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MULTI-PARAMETER RESPONSE OF SOFT ROCKS DURING DEFORMATION AND FRACTURING WITH AN EMPHASIS ON ELECTRIC POTENTIAL VARIATIONS AND ITS IMPLICATIONS IN GEOMECHANICS AND GEOENGINEERING

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The multi-parameter measurement system involve electric potential (EP) variations, electrical resistivity, acoustic emissions (AE), rock temperature (RT), acceleration in addition to the conventional displacement (strain) and load (stress) measurements. This study is concerned with the multi-parameter response of soft rocks during deformation and fracturing process. Some of experiments were carried out under purely mechanical manual loading without using the loading device, which may utilize AC current as power source. Therefore, the loading system is free of electric noise, which may be caused by the loading system. The authors presents the outcomes of these experiments and discuss of the implications of multi-parameter response in geomechanics and geoengineering.

Key Words : *multi-parameter response, sof rock, deformation, fracturing, experiment,*

1. INTRODUCTION

When rock starts to fail, the stored mechanical energy in rock tends to transform itself into different forms of energy. Experimental studies by Aydan and his group (Aydan et al. 2001, 2003) showed that rock indicates distinct variations of various measurable parameters such as electric potential, magnetic field acoustic emission, resistivity etc. besides load and displacement, which are called multi-parameters, during deformation and fracturing processes. Furthermore, some in-situ monitoring schemes were developed for structural safety of tunnels as well as for earthquake prediction studies (Aydan et al., 2005). These variations may be useful in predicting the failures of rock structures in geoengineering well as earthquakes in geoscience.

The authors undertook an experimental study to make further contributions to the understanding of multi-parameter variations including electric potential and electrical resistivity during deformation and fracturing process of geomaterials which ranges from crystals, gouge-like materials to rocks under different loading regimes (Aydan et al. 2001, 2003).

In this article, the authors describe the outcomes of the experimental studies on multi-parameter variations during the deformation and fracturing of geomaterials. The loading frame is free of electrical noise so that the effect of electric field of the loading system is entirely eliminated from samples. On the basis of the outcomes, the authors discuss their possible implications in geo-mechanics, geo-science and geo-engineering.

2 EXPERIMENTAL SET-UP

Tests were performed using an uniaxial compression testing machines at Rock Mechanics laboratory of Tokai University. The loading system is manually operated and it has the capacity of 10 tonf.. As the loading is manually performed, the electrical noise caused by the loading system in previous experiments is absent.

The applied load and induced displacement were automatically measured and stored on the hard disk of a laptop computer through an electronic logger. Electric potentials induced during the deformation of samples were measured through two electrodes attached to the top and bottom of samples using a voltmeter and logger unit (AGILENT A8670A) and data were simultaneously stored on the hard-disk of the laptop computer. The electrodes were isolated from loading frame with the use of isolators. Electric potentials were measured either as DC and/or AC. Two accelerometers were used to measure the acceleration resonses during fracturing.

Figure 1 shows an exploded view of a typical experimental set-up for samples. In addition to the above measurement system, acoustic emissions (AE) devices were used to measure the acoustic emissions during fracturing and sliding of samples.

