DETECTION OF INHOMOGENEITIES IN STRUCTURE OF FLOOD EMBANKMENTS BY MEANS OF D.C. RESISTIVITY, GPR AND FREQUENCY ELECTROMAGNETIC METHOD MEASUREMENTS – SHORT NOTE

Remigiusz MYDLIKOWSKI [1)]*, Grzegorz BEZIUK [2)] and Adam SZYNKIEWICZ [3)]

[1)] *Institute of Telecommunications, Teleinformatics and Acoustic, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, phone +48 071 320 2829, fax +48 071 320 31 89*
[2)] *Institute of Telecommunications, Teleinformatics and Acoustic, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, phone +48 071 320 3215, fax +48 071 320 31 89*
3) Institute of Geological Sciences**,** *Wroclawi Uniwersity, pl. M.Borna, 50-204 Wroclaw, phone +48 071 375 92 97*
**Corresponding author's e-mail:* remigiusz.mydlikowski@pwr.wroc.pl

(*Received* April 2007, *accepted* August 2007)

ABSTRACT
This paper presents results from the examination of flood embankments by means of three geophysical methods: GPR, mutual impedance of loop antennas measurements and D.C. resistivity method. In order to increase measuring accuracy, the mutual impedance measuring system works at a high frequency**.** Parameters of mutual impedance measuring system were presented. A method of mutual impedance measurement results was described. Flood embankments examination results showed that the simultaneous use of few geophysical methods increases accuracy of inhomogeneities detection in near-surface structure of the ground.

KEYWORDS: geodynamic geophysical methods, DC resistivity, GPR, mutual impedance, loop antennas, apparent resistivity

INTRODUCTION

Flood embankments are very important elements of hydro - protection systems. High water levels in rivers or other water reservoirs is not always the main cause of flooding. The poor condition of an embankment is, very often, the main reason why floods occur. Flood embankments are under the influence of many different factors that can weaken their structure. Therefore their condition should be evaluated frequently. According to Polish regulations every section of flood embankment has to be examined once in two years.

Examination of levee structure is carried out by sounding i.e. drilling holes in the ground and taking samples to assess its condition. Sounding should be carried out at three points for every kilometre of levee. Very often the places of drilling are chosen by visual estimation. This is not a precise method because the properties of an embankment can vary drastically with every meter and it is easy to overlook weak places on a levee. Additionally, taking into consideration that the total length of an embankment is equal to thousands of kilometres in every country, it is very difficult to carry out a thorough examination only by means of sounding. Therefore examination of levees should be carried out in two stages: firstly - preliminary examinations and secondly - sounding. Preliminary examinations should be carried out by means of one or few near-surface geophysical methods. These methods have to make it possible for examination in the fast way. Results of preliminary testing of levee should show places where strong inhomogeneities occur in the embankments. Sounding then has to be carried out in these places .

Geophysical electrical and electromagnetic methods can be successfully applied as methods of fast detection of inhomogeneties in flood embankments (Keller and Frishknecht, 1966; Kruk et al., 2000; Nabighian, 1991; Verma and Sharma, 1995). A global parameter that is determined by means of these method is apparent resistivity of the ground (Nabighian, 1988; Wilt and Stark, 1982). On the basis of changes in measured apparent resistivity traces places where occur inhomogeneities in examined section of levee can be found.

Another geophysical method that can be used to preliminary embankment examinations is GPR (GPR 2004 website). The result of GPR survey is the distribution of electric permittivity that gives information about inhomogeneities in the levee.

Preliminary examination of flood embankments has been the main subject of authors researches for the past few years (Beziuk and Pralat, 2003, 2004). During that period some surveys were carried out by means of D.C. resistivity method (Keller and Frishknecht, 1966) and measurements of mutual impedance of loop antennas working at the high frequency. Recently, in order to get more information about levee structures, GPR examinations have also been used.

