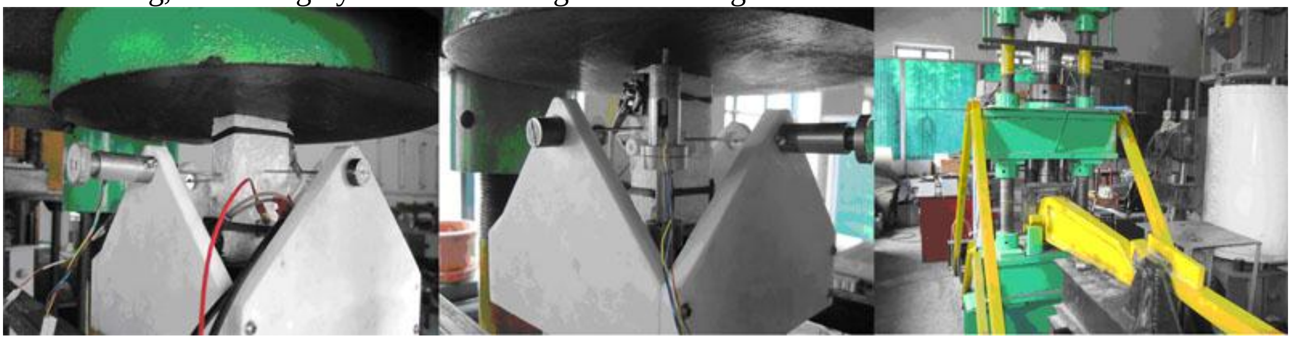

Fig.1 Photos of the lever press and specimen with sensors

This testing method (uniaxial compression) has been chosen because induced by it stress state in a specimen with prevalence of compression stresses in single direction is to a certain extent similarly to state of massifs, where tectonic stresses prevail over lithostatic stresses [Kropotkin et al, 1987]. From the point of view of mechanic of continua uniaxial stress state is supposed to be elementary and all rocks investigations always begin from it. Besides, this testing method is technically more simply realized. Specimen material is much more pliable than material of which the pressing soles are made; that is why a specimen compression may be supposed to occur between perfectly rigid, warp-free planes. Lateral surface of a specimen is free of stresses. But on its bearing faces – ends, by which pressure has been passed to it, conditions are defined by presence or lack of grease on the contact surfaces of specimen and press. In our case direct contact of specimen bearing faces and press plates is realized by lack of grease. On these surfaces strong bearing friction is created; possibility of mutual slipping of contact surfaces elementary parts is practically excepted. In a specimen complex (non-homogeneous) stress is created. Specimen volume elements located close to end faces are in a state similar to lithostatic compression. On the end faces edges an area of stress concentration with maximal difference of normal compressive stresses of diverging directions is formed. In this connection, here maximal tangential shearing stresses build up and cleavage cracks are possible. In the middle horizontal section of a specimen near its center irregular uniform compression with vertical component prevalence is observed, that brings to tensile deformation of a specimen in horizontal direction. It has to lead to both cleavage cracks and bond-failure cracks formation here. In testing of geomaterials for uniaxial compression main methodical difficulties arise when deforming in the range over ultimate stress. These difficulties due to rather high brittleness of rocks, it is most appreciably revealed by uniaxial compression. Just so in the new series of experiments marble has been chosen, not granite for example. For marble specimens' tests Chichkan deposit (Kyrgyzstan), in the form of a parallelepiped with the following dimensions 100x50x25 mm^3 and 80x40x20 mm^3 have been selected. Linear dimensions deviate from specified within ±0,1 mm, deviation from parallelism does not exceed 0,1 μm. In the experiments AE signals have been registered with piezosensors in the frequency range from 80 kHz to 2 MHz. The equipment has worked in standby mode, launch has been executed by the set threshold value exceeding of a signal on the output of measuring AE canal. Signals have been digitized by high-performance eight-canal unit of ADC USB 3000 and written onto hard disk of personal computer in automatic mode. More detailed description of experiment arrangement and methodology of wideband AE measurements are given in [Zakupin et al., 2006]. Note importance of registration and visual monitoring of AE signals form for rejection of industrial noise in AE events flow. To reject them great work on viewing of tens of thousands of AE events wave forms has been conducted. It has provided high quality of data for mathematical treatment and interpretation. As sensors for deformation (longitudinal and lateral) and loading registration the linear-variable differential transformers LVDT, designed for linear displacements measurements, have been used. Methodology of these sensors applying for deformations measurement is described in detail in [Zakupin et al., 2012]. Effect by electromagnetic pulses is executed by supply on graphite electrodes located on the side faces of a specimen (fig.1). Experiments under the conditions of only mechanical loading action, and also of external source of EM field effect, have been conducted. In the capacity of model sources of EI the rectangular pulse generator G5-54, capacitor discharger (CD), creating electric pulses with steepness of edge about 1 μs and peak voltage about 1kV, and also inductance coil for magnetic field creation have been used. In the case of CD effect it has been used the scheme of 10 dischargers following in 15 second intervals (one or two times in hour: CD10 and CD20). Amplitude of pulses has been chosen 800V stably. In the case of G5-54 generator the following parameters have been set: positive polarity, frequency 2 kHz, duration 60 μs, amplitude 50 V. Duration of generator operation has been chosen 1 hour. When combined exposure in 10 discharges of capacitor unit has been supplied after half an hour of generator effect that is 2 times. The scheme of the experiment with crossed electromagnetic field (Cr.EMF) is described in [Zakupin et al., 2009]. Interpretation of experimental data has been realized on the basis of AE activity temporal dependence diagrams analysis. Present form of representation most informatively reflects changes of a specimen deformation mode. To calculate AE activity by experimental data (files of registered signals) treatment has been fulfilled by running window with averaging of certain number of events storage times. As a result temporal dependences reflecting number of AE acts per second (this value is mathematically identified with derivative dN/dT) have been turned out. Analysis of AE activity diagrams means determination of a loading specimen reaction to electromagnetic field effect. This reaction is signified in presence of acoustic emission activity variations when a source of electromagnetic field is turned on.

