

## MONITORING DAMAGE AND DAMPNES IN FLOOD EMBANKMENT BY ELECTRICAL IMPEDANCE TOMOGRAPHY

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**Abstract.** The article presents a model of the measuring system for image reconstruction. Electrical impedance tomography was used to determine the moisture of the test flood blank on a specially built model. The Gauss-Newton methods have been applied very successfully in many areas of the scientific modelling. The basic information about the built model system is given. The finite element method was used to solve the forward problem. The level set method and the Gauss-Newton method were applied to solve the inverse problem.

**Keywords:** inverse problem, finite element method, electrical impedance tomography, flood embankment

### TOMOGRAFIA IMPEDANCYJNA DO WYZNACZANIA WILGOTNOŚCI W MODELU WAŁU

**Streszczenie.** W artykule zaprezentowano model systemu, układ pomiarowy oraz metody rekonstrukcji obrazów. Elektryczna tomografia impedancyjna została użyta do określenia wilgotności w specjalnie przygotowanym testowym modelu wału przeciwpowodziowego. Zastosowane metody gradientowe i topologiczne są bardzo skuteczne w wielu obszarach modelowania. Zostały przedstawione podstawowe informacje o koncepcji systemu. Do rozwiązania zagadnienia odwrotnego zostały wykorzystane metody zbiorów poziomowych i Gaussa-Newtona.

**Słowa kluczowe:** zagadnienie odwrotne, metoda elementów skończonych, tomografia impedancyjna, wał przeciwpowodziowy

### Introduction

This paper presents the new method examining the flood embankment dampness by electrical impedance tomography (EIT) [1-3]. Numerical methods were based on gradient techniques [8, 9, 12]. Discussed algorithms can be applied to the solution of inverse problems to determine a dampness in electrical impedance tomography. The finite element method coupled with Gauss-Newton or (and) the level set function has been used [4, 6]. The model of the flood embankment creates nonhomogeneous testing environment where object properties conductivity varied smoothly with one more coordinates. Surface potential measurements are performed at different angles of projection whereby the

information needed to determine an approximate distribution of conductivity inside the object is obtained. This idea has been used successfully in the context of the inverse problem in the flood embankment [5, 7, 10, 11, 13-15].

### 1. Flood embankment model

The flood embankment dampness was examined by electrical impedance tomography system. The examples of embankment's damage were presented in Figure 1 such as: piping, erosion outer slope, micro instability, drifting ice, slip circle inner slope, slip circle outer slope, wave overtopping, overflow and liquefaction.

