Modelling of Effects of Extreme Hydrological Events on the Protective Dike Construction

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Abstract- Mathematical models of protective dikes are used for forecasting of extreme hydrological situations. For purposes of calibration and verification of these models, the physical modelling is used. Physical model creates the dike of defined parameters (dimensions, material, time of loading, etc.) equipped with proper sensors and instrumentation, which is mostly tested in laboratory conditions. The results of two electronic methods monitoring investigated effects are discussed.

I. Introduction

Extreme hydrological events cause important losses in life and state economy. Therefore, the necessity of building protective constructions becomes substantial. The most frequent type of the protection is the piled up dike making the river bank robust and stable. Extreme hydrological events cause short-time extreme load of the dike construction and can cause its damage. Two basic affects, hydrostatic pressure and rush water infiltration to the internal space of the dike can cause changes of the basic physical properties of the construction. To avoid possible dike damage, the internal effects caused by rush water infiltration must be known. Two electronic methods mapping the internal state of the dike model have been used. High sensitivity and capability to indicate internal construction changes are the highlights of both methods, which offered new information needed for mathematic models completion, and their calibration and verification. The effort has been focused on achievement of optimal experiment conditions (e.g. probes construction, their geometry and placing in the internal dike space) to ensure maximum sensitivity, resolution and repeatability of results. This made possible to study physical properties of various materials used in the dike construction, as well as internal construction changes and observe infiltration process during its loading by rush water in laboratory conditions. Common requirement on sensors used to detect presence of water was the negligible influence on the dike physical properties. The methods used for observing of internal effects in dikes during their loading involve observing of the non-stationary temperature field progress, and measurement of changes of dike complex impedance or admittance respectively.

To be able to build up physical models of dikes, and work out the experiments, it was necessary to equip the laboratory with the needed apparatus, including electronic devices with suitable software, and the experimental flume with water management. Parameters of realized equipments have been verified by measurements on models of dikes comparable with a real dike as to the dimensions, but not as to the material used. The results of experiments have been completed by a video record.

2. Experimental equipment

2.1 Measuring Trace

For purposes of experiments, the measuring flume (Figure 1) *6.0 m x 1.0 m x 1.5 m* has been built. The flume construction is made from the *0.004 m* thick steel plate, equipped with piezometers. To be transparent, the *0.025 m* thick organic glass covered inside by wear protective film is used to create the opposite wall. Besides, the film is equipped with the *0.1 m x 0.1 m* raster field. The inflow section is also made from the *0.004 m* thick steel plate, dimensions of which are *1.0 m x 1.0 m x 2.0 m.* The section involves four handling valves allowing the water level control on the upstream face of the physical model of the earth fill dike.

The water discharge is measured by the inductive flow sensor. The measuring flume is terminated by the sand trap made from the same steel plate as in previous cases, and its dimensions are 3.0 *m x 1.0 m x 1.0 m*. The end of the measuring flume contains a collecting main capable of the measuring of the of infiltrated water discharge. Water is pumped into the system from the *35 m^3* storage tank.

Fig. 1 Measuring flume

2.2 Physical Model

Experimental flume let the building of physical models of earth fill dikes, the dimensions of which have been comparable with that of prototypes. For verification of electrical methods of infiltration curves measurements, the optical observation of these curves progress through the transparent wall of the flume has been worked out. To be able to ensure measurement credibility and repeatability, the models of dikes have been built from sand originated from the same mine. Besides, the sand has had defined grain ($d_{ef} = 1.6\ mm$). When building the models, strong attention to keep the dike material relative humidity in the interval of *0.78* to *0.89* has been paid. The model structure homogeneity has been reached by pressing the material using a plate vibrator.

For instance, geometrical dimensions of the typical physical model of the dike are:

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*

During the experiment, the level of the loading water has rapidly grown up to *0.78 m* and it has been kept constant during the rest time of forty five minutes measurement (Figure 2).