Results.

In the series of experiments on the spring presses we have received results which show responses of AE activity to EI to be registered with probability not less than 90% by fulfillment of the following conditions. Firstly, level of compressive loading ought to be not less than 70% from failure. Secondly, after load adding and its fixation the medium reaction depends on time, that is the more a specimen is exposed, the weaker a response will be. And finally, before a session of electromagnetic influence spontaneous acoustic emission must not to occur. The last aspect is considered in detail in the works [Zakupin et al., 2006], where the instances of spontaneous AE activation are shown and attempts to discern a response to EI against a background of spontaneous releases are given. On the figure 2 (a-f) the typical AE responses on specimens of salt (a), gabbro (b,c), granodiorite (d,f) and granite (e) are shown. In first experiments on the lever press in 2009 we for the first time could receive quantity assessments on responses. In this experiment (fig.3) we have revealed that AE reaction to EM field significantly exceeds reaction to additional mechanical loading. Besides, by different parameters of estimate of effect efficiency [Zakupin et al., 2009] the specimen reaction in this case is considerably stronger than in the experiments with other sources.

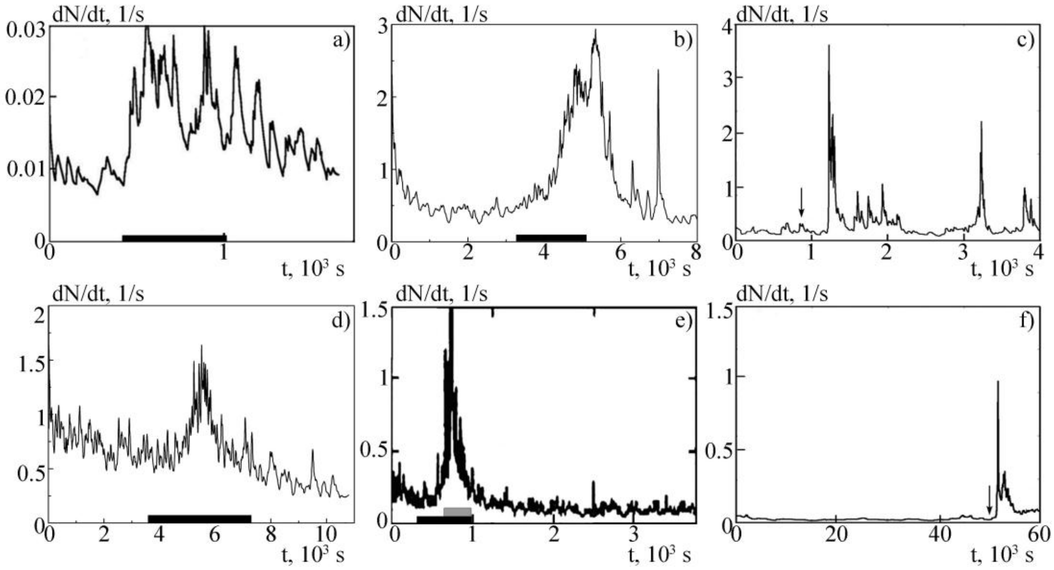

Fig.2 Instances of AE activity responses to electromagnetic influence (black bar: session of the generator G5-54, grey bar: session of magnetic field, arrow: series of discharges from the capacitor discharge device) in the experiments on the spring rheological unit UDI.

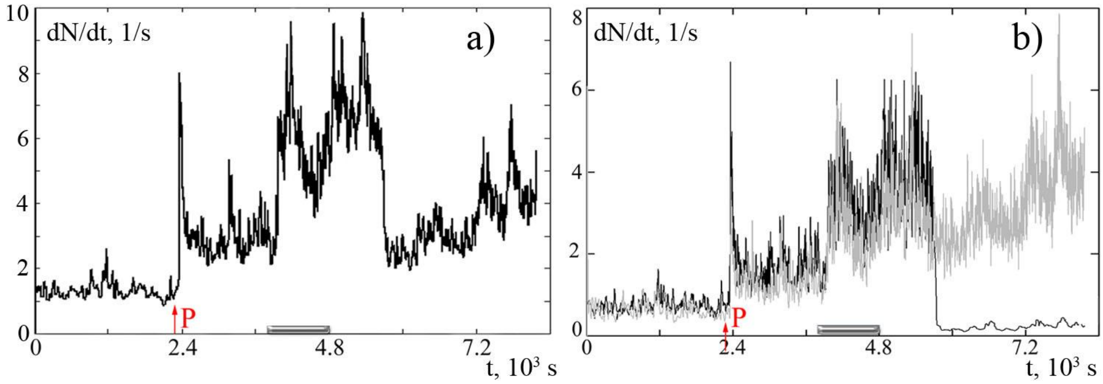

Fig. 3. (a) Temporal diagram of AE activity, (b) the same diagram with amplitude separation. Black bar on the time scale denotes the influence of Cr.EMF; P–stress increment.

