Monitoring System of the Temperature-Moisture Regime Placed at Spis Castle

[1]Ľ. Kubičár, [1,2]V. Štofanik, [1]V. Boháč, [3]M. Brček, [3]J. Vlčko, [1]C. C. Anibarro

[1] Institute of Physics SAS, Dúbravská cesta 9, 845 11 Bratislava, Slovakia
[2] Department of Radioelectronics, FEI STU, Ilkovičova 3, 812 19 Bratislava, Slovakia
[3] Department of Engineering Geology, Comenius University in Bratislava,
Faculty of Natural Sciences, Mlynská dolina G, 842 15 Bratislava, Slovakia
Email: ludovit.kubicar@savba.sk

Abstract. *Present paper deals with the principle of the hot ball method, with the construction of the moisture sensor and its application in areas of nondestructive testing of thermal-moisture regime within the rock mass. The sensor consists of a small cylinder having the diameter and length of 20 mm in which a small ball in diameter up to 2 mm is placed that delivers a heat in step-wise regime and simultaneously measures temperature. The sensor is prepared of the same material as the monitored rock. Spis Castle is placed on the travertine mound and is suffering deep-seated deformations. The paper introduces novel methodology for monitoring temperature and moisture in local position. The four sensors have been positioned in depths of 10, 40, 80 and 150 cm from the rock surface. Monitoring has been performed in the period from December 4th, 2008 up to January 17th, 2009.*

Keywords: hot ball method, thermal conductivity, moisture, rock mass

1. Introduction

Degradation of the stones is strongly influenced by moisture that in combination with temperature, salt and various biofactors, have high correlation with geographical location, microclimate and with the local hydrological conditions. Historic structures are predominantly built on rock massifs deteriorated by post genetic processes (predominantly weathering) and many decorative and ornamental parts of historic structures are constructed of easily cut porous materials. Both in the subgrade and the upper structure, the moisture plays a dominant role in their degradation and deterioration [1]. Therefore information regarding moisture-thermal regime of applied materials represent a basic assumption for a selection of a suitable procedure for preservation of historic monuments.

Spis Castle, a monument that was included in the UNESCO World heritage list (Eastern Slovakia, Hornádska kotlina Basin) is built on a travertine mound (Quaternary age) overlying the Tertiary soft rocks. Lateral spreading caused by the subsidence of strong upper travertines into soft claystone strata fractured and separated the castle rock into several cliffs. The differential movement of individual cliffs is the phenomenon influencing the instability of the monument.

In order to estimate the mode of failure and rate of displacement of rock cliffs several monitoring techniques are adopted:

- Monitoring of displacements carried out by the mechanical-optical crack gauge type TM-71 and the demec gauge (demountable mechanical crack gauge) type SOMET.
- Monitoring of displacements carried out by full automatic crack gauge type GEOKON 4.2.
- Monitoring of temperature-moisture regime within the rock mass body which is a subject of the presented paper.

Thermal conductivity sensor based on the hot ball method has been utilized for monitoring of moisture. This sensor in connection with the RTM 1.01 monitoring system records information on local temperature and thermal conductivity of the surrounding material. As thermal conductivity of a porous structure is a function of the pores distribution and their water content, this parameter can be used for monitoring of the moisture as well. This phenomenon allows the construction of a moisture sensor based on hot ball placed in a porous body. The moisture sensor can be calibrated in dry and water saturated conditions. For construction of moisture sensors, to cover various requirements of practice, a broad range of porous materials with different porosities can be utilized.

Monitoring methodology based on a simple instrument that is composed of a data logger in connection with a microprocessor is discussed. The monitoring system has been working under environmental conditions from December 4th, 2008 to January 17th, 2009.

2. Theory of the thermal conductivity sensor

Fig. 1. Model of the hot ball and its realization (left). Measuring cycle measured at sandstone for hot ball heat output q = 3.5 mW (right).

The principle of the thermal conductivity sensor is based on a model of the hot ball method that assumes a constant heat flux q from the empty sphere of radius r_b into the infinitive medium that starts to be delivered for times $t > 0$ (see Fig. 1 left) [2]. Then the temperature distribution within the medium can be characterized as follows

$$T(r,t) = \frac{q}{4\pi\lambda r^2}\left\{\sqrt{\frac{at}{\pi}}\left(1-e^{\frac{-r^2}{at}}\right)+r\cdot erfc\left(\frac{r}{\sqrt{at}}\right)\right\} \qquad (1)$$

where $erfc(x)$ is the error function defined by $erfc(x) = \frac{2}{\pi}\int_0^x \exp\left(-\zeta^2\right)d\zeta$ and λ and a are thermal conductivity and thermal diffusivity of the surrounding medium, respectively [3].

Function (1) gives a working relation of the measuring method based on the hot ball for long time approximation

$$\lambda = \frac{q}{4\pi r_b T_m(t\rightarrow\infty)} \qquad (2)$$

where T_m is stabilized value of the temperature response that is reached in the long time limit at the surface of the empty sphere with radius r_b. During stabilization time, the heat produced by the ball penetrates in a material volume from which the information is gained. Penetration depth is a sphere of diameter around 20 mm for stabilized temperature considering sensor diameter of 2 mm. Typical measurement signal is shown in Fig. 1 along with the characteristic points used to calculate thermal conductivity.

The measuring procedure consists of the specimen temperature measurement (base line), switching on the heating and simultaneously scanning the ball temperature. When the ball temperature is stabilized, the heating is interrupted and a period of temperature equilibration follows. When the temperature in the specimen is equilibrated the next measurement can be realized. The highest repetition rate (frequency) of the measurements depends on the thermal conductivity and it takes from 3 up to 40 minutes.

