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Monitoring of earth-fill dam and snow cover using EIS method

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***Abstract* – The paper describes some of the results of measurement changes electrical properties in the central sealing core of the earth-fill dam Karolinka (Czech Republic) before and after the reconstruction. Other results, shown like pilot measurement, are from the monitoring of snow cover (Austria). Both areas of experiments are done with the view of climate changes for obtaining more information about floods and dry. The measurement was performed using the method of electrical impedance spectrometry and a Z-meter III or Z-meter IV devices which were developed and constructed through the projects of international program EUREKA.**

I. INTRODUCTION

In recent decades, it is the widely discussed climate change around the world, and especially its causes. At present it is possible to register the growth of temperature, changing character of precipitation, melting glaciers and snow and rising global average sea level. It is expected that these changes will continue and that extreme weather events, which result in the type of risks of floods and droughts will become more frequent and intense. Impacts on nature, economy and health in various areas, territories and various economic sectors in Europe. The recent floods in the Czech Republic, Germany and Austria have caused the death of several people and extensive damage to property. As a result of extreme hydrometeorological events since 1980, of damage to property are rising, which is mainly due to changes in the use of the landscape, the increase in population, increasing wealth and development of human activities in the endangered areas. Although there are no exact quantitative projections of flood events, the European Union addresses these risks [1], [2]. There is a European programme for monitoring the environment and security through which are developing also national monitoring systems. Into these monitoring systems is possible to include the apparatuses which are developing and testing through international projects E!4981 and E!7614 in EUREKA program [3].

II. ELECTRICAL IMPEDANCE SPECTROMETRY

Changes that take place in soil of the dam are monitored through electrical variables based on the principle of the measuring method [4]. The real component (electrical resistance R) and the imaginary component (reactance X – apparent electrical resistance) of the electrical impedance $\mathbf{Z}$ are detected separately. It is possible to express the value of electrical impedance Z and the phase angle φ between I and U from the measured values. The measurement of electrical impedance $\mathbf{Z}$ is based on Ohm's relation for alternating current circuits, i.e. on the ratio of the phasor voltage $\mathbf{U}$ to the phasor current $\mathbf{I}$

$$\mathbf{Z} = \frac{\mathbf{U}}{\mathbf{I}} . \tag{1}$$

The frequency characteristic of impedance $\mathbf{Z}$ can be expressed as a function of a complex variable in algebraic (component) form

$$\mathbf{Z} = R + j\,X , \tag{2}$$

where R is the resistance (electrical resistance) independent of the frequency and X is the reactance that changes with frequency.

The modulus of the vector of impedance $|Z|$ can be expressed using the Pythagorean theorem in the form

$$|Z| = \sqrt{R^2 + X^2} \tag{3}$$

and the phase shift is expressed by the relation

$$\varphi = arctg\left(\frac{X}{R}\right) . \tag{4}$$

Electrical impedance is a basic property characterizing the linear load of alternating current circuits. It is always higher or equal to the real electrical resistance in the circuit and depends on apparent resistances, i.e. the inductance (reactance of the inductor) X_L and the capacitance (reactance of the capacitor) X_C of individual elements of the AC circuit. This means that the porous medium can be described by the electrical impedance of an equivalent electric circuit formed by a combination of a resistor, an inductor and a capacitor. Their connection in a circuit can be in series (the phasor current is common for all elements of a circuit), or in parallel (the phasor voltage is common for all elements of a circuit) which has appeared to be more suitable for measurement in the studied porous medium.

Also, it is possible to express the admittance **Y** of a medium (the inverse value of electrical impedance)

$$\mathbf{Y} = G + jB, \tag{5}$$

where G is the electrical conductance that expresses the capability of the monitored earth medium of conducting well the electric current I and B is the susceptance (apparent electrical conductivity). The electrical conductance G, however, can also be expressed from the property of the conductor

$$G = \sigma \frac{A}{l}, \tag{6}$$

where σ is the conductivity (environment property) of the medium, A is the cross-sectional area of the conductor formed by the substances between indicator electrodes and l is the length of the conductor in which the electric voltage is generated (in order to be a direct conductor, $l >$ 2 m is not recommended).