Thus, it can be expected, that response of medium, loading on which continuously increases, will be clearly distinguish against a background of increasing AE activity (background). For beginning it is appropriately to consider the results of experiment, when technology of work with spring press is kept, that is EI sessions, as early, are conducted on quasi-stationary loading levels. Radical distinction of this experiment from previous is that measurements are continuously conducted, there are no loss neither when AE registering, nor other parameters (on the spring press at the moment of loading increasing registration was stopping because of enormous number of noises). EI sessions have been conducted by unified scheme: at every level of quasi-static loading, in first hour after addition loading and after 5 hour after it. Crossed EM field has been chosen as EI source because it is more effective by previous experiments data. Now let us consider the experiments, when quasi-stationary mode has been combined with mode of continuous growth of compression force (3.677 MPa per hour). In one of them the specimen has been failed only under the influence of compressive loading, and in the other experiments different kinds of EI have been applied. To compare this with other cases note the features of the experiment without EI: load increase at all stages of loading up to the specimen failure excites gradual increase of AE activity (without sharp bursts); in quasi-stationary mode the longitudinal deformation are not changing, but lateral deformations are growing. For the experiments with EI we confine ourselves to demonstrate acoustic and deformation responses to EI. In the fig.5 AE responses to 4 kinds of EI are shown. Note a significant distinction of AE in the mentioned diagrams from that we can observe on the fig.4d (without EI). First of all, it concerns to numerous bursts aroused by EI sources, which sometimes are matched by the level with trancritical values before the specimen's failure.

