

MONITORING OF THE SOIL STATUS USING ELECTRICAL IMPEDANCE SPECTROMETRY METHOD DEVELOPED IN PROJECT E!3838 OF THE EUROPE INTERNATIONAL PROGRAM EUREKA

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Abstract – The non-traditional method for the soil status and its change monitoring was used. The method is electrical impedance spectrometry (below EIS), which is developed within the Europe international project E!3838 of EUREKA program. EIS monitors electrical impedance in complex form and its changes caused by the load of the environment or construction by water. For this work was developed and realized unique apparatus Z-meter with 128 monitoring channels. Using the EIS method, progress of water infiltration and deformations outside or inside of the dike body can be indicated.

Keywords: soil status, monitoring, EIS-Method

1. INTRODUCTION

Frequent floods initiated intensive effort oriented to the hydrological situation forecasting in regions endangered by water and to the protective dikes building. Knowledge of dike properties and mechanisms of their damage by water makes possible to size up the importance of the endangering, and to ensure the life and possession protection in the risk region in advance. For purposes of forecasting the hydrological situation, mathematical modelling is applied. But monitoring environment is complicated. It has three components – earth as solid, water as liquid and air as gas. Also the processes passing of them are very difficult to describe of mathematical forms. The complexity of the problem lies in the unsteady flow of water in unsaturated soil media. The experimental results show that hydraulic conductivity coefficient of the unsaturated soil reaches the magnitudes more than thousand times lower in comparison with saturated soil. Therefore monitoring is non-changeable way to take information about them.

The impedance method takes advantage of the electrical impedance measurement in complex form in different parts of the dike (on the surface and inside) or soil environment.

The method of electrical impedance spectrometry will be used in conception of the device Z-meter. Methods, monitoring apparatus, and handling and evaluating software packages are built and tested within the project E!3838 of

EUREKA program. The experiments have been carried out in laboratory conditions in the Laboratory of Water Management Research at the Institute of Water Structures of the Faculty of the Civil Engineering of Brno University of Technology and the measurements have been done also in real conditions together with the company GEOtest Brno, Inc. (leader of the project). At the project E!3838 of EUREKA program active cooperate the teams of partners from CH, IT, SK, CY.

2. ELECTRICAL IMPEDANCE SPECTROMETRY METHOD

While Ohm's Law applies directly to resistors in DC or AC circuits, the form of the current-voltage relationship in AC circuits in general is modified to the form

$$Z = \frac{U}{I} \quad (1)$$

where I and U are the rms or "effective" values. The quantity Z is called impedance. For a pure resistor, $Z = R$. Because the phase affects the impedance and because the contributions of capacitors and inductors differ in phase from resistive components by 90 degrees, a process like vector addition (phasors) is used to develop expressions for impedance (Fig. 1). More general is the complex electrical impedance method.

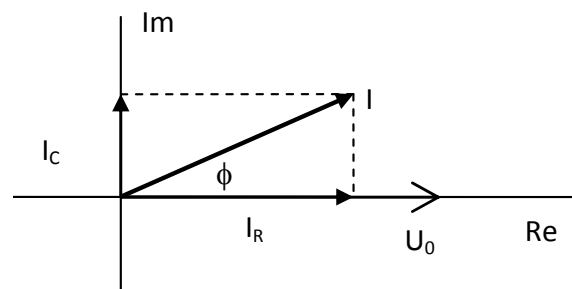


Fig. 1. Phase diagram.

The physical principle of the EIS method takes advantage of measurement of frequency dependence on the material impedance in complex form. This measurement was realized in different parts of the dike (on the surface and in the dike) in laboratory conditions and in situ too.

The electrical impedance Z (or admittance Y) of the soil between two electrodes (two electrodes make up one probe) constitute the local electromagnetic properties of the soil in measured profile. The electromagnetic properties are recorded in the measured resistance R and reactance X . But these measured parameters combine also the parasitic impedance of the probe, the cable, electrode effect, and the soil itself. The electrical impedance can be calculated in Cartesian (R and X), or polar ($|Z|$ magnitude and phase angle Φ) coordinates. These parameters are related as follows

$$Z = R + jX = |Z|e^{j\Phi} = \sqrt{R^2 + X^2}e^{j\Phi} \quad (2)$$

The complex impedance Z of the unsaturated porous soil material describes its properties (Fig. 1) - The solid part (grains) is formed by insulating materials characterized by their dielectric constants and represents the imaginary part of the measured impedance; water containing mineral salts is a conductive material. The degree of saturation of the material strongly influences the real part of the measured impedance.

Therefore, the measuring equipment must enable to determine both parts of the impedance Z . The goal of the measurement and calibration of the system is to extract the impedance of the soil from the measured total impedance.