III. CONSTRUCTION OF THE PROBES

The construction of the probes always going out from the knowledges of the method of instalation and of the environment, where the apparatus will be used. These facts are perceived very positive.

For instance due to the construction of the probes used (Fig. 1) and the way of their placing in the sealing core of the dam (total lenght is 13 m) it is possible to characterize the application of the EIS method to the monitored structure as non-destructive and invasive. The conductive part of the probe is made of a stainless tube of 0.025 m in diameter and 0.050 m long; the non-conductive part is made of a polyamide tube of the same diameter in irregular lengths (from 0.050 m to 1.000 m).

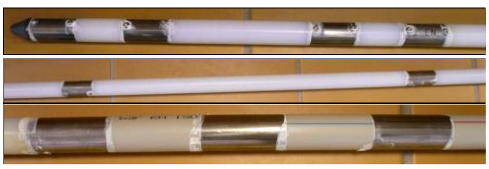

Fig. 1. Positions of electrodes on a divided rod probe with the indication of the length of electrodes.

When the expeditionary measurements were used it was applied divided rod probe in total lenght 0.375 m with eight electrodes for better handling during shipment. The probe that was used for probing of snow cover is shown in Fig. 2.

The length of electrodes were 0.025 m and alternated with 0.025 meters long insulators made of polyamide. Diameter of the tubes were 0.012 m. To prevent penetration of moisture into the compartment with the conductors (parasitic electrical resistance), the individual parts of the probe were connected using to the sealing no-conductive silicone material that also seals the probe at the surface layer.

Fig. 2. Positions of electrodes on a divided rod probe with the indication of the length of electrodes.

IV. Z-METER III DEVICE

Monitoring changes of electrical characteristics of the snow cover was carried out with the apparatus unit Z-Meter III with optional number of measurement points [5]. To realize the device was elected signal processor latest development series measuring electric impedance of the company "ST Microelectronics", the 32-bit processor allows only two-wire terminal connection measurement. The basic device parameters are listed in Tab. 1., structural design device of Fig. 3 The device is a battery with an estimated time of 8 hours of continuous operation with rechargeable 12 V source. The device allows measurements from one selected frequency or in frequency range.

Fig. 3. Z-meter III device.

Table 1. Basic parameters of Z-meter III.

Parameters	Z-meter III
impedance range	100 Ω – 1 MΩ
frequency range	1 kHz – 100 kHz
accuracy measurement module	±2% from range
precision measurement phase	±2°
communication interface	USB, SD card
no. of measurement points	1, 8, 16, 32, 64, 128
switch	internal, external
power	battery

V. THE EXAMPLE OF APPLICATIONS

One possible use of the measuring apparatus is watching earth dams and changes occurring in areas of anomalies detected at various loads of soil by water. Listed is an example of the result of the continuous monitoring of water works Karolinka in Czech Republic. Because the ion composition of snow cover has an effect on electrical conductivity, pilot measurements were also made in the measurement of layers of snow. An example of the result obtained from the Austrian Alps is shown. Chemically pure water has low electrical conductivity; with an increasing concentration of ions in it, its conductivity is rising. [6]. Electrical conductivity is one of the variables which can be determined using the method of electrical impedance spectrometry (EIS)..

A. The earth-fill dam of the Karolinka water reservoir

Monitoring of the earth-fill dam of the Karolinka water reservoir in CZ (referred to hereinafter as VD Karolinka) was commenced under the auspices of the project E!4981 and is further carried out through the project E!7614. The main investigator of the projects in the programme EUREKA is the company GEOtest, a.s., and the second initiator of monitoring is the cluster CREA Hydro&Energy, o.s. Monitoring of changes that take place in the soil of the dam using the method of electrical impedance spectrometry was commenced in March 2011 and are continue at intervals of at least once a month. Since the Karolinka reservoir was commissioned in 1985, inrushes of water have been occurring on the downstream face until the present time, with a different intensity of seepage. These observations have resulted in a decision to take a technical measure that will lead to the abatement of the existing adverse state or to its full elimination.

