10th IMEKO TC10 Conference on
**Technical Diagnostics**
Budapest, HUNGARY, 2005, June 09-10

# Two Non- invasive Methods of Dike Monitoring and Their Results

*Jana Pařílková, Ivan Krejčí, Jaroslav Veselý*

Brno University of Technology, Faculty of Civil Engineering, Institute of Water Structures,
Laboratory of Water Management Research, Brno, Czech Republic
HAAL Elektro, Ltd., Brno, Czech Republic

**Abstract –** Two original electrical methods (temperature scalar field and electrical impedance spectrometry) of piled up dikes status monitoring are described. Using these methods, progress of water infiltration and deformations outside or inside of the dike body can be indicated. Some results are shown and discussed.

Keywords: dike, thermistor, electrical impedance.

## 1. INTRODUCTION

Frequent floods initiated intensive effort oriented to the hydrological situation forecasting in endangered regions, and to the protective dikes building. Knowledge of dike properties and mechanisms of its damage by water makes possible to evaluate the degree of endangering, and to ensure the life and possession protection in risk regions. For purposes of forecasting the hydrological situation, mathematical modelling is applied. Because monitored environment involves the boundary of all three phases of matter – solid, liquid and gas, the processes occurring on it are very difficult to be described mathematically. Besides, the non-stationary flow of water in unsaturated soil media brings additional complication to the mathematical modeling of observed phenomena. Therefore, the method of their monitoring on physical models of dikes is the only way how to reach real information about them. Physical models are used for study of dike properties and destructive effects. The models, piled up experimental dikes of defined shapes and dimensions, are built in special flume in laboratory conditions.

### *1.1 Physical Model*

The size of physical models of earth fill dikes situated in the measuring flume had almost the same size as prototypes. To make the optical observations of the development of infiltration curves in time and space easier, the models were built of unscreened sand from Bratčice with the effective grain size:
$d_{ef} = 1{,}57\,mm$, material inequality grading number $U = 7{,}42$; the relative humidity of material prior to first loading varied between (*0,78* and *0,89)*; the material temperature varied between (*13,3* and *21,5)°C*; the laboratory air temperature varied between (*13,2* and *21,9)°C*; relative air humidity in the laboratory varied between (*0,38* and *0,58)*; 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 elevation | *0,8 m* |
| Dike width in the crest | *0,4 m* |
| Dike length in the crest centre | *1,0 m* |
| Slope of up-and down-stream faces | *1 : 2* |
| Dike width at foundation with given slope | *3,6 m.* |

The dikes were built straight on the steel bottom of the measuring flume, which simulated impermeable bedrock.

### *1.2 Experiments*

Experiments carried out on physical models can be divided into four groups:

a) measurements of the water infiltration process inside of the dike body;
b) measurements of the dike deforming process during the crest overflow;
c) monitoring of structural changes of the dike construction (these methods can be used no only for structural changes of the dike, but also for structural changes of the stream bank or river bed),
d) monitoring of water pollution propagation.

Some of these laboratory measurements are shown in Fig.1. During the entire experiment, the dike models were loaded by water of the constant level *0,789 m* above the channel bottom. The development of the water infiltration, represented by infiltrating curves, is illustrated in Figure 2. Measurement of infiltration curves development was stopped after *1 hour*.

a) Infiltration process inside of the dike in laboratory conditions

b) Monitoring of the crest overflow

c) Monitoring of structural changes of the dike construction and of the river bed

Fig.1 Laboratory applications of two electrical methods

### *1.3 Methods of measurement*

Two original electronic methods have been used (except usual visual and piezometric methods) for measurements on physical models of piled up dikes. They made possible to observe dike properties and their changes because of water acting inside of the dike during its loading.

The first method – is based on the monitoring of the temperature scalar field and its changes in time inside of the dike body. The thermistor sensors have been used for the temperature *T [K]* to electrical resistance *R [Ω]* conversion. The thermistor conversion parameters are expressed by la of Wilson's relationship:

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

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

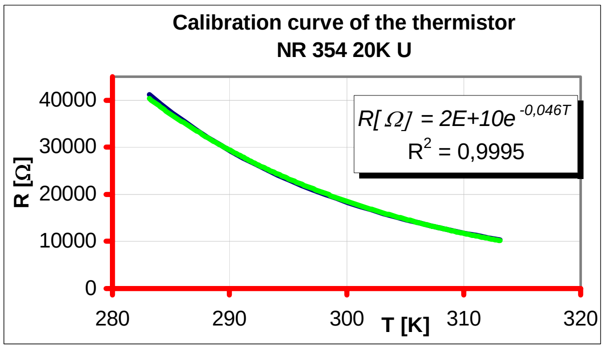


Fig.2 Calibration curve within measured temperature range

The thermistor are supplied by the constant current. The temperature properties of the dike material are computed from the change of electrical voltage drop during the time of infiltration. The results of the calibration experiment are shown in Fig.3.