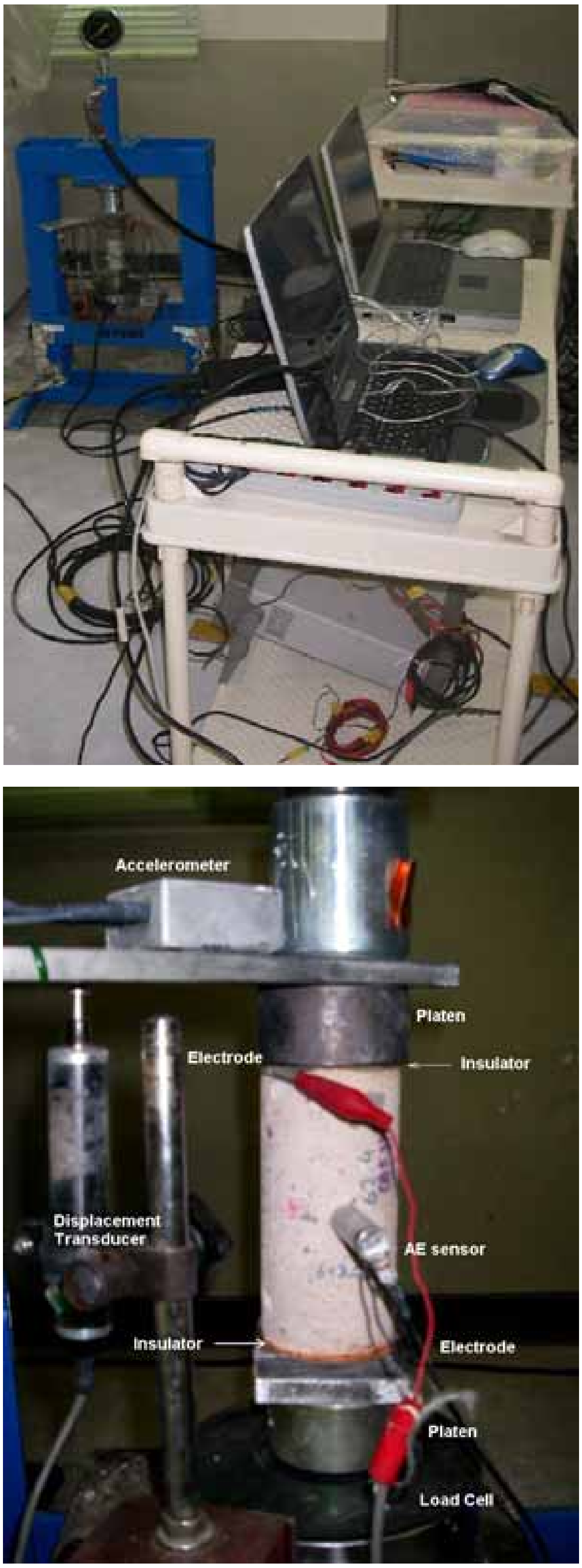

Figure 1. Experimental set-up

3 EXPERIMENTS ON ROCK SAMPLES

Soft rocks were Oya tuff, Yui sandstone, Asuyama tuff from Japan, tuffs of Avanos, Zelve, Derinkuyu of Cappadocia region of Turkey and soapstone (steatite or talc-schist). Soapstone particularly contains no piezo-electric substance.

Samples were loaded by increasing the load in steps. In some tests, short-term constant loading was imposed in order to observe electric potential response during load increase and creep loading.

Figures 2 to 9 show the experimental results on the multi-parameter responses of rocks mentioned above.

