Moisture Sensor for the Monitoring of Temperature-Moisture Regime in Volcanic Tuffs Located in Brhlovce Village

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Abstract. *The field research is based on in-situ monitoring of the temperature-moisture regime of natural rock mass in volcanic tuffs localized in the Tekov Museum of rock dwellings in Brhlovce preserved as historical heritage. The temperature and moisture changes are the parameters that influence deterioration processes of rock massive. The moisture probe uses the increase of thermal conductivity of porous structure when pores are filled by air/vapour, water or ice. The correlation between thermophysical properties and water content in pore exists. For this kind of measurements we calibrate the moisture sensors and determine change of thermal conductivity of porous material for dry and water saturated states in the temperature range that is typical for the locality climate. The moisture monitoring in the field conditions at different depths in the rock massif when they are exposed to climate changes was studied by moisture probes. The experiment was carried out for the needs of correlations between laboratory and field research.*

Keywords: Moisture Probe, Thermal Conductivity, Calibration

1. Introduction

The problem of thermal transport phenomena in the presence of moisture content in porous materials are in high interest of building industry as well as in the area of preservation of historical buildings and monuments. In the nature the water phases are always present in pores in different forms. The massive rock materials in natural conditions are exposed in time to the climate changes like the sun radiation, precipitation and evaporation, freezing and thawing causes deterioration processes of rocks. The resulting thermal conductivity of a porous tuff rock material is a function of the fluctuation of water content in pores (porosity 40-60%). The calibration of the moisture probe from dry to water saturated material sets the working range of measured water content in rock mass.

2. Physical model

In principle, the moisture probe is based on hot ball sensor (HB) in combination with rock cylinder drilled out of tuff massive assembled in a proper way. The measurement principle is based on generation of the heat pulse in the step-wise form and recording the temperature response to this heat pulse. Model for the arrangement on Fig.1 (down) assumes a constant heat flux $\boldsymbol{q}$ from the empty sphere of radius $\boldsymbol{r_b}$ (radius of hot ball probe) into the infinitive medium that starts to be generated for times t > 0 (Fig. 1 down). Then the temperature distribution within the medium is characterized by Eq. 1 [1, 2, 3]. The solution of the partial differential equation of the heat conduction for this experimental technique is the temperature function (Eq. 1) that describes the temperature response on Fig. 1.

$$T(t,R) = \frac{qR}{\lambda}\left\{1 + \frac{1}{z_1 - z_2}\left(z_2 w\left(-iz_1\sqrt{t}\right) - z_1 w\left(-iz_2\sqrt{t}\right)\right)\right\} \qquad (1)$$

Where $z_{1,2} = \frac{\lambda}{2\sqrt{\kappa}C_s}\left(-1 \pm \sqrt{1 - \frac{4C_s\kappa}{\lambda R}}\right)$, $w(x) = e^{-x^2}\Phi^*(-ix)$, T – temperature, t – time, r – radial space coordinate, ***R*** – radius of the sensor, ***q*** – heat flow density at sensor, ***λ*** – thermal conductivity, ***κ*** – thermal diffusivity, ***Φ**** – complementary error function, $\boldsymbol{C_s}$ – heat capacity of unit area of sensor surface, $\boldsymbol{C_s = C/4\pi R^2}$ – heat capacity of unit area of sensor surface, ***C*** – heat capacity of sensor. The thermophysical parameters ***λ, κ*** and ***C*** are calculated from the temperature response (Fig.1.) by fitting procedure using model (Eq. 1).

3. Experiment

The Hot ball probes before inserting to the stone cylinder were primarily calibrated in baths having different thermal conductivity to obtain the basic probe parameters to calculate thermal conductivity and thermal diffusivity from the temperature response. Calibrated sensor inserted in a tuff core creates the moisture sensor (Fig. 1. bottom).