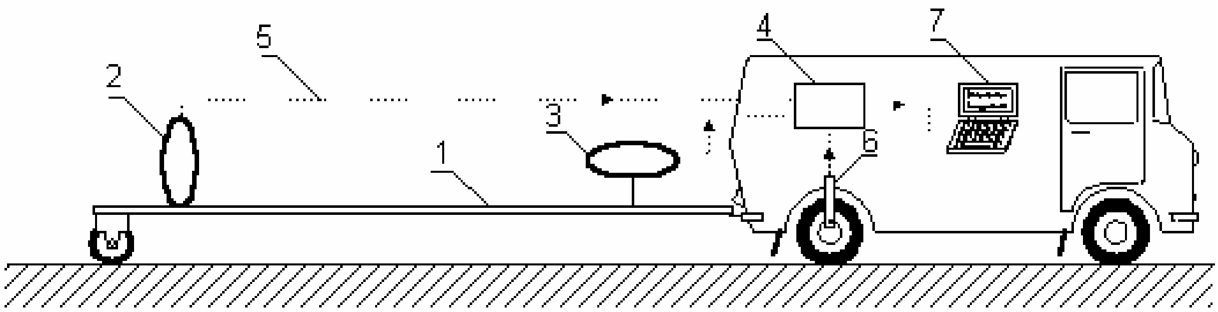

Fig. 1 Diagram of measuring system: 1 – cart, 2 – source antenna, 3 – measuring antenna, 4 – A/D converter and RS 232 transmission system, 5– fibre-optic cable, 6 – system displacement meter, 7 – portable computer.

The paper contains the description of a system for measuring the mutual impedance of loop antennas. A method of interpretation of mutual impedance measurement result is described. Measurement results of flood embankments carried out by means of D.C resistivity, mutual impedance and GPR are presented. The results indicate usefulness of simultaneously using a few geophysical methods for levee preliminary examinations.

MEASURING DEVICES

As mentioned earlier, measurements of flood embankments sections were carried out by means of three geophysical methods: GPR, mutual impedance measurements and D.C. resistivity method. A system for measuring the mutual impedance of a system of loop antennas operating at a frequency of 1 MHz, shown in Figure 1, requires additional description because it has been designed and built from 1994 to 1997, at the Institute of Telecommunications and Acoustics at Wroclaw University of Technology (Beziuk nad Pralat, 2003, 2004; Pralat 1994, 1997). GPR measurements were carried out by means of georadar type RAMAC/GPR with a 250 MHz shielded antenna. However D.C. measurements were carried out by Polish device LPH03. Measuring equipment used for D.C. resistivity and GPR methods are commercially made and will not be described in the paper.

The construction of the system for measuring the mutual impedance is similar to the others described in the literature (McNeill and Bosnar, 1999; Wright and Chew, 2002). It measures magnitude and phase of mutual impedance for: horizontal coplanar, vertical coplanar, vertical coaxial and perpendicular loop antennas arrays. The system consists of a measuring van and cart (1) towed by it. The cart is made of plastic whereby it has no effect on the electromagnetic field radiated by source antenna (2) attached to it. The magnetic moment of source antenna can be changed from 0.17 to 3.6 [Am^2]. A field measuring antenna (3) is also attached to the cart. Both antennas are situated 0.5 m above the ground. The spacing between the antennas is adjustable from 2 to 6 m. The signal from the field measuring antenna is supplied to a/d converter (4) and then via a RS232 link is sent to PC (7). There is fibre-optic link (5) between the field source and the meter. The signal transmitted via this link is used for the measurement of the impedance phase. It is also used in a system eliminating the primary field originating from the source antenna whereby measurements can be performed using all the antenna configurations described above. The system includes system displacement measuring unit (6) with a measuring resolution adjustable from 0.05 m to 1.6 m.

Another issue is the penetration depth of the described system. According to Spies (1989) the depth of investigation in EM surveys depends on the following factors: sensitivity and accuracy of the measuring system, complexity of the investigated medium and an ambient and inherent noise level. Because we did not have the exact information on the structure and parameters of the levees, we were unable to compute the penetration depth with the forward modelling method. Therefore the system's penetration depth was experimentally determined by comparing the measurements obtained by means of the system with the ones yielded by the D.C. electrical resistivity methods. The penetration depth was also estimated by the measurements of some sections of the levees that contain visible inhomogeneities such as a pipe culvert. One can notice that penetration depth was determined through examining levees and because of a particular levee' structure it can be different for investigation of other media. Penetration depth of the system can be changed by changing the spacing between the antennas and their configuration but it should be noticed that a maximum distance between antennas at which the system works correctly is equal to 10m. The maximum penetration depth is equal to the spacing between the antennas for perpendicular loops and horizontal coplanar loops. Whereas for vertical coplanar loops and vertical coaxial loops the system's

