SÁMUEL MIKOVINY DOCTORAL SCHOOL OF EARTH SCIENCES

Theses of doctoral dissertation

GEOELECTRICAL METHODS FOR THE INVESTIGATION OF BARRIER SYSTEMS IN MODERN LANDFILLS

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I. SCIENTIFIC BACKGROUND AND AIMS

The foundation insulation of the increasing number of modern landfills is frequently built by the use of geomembranes. Geomembranes are special polymers (e.g. HDPE) which are capable of retaining percolates from the waste deposits and, in addition, possess excellent electrical insulation properties. Taking advantage of their high resistivity, it becomes possible to investigate the foundation insulation systems of landfills in terms of geoelectricity. The main point of the method lies in the fact that a current of substantial amperage can flow through the geomembrane of high resistivity if a failure has arisen a failure somewhere in its surface. The current flowing though the failure changes the potential values (potential difference values) that can be measured on the surface of the landfill and in the surrounding area.
In the practice so far, geoelectric measurement systems of a built-in construction have been used for the examination of the geomembrane insulation of landfills. The term built-in construction means that sensing electrodes with in a net-like arrangement are built in the clay liner before the geo-membrane is laid on the foundation. The electrode points are carried by means of a cable system outside the landfill, where the spatial distribution of the potential field is scanned, while the source electrode is earth connected within the landfill, on its surface, and the drain electrode is earth connected outside the landfill at a considerable distance from it (Hix 1998).
The spacing of the electrode network is designed on the basis of the structure of the landfill and its physical and geometric conditions. In addition, economic considerations also play an important role. From the aspect of detecting leakage, densely laid sensor points would be advantageous.
Tests of the lakage-free condition of the geomembrane can be divided into two parts: tests in the construction period of the landfill, and measurement tests (monitoring) in the operation period. The main difference between the two periods is given by the thickness of the waste disposal.
It may happen that during operation the built-in geophysical measuring system designed to detect leakage in the geomembrane fails and its repair is impractical and thus cannot be used for further test measurements. It may also be the case that in several landfills constructed earlier, no sensor electrodes were laid under the landfill prior to its construction. It is for such cases and for controlling the existing built-in systems that a new mobile leakage-finding method presents a solution, in which the current and the drain electrode are laid in a similar way to that in the case of the built-in system in order that the geo-electric measurements applied should be appropriately sensitive for finding the places of leakage. By the arrangement of the source and the drain electrodes, the current is forced through the geomembrane and, in particular, through its leakage. The potential measurements (potential differences) can be carried out by means of electrodes installed on the surface of the waste and by means of what are called remote electrodes. The dissertation investigates the applicability of the mobile leakage-finding procedure using synthetic and in-situ geoelectric data. The investigations are performed using various types of landfill models with high inhomogeneity. New evaluation methods are developed for the determination of the parameters of landfills, including first of all the faults and insufficiencies of the geomembrane, and they are used on synthetic and field problems.

II. ACCOMPLISHED INVESTIGATION

The dissertation makes an overview of the main types of landfills described in the professional literature, their characteristics and the properties of their geomembrane layer. It

summarises the results published in the professional literature so far concerning the geoelectric foundation insulation testing of landfills.
Theoretical investigations are performed on landfill models of various geometry and inhomogeneity for the purpose of developing a new geoelectric method. The Spitzer 3-D programme operating on the principle of finite difference method is used for the modelling (Spitzer 1995). Due to the highly complex structure of landfills also in geoelectric terms, only 3-D models are used.
In evaluating the results, potential and potential difference distribution maps are used, the possibilities and results of normalizing are examined, and so is the possibility of various filtering processes in order to reduce noises and thus to emphasise the leakage signal of the geomembrane isolation.
The methods currently used in the approximative solution of the geophysical inverse problem are reviewed, and a new method is developed so-called iterative simultaneous successive approximation method. By using the suggested method, various geoelectric data sets are evaluated together for the purpose of determining the structure of landfills. 3-D parameter sensitivity examinations are performed concerning the other object in the landfill. The leakages and inhomogeneities in the 3-D model structures as well as the effects of the individual layer characteristics on each other are examined by means of parameters sensitivity tests, for which the parameter sensitivities and test results defined and achieved by Gyulai (1989) are used.
The new method developed is essentially a complex interpretation method for solving the inverse problem and improves the evaluation results in a similar way to joint inversion (Gyulai and Baracza 2012).