The manager of the water reservoir, the state-owned enterprise Morava River Basin has undertaken the basic steps for the safety of the reservoir, such as a drainage system on the downstream face of the dam and the lowering of the water level in the reservoir, and invited to tender for the reconstruction of the dam, what was realized in 2013. Part of the dam repair, which is to help reduce seepage across the dam body, was to build a grout curtain in the upper part of the sealing core of the dam (a 0.6 wide conventionally dug cut-off diaphragm wall from clay-cement slurry), to raise the sealing core according to the current standards. In March 2011, four probes were installed into the sealing core from the dam crest of VD Karolinka (Fig. 4) for measurement using the method of electrical impedance spectrometry.

Fig. 4. Placing and installation of probes of the EIS method, downstream face of the earth-fill dam of VD Karolinka.

The placing of probes, their total length 13 m, the length of measuring electrodes 0.05 m and the position of sensors on the probe – irregular division were based on the position of the observed inrushes of water, on the knowledge of the characteristics of the materials used and on the technical documentation of dam construction.

B. Monitoring of snow cover in Austria

On 30 January to 1 February 2013, snow cover was monitored using the method of electrical impedance spectrometry (EIS) in the area of Wildschonau in Austria [7]. This area is located to the northeast of Innsbruck. Snow is a very specific and complicated form of the solid state of water. The basic physical property of snow, therefore, is its isotropy. Only 3% of newly fallen snow are formed by ice crystals; 97% come to air gaps between the crystals. There are many classification scales for determining the characteristics of snow [8]. Table 2 gives a classification scale of toughness/hardness for manual measurement or determination of what suffices to disturb a layer of snow.

Table 2. Manual differentiation of snow toughness [9].

Toughness	Test of toughness	Resistance R [N] (mean values)	No.	Colour
very soft	fist	20	1	
soft	four fingers	90	2	
middle hard	one finger	260	3	
hard	pen	600	4	
very hard	knife	900	5	
ice	ice		6	

VI. THE EXAMPLE OF OBTAINED RESULTS

In this part are shown some types of results which is possible to obtain from application of EIS method.

A. The earth-fill dam of the Karolinka water reservoir

Monitoring carried out regularly once a month using a Z-meter III device is supplemented by measurement during extraordinary situations – a higher intensity or frequency of precipitation (rain, snow), a rise or drop of the water level in the reservoir, frost, etc.

A three-terminal connection of electrodes is used on a probe, which requires the application of an adapter. Due to the characteristic of soil, monitoring is carried out at a frequency of f = 8,000 Hz with the time of switching between measurements t = 0.100 s; the number of repetition on one sensor was n = 10. Fig. 6 shows the patterns of the monitored climatic conditions and the water level in the reservoir at the time when a sharp drop in the water level in the reservoir is evident.

In the year 2013 it was sealed the upper part of the dam in the form of a concrete vertical sealing curtain that reach a depth of 10.0 m to 19.0 m into the construction of the dam.

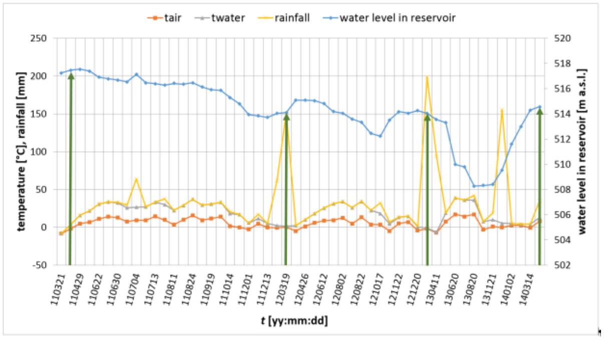

Fig. 6. Time curves of monitored parameters.

The measurements were taken in the days 31.3.2011, 19.3.2012, 5.3.2013 – before reconstruction and 17.3.2014 – after reconstruction. It can be stated that the climatic conditions and water level in reservoir were very similar (Fig. 6), with the exception of 2011. The pattern of changes in the electrical conductance G of the dam soil is documented from the existing measurements in graphs VL_1 to VL_4 (Fig. 7).