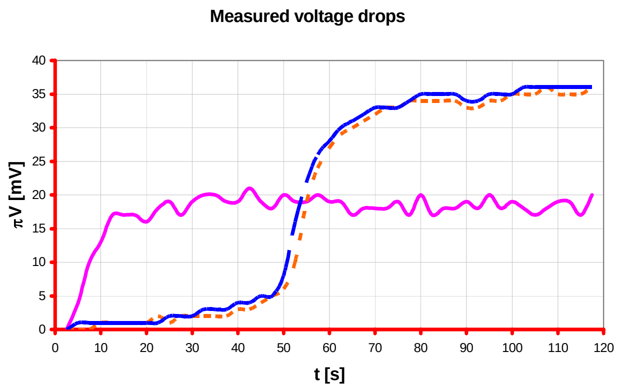


Fig.3 Measured voltage drops

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 electrical impedance (or admittance) of the soil between measuring electrodes can be calculated in Carthesian (R and X), or polar (/Z/ and *θ)* form. These parameters are related as follows:

$$Z = R + j\,X = |Z|\cos\theta + j|Z|\sin\theta , \qquad (2)$$

The complex impedance of monitored material, which is created by the solid part, more or less saturated by water, describes its complex properties:

- The solid part (the earth structure) is made from insulating materials characterised by their dielectric constants and creates the imaginary part of measured impedance.
- Water containing mineral salts is a conductive material. Degree of water saturation (water content) of the dike material dramatically influences the real part of measured impedance.

Therefore, the measuring equipment must be able to determine both parts of the impedance. The impedance spectrometer constructed for experimental purposes, takes advantage of the comparison of the measured impedance with the standard resistance the electrical resistance of which is well known, and its reactance is negligible within useful frequency band.

## 2. TEMPERATURE FIELD

Thermistor sensors [1] 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 thermal 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. Applied thermistor sensors had diameter smaller than 2 mm, comparable with the size of effective grain of the physical model material, so that they did not affect the dike properties. The thermistor probe is in detail shown in Fig.4.

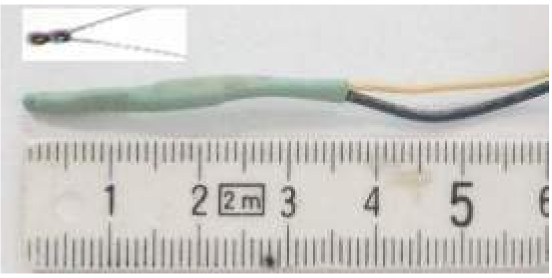

Fig.4 The thermistor sensor and the probe

There were 128 thermistor sensors in the matrix. The unique data logger supplies the sensors by the constant current, provides switching of channels, and measures voltage drop on sensors. Measured voltage drops are digitized in a 12-bit ADC and processed in the embedded digital signal processor, which controls the data logger function and sends data to the PC via the asynchronous serial link.

"The window" of measuring software TERM 1.5 is shown in Fig. 5

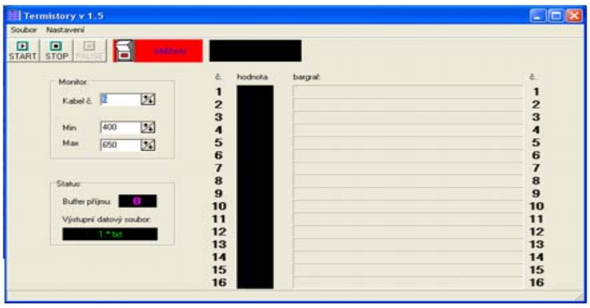


Fig. 5. Measuring software TERM 1.5

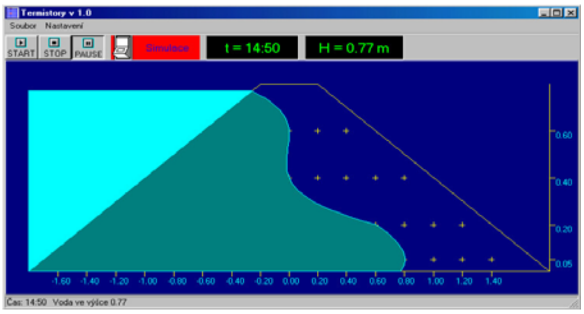


Fig.6 Visualisation of measured data

The measuring software TERM 1.5 makes possible to do computer animation, as shown in Fig.6. The software makes possible to record the history of the process of infiltration with sampling period of *500 ms* in all 128 channels. The overall time of the measurement is limited only by the PC memory capacity. Figure 6 illustrates the final user interface of the software. The results – infiltrating curves in Fig. 7 are evaluated using the software product Surfer. The curves in the Fig.6 and 7 present the same time moment of the voltage drops from the thermistor sensors placed in the physical model of the dike.