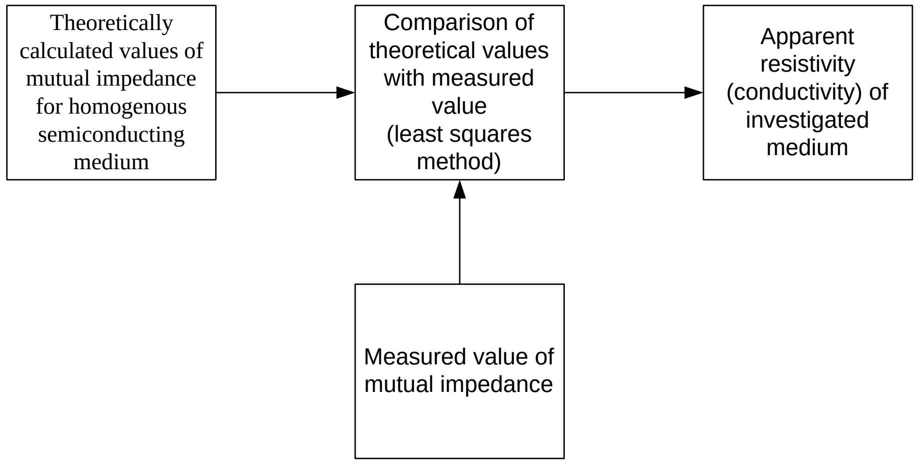

Fig. 2 Algorithm for interpreting mutual impedance measurement results.

penetration depth is 1-2 m greater than the spacing between the antennas. Obviously in the case of a very conducting ground, penetration depth of the system is smaller than mentioned above.

INTERPRETATION OF MEASUREMENT RESULTS

The mutual impedance of a system of loop antennas is not a quantity which characterizes the investigated conducting medium. It is an indirect quantity on the basis of which the parameters of investigated conducting medium, such as apparent resistivity, can be determined. There are several definitions of apparent resistivity of conducting half space. The differences between them are mainly due to the different methods used for measuring apparent resistivity (Kruk et al., 2000; Wilt and Stark, 1982). In this research, we used the commonly known interpretation method (Frischknecht, 1967; Kruk et al., 2000; McNeill, 1980; Nabighian, 1991). It consists of finding the best match between the measured data and the theoretical curves. The only difference being that in mentioned papers apparent resistivity was determined from the measurements of the mutual impedance of antennas placed on the ground's surface while in this paper apparent resistivity is determined for antennas situated at a certain height over the investigated medium. A schematic algorithm for interpreting mutual impedance results is shown in Figure 2.

Interpretation consists in determining a theoretical mutual impedance curve for a homogenous medium as a function of changes in its conductivity for a given configuration of antennas, the spacing between them, the height at which they are situated and their operating frequency and then comparing the measured mutual impedance values with the calculated theoretical values. Using the least squares method a theoretical mutual impedance value is calculated for a homogenous medium, which is closest to the measured value. In other words, interpretation consists in the minimization of this function

$$g=\left[\frac{Z}{Z_0}_M-\frac{Z}{Z_0}_T(\sigma)\right]^2, \qquad (1)$$

where: $\frac{Z}{Z_0}_M$ is the measured mutual impedance value and $\frac{Z}{Z_T}(\sigma)$ is the theoretically determined mutual impedance value. The resistivity (conductivity) value for which such a theoretical mutual impedance value is found is the sought resistivity (ρ_a) or apparent conductivity (σ_a) of the medium. Since measurements are performed for media having a different structure and the measured mutual impedance values are compared with values theoretically determined for a homogenous medium, the resistivity value which is found is called apparent, i.e. it is equivalent to the average of the resistivities of the investigated medium's particular layers. Thus the medium's apparent resistivity is a function of the particular layers' resistivity and thickness. The interpretation of measurement results is demonstrated step by step in Figure 3.