3. Z-METER

According to an equivalent diagram of the circuit of measured impedance (Fig. 2), electric current is divided into two orthogonal components, real I_R flowing through the real component of the equivalent impedance R , and imaginary I_C flowing through the equivalent capacity C .

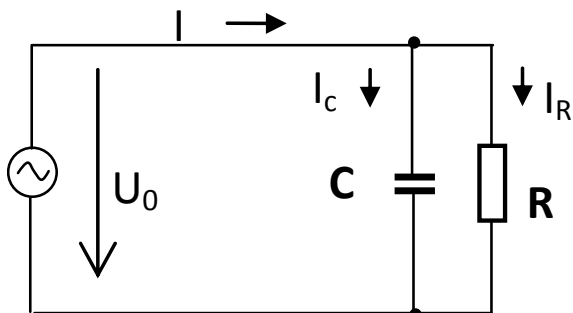


Fig. 2. Equivalent diagram of measured impedance.

In a vector diagram (Fig. 3), the reference vector is the vector of voltage U , with which the real component of current I_R is in phase and the imaginary component is perpendicular to it.

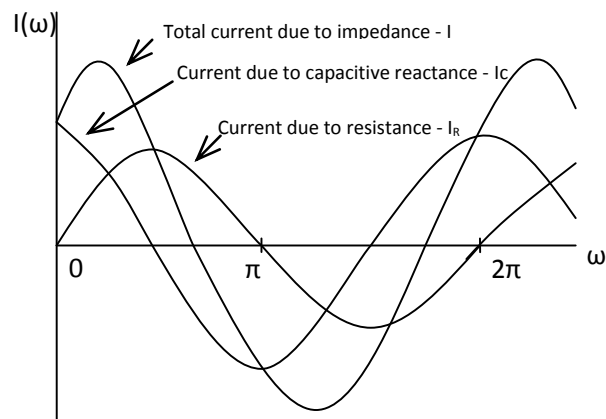


Fig. 3. Illustration of courses of currents with time.

For measurement in the real environment, a measuring device Z-meter 2 with basic parameters according to Tab.1 and special measuring probes were made [1].

Table 1. Basic parameters of the Z-meter

Parameters	Z-meter
Range of impedances	10 Ω – 1 M Ω
Frequency range	100 Hz – 20 kHz
Accuracy of modulus of impedance	+/- 2 % of the range
Accuracy of phase	+/- 2°
Level of measuring voltage	500 mV – 5 V with an interval of 500 mV
Communication with a PC bus	USB (COM port), LAN, GSM, CF card
Integrated electric switcher	128 measuring points, each with 4 electrodes

3.1 Measuring Route

At the beginning of the measuring route, there is a source DDS 1 of measuring harmonic signal with adjustable frequency and amplitude, generating sine voltage U_0 with frequency f_0 . Generated voltage U_0 with phase $\varphi_0 = 0$ is conveyed to the measuring electrical impedance Z_x and is considered as reference one. Thus $U_x = U_0$. The block marked I/U senses electric current I_x flowing through measured impedance Z_x and converts it into voltage U_{ix} . The conversion coefficient (range) is adjustable through DSP. This output voltage is measured (sampled) by an AD converter ADC 2.

There is generally a phase shift φ between electric current I_x and voltage U_x , depending on the character of measured impedance.

Based on this model, where voltage U_x is referential with phase $\varphi_0 = 0$ and current I_x is formed by the real and imaginary components (resistance and reactance), the resulting measured value of impedance will be represented by a parallel combination of resistor and reactance of the capacity character.

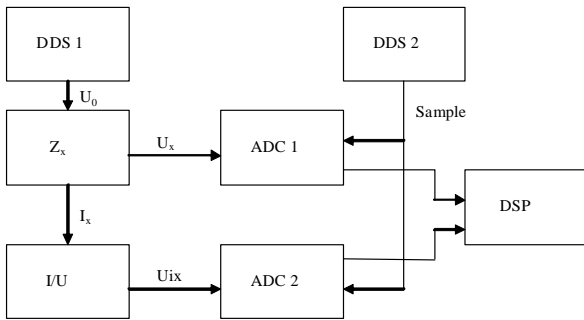


Fig.4. Principal block diagram of digital measurement of impedances.

3.2 Conception of the device

For planned long-term experiments in the field, it was, therefore, necessary to modify the device. This means to have the possibility to operate measurement without mains supply, i.e. only from a built-in, or an external lead battery. This is also connected with the requirement to minimise the input for achieving the maximum time of operation with the given capacity of the battery.

