

Dike Monitoring Using Temperature-to-Electrical Resistance Conversion and Electrical Impedance Methods

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Abstract- Two original electrical methods of dikes monitoring (temperature scalar field and electrical impedance spectrometry) are described in detail. The methods are the measurement of the temperature scalar field and its progress in time in the observed water structure space (the thermistor probes are used for the temperature to electrical resistance conversion), and the electrical impedance spectroscopy (EIS), which monitors electrical impedance and its changes caused by the load of the construction by water. Using these methods, the non-stationary movement of the free water level in the dike and in the river can be indicated. The methods also enable to detect the piping in the dike due to the activity of animals or monitoring of the water pollution. Some results are shown and discussed. The experimental results, carried on physical models of protective dikes and regular bodies, were used for calibration of mathematical models. At present, owing to the optimistic conclusions, the new EIS apparatus operating in real environment conditions is built.

I. Introduction

Protective dikes are heavily loaded for a short term during extreme hydrological situations. Infiltrating water can cause changes of their sturdiness and stability. The complexity of the problem lies in the non-stationary flow of water in saturated and unsaturated soil media. The experimental results show the hydraulic conductivity coefficient of unsaturated soil reaches magnitudes more than thousand times lower comparing with that of saturated one. The knowledge of the physical properties of the soil materials of the dike and the mechanism of its destruction by flowing water help solve the problem of the protection the environment. For this purpose the physical and mathematical modeling is applied. The soil medium involves all three phases – solid, liquid and gas. The processes occurring in it are very difficult to be described mathematically. The laboratory electronic measuring equipments [1], based on the temperature field mapping and measurements of dike material impedance have been designed and tested at the laboratory of the applicant. Determination of the free water level movement is substantial for the stress, stability and the solution of inverse problems of the hydraulic conductivity of unsaturated soils. The goal of the research [2] is the transfer of laboratory tested methods of free water level movement and changes out-and-in-side of the dike into the real world. Thus, optimization of probes and instrumentation are necessary. The application of gained knowledge is also important for calibration and verification of mathematical models.

1.1 Physical Model

The models were built of unscreened sand from Bratčice with the hydraulic conductivity $k = 1.78 \cdot 10^{-4}$ m/s and with the effective grain size $d_{ef} = 1.57$ mm. The material inequality grading number $U = 7.42$, the initial relative humidity of the material (prior to the first loading) varied between (0.78 and 0.89). The temperature of the material varied between (13.3 and 21.5) °C; the laboratory air temperature between (13.2 and 21.9) °C, the relative air humidity in the laboratory between (0.38 and 0.58) and the water temperature in the storage tank varied between (12.7 and 18.7) °C. The material was compacted by a plate vibrator.

Geometrical dimensions of physical models of dikes:

Dike height	0.8 m
Dike width at the crest	0.4 m
Dike length in the centre of the crest	1.0 m

Slope of up-and down-stream faces $1 : 2$
Dike width at the foundation
with the given slope $1 : 2$ 3.6 m .

The dikes were built in the flume with the steel bottom simulating impermeable foundation.

1.2 Experiments

Experiments carried out on physical models are divided into four groups:

- measurements of the free water level movement in the dike;
- measurements of the breaching process during the overtopping;
- monitoring of the structural changes due to internal erosion (piping), activity of animals and surface erosion on both slopes of the dike and also of the stream bank and the river bed;
- monitoring of the water pollution.

Some of these laboratory measurements are shown in Fig.1. During the experiments, the models were loaded by water with constant level 0.789 m above the channel bottom. In Fig.1a movement of the water level on the upstream face is shown. The process of the water infiltration is illustrated in Fig. 1b. Measurements of the free water level of the infiltrating water were stopped after 1 hour .

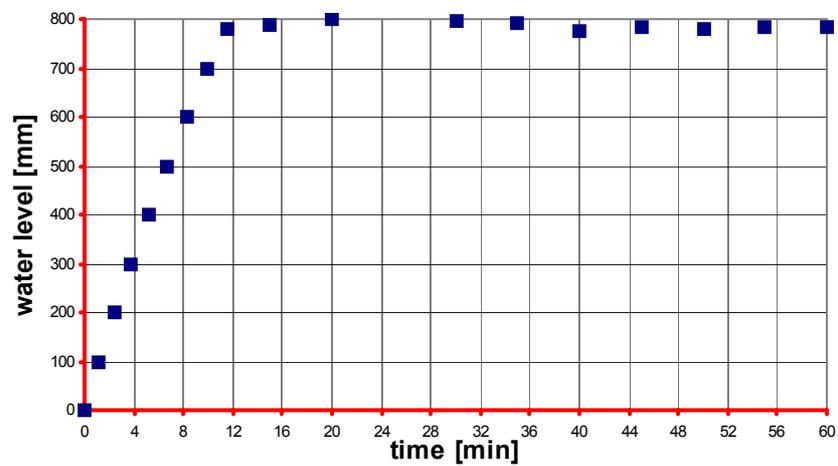


Figure1. a) The movement of the water level on the upstream face of the dike, b) the process of infiltration in the dike