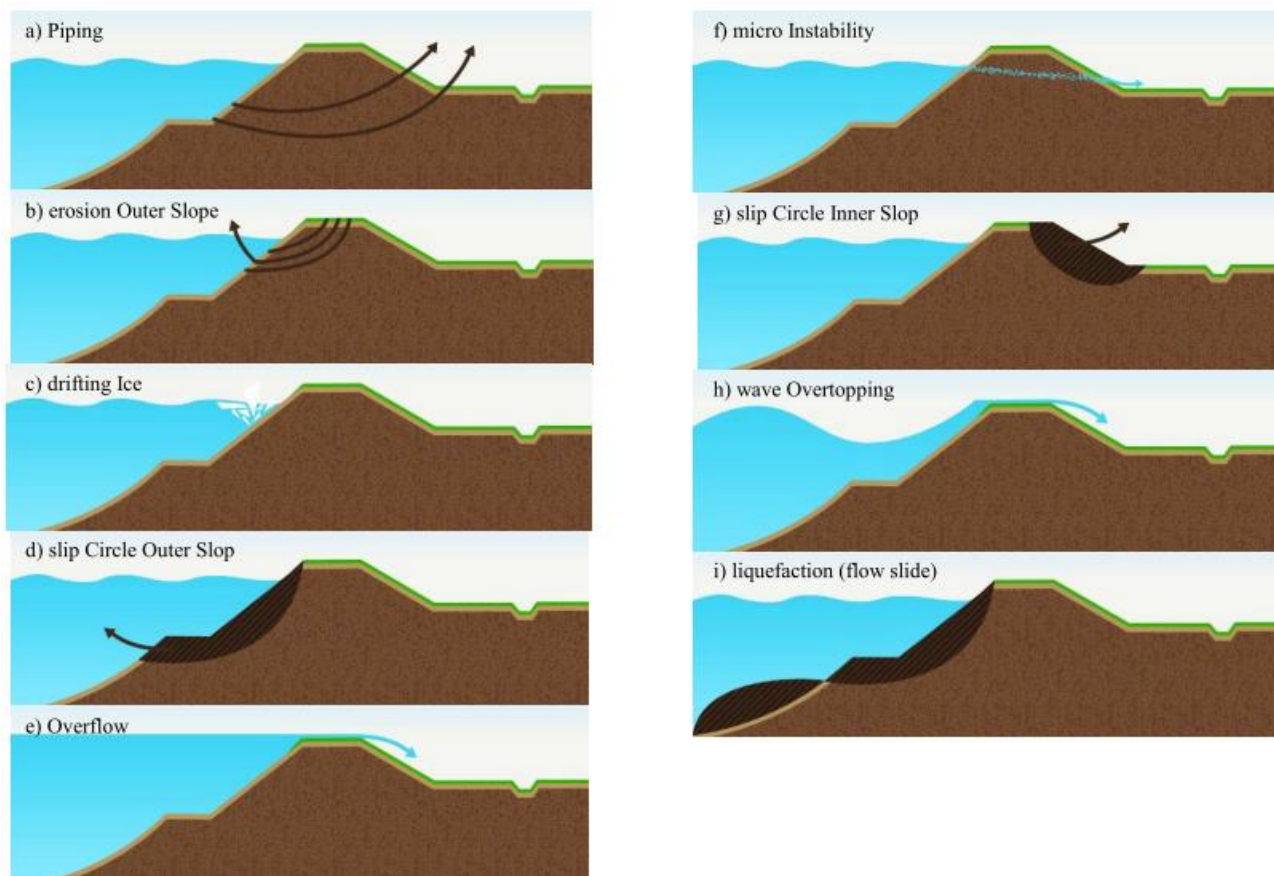


Fig. 1. The model of the flood embankment

The architecture of the flood embankment system is shown in Figure 2.

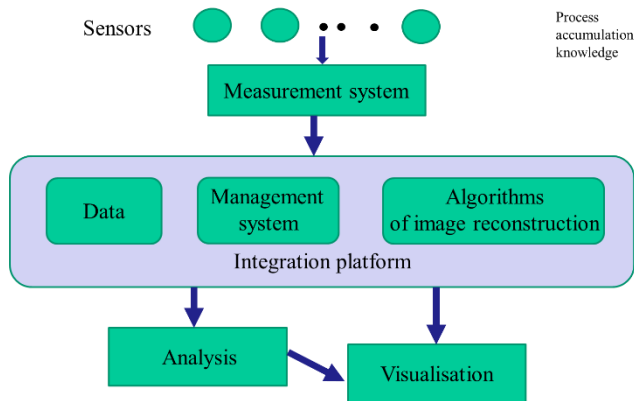


Fig. 2. The architecture of the flood embankment system

There is well known that for EIT scanning system with 16 electrodes on 2 dimension, we can get 13 independent electrode-to-electrode measurements and 8 independent potential distributions and 104 linearly independent values. The distribution of potentials on the edge of saturated sand and the top of the bank is linear, it may be because the electrode was placed near the edge. Surface potential measurements are performed at different angles of projection whereby the information needed to determine an approximate distribution of conductivity inside the object is obtained.

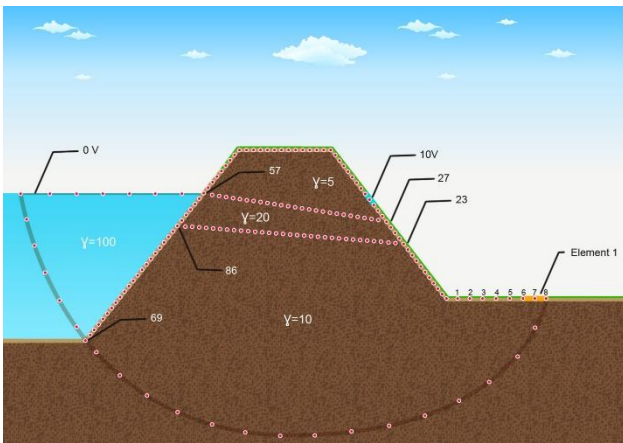


Fig. 3. The distribution of elements on the edge of the flood embankment

The example of embankment’s model was shown in Figure 3. This object was divided into 57 elements, 111 nodes. Each element consists of three nodes. The red element symbolizes the electrode 10V. In black marked 0V ground potential. For the area of  $\gamma_4$  is water. The measurement voltage is from node 1 to 57 - 28 items (27 electrodes from node 2 at the second node to node until the number 56, in addition to node 32 where it was applied 10V). Green color indicated the first item.