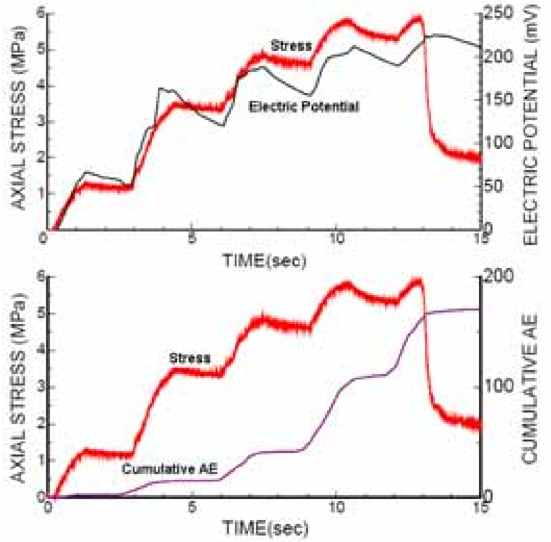

Figure 2 Multi-parameter response of Oya tuff

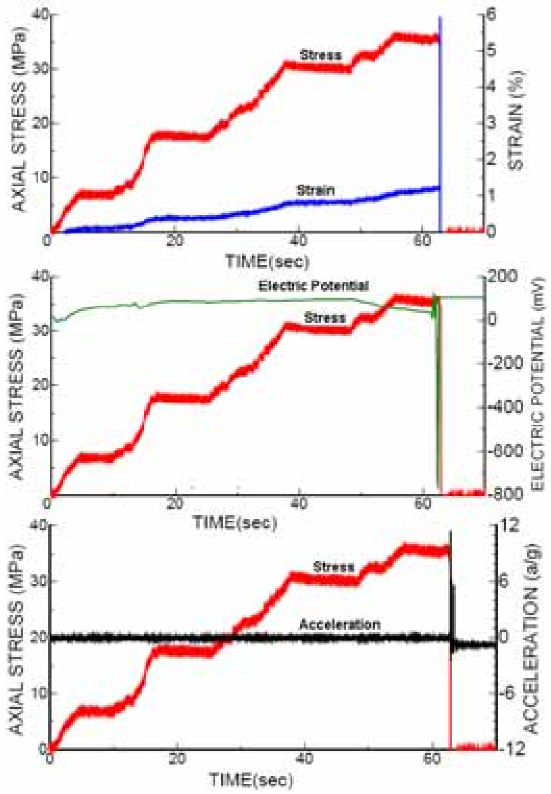

Figure 3 Multi-parameter response of Asuwayama tuff

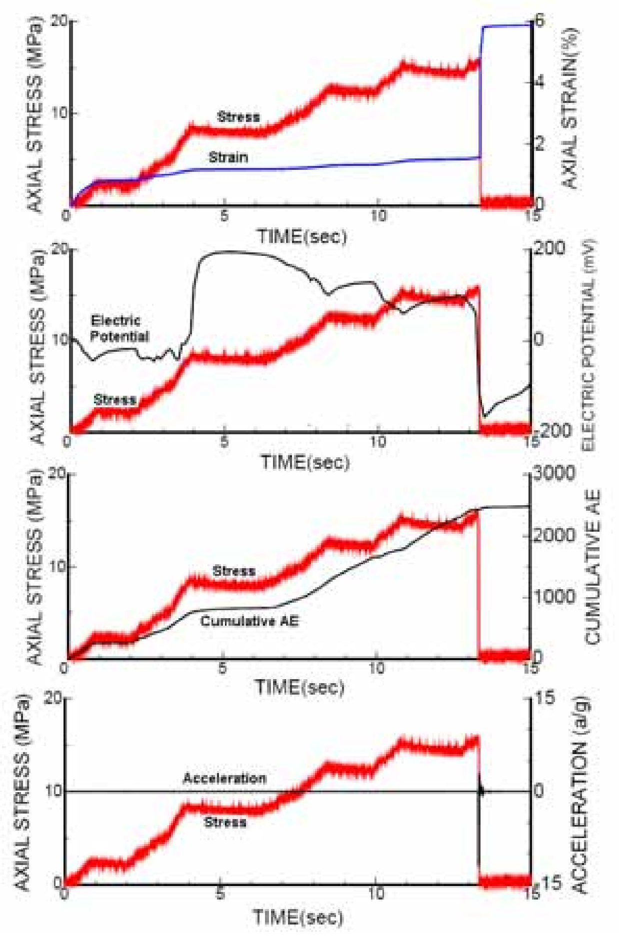

Figure 4 Multi-parameter response of Yui sandstone

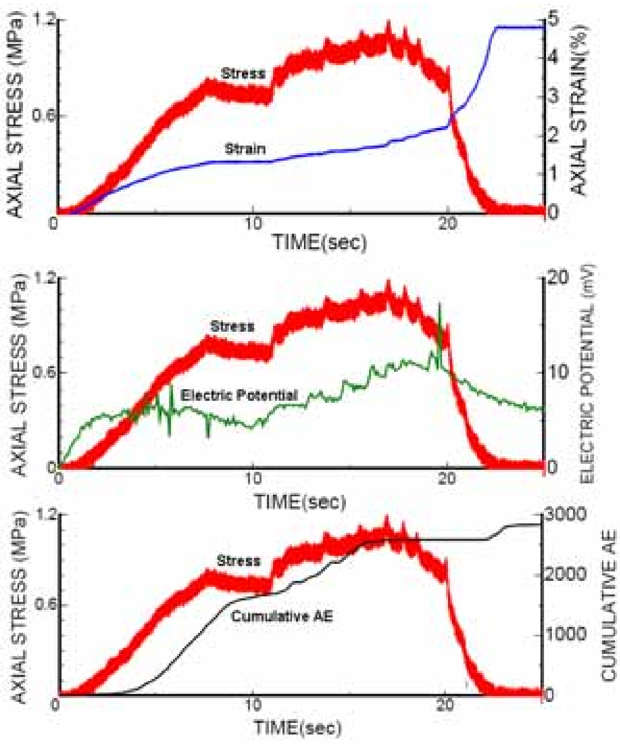

Figure 5 Multi-parameter response of Avanos white tuff (pumice)