Figure2. Examples of the laboratory experiments – surface erosion of the stream bank, progressive destruction of the dike and of the riverbed

II. Temperature-to-electrical resistance conversion method

Electrical resistance method – is based on the monitoring of time dependence of the temperature scalar field. The thermistor sensors have been used for the conversion of the temperature $T [K]$ to electrical resistance $R [\Omega]$ by the Wilson relationship:

$$R = Ae^{B/T}, \quad (1)$$

where A is a constant describing the material and the shape of the quasi-conductor and B is a constant describing the material properties of the construction of the thermistor probe.

For the conversion, thermistor sensors have been used. The 128 temperature sensors (thermistor pearls) have been placed to defined positions to create space matrix inside of the dike. The goal of the measurement is to capture the point of the temperature jump caused by the contact of infiltrating water with the sensor. Well-known sensor position and system time make possible to observe the process of infiltration in the space of the sensor matrix, and to reconstruct the progress of this effect in time. Principal block diagram, typical shape of the temperature jump when water is contacting the sensor, and thermistor sensor (diameter is smaller than 2 mm) are shown in Fig. 3.

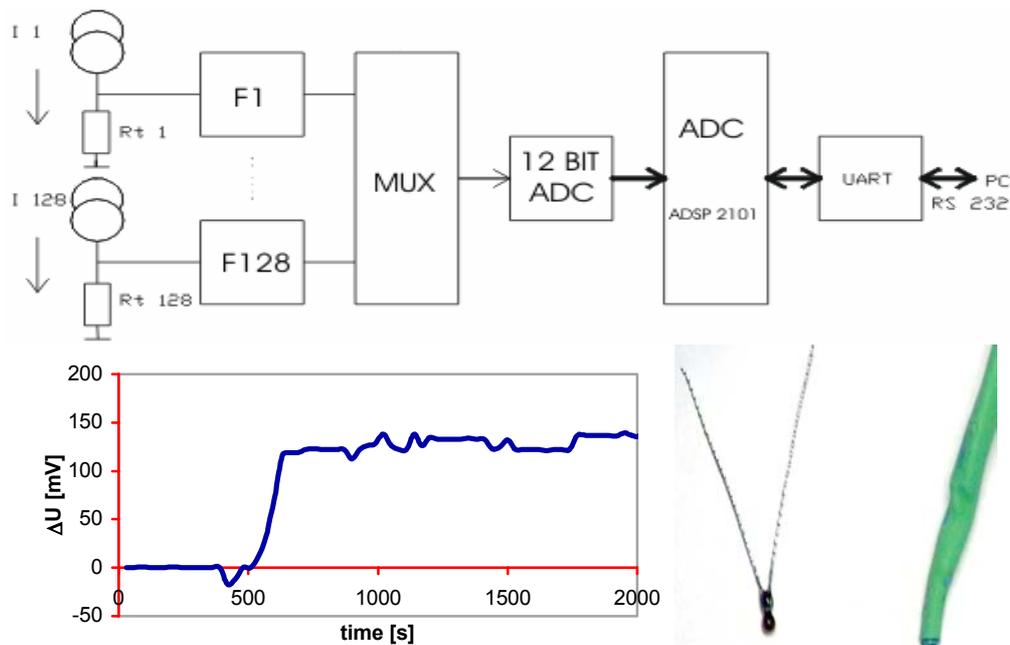


Figure3. a) Principal block diagram, b) typical shape of temperature jump, c) thermistor pearls and sensor

The results – infiltration curves were worked up using the Surfer program. An example of evaluation is shown in Fig. 4 (time interval is 2 minutes) including animation output from the TERM 1.2 software. The curves are isotherms measured during the process of infiltration. Deformation of curves indicates material non-homogeneity.

