A new creep monitoring system and its utilization for the creep behavior of Çankırı rock salt

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Abstract. Creep experiments are of paramount importance for assessing the long-term stability of rock engineering structures. The major issue in creep tests is how to keep sustained loading constant on samples and to monitor displacement and other parameters throughout experiments without any interruption for long durations. Available cantilever type creep devices capable of carrying out various creep tests have been recently improved and used in this study. In addition, an impression creep device capable of applying a tip pressure up to 134 MPa for an indenter of 3 mm in diameter has been used with a purpose as an index creep testing technique. All devices are equipped with displacement transducers and acoustic emission sensors, which operate independently from conventional electrical power supply. The new monitoring system used in these creep devices is described and its utilization for evaluating creep responses of rock salt samples from Çankırı Province of Turkey are presented and discussed.

Keywords: Creep Test, New Monitoring System, Rock Salt.

1 Introduction

Long-term stability of rock engineering structures is of great importance and it requires the determination of long-term properties of surrounding rock from creep tests. The creep tests have been used in the field of rock mechanics and rock engineering for decades (e.g., Aydan 2016; Aydan et al. 2014). Nevertheless, the most important issue is how to keep the sustained load constant and cantilever type creep devices are useful for this purpose and the loading system is independent of power supply. Another very important issue is how to monitor displacement and additional parameters such as acoustic emissions, temperature and humidity during experiments for long durations.

The Rock Mechanics Laboratory of the University of the Ryukyus has recently improved their experimental facilities. Cantilever type creep devices have been acquired for carrying out creep tests under the conditions of uniaxial and triaxial compression, Brazilian, bending, and double shearing tests. In addition, an impression creep device capable of applying a tip pressure up to 134 MPa for an indenter of 3 mm in diameter has been developed with a purpose as an index creep testing technique.
In this study, the authors developed a new monitoring system for continuous measurement of displacement, acoustic emissions in addition to environmental parameters and utilized in uniaxial compression, Brazilian tensile and impression creep tests on the rock salt of Çankırı of Central Turkey. This new monitoring system and experimental results have been explained and its utilization for evaluating long-term properties of rocks have been discussed.

2 Creep Testing Device

Rock Mechanics Laboratory of University of the Ryukyus improved its facility. Fig. 1 shows the cantilever type creep device has a maximum loading capacity of 50 kN (Ito and Akagi, 2001; Ito et al. 2016; Aydan et al. 2014). Presently there are two creep devices with 50 kN capacity and one 0.6 kN creep device. The multi-stage creep experiments are possible and the load increments can be in the order of 0.1 kN (Fig. 1a). For samples with a diameter of 50 mm, the creep responses of rocks with a UCS of 50-60 MPa can be evaluated through this creep testing device. However, if the diameter of samples is less than 50 mm, much higher stress levels are possible. In addition, two impression creep devices capable of applying a tip pressure up to 134 MPa tip pressure is available (Aydan et al. 2011). The tip of the cylindrical impression rod has a diameter of 3 mm and its shape is specially designed against buckling of the rod (Fig. 1b).

3 Monitoring System

The creep devices are equipped with displacement transducers and acoustic emission sensors, which operate independently from conventional electrical power supply so that creep responses can be measured for long durations. The continuous monitoring is possible during multi-stage loading with the consideration of sampling interval. The monitoring system is described in this section.

3.1 Displacement and Environmental Monitoring System

Reliable, accurate and long-term monitoring of displacement as well as environmental parameters such as temperature and humidity is essential during creep tests.
Furthermore, the power supply is another critical issue for displacement monitoring and application of the loads in the creep tests. As we utilize cantilever type creep devices, the load is kept constant and there is no necessity to monitor load itself. However, we utilize displacement transducers with a maximum capacity of 10 mm with an accuracy of 3 microns. The device operates with two A3 type alkali batteries and it is equipped with temperature and humidity sensors (Fig. 2a). The amplifier and logger unit can measure and store the displacement, temperature and humidity at a chosen time interval. The time interval is generally selected as 10 minutes. The displacement transducers are fixed to the bottom platen and measure the deformation of samples as the relative displacement between upper and bottom platens (Fig. 2b).