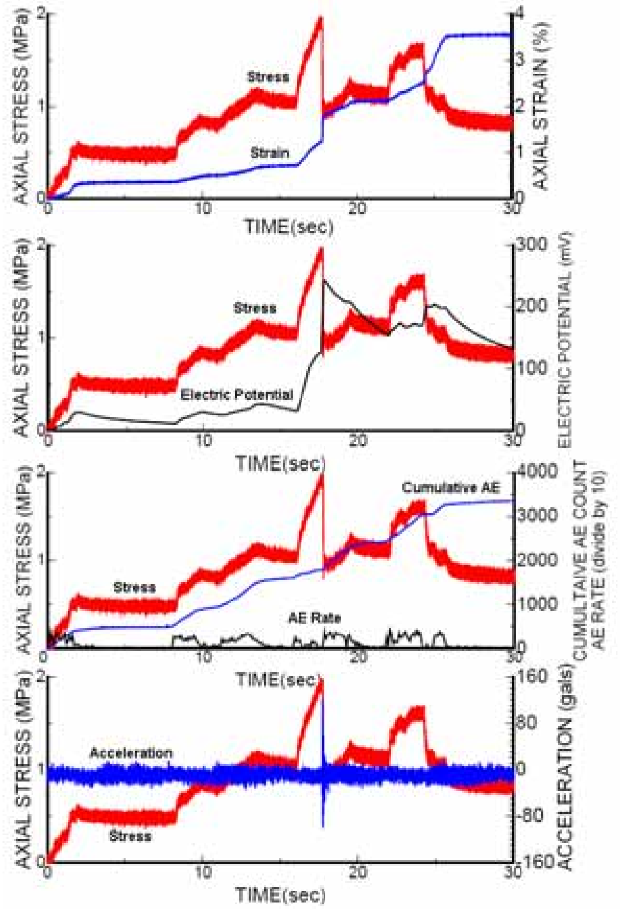

Figure 6 Multi-parameter response of Avanos yellow tuff (marl-like)