The second key requirement is for the data interface of the meter. It was required to have the possibility to archive measured data directly in the device for the later mass download into a PC on the one hand, and to have the possibility of remote access on the other hand. It seemed the most appropriate to access through the Internet: whether directly through the Wi-Fi network of the provider of the Internet connection or by means of the network of a GSM operator.

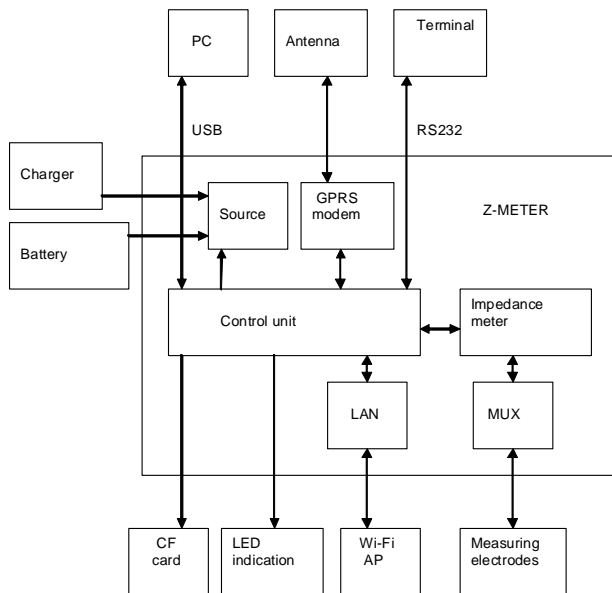


Fig.5. Block diagram of a Z-meter device.

Regarding these requirements, it was necessary to prepare the conception of the device as modular. The selected system of the 19" case has enabled to easily extend it by other attachments/modules. It is, thus, mainly a new

power-supply attachment [1, 2] and an addition of a control/communications attachment. The block diagram of a Z-meter device is shown in Fig.5.

4. EXSAMPLE OF THE RESULT

The method of the electrical impedance spectrometry [1] has been used to the measurement of the mentioned above physical properties. In laboratory conditions were measured the changes of the electrical impedance caused by the water level and the structural changes of the soil medium and state of the dike, piled up in the laboratory flume, or by the pollution. The stainless steel electrode (red colour lines) system consisting of several electrode pairs or twisted-pair in sensors matrix (black points) has been plugged-in to the dike. In this case two-terminal method of impedance measurement was used and is shown in the Fig.4.

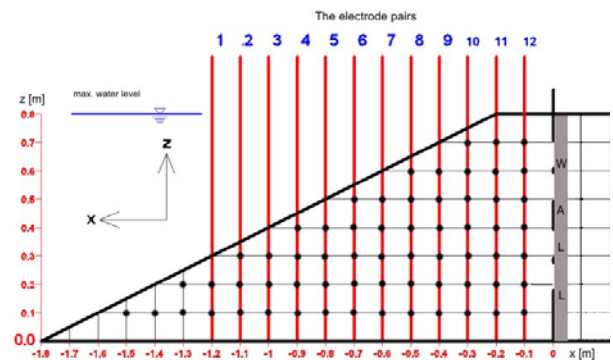


Fig. 6. The scheme of installation of pair electrodes into the dike.

Electrodes E1 and E2 create the electrode pair (on the picture is only one from the pair), which is supplied by the a.c. signal of selected amplitude and frequency generated in the digital synthesizer (A.C). The impedance meter (Z-meter) is connected in parallel to the a.c. power supply. This creation is simple and makes possible good manipulation with electrodes and the instrumentation. Nevertheless, this simplicity adds the transient resistance error to the results, and, therefore, the use of this method is limited on cases of observing the water infiltration process. The example of dike status monitoring by different measurement methods and devices in laboratory conditions is shown in the Fig.5.

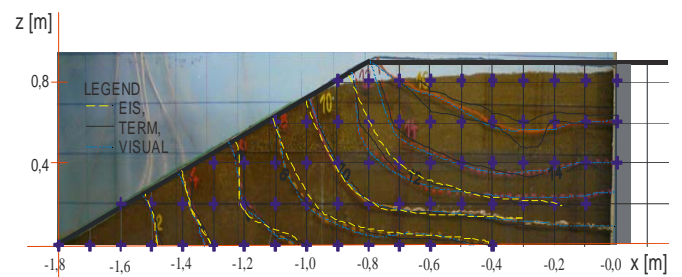


Fig. 7. Infiltrating curves (time step – 2 minutes, daggers – positions of the probes).

For the free water level monitoring inside of the dike body, for the changes of moisture of soil and for detection

boundary between water and sediment the method and apparatus was used in real conditions too. The stainless steel electrode system consisting of several pairs of electrodes has been build into the dike and sewage storage basin. The obtained results were calculated as rate of measured electrical conductivity G in relation to first measured value G_p .

$$G = \frac{1}{R}, \quad (3)$$

where electrical conductivity G [S] is inverse value of the real part R of measured impedance Z (2).