The distribution of potentials on the edge of the flood embankment results can easily check the state of saturation in the layer of sand  $\gamma_2$ . The greater permeability of the sand is lower potential at the edge of the flood embankment. The lower permeability area  $\gamma_3$  is lower potentials. As you can see from the chart the impact of water conductivity in a very small influence on the distribution of potentials in most places (at the edge of the flood embankment and on the border between the saturated sand and the top layer of dry sand and the boundary between the saturated sand and a lower layer of the bank). Only the results differ on the border of the bank - the water. The distribution of potentials on the border of saturated sand and the top of the bank is linear, it may be because the electrode was placed near the 10V and the other side of the border of three centers is 0V.

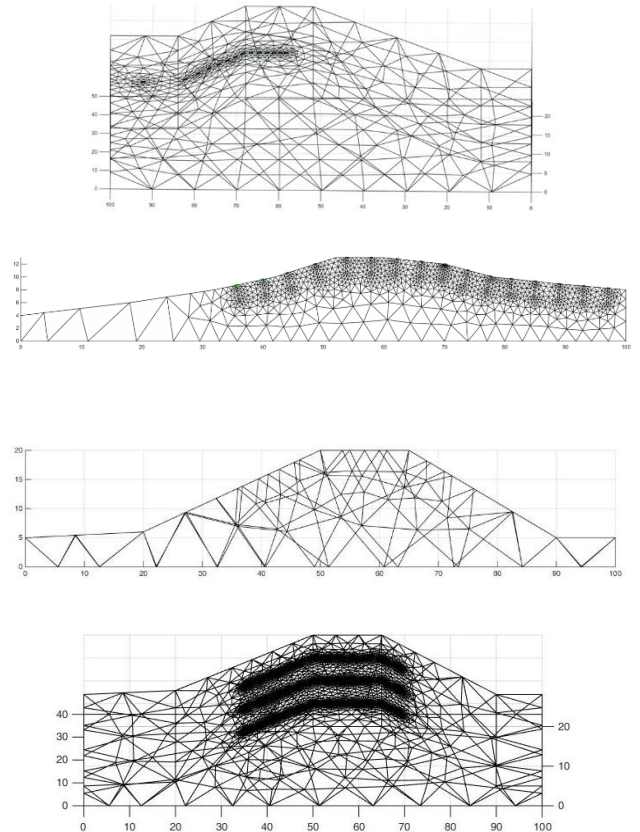


Fig. 4. Numerical models of the flood embankments

Figure 4 presents the numerical models of the flood embankments. EIT measurement models of the flood embankment are shown in Figure 5 and 6. The laboratory prototype model with devices is presented in Figure 7.

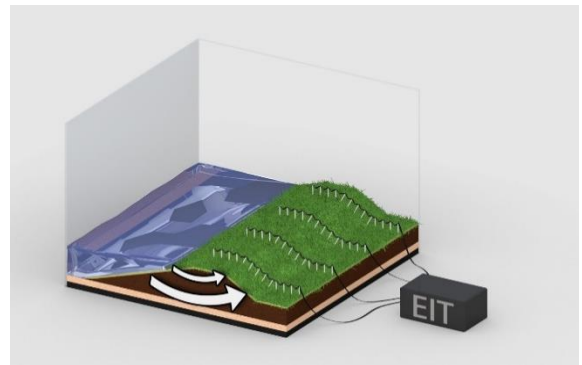


Fig. 5. The EIT measurement model I of the flood embankment

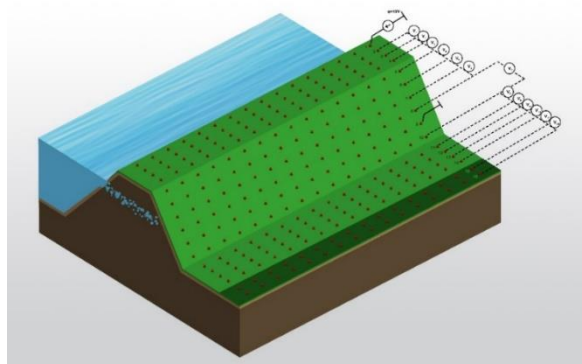


Fig. 6. EIT measurement model II of the flood embankment





Fig. 7. The laboratory prototype of the measurement system

## 2. Image reconstruction

Electrical impedance tomography is known that the inverse problem is nonlinear and highly ill-posed. The forward problem solution in EIT consists in determining potential distribution inside the region  $\Omega$  under given boundary conditions and full information about region under consideration. That is in solving Laplace's equation:

$$\text{div}(\boldsymbol{\gamma} \text{grad } \mathbf{u}) = 0 \quad (1)$$

where  $\mathbf{u}$  - voltage,  $\boldsymbol{\gamma}$  - conductivity.