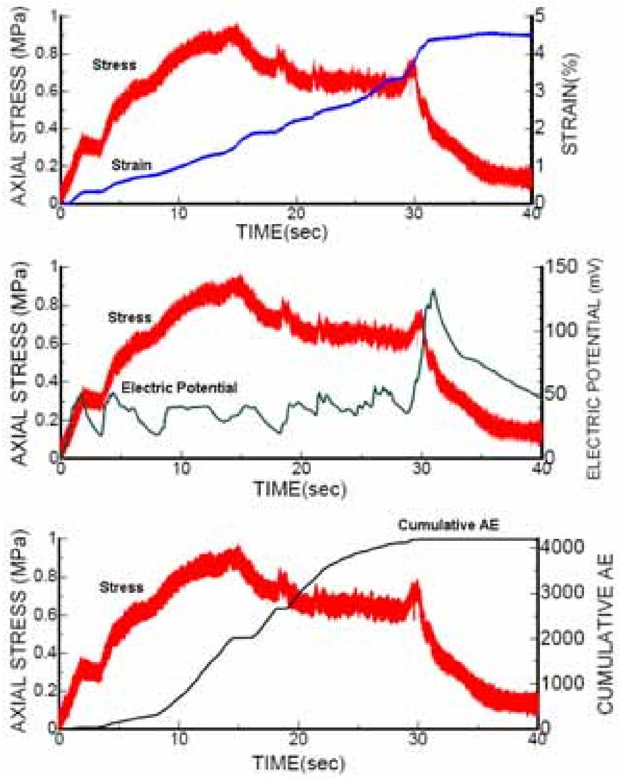

Figure 7 Multi-parameter response of Zelve tuff

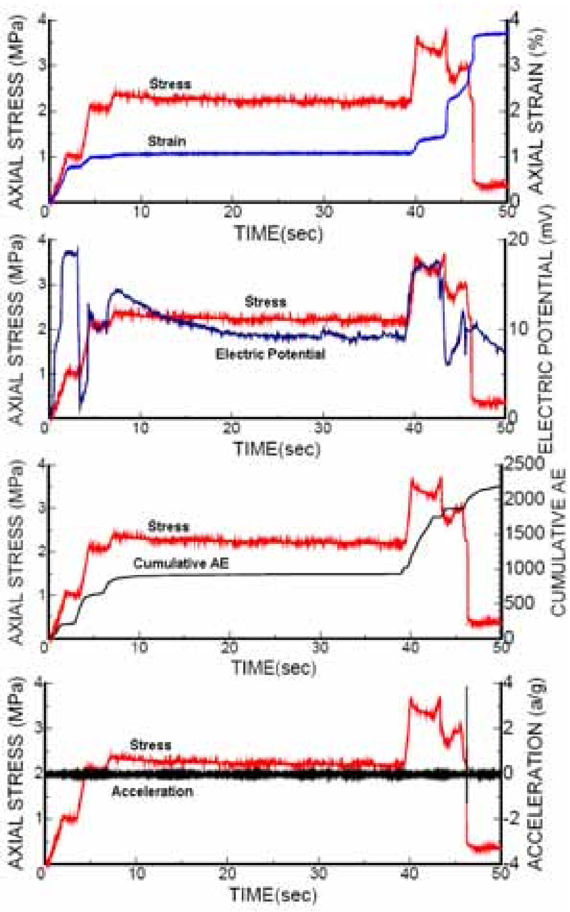

Figure 8 Multi-parameter response of Derinkuyu tuff

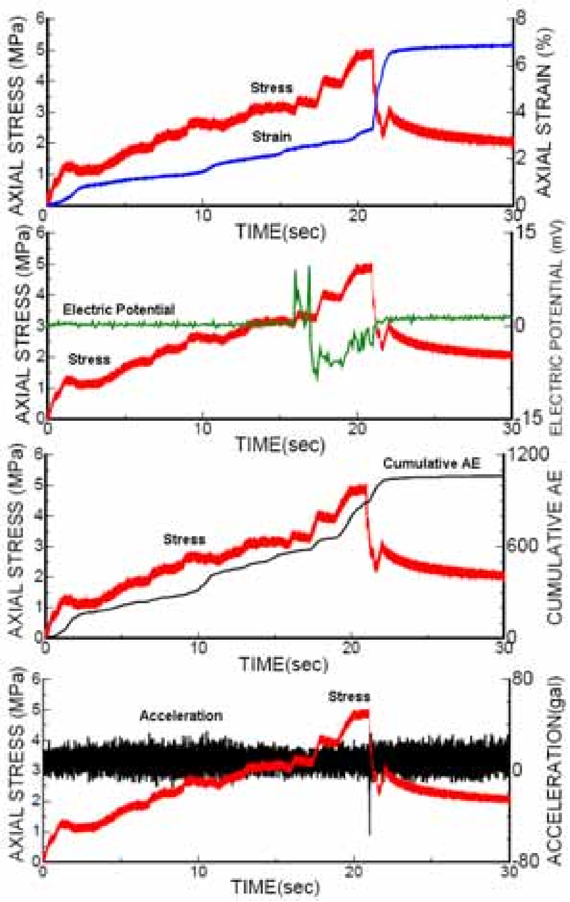

Figure 9 Multi-parameter response of soapstone

As seen from the experimental results, the deformation and fracturing of rock cause the distinct variations of electric potential and acoustic emissions in addition to conventional parameters such as displacement (strain) and force (stress) . Inspite of possibility of electrical noise from the loading devices in experimental results reported and discussed by Aydan et al. (2001, 2003) previously, the same statements regarding the electric potential responses: can be quoted herein:

1) Electric potential responses are closely related to actual strain response and they resemble to associated axial strain responses.

2) Bay-like variations of electric potential are distinctly observed before the rupture of samples.