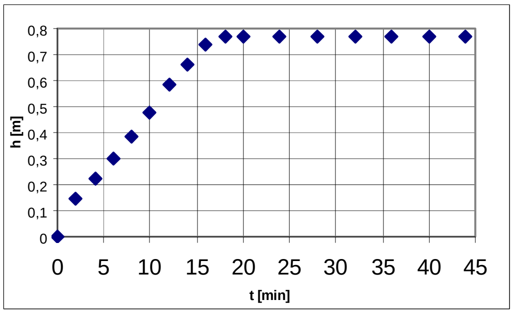


Fig. 2 Development of the upstream face level of the dike model

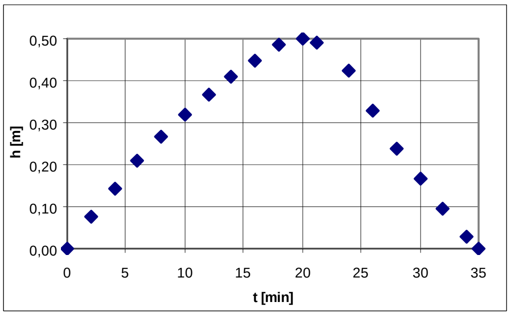


Fig. 3 Regimen of load acting on a cubic body

Experimental measurements have been also carried out using cubic shape of the dike body (*0.5 m x 0.5 m x 0.5 m)*. The goal of these measurements was to test the sensitivity of methods on surface fluctuations in the upstream face of the dike. The water-table level progress at these experiments is illustrated in Figure 3. When grew, the maximum 0.*5 m* level has been kept constant during the rest of thirty five minutes measurement.

II. Temperature field mapping

The process of water infiltration to the dike material changes the position of the free water level in the space of the dike during the structure load by rush water. Thus, the process can be expressed as the non-stationary scalar field in non-saturated environment, the shape of which in certain time t_n is known as infiltration curve or surface respectively, and which creates sharp boundary between wet (saturated) and moist (non-saturated) environments. In general, this boundary is accompanied by a temperature jump. This fact makes possible to transfer the change of water content to the change of temperature, which can be easily measured by electrical methods.
Hence, the basic principal of the method is to capture the temperature jump moment which indicates the water infiltration to the place of the temperature sensor, as shown in Figure 4a. For these purposes, temperature sensors have been placed to the model dike construction to defined positions so that they create spatial matrix.
For temperature measurement, the thermistor sensors have been used. The advantage of this solution is good sensitivity and small dimensions of sensor. The temperature characteristic of the thermistor sensor is non-linear and can be expressed as:

$$R = A\, e^{B/T} \quad , \qquad (1)$$

where R is electrical resistance, A, B are material constants of the used semiconductor, T is absolute temperature of the environment.

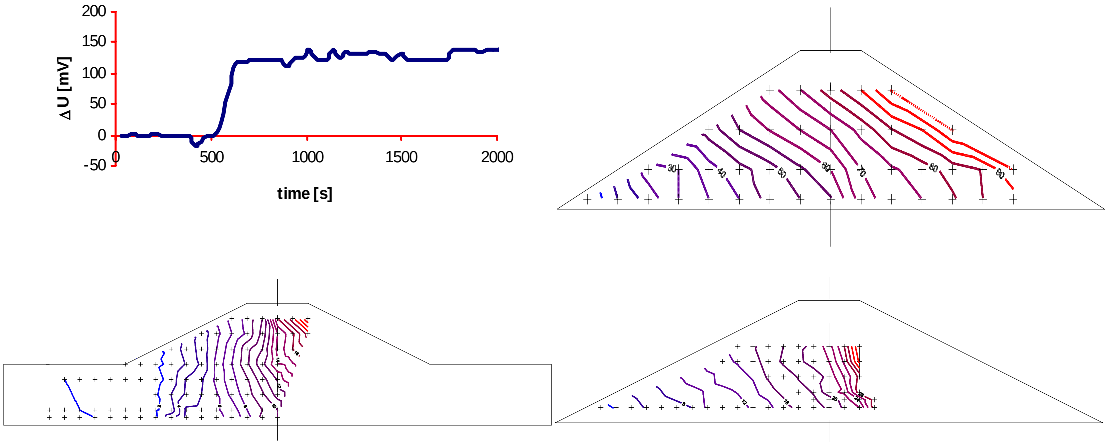


Fig. 4 a) typical shape of the temperature jump when water contacts the sensor
b) Infiltration curves. Parameter – time interval *5 minutes*, dike with impervious subsoil.
c) Infiltration curves. Parameter – time interval *2 minutes*, dike equipped with systematic drain placed at the heel of dike.
d) Infiltration curves. Parameter – time interval *2 minutes*, dike with pervious subsoil.

As sensors, 128 thermistor pearls, the diameter of which was smaller than *2 mm*, have been used and the corresponding DSP controlled data logger [1] capable of the supplying the sensors, as well as the data acquisition, has been built. The data logger cooperates with the PC host computer. The PC and DSP software packages make possible to measure, store and visualize results with sampling frequency of *2 Hz*. The results of experiments on various modifications of the dike construction monitoring temperature field development inside of the dikes are in Figure 4b, c, d. The diagrams show the infiltration curves in the longitudinal cross section of the dikes measured during rush water action. Sensor positions are signed by crosses. Each curve corresponds with certain time of the experiment. The final shapes of curves have been smoothed using the spline method. Figure 5 illustrates the water infiltration animation using the processing software [2].