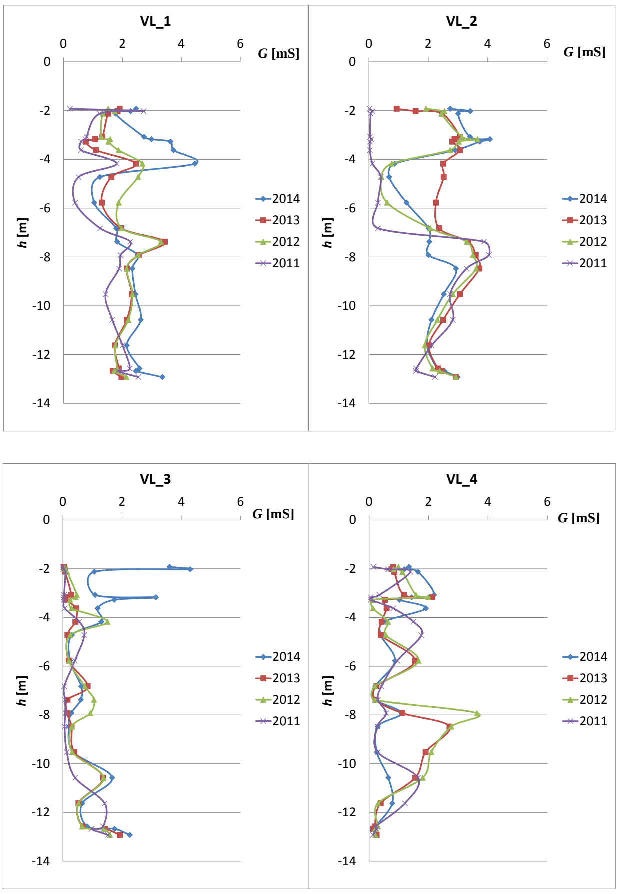

Fig. 7. Monitored curves of electrical conductance of soil in March of the years 2011 to 2014.

The monitored levels are processed from the dam crest at the elevation 0.00 m. The higher values are evident on probes 1 and 2, which correlates very well with the observed seepage sites on the downstream face of the dam.

Other view is possible to do through the maps of electrical conductance (Fig. 8). In the years 2011 to 2013 is very well observable region of increased electrical conductivity (higher water content is shown blue color) at a depth of about 8 m, distance around 40 m. This problem doesn't occur in the year 2014 (after the wall instalation). They are, however, recorded higher values of *G* at a depth of 2 m below the top of the dam. Because they appear along the entire length of the reference section, and only in 2014, it is possible to infer the process of "maturation" of the installed sealing wall.

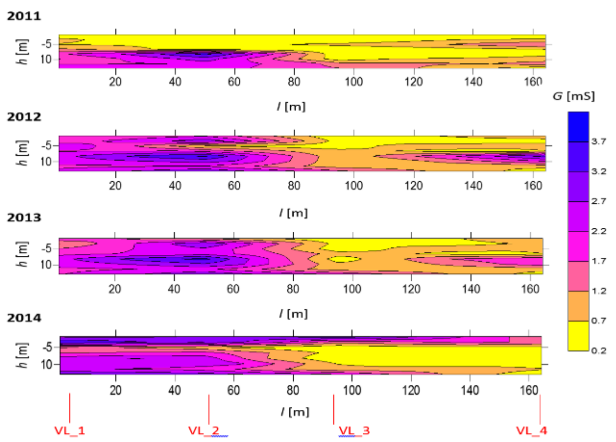

Fig. 8. Maps of electrical conductance measured on March of each year.

B. Soluted profile

Soluted profile was located in the village of Oberau. There, we carried out test measurements of electrical properties of snow (Fig. 9), which were made by one divided rod probe using eight sensors at different height levels. The following graphs always show the earth's surface at the level $h_x = 0.00$ m. Although the probe used was short for measuring meteorological variables, it corresponds with the limit of measurement of near-ground minimum temperatures at a height of 0.05 m above the earth's surface and shows the suitability of the placement of meteorological stations at a height of 2 m above ground. Air is taken as an insulator, but it depends on its humidity, i.e. the stronger frost is, the better air as an insulator is, because air humidity occurs in the form of poorly electrically conductive ice crystals. Snow in general should be a better electrical conductor because not only ice crystals, but also the form of free water occur in snow cover. When measuring the conductance of snow, it would be possible to expect the opposite pattern. Because the measurement shows the opposite, it can be stated that this snow is very loose (in which the distances between the individual snowflakes are too great and the produced pores are filled by air), but has different thermal properties than air above snow cover has.