The scheme of measured area in the dike is shown at Fig. 8. Some of dike monitoring results are shown in Fig.9. For the data evaluation was used software SMS 9.2.

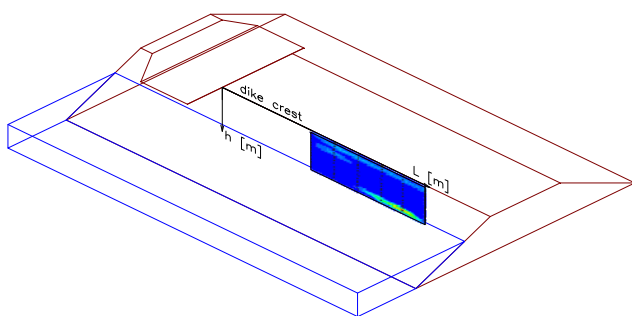
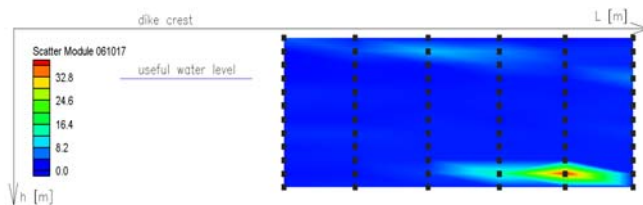
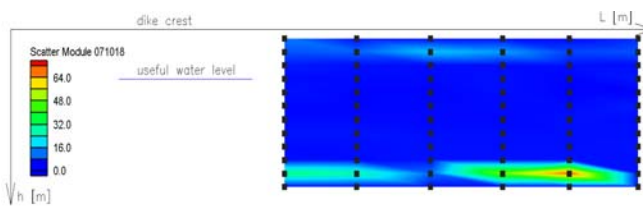


Fig.8. The scheme of measured area in the dike.



a) the status of the dike – the first measured electrical conductivity



b) the changes of the dike's status calculated as rate G to G_p

Fig. 9. Example of the result of monitoring changes of electrical conductivity in pond's dike (black point – probes).

5. CONCLUSIONS

Based on the findings from the measurement performed in real conditions, it can be stated that monitoring the changes in electrical impedance of the environment by the non-invasive method EIS is possible. When applying the method for sensing the course of the water level in soil,

a two-electrode connection is convenient. It is sufficiently accurate, sensitive and the obtained courses are clearly reproducible. If it is necessary to know the vertical position of the monitored changes, it is suitable to apply measurement with a vertically divided system. It is recommended to perform evaluation, from the view of its unambiguousness, as relative.

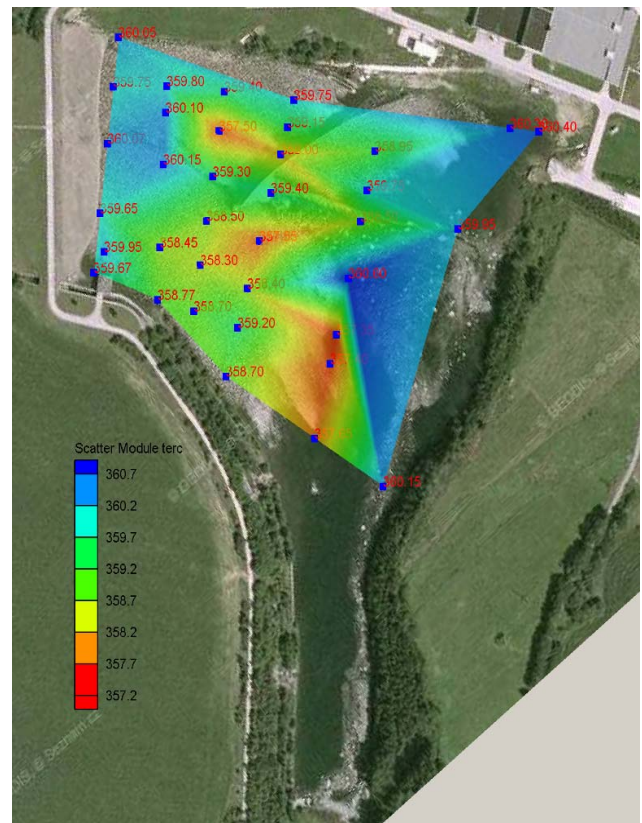


Fig. 10. One of the results of monitoring sludge level in settling tank

ACKNOWLEDGMENTS

Authors would like to acknowledge the MEYS. Without the financial support of EUREKA program in the Czech Republic these works could not be realized.

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