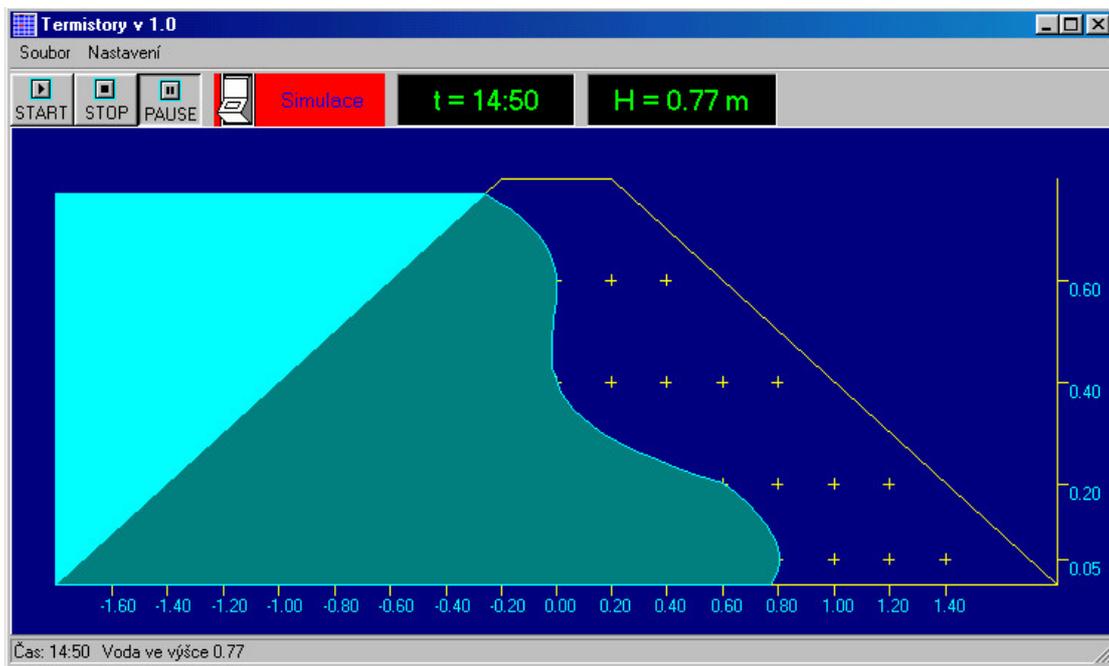
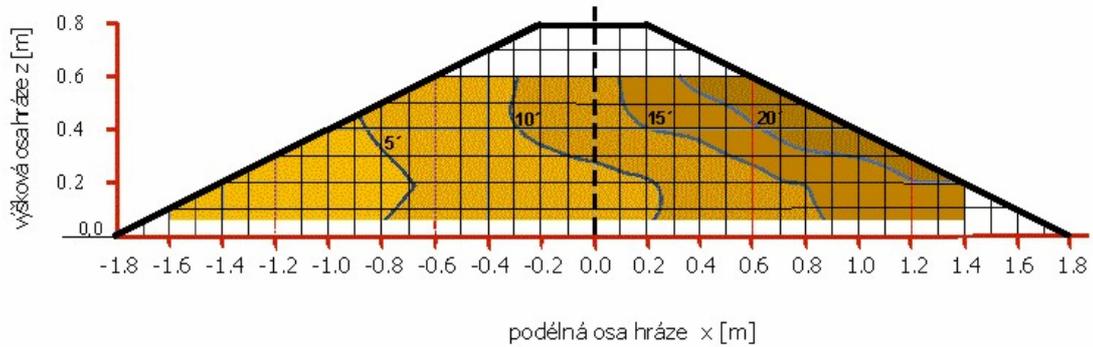


Figure4. Infiltration curves (time interval 2 minutes)

2.1 Mathematical modelling

The comparison between results obtained by experiments (solid line) and numerical modelling (broken line) is shown in Fig.5. The numerical model is described in [1].