3.2 Acoustic Emission Monitoring System

Acoustic emissions (AE) occur in samples during loading and deformation process. Particularly, AE monitoring is also another important parameter during creep tests to evaluate the internal crack formation and its evolution with time. Tano et al. (2005) developed a portable AE monitoring system to monitor the rock engineering structures in long term. This system was applied in many projects in Japan, Turkey, and Egypt (e.g., Tano et al. 2005, 2016; Kumsar et al. 2016). This system was shown to be useful for monitoring acoustic emission creep tests (Aydan et al. 2011). This system has been recently improved against condensation in order to eliminate noises, external gain adjustment and power and signal check units. Fig. 3 shows the AE system and its utilization during a test.

Fig. 3. (a) AE monitoring unit and (b) its attachment to a rock sample during a creep test.
4 Sampling and Samples

Several rock blocks were obtained from a rock salt mine in Çankırı and they were cored to obtain samples for uniaxial compression and Brazilian tests. Rectangular prismatic blocks, which were available at the mine were utilized for impression creep experiments. Cored samples were cut to designated sizes and their ends were grinded. Fig. 4 shows the samples prepared for this experimental study.

![Fig. 4. A view of samples prepared for short-term and long-term mechanical properties.](image)

Before the short-term and long-term tests, some physical properties such as unit weight, s-wave and p-wave velocity of rock salts were determined. The unit weight of the Çankırı rock salt samples range between 19 and 20.8 kN/m$^3$ with a mean of 20.1 kN/m$^3$. Average s-wave and p-wave velocities of the Çankırı rock salt samples were 1358.7 m/s and 3311.83 m/s, respectively. Furthermore, some samples were prepared for triaxial experiments on rock salt.

5 Short Term Tests

Some short-term experiments were carried out to determine mechanical properties under uniaxial compression, Brazilian tests triaxial compression and impression tests. Figs. 5 and 6 show examples of the strain-stress responses of Çankırı rock salt samples under uniaxial compression, Brazilian impression compression tests and triaxial strength envelope. As noted from the figures, Çankırı rock salt samples exhibit elasto-plastic behavior from the very low-level applied stress. The uniaxial compressive strength ranged between 19-26 MPa while the tensile strength from Brazilian test obtained to be ranging between 1.66 to 2.5 MPa.

![Fig. 5. Strain-stress responses under uniaxial compression (a) and in Brazilian test (b).](image)
6 Creep Tests

6.1 Uniaxial Compression Creep Experiments

Five creep experiments have been carried out so far and Fig. 7 shows one example of the responses measured displacement and acoustic emissions (AE) during a compression creep on a sample numbered crs-pc-2cc. In this particular experiment, the load was increased in steps. The compressive stress acting on the sample was 4.9, 9.8, 17.5, 19.1 MPa. The load was lowered at 69050 minutes (1150.8 hours, 47.95 days) to obtain the permanent deformation and it was attempted to reload to the stress level of 19.1 MPa. However, the sample failed during the re-loading. When the stress level of 19.1 MPa is roughly equal to the 95 % of the short-term uniaxial compressive strength of the rock salt. The other four samples were failed when the stress was increased to 19.1 MPa. The creep duration before failure ranged between 100-400 hours.

6.2 Brazilian Tensile Creep Experiments

In short-term experiments, the Brazilian tensile strength ranged between 1.66 and 2.5 MPa. Four Brazilian creep experiments were carried out and an example of time-displacement and acoustic emission responses is shown in Fig. 8. The lowest tensile stress was 238 kPa and the highest tensile was 1447 kPa. The failure time was less than 20
minutes. The 5th Brazilian creep experiments under a tensile stress of 1415 kPa have been continuing for more than 2500 hours without any major fracturing.

Fig. 8. Time-displacement and acoustic emission responses of the sample denoted crs-i-B-5.

Fig. 9. Time-displacement and acoustic emission responses of the sample denoted crs-pc-ic2.

6.3 Impression Index Creep Experiments

Aydan (2016) and Aydan et al. (2008, 2011) suggested this method could be a useful technique as an index creep testing. The most important issue is how to designate the stress ratio in this technique. The short term-test using the indenter could be the simplest yet efficient procedure for evaluating the stress ratio in this testing technique. Four experiments were carried and Fig. 9(a) shows an example of responses observed during the experiment of a sample numbered crs-pc-ic2. Fig. 9(b) shows the state of sample after the test. As noted, permanent displacement occurred and there is a cylindrical hole together with radial fractures. The plastic zone is roughly twice the indenter radius. The tip pressure was about 134 MPa when the experiment was terminated.