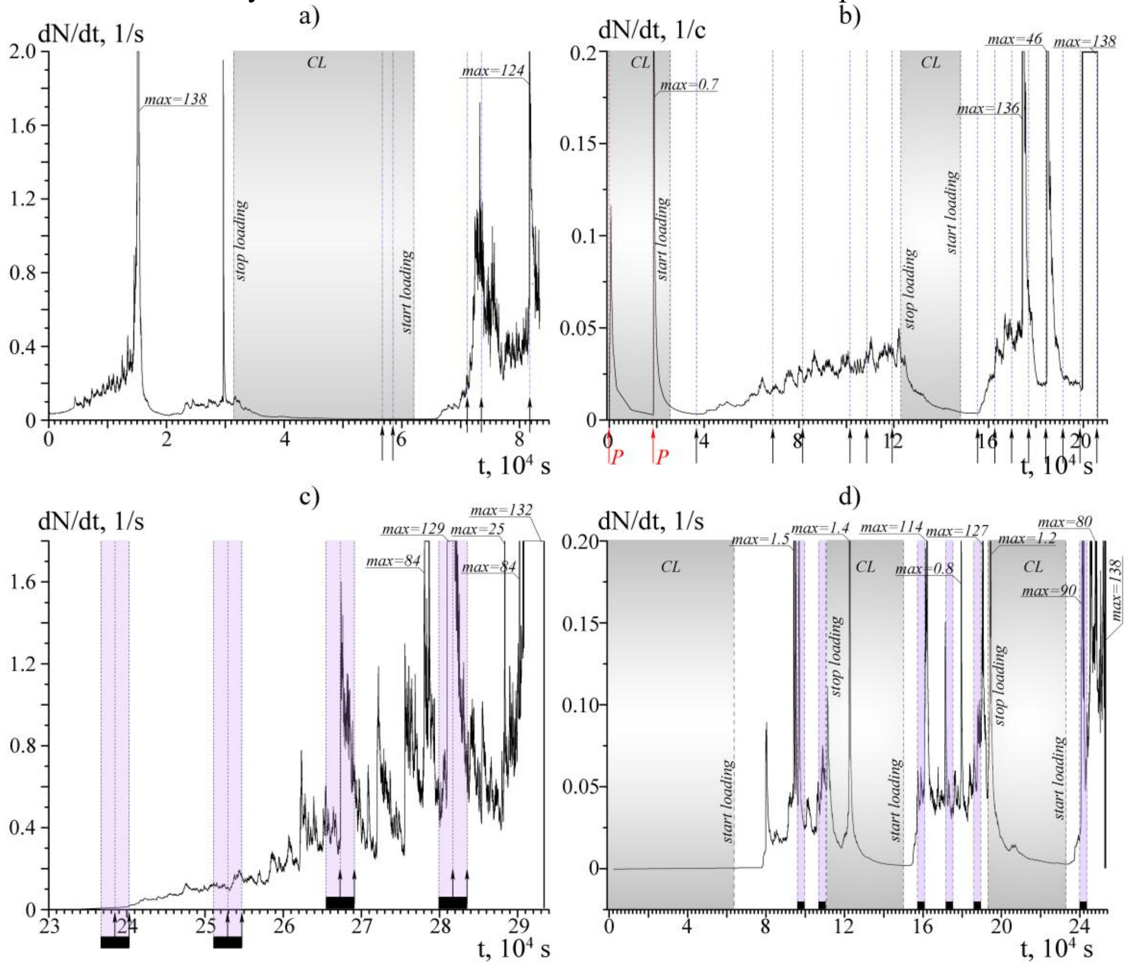

Fig.5 Instances of AE activity responses to the electromagnetic influence (bar – session of the G5-54 generator (c), bar – Cr.EMF session (d), arrow – series of capacitor device dischargers) in the experiments on the spring rheological unit UDI.

Responses to EI in the strain field are not so regular as in the case with acoustic, individual cases are shown in the figure 6. So in some experiments in the constant loading mode (CL) strengthening (decrease of ez by constant stress) is observed. It was found, that by influence on a specimen with powerful EM discharges in the CL mode (7-8 hours after its beginning), when a specimen is strengthened, variations of longitudinal deformation are observed, and in acoustic it is not reflected in no way at that (fig.6 a, b). In the quasi-stationary mode on the spring press, we have noted, that long-term exposure of a specimen under the constant loading brings to significant loss of excessive reserves of elastic energy. In this case EI does not effect on AE. However, as we can see, the influence still exists, that can be linked to stability of loading, which is kept up with the lever press. Also significant changes of deformations have been registered in the experiment with combined EI (pulses of the G5-54 combined with dischargers from capacitor discharger). Opposite to the experiment without EI change of lateral deformations is characterized with sharp spikes, and both ways increase and decrease at that (fig.6d). It is notably, that all significant variations accurate concur with first or second series of discharges. As the responses of longitudinal deformation have been registered in the CL mode too, we have conducted the restoration test of loading on the spring presses. For this experiment we have chosen crossed field as source of influence and done for several reasons. As it has been shown early EI influence is most effective in the last sessions (at loads more than 80% from fracture).