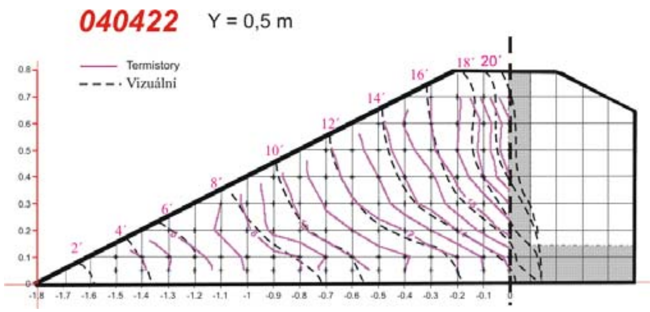


Fig. 7 Infiltrating curves (time step 2 minutes)

## 3. ELECTRICAL IMPEDANCE SPECTROSCOPY

The method of the electrical impedance spectroscopy [1, 2] has been used for measurements of structure and state of the dike built in the laboratory flume. The stainless steel electrode system consisting of several electrode pairs has been plugged-in to the dike. The stainless steel rod electrodes have the diameter of *0,015 m* and the length of *1,5 m*. Electrode pairs arrangement is shown in Fig. 8. In this picture, the two-terminal method of impedance measurement is shown. Electrodes 1 and 1a create the electrode pair (only one electrode of the pair is visible), which is supplied by the a.c. signal of selected amplitude and frequency generated in the programmable digital synthesizer. This configuration 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 water infiltration process or monitoring of water pollution propagation (Fig. 9, 11).

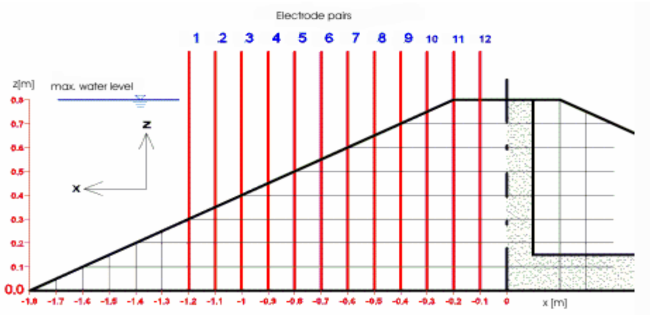


Fig. 8 Installation of pair electrodes into the dike

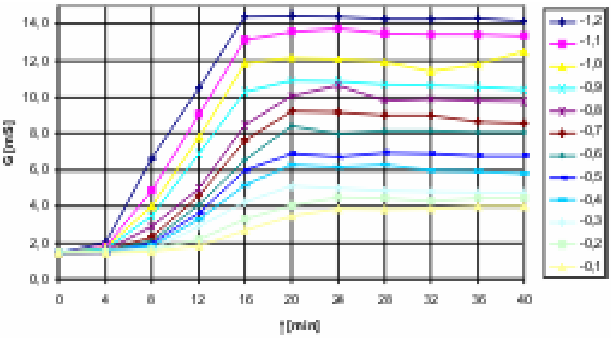


Fig. 9 Impedance reaction on the rush water level measured by two terminals measurement

The set of calibration experiments were made for monitoring of water pollution propagation. Resistance *R* resp. its inverse value – electrical conductivity *G* versus salt concentration curves at different measuring areas and resistance *R* versus water depth *h* measured in NaCl solution with one 0.25% salt concentration at different frequencies are shown in Fig.10 a and b respectively.