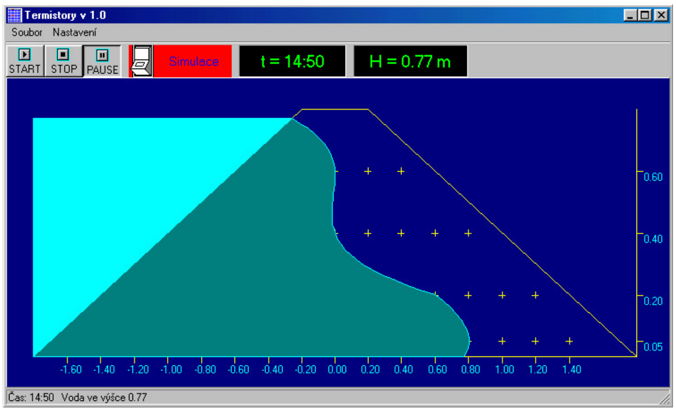
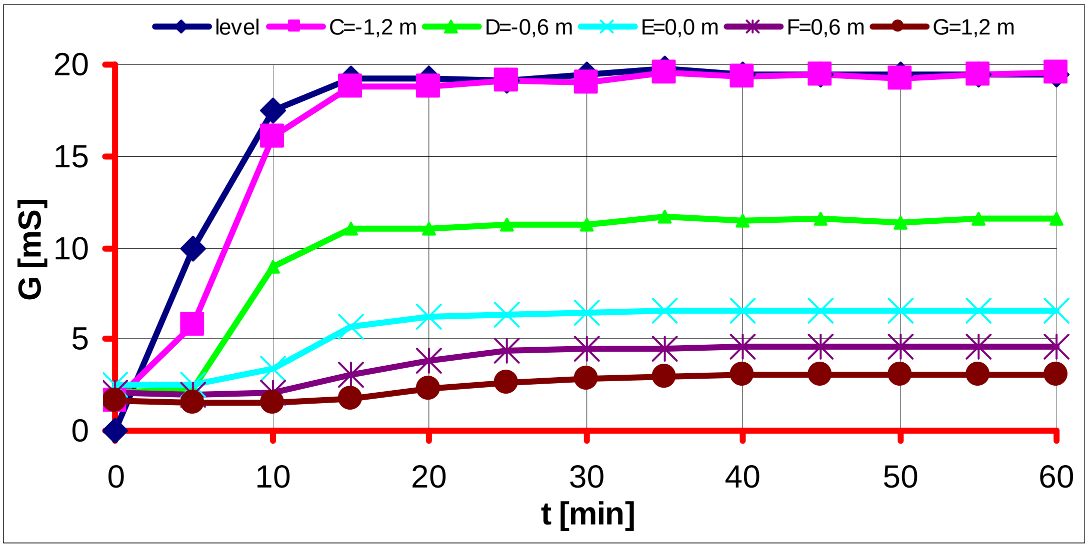


Fig. 5 Visualisation of measured data

III. Impedance measurement

Another electrical method capable of the indicating of infiltrating and rush water levels, and the determination of dike deformations is based on the change of the electrical impedance. This method takes advantage of dike material electrical impedance measurement and observing its change during rush water acting, in another words, transfers changes of material saturation by water to material electrical impedance changes. For water level measurement, the two-terminal method has been used, while for surface deformation localization, the four-terminal method has been applied for its better accuracy and sensitivity, because of parasitic impedances influence elimination. Proper measurement technique involving impedance spectrometer and stainless steel electrodes have been designed and built [1]. Lately, the electronic switch capable of automate switching up to 8 four electrode channels was built. This made possible to minimize dead time and propagation delays between samples connected with manual manipulation with electrodes, as well as to improve the reproduce ability of results [3].

As the example, the graphic interpretation of the rush water level acting on the dike uses the admittance curves, because conductance of the water saturated material sensitively correlates with the water level movement as shown in Figure 6a and 6b, which describe one-shot and alternate loading of the dike.