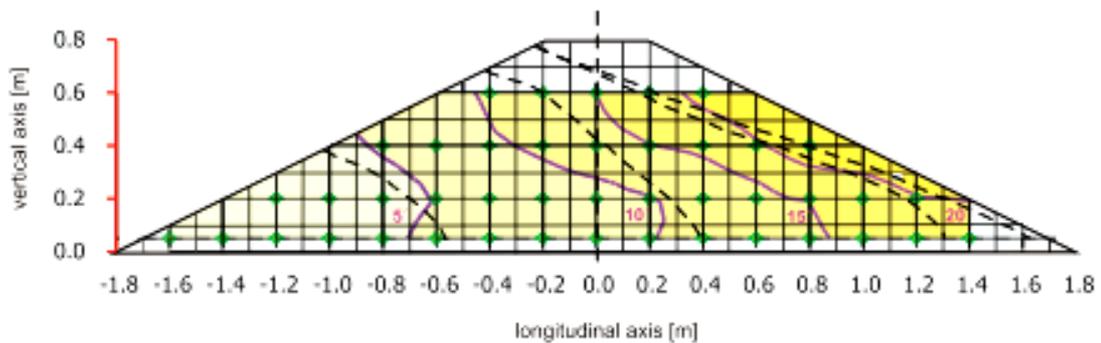


Figure5. Results obtained by experimental measurements (solid line) and numerical solution (broken line)

III. Electrical impedance method

The second method, the electrical impedance spectroscopy method (EIS) takes advantage of the impedance measurement in a complex form in different parts of the dike (on the surface and inside the dike). The electrical impedance Z (or admittance Y) of the soil between electrodes can be calculated in Cartesian (R and X), or polar ($|Z|$ and θ) coordinates. These parameters are related as follows:

$$Z = R + jX$$

or $Z = |Z| \cos \theta + j|Z| \sin \theta = |Z| e^{j\theta}$, (2)

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

The complex impedance Z of the un-saturated porous material describes its properties:

- The solid part (grains) is formed by insulating materials characterised 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 impedance spectrometer (Z -meter) constructed for experimental purposes, takes advantage of the comparison of the measured impedance Z with the standard resistance R_n , the electrical resistance of which is well known and its reactance X_n , is negligible within useful frequency band f (Fig.6).

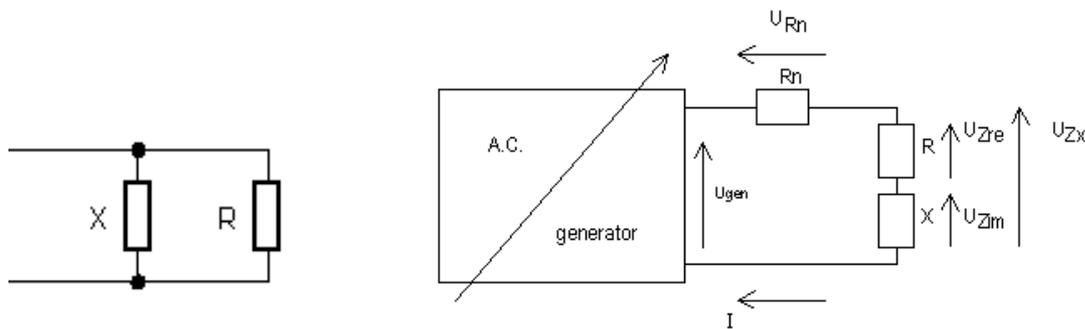


Figure 6. Equivalent electrical circuit and block scheme of developed Z -meter device

The device includes current supply I_c , own electrical impedance Z meter and external electronic switcher. It enables to measure in one frequency or in a given frequency range. In both cases two or four terminal electrode system may be used for measurement. The system with four terminal electrodes eliminates the influence of the lead-in cable resistance Z_{C1} , Z_{C2} and the transition resistance between electrode and environment Z_{T1} , Z_{T2} . Differences in these systems are shown in Fig. 7a,b.

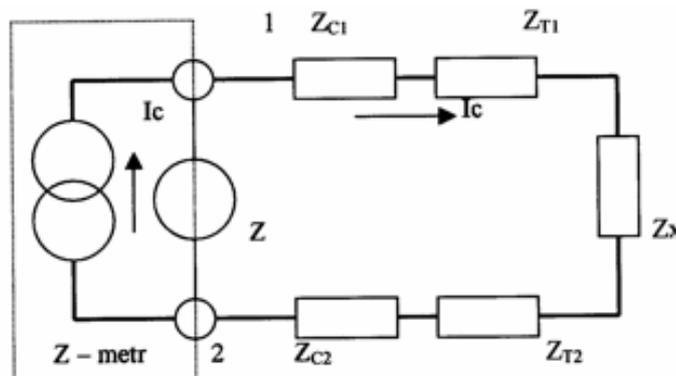


Figure 7a. Two-terminal electrode system connection; unknown electrical impedance Z_x is measured between the point 1 and 2 and is calculated from the relationship $Z = Z_x + Z_{C1} + Z_{C2} + Z_{T1} + Z_{T2}$