FIELD MEASUREMENT RESULTS

Figs. 4a – 4d present examples of results of examined sections of flood embankment by means of three methods: D.C. resistivity, mutual impedance of horizontal coplanar loops, mutual impedances of vertical coaxial loops and GPR. D.C. resistivity measurements were carried out at every 10-meters, for Wenner array with electrode separation equal to 10 meters. Mutual impedance measurements were carried out at every 0.2 meters with antennas spaced equally at 5 meters. However GPR measurements were carried out at every 0.3 m at a frequency of 250 MHz.

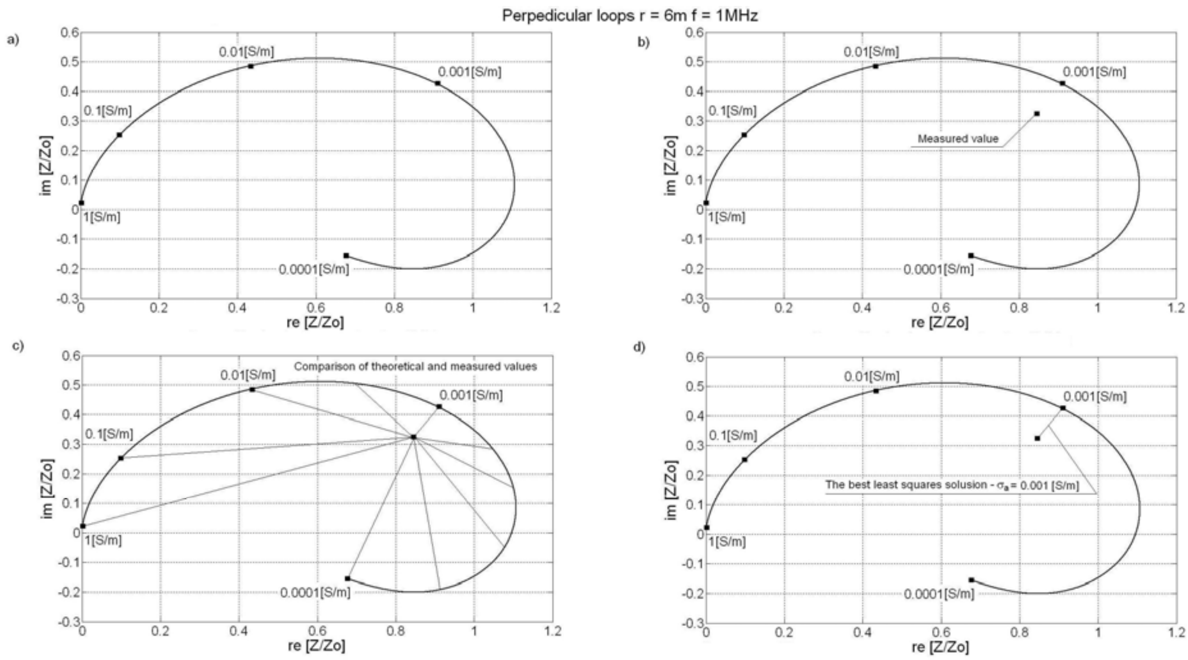

Fig. 3 Example of mutual impedance measurement interpretation: a) determination of theoretical mutual impedance curve, b) measurement of mutual impedance, c) comparison of all theoretical mutual impedance values with measured mutual impedance value, d) determination of medium's apparent conductivity by least squares method.