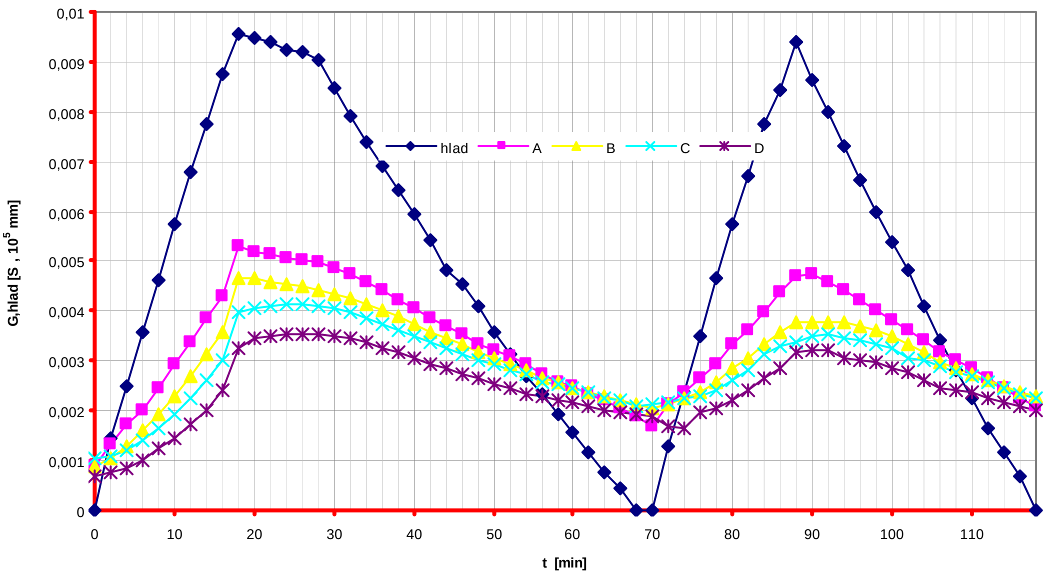


Fig.6 Admittance change of the dike material during one-shot a) and alternate b) load by rush water

Another type of experiment taking advantage of the four electrode measurement shows the result of the indication and localization of mechanical deformation of the dike structure. The typical creation of the experiment is depicted in Figure 7. As shown in Figure 8a, the dike was deformed by removing of material from the dike top surface. Figure 8b illustrates the difference between resistivity of the deformed dike construction and original dike structure. As can be seen, the correspondence of the difference with the hole location is visible.

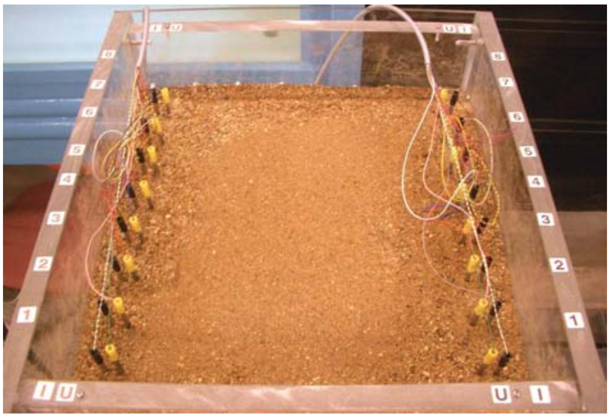


Fig.7 Basic creation of four electrode experiment

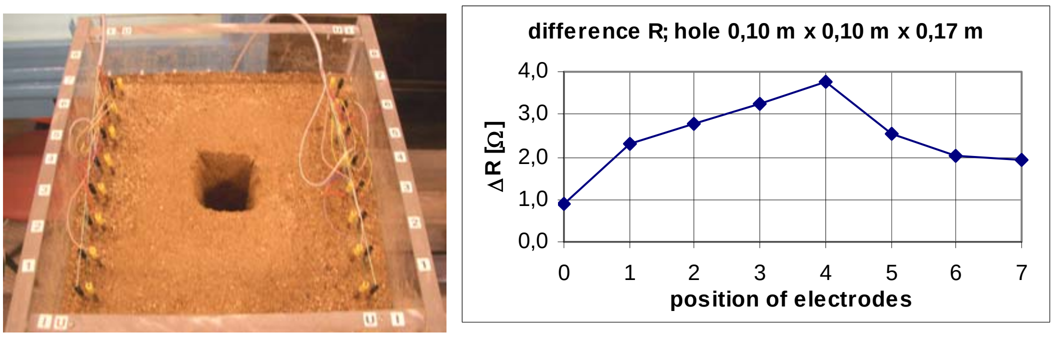


Fig.8 Shape deformed structure top view (a), and measured resistivity difference (b)

IV. Conclusions

Two non destructive electronic methods of observing internal effects in the protective dikes during their loading of rush waters have been successfully tested. The results of experiments contributed to the study and mathematical modelling of these effects [1]. The research is worked out within projects 103/01/0057 and 103/04/0741 granted by the Grant Agency of Czech Republic (GAČR).

The experiments and experience from series of measurements show advantages and disadvantages of both methods. The advantage of the temperature field mapping is sufficient density of sensors in tested space. Good sensitivity is constrained by the temperature difference between rush water and the dike material (usually sufficient, > *1 °C*). Disadvantage of the method is the possibility to observe only one-shot event of the soil saturation, because the saturation of the dike structure by water causes increase of the temperature inertia of the construction.

The impedance (or admittance) measurements bring good results in measurements of alternate loads of tested structures of dikes and have good reproduce ability. On the other hand, low density of electrodes and long sampling period (*120 s*) do not let observe fast and fine changes of saturation.

As can be seen, it is suitable to use both methods for their complementarity.

References

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