The objective function is formed following:

$$F = 0.5 \sum_{i=1}^n (\mathbf{U} - \mathbf{U}_m)^T (\mathbf{U} - \mathbf{U}_m) \quad (2)$$

where  $n$  is a projection angle,  $\mathbf{U}_m$  - the measured voltage,  $\mathbf{U}$  - the calculated voltage by solving the equation (1).

A Gauss-Newton method is deployed to the regularized tangential movement problem. The electrodes move tangentially to the domain at each iteration and so do not in general lie on the boundary of the domain after each iteration. These are thus projected back onto the fixed domain by computing the nearest boundary simplex of the finite element mesh. The Gauss-Newton algorithm is following form:

$$\boldsymbol{\gamma}^{k+1} = \boldsymbol{\gamma}^k + \alpha (\mathbf{J}_t^k \mathbf{J}^k + \lambda \mathbf{W})^{-1} \cdot (\mathbf{J}_t^k \mathbf{W} (\mathbf{u}_m - \mathbf{h}(\boldsymbol{\gamma}^k)) - \lambda \mathbf{W} \boldsymbol{\gamma}^k) \quad (3)$$

where  $\boldsymbol{\gamma}$  denotes the vector of the unknown conductivity,  $\alpha$  is the step size,  $\lambda$  is a regularization parameter,  $\mathbf{J}^k$  is the Jacobian matrix,  $\mathbf{W}$  is a regularization matrix and  $\mathbf{h}(\boldsymbol{\gamma}^k)$  is the observation model derived from a finite elements model.

The forward problem solution in EIT consists in determining potential distribution inside the region under given boundary conditions and full information about region under consideration, that is in solving Laplace's equation. In this paper there was proposed combination the Gauss-Newton method, the level set

method and the finite element method to solve the inverse problem. The representation of the boundary shape and its evolution during an iterative reconstruction process is achieved by the level set method. The image reconstruction in the different geometrical model of the micro instability was presented. The conductivity of searched objects is known. Figures 8, 9 show the simulation of one and two objects. The image reconstruction obtained by the Gauss Newton Level Set Method with simulation data was shown in Figure 10. Picture 11 shows the image reconstruction obtained by the Gauss Newton method with real data: the model (a), data taken after 15 minutes (b), after 30 minutes (c). Figure 12 presents the image reconstruction of the 3D model of the flood embankment.