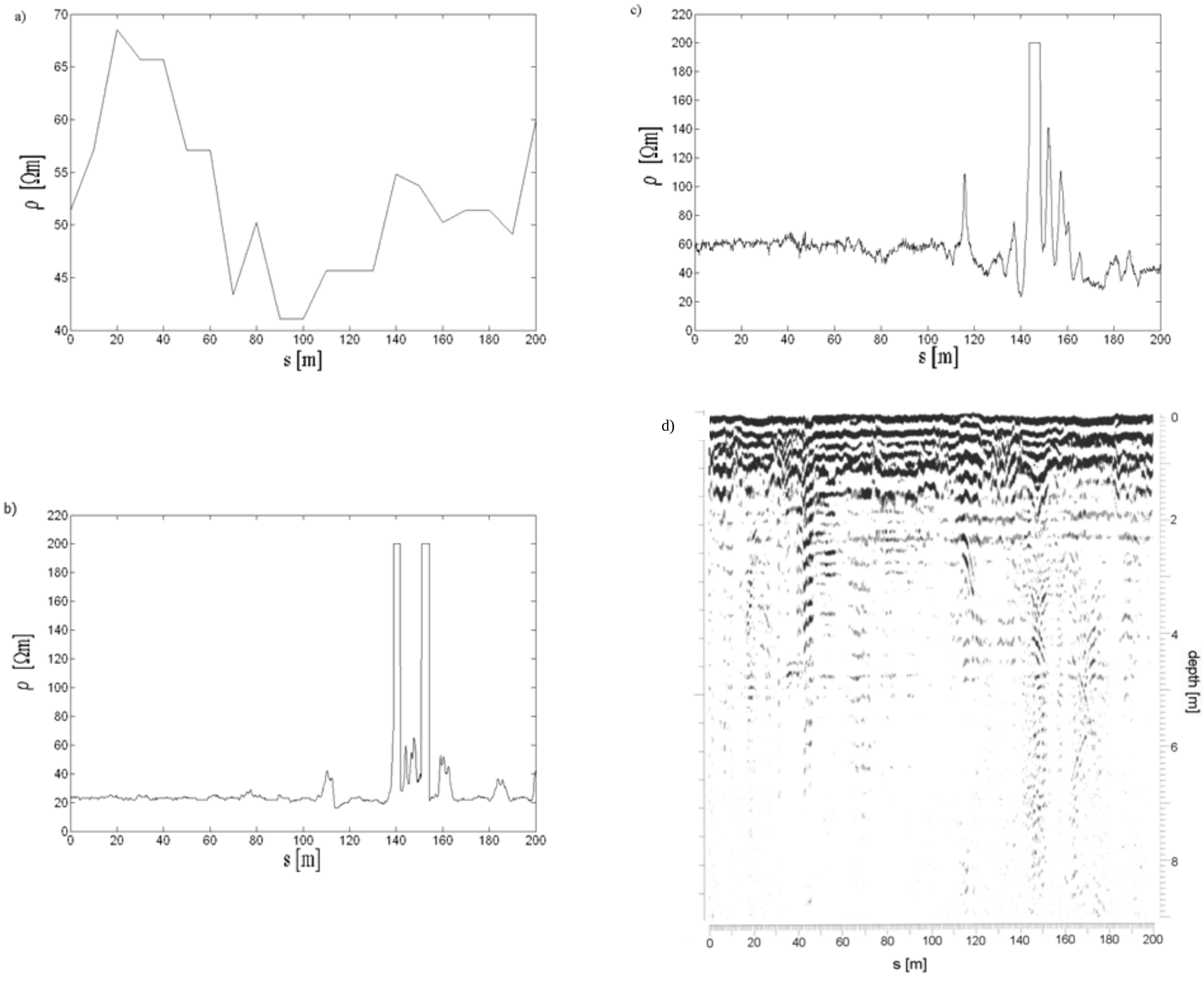

Fig. 4 Results of surveys flood embankments by means of: a) D.C. resistivity, b) mutual impedance of horizontal coplanar loops, c) mutual impedance of vertical coaxial loops, d) GPR.

Analyzing the results of measurements it is evident that inhomogenities occurred in the 150m area of the levee is clearly visible on curves which are interpretations of measurement results of mutual impedance. In Figures 4b and 4c we observe the increase of measured resistivity of the tested ground around 150m of levee. The results were also confirmed using the GPR method (Fig. 4d). This figure clearly shows distortion of image of tested fragment of levee on 150m. Both methods show inhomogenities around 110m of the levee. These inhomogenities are not so evident in Figures 4 b,c (increase of resitivity), 4d (distortion of image). Inhomogenities on 110 and 150m of the levee are not so clear visible on the curve obtained from DC Resistyvity measurements (Fig. 4a). The reason for this could be that measurements were done less often, that is, they were taken every 10 meter. DC Resistyvity method shows clearly certain inhomogenities between 20 and 40 m of levee. These inhomegenities can be seen as an increase of apparent resistivity (Fig. 4a) on this part of the levee. This change in the structure of the levee is also confirmed by GPR method. On Figure 4d, we also observe certain image distortions between 20 and 40 m of the levee. These inhomogenities could not be detected by measurements of mutual impedance.