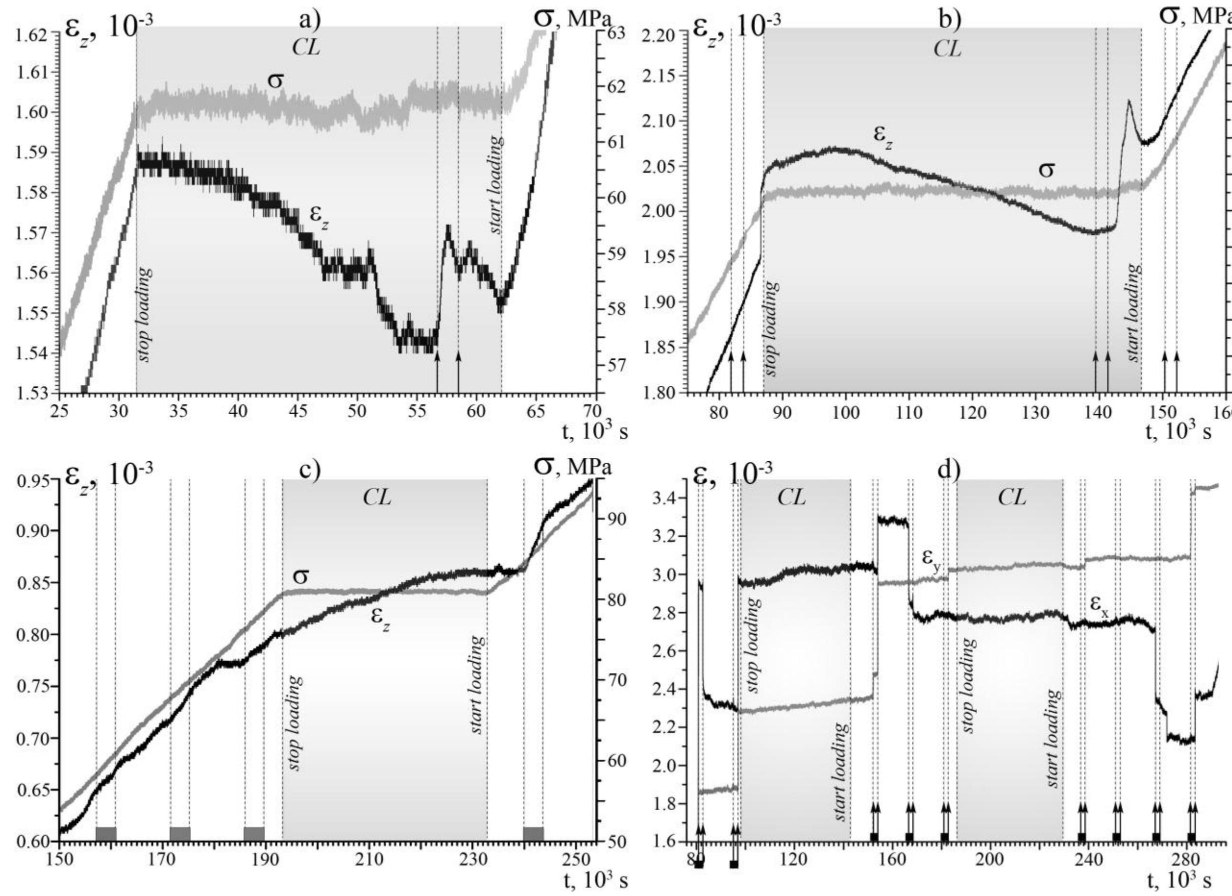

Fig.6. Load and deformation. Electromagnetic influence: arrow – series of capacitor device dischargers, bar – Cr.EMF session (c), bar – session of the G5-54 generator (d)

The exception is just influence of crossed field involving early loads too. Besides that, only in the experiments with this source the responses have been registered, which are continuing for a long time even after loading stoppage. As it is seen from the figure 5d the activity peaks in the CL mode (aftereffect) have been occurred higher than the major responses. It is worth to remark, that EI by prolonged CL close to its end doesn't effect, that has been noted in the original works [Bogomolov & Zakupin, 2008] as well. Here we don't give the AE data (AE responses, received in the CL, are good presented in the fig.2), set our attention only on the deformation curves. The results are shown in the fig.7.