Seismic electrical signals (SES) are generally observed before the rupturing of samples. These signals generally coincide with axial splitting type fracturing. However, seismic electric signals are less apparent for non-piezoelectric materials as compared with samples containing piezo-electric substances

During step-like loading path, which may resemble multi-stage creep tests, the measured responses of electric potential, responses of various rock samples are closely related to the loading paths. Particularly, the rate of electric potential development during load increment is very high and it tends to decrease, as the load is kept constant. However, it becomes asymptotic to an electric potential level greater than that induced in the previous load step. Since the strain rate is quite high during load increment and tends to decrease once the load is kept constant, the electrical potential response seems to be closely associated with the strain rate response of the sample. Before the peak strength of the sample was achieved, a bay-like electric potential response was observed.

Fundamentally, the observed acceleration responses are similar to each other. The acceleration responses start to develop when the applied stress exceeds the peak strength and it attains the largest value just before the residual state is achieved as seen in Figure 2. This pattern was observed in all experiments. Another important aspect is that the acceleration of the upper platen is much larger than that of the lower platen. This is also a common feature in all experiments. In another word, the amplitude of accelerations of the mobile part of the loading system is higher than that of the stationary part.

Acoustic emisson responses are closely related to fracturing of rocks and the responses are closely linked wth electric potentil variations. Therefore, the anamolous responses related to fracturing may be inferred and confirmed by the simulatenuous monitoring together with electric potential and/or electric resistivity, which was not presented herein.

4 THEORETICAL MODEL FOR ELECTRIC POTENTIAL RESPONSES

There are many explanations why electric potential development occurs during deformation and fracturing and sliding of geomaterials. As discussed by Aydan et al. (2001,2003) most explanations are based on the existence of piezo-electric substances contained in rocks and the polarization of fracture surfaces during fracturing and sliding. If such concepts are true, then it is impossible explain electric potential development during deformation, fracturing or sliding of non-piezoelectric materials as they are presented in previous sections. Therefore, it seems that a different mechanism should be put forward for the electric potential development in such non-piezoelectric substances. The first author's opinion is that the momentum imposed on samples during testing may also be the main cause of electric potential development during deformation and fracturing.

The authors quot herein a model of Aydan et al. (2003) for the electric potential development, which may be caused by the piezo-electric substances and/or the momentum imposed. The piezo-electric potential development is generally associated with mechanical loading (i.e. Ikeya et al. 1997). The theoretical background for electric potential development due to piezo-electric component is well established so that there is no need to the repeat the same content herein. The electric potential development is also caused by the momentum associated with the state of stress and straining imposed on geomaterials. Therefore, the electric potential development should depend upon the evolution stress state and associated straining with time. In other words, the electric potential response during loading process will closely follow the momentum response. Figure 13 shows an application of this concept to a visco-elastic substance with a given finite mass, subjected to a load path as shown in the figure under the consideration of inertia term during loading. The details of the theoretical formulation for this particular condition can be found elsewhere (Aydan 1997). The computations are carried out by assuming that the substance has either piezo-electric property or not in addition to the component resulting from the momentum. As observed from the figure, the electric potential disappears for non-piezo-electric substance when the momentum disappears. On the other hand, the electric potential becomes stationary for piezo-electric substances. Figure 14 shows the computed responses by omitting the inertia term in computing responses of strain, strain rate and associated electrical potential for piezo-electric and non-piezo-electric substances.

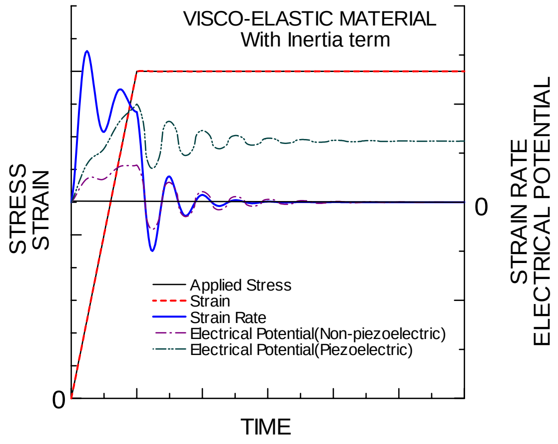

Figure 10: Computed responses of various parameters during a uniaxial loading with consideration of inertia