CONCLUSION

This paper presents examples of examination section of flood embankments by means of three geophysical methods: GPR, mutual impedance measurement and D.C. resistivity measurements. The system for measuring of mutual impedance of loop antennas, developed at Wroclaw University of Technology, was described. The system works at high frequencies in comparison with other known geophysical EM systems.

Inhomogenities which occur on the levee can be characterized by several electrical parameters. Holes made by animals living around water bodies are characterized by a large value of resistivity and small value of electrical permittivity. This kind of inhomogenities can be easily detected by high frequency electromagnetic methods: GPR or measurements of mutual impedance. Structure weaknesses of levee caused by high level of ground water are characterized by high level of electrical permittivity and low resitivity. Depth of penetration of electromagnetic waves is small due to the fact that, in this medium electromagnetic waves are strongly attenuated. Therefore, the occurrence of this kind of inhomogenities can be detected by DC Resistyvity method, because in a moist medium electrical conductivity is very good. Summarize the results of examination indicated on necessity using of a few geophysical methods. It enables to detect in non-invasive way all inhomogeneities in the structure of examined section of embankment.

Presented results of surveys can help in a variety of other works that require an assessment of the near-surface structure of the ground, e.g. road construction.

REFERENCES

Beziuk, G. and Pralat, A., 2003, Examination of flood embankments via measurement of mutual impedance of loop antennas operating at high frequency. 2003 IEEE International Geoscience and Remote Sensing Symposium, Toulouse, France.

Beziuk, G. and Pralat, A.: 2004, Determination of apparent resistivity through high-frequency electromagnetic measurements. Near Surface 2004 - X European Meeting of EAEG, Utrecht, The Netherlands.

Frischknecht, F.C.: 1967, Fields about an oscillating magnetic dipole over a two-layer earth, and application to ground and airborne electromagnetic surveys. Quarterly of The Colorado School of Mines 62.

http://www.gpr2004.tudelft.nl

Keller, G.V. and Frischknecht, F.C.: 1966, Electrical methods in geophysical prospecting, Pergamon Press, New York.

Kruk, J., Meekes, J.A.C., Berg, P.M. and Golema, J. T.: 2000, An apparent-resistivity concept for low-frequency electromagnetic sounding techniques. Geophysical Prospecting, Vol. 48, 1033-1052.

McNeill, J.D.: 1980, Electromagnetic terrain conductivity measurement at low induction numbers. Technical note TN-6, Geonics Ltd, Toronto.

McNeill, J.D. and Bosna, M.: 1999, Application of “dipole-dipole” electromagnetic systems for geological depth sounding. Geonics Technical Note TN-31.

Nabighian, M.N.: 1988, Electromagnetic methods in applied geophysics, Volume 1, Theory, Society of Exploration Geophysicist (SEG).

Nabighian, M.N.: 1991, Electromagnetic methods in applied geophysics, Volume 2, Applications, Society of Exploration Geophysicist (SEG).

Pralat, A. and Cywinski, O.: 1994, Location of inhomogeneities in conducting medium with measurements of electromagnetic field phase. Annual Report of Institute of Telecommunications and Acoustics, Wroclaw University of Technology. No I-28/SPR-033/94. Wroclaw, Poland, (in Polish)

Pralat, A.: 1997, Influence of inhomogeneities in conducting medium on coupling between two magnetic dipoles working at high frequency. Annual Report of Institute of Telecommunications and Acoustics, Wroclaw University of Technology. No I-28/SPR-062/97. Wroclaw, Poland, (in Polish).

Spies, B.R.: 1989, Depth of investigation of electromagnetic sounding methods. Geophysics 54, 872-888.

Wilt, M. and Stark, M.: 1982, A simple method for calculating apparent resistivity from electromagnetic sounding data. Geophysics 47, 1100-1105.

Wright, D.L. and Cheb, W. C.: 2002, Enhancement to and characterization of the very early time electromagnetic (VETEM) prototype instrument and applications to shallow subsurface imaging at sites in the DOE complex. Final Report U. S. Department of Energy, 69.

Verma, S. K. and Sharma, S. P.: 1995, Focused resolution of thin conducting layers by various dipole EM system. Geophysics 60, 381-389.