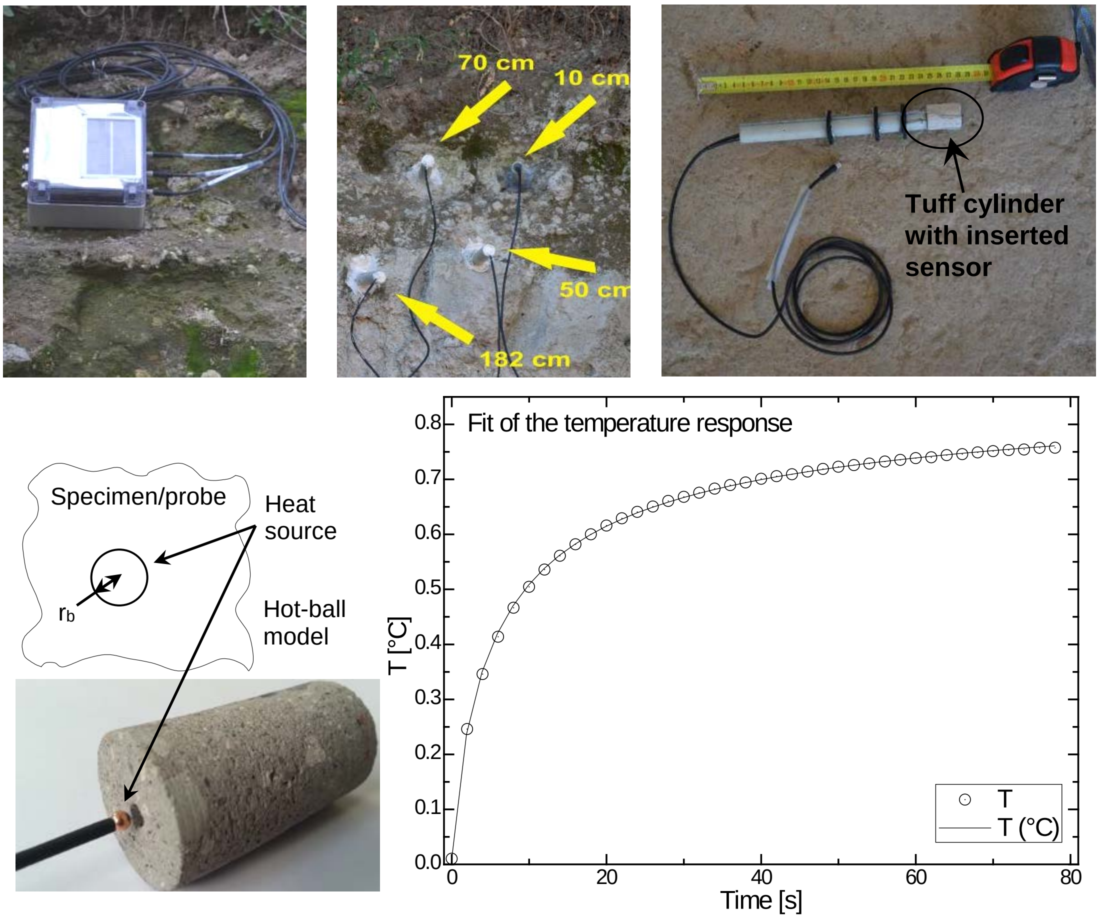

Fig. 1. The electronic instrument RTM powered by solar unit in connection with the moisture probe (left up), the current location of the probes in rock massif (middle up) and the moisture probe ready to be mounted to rock massif with the holder made of plastic tube sealed with rubber rings to prevent air and moisture transport to the 10cm measurement depth (right up). The model of the hot ball sensor with the photo (down left) and the fit of measured temperature response by temperature function (down right).

The next calibration was done for the dry and moisture saturated states. The measured value of heat flux and temperature maximum q/T_m inside the moisture sensor represents thermal conductivity that is changing in dependency of moisture content from 0 up to 100 % (Fig. 2.).

4. Results

The moisture probes were calibrated in dependence of temperature in both – the dry and moisture saturated regime. The calibration data in dependency of the temperature for the moisture sensors made of tuff stone cylinders in dry and moisture saturated states are presented. The thermal conductivity values of moisture probes which correspond to change of moisture content in temperature-moisture dependency calibration procedure were measured in thermostated chamber RTB 1.02. The dry-moisture calibration was performed in laboratory conditions for the range of temperatures from -20 up to 40 °C. After calibration the moisture sensors were inserted in the tuff massif at Brhlovce. Monitoring in tuff massive at depths of 10, 50, 70 and 182 cm was started to run.

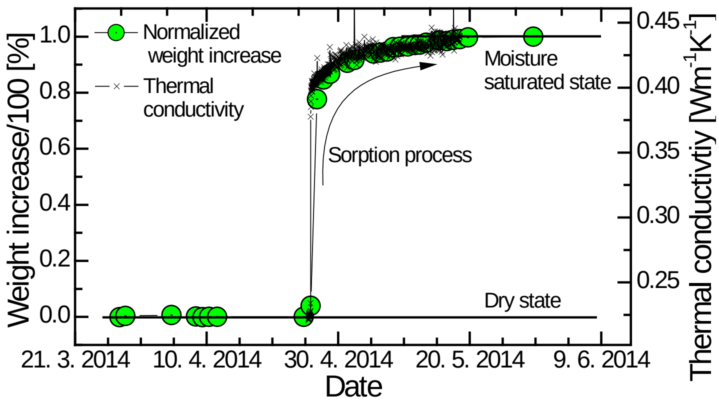

Fig. 2. Sorptivity (moisture content) is related to the pores volume measured by weighting method for the probe made of tuff. The change of thermal conductivity about 50% from dry to moisture saturated state is correlated to normalized weight data during saturation. This difference represents 100% of humidity scale in between dry and fully saturated pores by water [3].