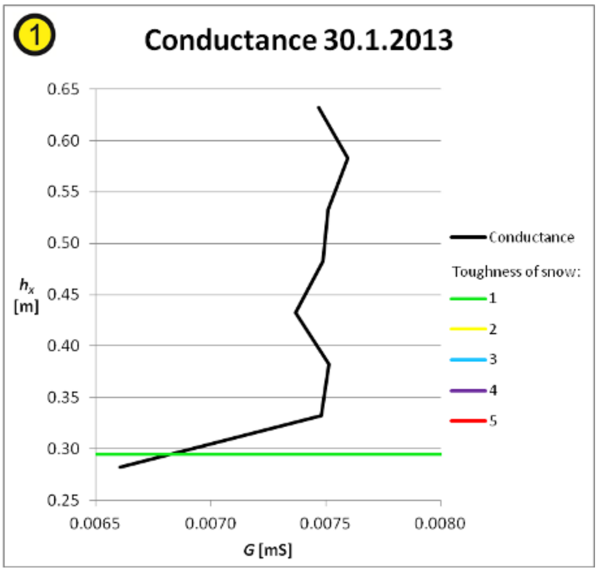

Fig. 9. Snow conductance.

Susceptance (Fig. 10) is an electric characteristic directly dependent on the measurement frequency, through which the transition between the individual layers of snow cover can be detected.

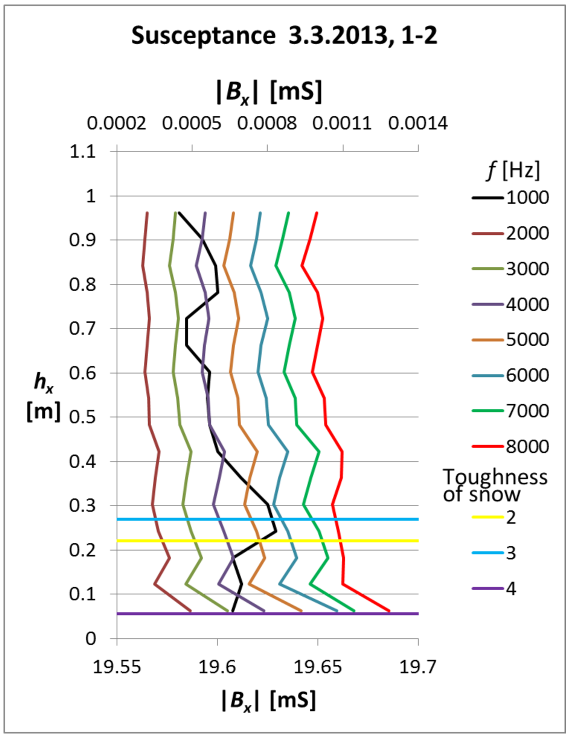

Fig. 10. Sample of measured susceptance.

The lower horizontal axis (Fig. 10) of the measured values of susceptance applies to the frequency 1000 Hz (the black curve); the upper axis applies to the other measured values. It must be said that in the frequency 1000 Hz was obtained bad results in many applications. Though CPU manufacturer guarantees the frequency for measuring, it can be said that is not appropriate. At frequencies from 2000 Hz to 8000 Hz, the character of curves is similar: the values of the monitored electrical variables show a growth towards the earth's surface. Susceptance, which differentiates the structure of snow cover layers, is a significant variable for determining snow cover layers.

VII. CONCLUSION

The monitoring equipment, and the results have helped identify local anomalies in the dam, supported the call of their rehabilitation and monitor the effectiveness of the security measures.

In the case of measurement vrtev snow is a pilot experience in the application of the method in completely different conditions of measurement of porous media.

On the basis of experience and cooperation with practice can be recommended that the monitoring of porous environment is first necessary to make their identification through frequency analysis using Z- meter device. Subsequently, it is necessary, depending on the observed phenomenon and its evaluation select procedure measurement.

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