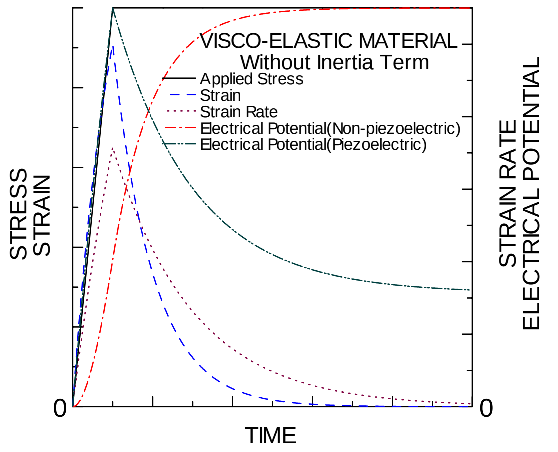

Figure 11: Computed responses of various parameters during a uniaxial loading without consideration of inertia

A final computational example of electrical potential development during creep failure is shown in Figure 15.

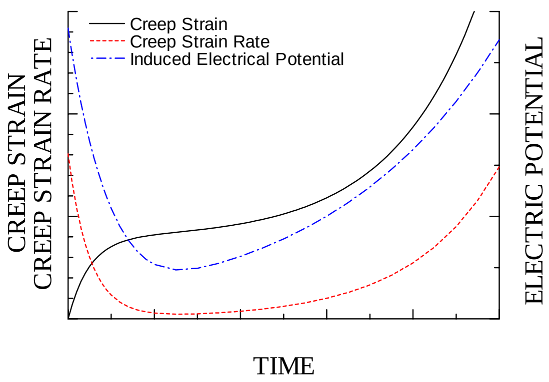

Figure 12: Computed responses of various parameters during creep failure

While the responses shown in Figures 13 and 14 are for linear deformation behaviour, the responses shown in Figure 15 involves the fracturing in the non-linear behaviour range. As noticed from the figure, the electric potential development is bay-like as observed in experimental results presented in previous section. The theoretical models described herein may be said to be capable of simulating the responses observed in experiments.

5 CONCLUSIONS

This experimental study was undertaken to make further contributions to the understanding of electric potential variations during fracturing and sliding process of piezoelectric and non-piezo-electric geomaterials. From the experimental results described in this report, the following conclusions may be drawn:

1) The experimental results clearly indicate that the deformation, fracturing and sliding processes induce electric potential in geomaterials.

2) The magnitude of induced electric potential both depends upon the piezo-electric characteristics of minerals or grains and the moment caused by the separation of electrons of minerals as a result of deformation and inter-crystal or inter-grain separation and/or sliding during dislocations as a result of fracturing or sliding.

3) The amplitude of accelerations of the mobile part of the loading system is higher than that of the stationary part. This feature has striking similarities with the strong motion records nearby earthquake faults observed in the recent large in-land earthquakes

4) The amplitude of accelerations during the fracturing of rocks is directly proportional to the energy stored in samples before the fracturing.

5) The experimental results presented in this article are considered to be very important to both engineers for predicting potential rock bursting in deep high-level waste disposal projects and mining and scientists who are closely associated with earthquake prediction projects based on multi-parameter monitoring systems.

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軟岩の変形・破壊過程に伴う多重パラメータ応答および地殻力学・地殻工学におけるその利用の可能性について

藍檀オメル、太田良巳、田野久貴

多重パラメータシステムは従来の荷重（応力）、変位（ひずみ）と別に温度、地電流、電気抵抗、AEなどを含むものである。本研究では変形・破壊過程に伴う軟岩の多重パラメータ応答を実験的に検討している。本研究で報告している実験結果はAC電源を要する載荷を使わず、手動型の載荷装置を用いて行ったものである。したがって、載荷装置による電気ノイズを防ぐことができたものである。本論文では行った変形・破壊固定における軟岩の多重パラメータ応答について報告し、地殻力学および地殻工学の分野でその利用について論じている。特に地学の分野で地震予知、地殻工学で掘削中岩盤構造の安定性評価や維持管理にその利用の可能性が高いと判断できる。