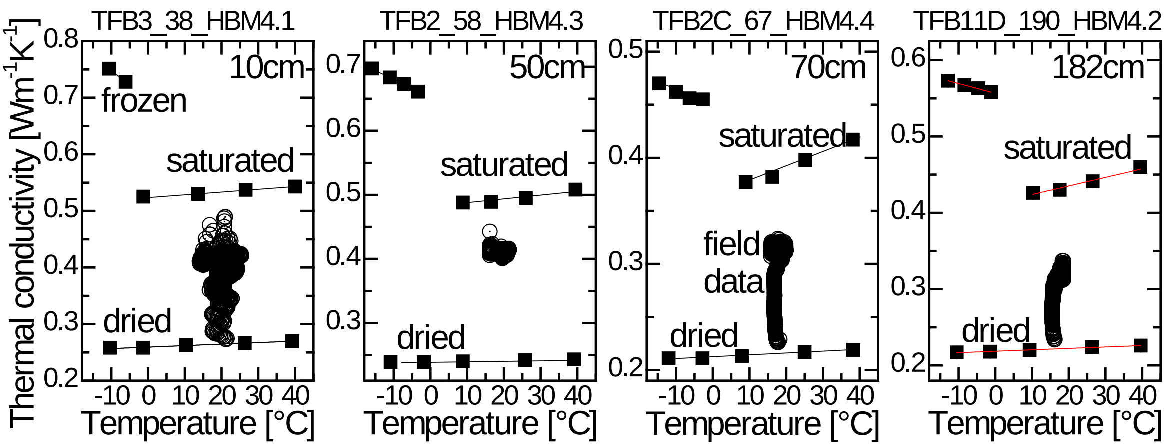

Fig. 3. Calibration of old probe made of tuff stone in dry and moisture saturated state. The calibration lines below zero temperature represent thermal conductivity in frozen state because of jump change after the phase change of water. Data between calibration lines represent field measurements from first month after inserting into the massif.

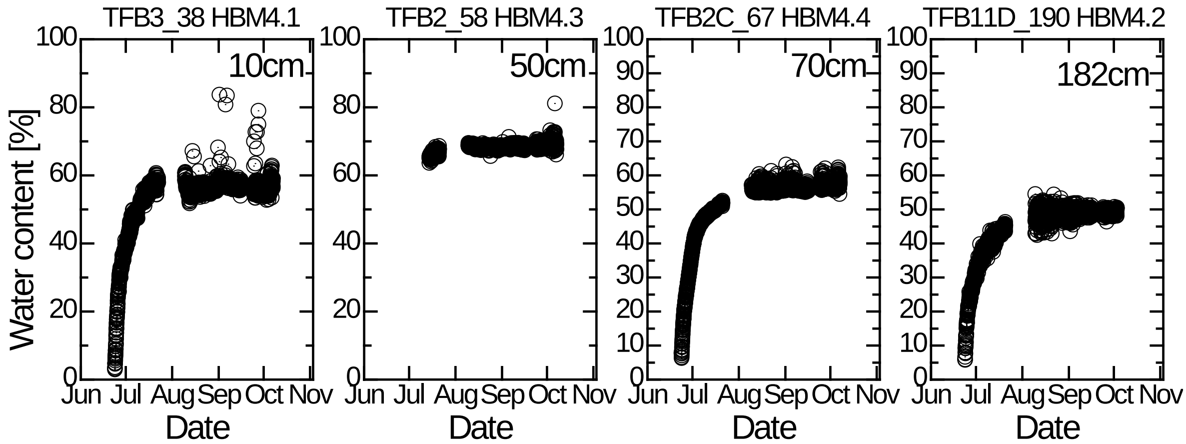

Fig. 4. Field data from Fig. 3. recalculated to a relative water content according the equations of calibration lines drawn for a time period of 3 months after insertion (up). The increase during the first month satisfies to speed of sorption found in laboratory during the calibration on Fig. 3.

5. Conclusions

For the calibrated moisture sensors the variation of λ with variation of moisture content as a parameter, the temperature dependency was found. The moisture change measured as the value in between the maximum and minimum values of λ that define the moisture sensitivity and in the case of this probe it was about 0.5 $Wm^{-1}K^{-1}$ in a given temperature range. For different moisture content a linear dependency is valid, so one can recalculate measured values of λ to the moisture content from this calibration. At the first month of monitoring the rapid increase is evident and gives an image on difference between the dry and stabilized state that corresponds to the moisture content in massif about 50-60%. The data on bottom were recalculated to absolute water content related to a volume of one cubic meter according the equations of calibration lines drawn on Fig. 2 and Fig. 3. Their values in currently saturated state for 50-70% are about 280 to 480kg m^{-3}. This experiment will be helpful in monitoring the moisture in field research, because values of thermal conductivity are defined in extreme dry and wet conditions (Fig.3, 4).

Acknowledgements

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