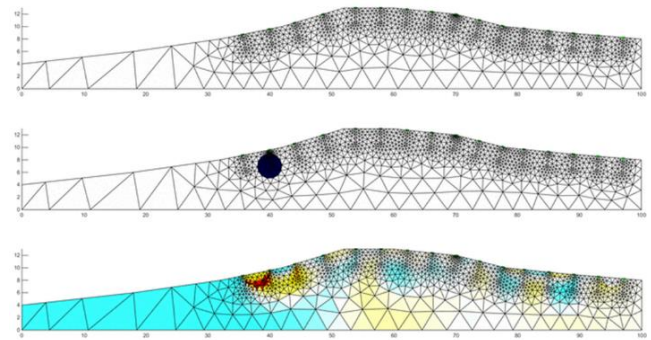


Fig. 8. The model of the one objects and image reconstruction

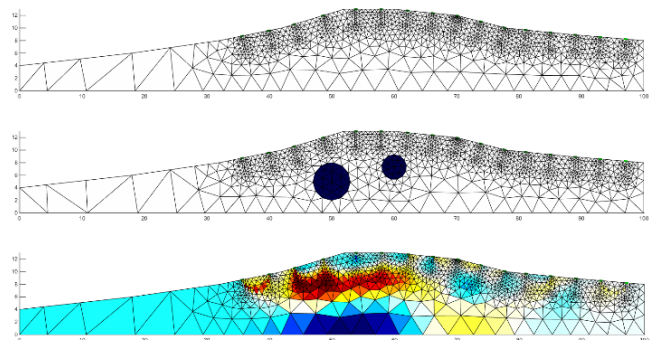


Fig. 9. The model of the two objects and image reconstruction

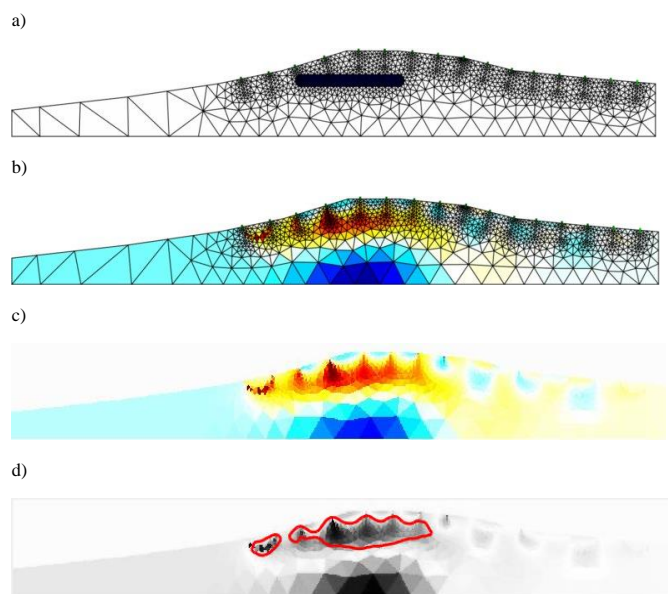


Fig. 10. The image reconstruction obtained by the Gauss Newton Level Set Method with simulation data: a) the model, b) the reconstructed image, c) the image without mesh, d) the level set method component after 15 iterations

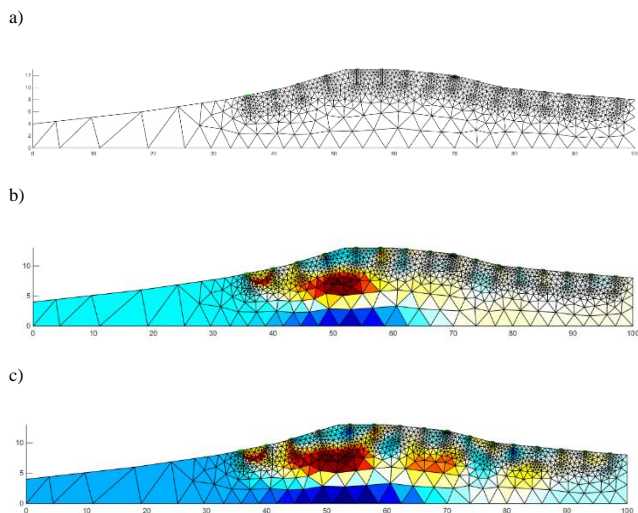


Fig. 11. The image reconstruction obtained by the Gauss Newton method with real data: a) the model, b) data taken after 15 minutes, c) after 30 minutes

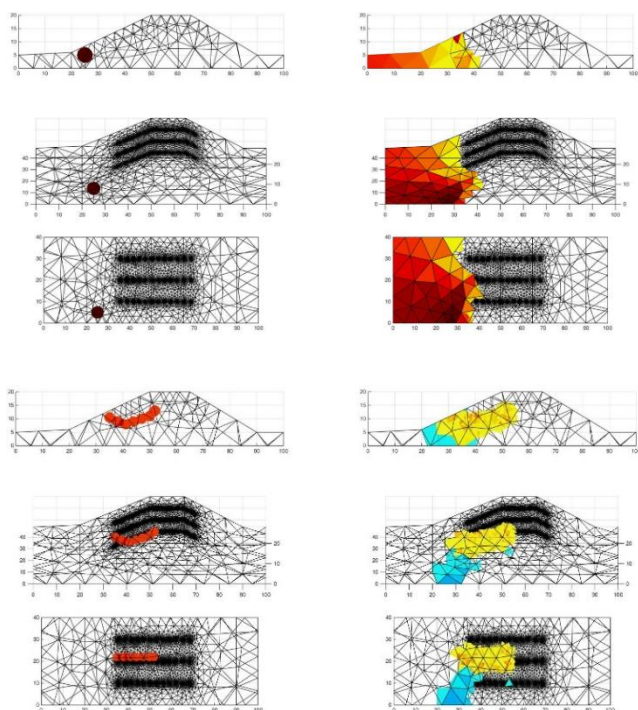


Fig. 12. The image reconstruction 3D model of the flood embankment

### 3. Conclusion

New nondestructive methods of the monitoring flood embankment model were tested. There were used iterative algorithms where repeatedly the shape boundary evolves smoothly and the searched object is detected. The combination of the proposed algorithms and the line measurement is effective in the simulation and the laboratory experiment. The finite element method was used to solve forward problem. The presented techniques are successful to identify the unknown properties of the object. Image reconstruction for identifying the unknown shape of an interface in a problem motivated by electrical impedance tomography can be done by proposed method. The Gauss-Newton and level set function techniques are useful in this system. The application depends on a specially built model. The proposed method was verified by simulations and its main components were verified experimentally in the laboratory. The presented method determines the moisture of the test model. Applying the line measurement model is enough effective to solve the inverse problem in the moisture flood embankment.

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