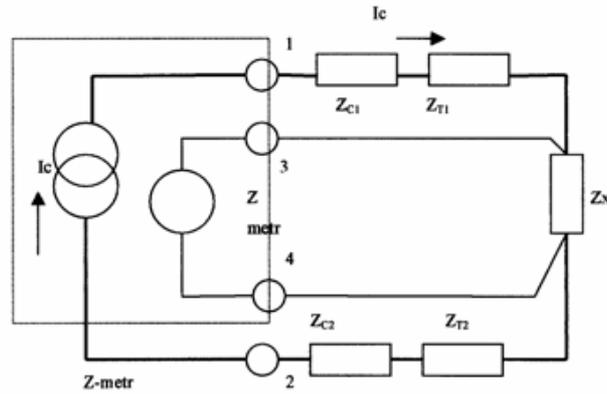
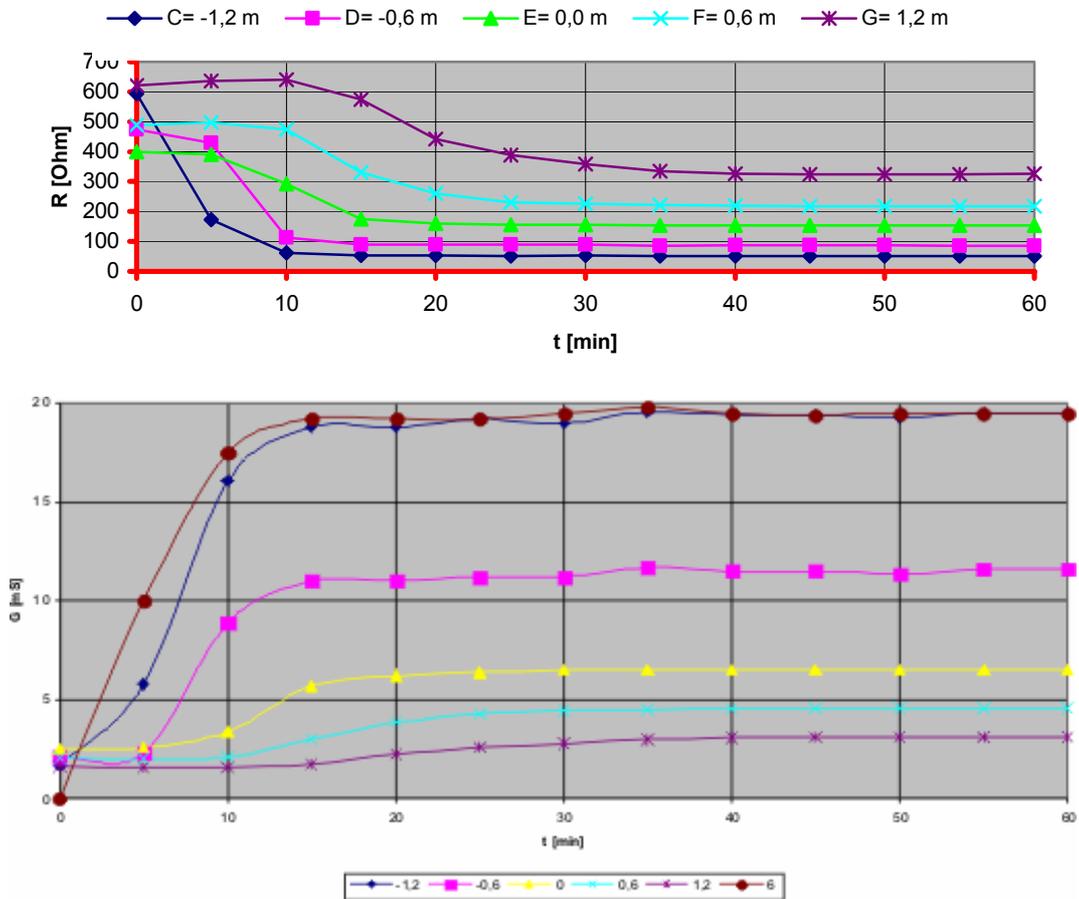


Figure 7b. Four - terminal electrode system connection, 1,2–current electrodes, 3,4–potential electrodes; unknown electrical impedance Z_x is measured between the point 3 and 4, therefore $Z = Z_x$. The electrical impedance spectroscopy (EIS), capable of the indication of free water level inside of the dike, and loading water level has been used. This method took advantage of dike material electrical impedance measurement and observing its change during water acting. For water level measurement, the two-terminal method has been used. Some of reached results are shown in Fig.8.