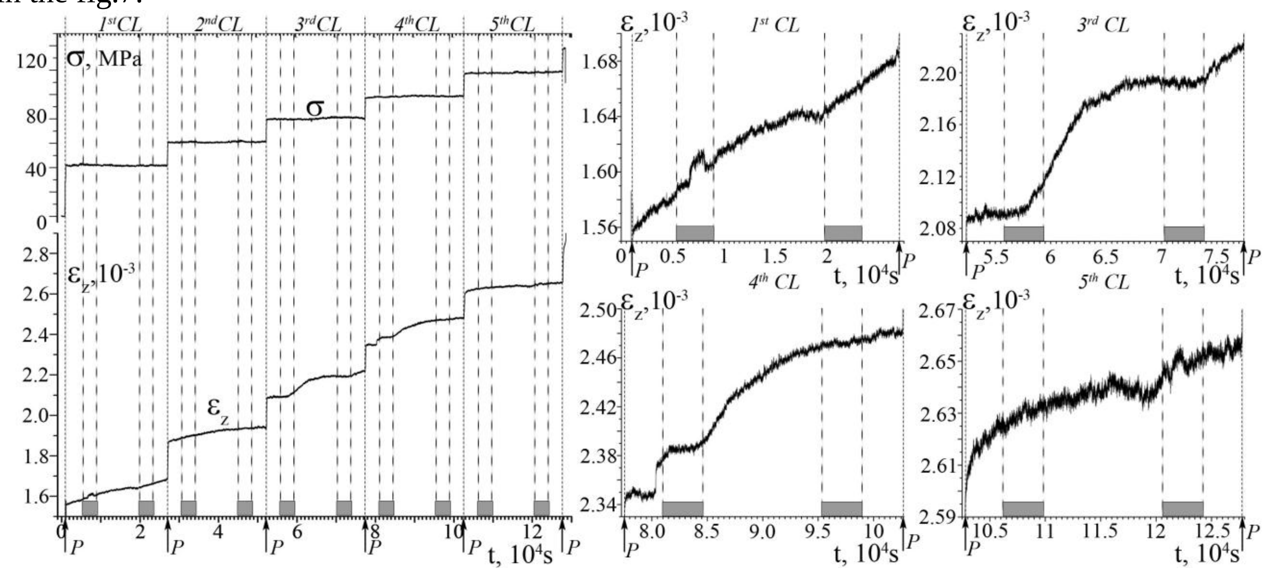

Fig.7. Load and deformation. Electromagnetic influence: bar – session of the Cr.EMF

As follows from the fig.7 from 5 steps in 4 cases one can see changes of longitudinal deformation (lateral components have not appreciably changed during EI) during the periods of crossed field influence. These changes can be registered both by first sessions and by recurrent. And, finally, pass to the experiment description, in which there were not quasi-stationary modes. For experiment loading rate 3.677 MPa per hour has been chosen. In this case crossed field have also been applied. The results are shown in the fig.8.