7 Comparisons and Discussions

It is well known that the long-term strength (i.e. uniaxial compression strength, tensile strength or impression strength) \( \sigma_s(t) \) of rocks decreases with time and it is expressed in the following forms (Aydan et al. 1995; Aydan 2016).

\[
\frac{\sigma_s(t)}{\sigma_s} = \alpha + (1 - \alpha)e^{-b(t^* - 1)} \quad (1); \quad \frac{\sigma_u(t)}{\sigma_s} = 1 - b \ln(t^*) \quad (2); \quad \frac{\sigma_s(t)}{\sigma_s} = \alpha + (1 - \alpha)(1 - b \ln t^*) \quad (3)
\]
where $\alpha$: The ultimate normalized strength of rock or creep initiation stress level, $\tau$: The duration of short-term strength ($\sigma_s$) test; $b$: empirical constant and $t^* = t/\tau$.

Aydan et al. (2011) suggested the failure time for uniaxial compression, triaxial compression, Brazilian and impression creep experiments obey the same function when the stress ratio remains the same. Fig. 10 compares the failure time of Çankırı rocksalt samples tested in Brazilian, impression, and uniaxial compression creep experiments. From experimental results, it is very interesting to note that if the stress ratio remains same, the failure time of the samples irrespective of the type of experiments are very close to each other in accordance with the earlier findings (Aydan et al. 2011). Furthermore, the failure times of samples tested under uniaxial compression and Brazilian creep experiments are also similar to those of impression creep experiments.

Regarding elasto-visco-plastic behavior, the intuitive (empirical) model proposed by Aydan et al. (2003) and the rheological model suggested by Perzyna (1966) are used for the interpretation of experimental responses. For a given stress level, Aydan (2016) slightly modified the previous model to account initial deformation (elastic deformation) as follow

$$\varepsilon_c = \varepsilon_o + A\left(1 - e^{-t/\tau_1}\right) + B\left(e^{t/\tau_2} - 1\right)$$

where $A, B, C, \tau_1, \tau_2$ are constants to be determined from experimental results. Aydan et al. (2011 2014), the total creep strain according to Perzyna model can be derived as given below:

$$\varepsilon = \frac{\sigma_e - \sigma_y}{E} + \frac{(\sigma_e - \sigma_y)}{H}\left(1 - e^{-\frac{H}{\tau_2}}\right)$$

where $E, H, \sigma_y, \sigma_e, C_p$ and $t$ are elastic modulus, plastic hardening modulus, yield stress, applied stress, plastic compliance, and time, respectively. Intuitive and rheological models to responses measured during a selected impression creep test (crs-pc-ic2) are compared in Figure 16. The parameters of the intuitive model were obtained as

$$\varepsilon_o = 1.377; A = 0.3; B = 0.4; \tau_1 = 6; \tau_2 = 35$$

As for the rheological mode, the parameters of Eq.(5) for the impression test numbered crc-pc-ic2 are obtained as follow

$$\sigma_y = 39.1; H = 123.7; E = 140.2; C_p = 3690$$

![Figure 10](image)

(a) Long-term strength (b) Elasto-visco-plastic model

**Fig. 10.** Comparisons of experimental results with estimations obtained from Eqs. (1) to (5)

8 **Conclusions**

The experimental studies presented in this study have been still continuing. This study
is also unique in a way that three different experimental techniques are utilized for the same rock. One of the main purposes is to explore the suitability of impression creep tests as an index test (Aydan et al. 2011; Aydan 2016) and the results are quite promising that there is a high possibility for the utilization of the impression creep as an index creep test. The preliminary experimental result clearly demonstrated that both conventional and index tests could be quite comparable and similar type responses are observed. As pointed out in previous section, the most critical aspect is the definition of the stress ratio in impression creep tests, which is easily obtained in conventional creep tests. If short-term tests on samples using the impression testing indenter are carried out, the results obtained from impression creep tests should yield almost the similar type material properties for time-dependent behavior of rocks.

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