Time changes of a) the electrical resistance and b) the electrical conductivity in dike. Figure 8. Impedance reaction on the rush water level measured by two-terminal

The four-terminal method has been applied for the dike deformation localization. If the changes of the surface of the dike are to be monitored, the use of the second (potential) pair of electrodes, connected with potential terminals of the Z-meter, is necessary. The method eliminates influences of parasitic impedances, so that fine impedance changes can be detected. One of reached results is shown in Fig. 9. Measurement is realized as relative. In this figure is shown influence of volume changes

(decrease volume) of the monitored profiles. It is evident from this figure, that four – terminal electrode system can detect the surface changes as well as the changes inside the monitored soil medium. But it does not permit to localize vertical position of these changes (the system measures the total profile between electrodes). Therefore four - terminal electrode with different construction were developed and tested (Fig.10). In this system narrow electrical field of current electrodes in prescribed vertical position is desirable. So the second potential electrode in the same place enables to monitor the changes of the soil medium. Further development of special divided electrode system would enable to observe surface changes of the dike, as well as the structural changes due to internal erosion (piping), activity of animals and surface erosion on both slopes of the dike and also of the stream bank and the river bed.

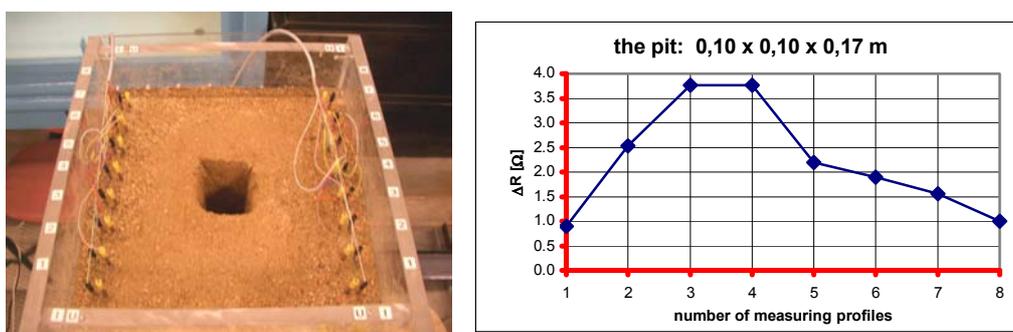
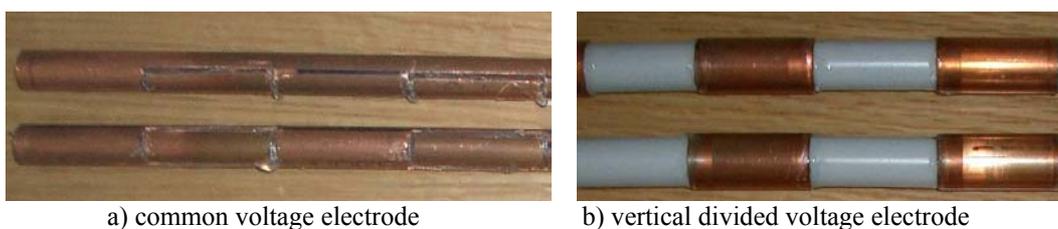


Figure 9. a) The view of surface deformation; b) the result of measurement



a) common voltage electrode

b) vertical divided voltage electrode

Figure 10. Construction of vertically divided current electrode

The detection of water pollution propagation simulated by water salinity changes has been another application of EIS. Suitable measurement technique involving impedance spectrometer and stainless steel electrodes have been designed and built.

III. Conclusions

Two electronic methods observing internal effects in the protective dikes during their loading by water have been tested. The experimental results contributed to the study and mathematical modelling of these effects [1]. Both methods show the possibility how to observe dynamic effects of water infiltration and deformations inside of the dike in laboratory conditions. Comparing with usually used visual methods, the capability of the discovering material non-homogeneities, together with the possibility of indicating the internal dike status, are important contributions of these methods. The results that have been reached on prototype-like models show the possibility of the application of both methods on real dikes. The results also show further possibility of improvements in sensitivity and information content of used methods. As to the thermistor application, the future use of the anemometric method promises improvement of the method sensitivity in cases of small temperature difference between dike material and infiltrating water. The development of new electrode system and impedance spectrometer capable of the multichannel 3D impedance monitoring is in progress. The research is worked out within projects 103/01/0057 and 103/04/0741 granted by the Grant Agency of Czech Republic (GAČR).

References

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