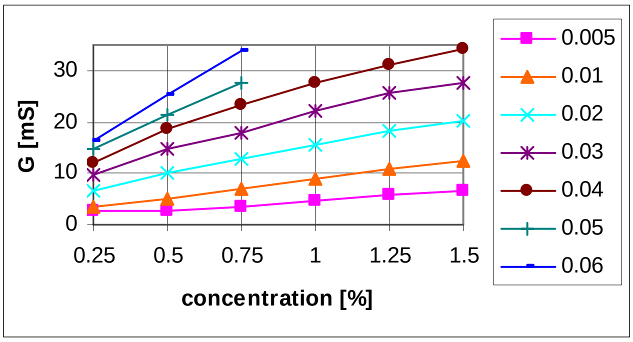


Fig. 10a Electrical conductivity *G* versus salt concentration at different tested areas

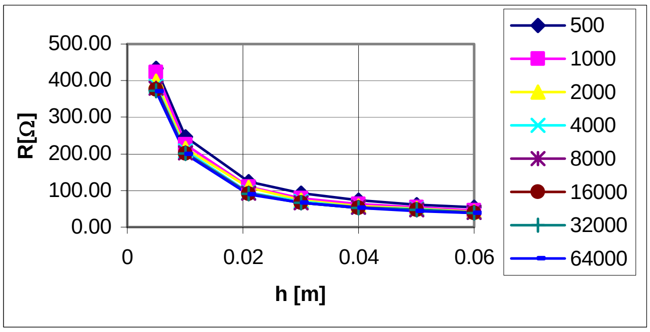


Fig. 10b Electrical resistance *R* versus water depth *h*

As shown in this picture, the distance between electrodes and effective square of electrodes are very important parameters that must be kept constant during the experiment. Coming from realized calibration experiments, frequency *f = 8 kHz* was selected for measurements on the constant frequency.

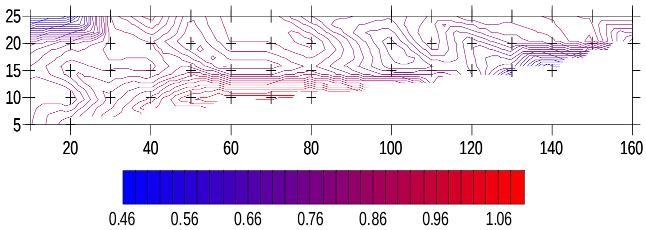


Fig.11 Changes of electrical conductivity (from 0.45 mS to 1.05 mS) in the layer of 0.01 m under the water level; area of the interest was 1.60 m x 0.25 m, the cross marks sign measurement places

If changes of the dike structure or shape are to be monitored, the use of the second (potential) pair of electrodes, connected with potential terminals of the Z-meter, is necessary (four –terminal method). In this case, influence parasitic impedances are eliminated so that fine impedance changes are possible to be indicated (Fig. 12).

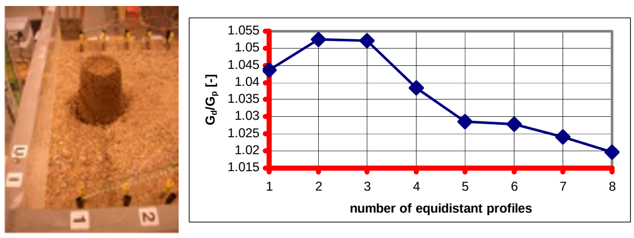


Fig 12 Influence of increased volume of monitored profile on electrical conductivity

## 4. CONCLUSIONS

Both methods show the possibility to observe dynamic effects of water infiltration and deformations inside of the dike in laboratory conditions. Comparing with frequently used visual methods, the capability of discovering material inhomogeneities, together with the possibility of indicating the internal dike status, mean the important contribution of these methods. The results that have been gained on prototype-like models show the possibility of the application of both methods on real dikes. The results also show further possibility of improvements of the sensitivity and information content of used methods. As to the thermistor application, their use in a form of anemometer is planned. The use of the anemometric method promises improvement of the method sensitivity in cases, when dike material and infiltrating water have the same temperature. Further development of special divided electrode system should make possible to observe structural changes of the dike construction, as well as its deformation. The research goes on, and is carried out within the granted projects No 103/01/0057 and 103/04/0741 (Czech Grant Agency).

## REFERENCES

[1] J. Pařílková and comp., "Non destructive methods of protective dikes monitoring", Final report of the grant project 103/01/0057, *Czech Grant Agency*, 2003.
[2] J. Pařílková and comp., "Optimization of monitoring methods of free water level movement and its affects in earth dikes", Partial report of the grant project 103/04/0741, *Czech Grant Agency,* 2004.

AUTHOR(S): Jana Pařílková, Ing., CSc., Jaroslav Veselý, Doc., Ing., CSc., Brno University of Technology, Faculty of Civil Engineering, Institute of Water Structures, Laboratory of Water Management Research, Veveří 95, 602 00,Brno,Czech Republic, phone +420541147284, +420541147280, Fax +420541147288, parilkova.j@fce.vutbr.cz, vesely.j@fce.vutbr.cz
Ivan Krejčí, Ing., CSc., HAAL Elektro, Ltd., Zeiberlichova 23, 644 00, Brno, Czech Republic, phone +420541219719, ikrejci@haalik.cz