The hot ball is composed of two parts that, on one of it generates constant heat and the second one measure the temperature response (patent pending). The RTM 1.01 instrument in connection with the thermal conductivity sensor was constructed in a manner that can work in the regime of a single measurement or in the monitoring regime. Simplified block diagram of the RTM 1.01 instrument is shown in Fig. 2. With assistance of any PC with standard USB interface, one can set the configuration of the instrument, as well as download measured data stored in the instrument's memory. Currently, additional electronic units that will support wireless data transfers are under construction.

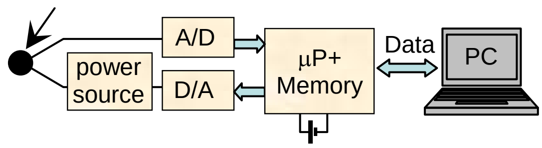

Fig. 2. Simplified block diagram of the RTM 1.01 instrument.

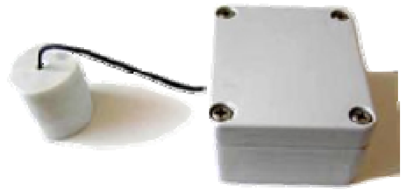

Fig. 3. The RTM 1.01 instrument in connection with the hot ball arranged as a moisture sensor.

3. The moisture sensor construction and in situ application

The true moisture sensor is based on the hot ball inserted into the cylinder made of porous material (Fig. 3). Such moisture sensor is then calibrated for dry and water saturated conditions. Later the sensor is fixed in a place, where one needs to have information on moisture. A choice of the cylinder material porosity allows measurement of a broad range of moisture. Such moisture sensors can be used for highly inhomogeneous wall structure as well as any natural stone or natural rock body.

Porous materials situated in natural conditions are exposed to sun radiation, precipitation, evaporation, frost and thaw phenomena. The mentioned processes form the water phases found in pores (gas, liquid, solid). Then the resulting thermal conductivity of a porous material is a function of the content of the pores.

We have applied the moisture sensors for monitoring the thermal – moisture regime in the rock mass forming a subgrade of Spis Castle (Fig. 4). Four holes were drilled (one for each moisture sensor) in a distance of 2 m and up to depths of 10, 40, 80, and 150 cm from the rock surface in a horizontal direction. The cylinder with 20 mm diameter for the moisture sensor was cut from the drilled core. The sensor configuration together with the drilled hole is shown in Fig. 5. The four sensors were previously calibrated in laboratory for dry and water saturated conditions. A paste made by mixing of water with travertine powder obtained during drilling was used to fix the sensors into the holes. The rest of each hole was filled by small pieces of travertine core combined with travertine paste up to the surface. To prevent diffusion of the water into the borehole, the opening heads were sealed by silicone paste. The four RTM 1.01 instruments have been configured appropriately considering measuring repetition rate, temperature and moisture changes. The in situ monitoring was performed in the period from December 4th, 2008, up to January 17th, 2009 (Fig. 6).

Fig. 4. Spis Castle.

Fig. 5. The moisture sensor and hole configuration.

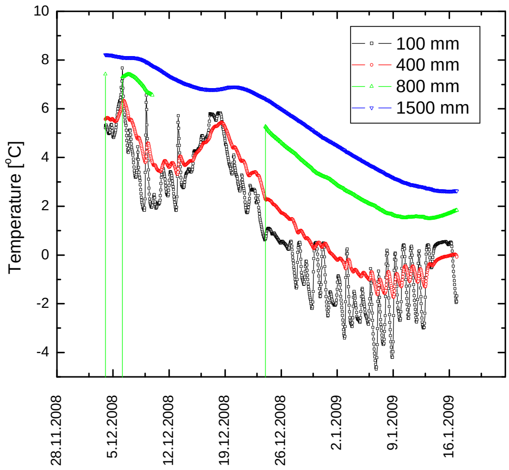

Fig. 6. Temperature variations of monitored rock mass for different depths, during the period of December 4th, 2008 – January 17th, 2009. Parts of data from the depth 40 cm are omitted due to the instrument failure.

4. Conclusions

Data on temperature obtained from all four positions during monitoring period are shown in Fig. 6. Temperature variations due to the day/night period are recognizable for depths of 10 cm and 40 cm, when sky was clear. Temperature at all four positions has fallen down within one month period. The moisture has risen in the period of monitoring for all four positions, however it is not possible to establish a measure of this rise due to need of additional calibration measurements.

Generally the accuracy of measurements is within 10% (compared with pulse transient method and data from literature) and the precision (reproducibility) is better than 1%.

The hot ball sensor belongs to the family of the multi-parametric ones. The sensor in combination with porous structure of the multifunction material can offer a range of information. In our case, the sensor can be used for determination of the moisture content. Processes, like thawing, freezing, drying, etc. can be monitored. It should be stressed that the listed processes are always starting from the material surface. One can monitor the fronts of the propagated effects by fixing the sensors to different material depths.

Acknowledgements

This work was supported by the EU project ACOUTHERM GRD3-2001-60001, by the project APVV 0497-07 and by the VEGA projects 2/0146/08 and 1/0499/08. Authors would like to express thanks to Mr. Markovič for his technical assistance.

References

[1] Vlčko J. Extremely slow slope movements influencing the stability of Spis Castle, UNESCO site. Landslides. - Vol. 1, No. 1 (2004), 67-71.

[2] Kubičár Ľ, Vretenár V, Štofanik V, Boháč V. 2008, Thermophysical sensors: Theory and application of the hot ball, Int. J. of Thermophysics, sent for publication.

[3] Carslaw HS, Jaeger JC. 1956, Conduction of heat in solids, Oxford, Clarendon Press, 348.