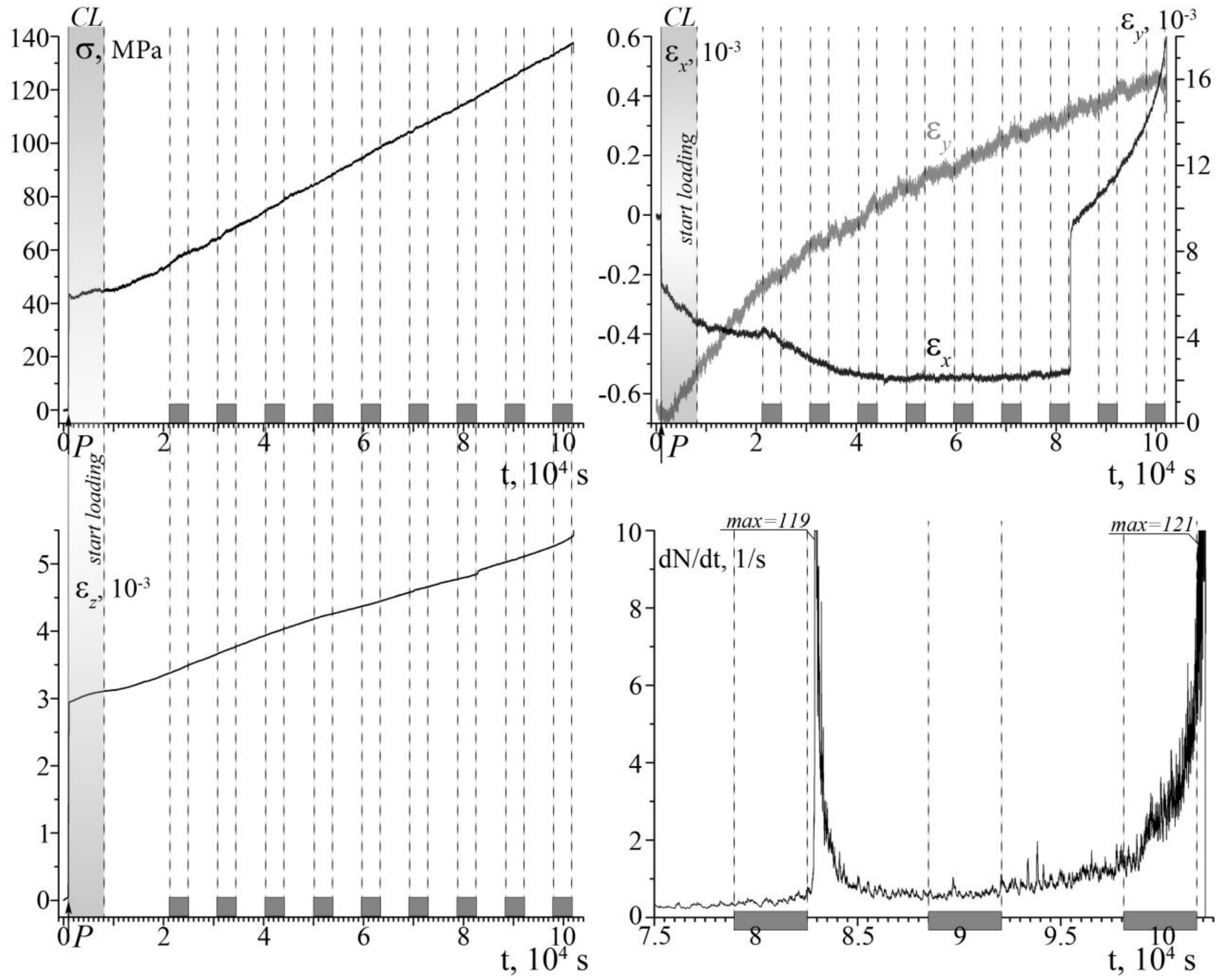

Fig.4 Load, deformation and AE activity in experiment with loading rate 3.677 MPa per hour

Now try to summarize the experiments' results. First of all, we are interesting in issues on responses to EI, comparison with the experiment without EI, and also existence of difference between deformative curves by different deformation modes. In the chart 1 the general characteristics are shown. As it is seen from the chart in the two last experiments with crossed field the results are comparable. Strong responses have been observed and, besides that, there are significant changes of volume deformation. Significant change of lateral dimensions registered in these tests has not been observed in the previous experiments, including the experiment with crossed field, but in the combined mode of loading. Responses in deformations have been absented, but there have been significant responses of AE in that experiment.

Loading order: CL+3.677 MPa per hour constant loading rate							
EI	σ, MPa	ε_x 10^{-3}	ε_y 10^{-3}	ε_z 10^{-3}	AE counts	AE response	Def. response
CD (20)	142	0,06	4,4	6,5	11977	+	+
CD (10)	93	0,02	0,2	2,5	55195	+	-

G5-54+CD(20)	119	3,4	3,2	2,5	36458	+	+
P	122	2	1,25	5,5	18129	n/a	n/a
G5-54	155	1,5	2	4,6	17456	+	-
Cr.EMF	95	1,1	0,91	0,9	16887	+	+
Loading order: CL							
Cr.EMF	139	0.2	12.6	2.9	40629	+	+
Loading order: 3.677MPa per hour constant loading rate							
Cr.EMF	138	0.6	15.9	5.5	46065	+	+

Explanations: P – mechanical loading without EI, for σ and ε the maximum values are given

May be this experiment falls out of three experiments, but efficiency of the present method of effect is most high. In addition let us note the circumstance, that against the background of weak deformative activity the AE responses have been registered in that experiment at the early stages. Perhaps, just this fact has brought to fracture by stresses significantly lesser, than for the rest of sample group of specimens.

Resume. Results of the experiments have demonstrated effect of external combined forces applying to have a sufficient potential for modification of the defects accumulation process in the geomaterials. AE sensitivity to EI becomes apparent by loads more than 70%. EI exerts on character of both lateral deformation components, and longitudinal component. From the viewpoint of EI effect on AE and volumetric deformation the results talk about high efficiency of external electromagnetic fields effect on cracking kinetics in loading rocks, particular to crossed electromagnetic field.

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Citation

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