III. NEW SCIENTIFIC RESULTS

Thesis 1

Theoretical experiments are used to verify that by installing source electrode 'A' on the surface of the isolated landfill site and by installing drain electrode 'B' in the very far distance from the isolated area and by using potential measuring electrodes 'MN' it is possible to develop a geo-electric measuring system which is particularly sensitive to failures in the geomembrane of landfills. In the case of Pole-Pole arrangement, measuring electrode 'N' of the measuring arrangement used is located in the very far distance from the insulated area of the landfill, and in the case of Pole-Dipole arrangement it is located within the isolated landfill area. For this purpose 3-D modelling examinations are used and they verify that areal and/or profile geoelectric measurements on the landfill surface are suitable for testing landfills of small and large thickness (5-20m).

Thesis 2

A new normalizing procedure is introduced for determining the failures of the geomembrane and their location. This combines the advantages of the two different versions of normalizing used in practice.

$$\eta^* = \frac{1}{2}\left(\frac{a-b}{a} + \frac{a-b}{b}\right) = \frac{a^2-b^2}{2ab},$$

where 'a' is the value of the data with geomembrane leakage and 'b' is that of the data without geomembrane leakage.

Thesis 3

Visualising on a map potential and potential difference distribution (along axis X or Y) measured on the surface, plotting the normalised values of the measurement data and the geophysical filtering of the distribution maps verify that it is possible to identify the leakages in the geomembrane layer of landfills of small thickness (1-5m) together with their location (also 1-2m).

Thesis 4

An iterative simultaneous successive approximation method is developed for examining landfills, which represents the solution to the inverse problem, for the joint evaluation of various geophysical measurement data, including determination of all the parameters of a landfill. This includes

a. determining the geometrical and physical parameters of the landfill,
b. determining the leakages of the geomembrane,
c. differentiating between the leakages of the geomembrane and inhomogeneities of the waste.

Thesis 5

Model calculations are used to verify that areal and/or profile geoelectric measurements on the landfill surface with calculating apparent resistivity are also suitable for testing landfills of large thickness. Leakages in the geomembrane reduce apparent resistivity both for small and large waste thicknesses in potential measurements. In potential difference measurements a leakage increases the values of apparent resistivity between the source and the rupture and decreases it following the leakage. A 'rough' inhomogeneity above the leakage, however, affects the location of this transition.

Thesis 6

The evaluation of mobile site measurement data on the surface by the method of iterative simultaneous successive approximation verifies that the mobile geoelectric method is suitable for exploring the failures in the geoemebrane even of landfills with large thickness (20m). The new method developed is used for determining the other parameters of the landfills as well.

Thesis 7

A parameter sensitivity method is developed for the geoelectric testing of landfills. It is verified that the parameter sensitivities calculated from apparent resistivity obtained by potential measurements and potential difference measurements show substantial differences depending on the landfill structure. The parameter sensitivities

a. are suitable for selecting the measurement system of research projects,
b. assist determining the initial, start model in the inverse problem,
c. are necessary for using the iterative simultaneous successive approximation method.

PRACTICAL APPLICATION OF THE RESULTS

In the construction and the operation periods of modern landfills with geomembrane foundation isolation, it is important to know whether percolates escape from the waste through the foundation isolation into the geological environment or not. One possibility for establishing this is geophysical monitoring, the measurement method of which may be provided by a built-in measuring system under the geomembrane insulation. The other possibility is provided by using a mobile measuring system on the waste surface. Both geo-electric methods apply the same operation principle to explore the leakage locations in the geomembrane as the locations of the current escape. The methods of 3-D modelling and those for evaluating site data presented in the dissertation can be successfully applied for testing landfills from geoelectric aspects, e.g. geometrical characteristics, inhomogeneities and physical properties of the waste dumped. It is possible to show the effects of the inhomogeneities of the waste layers concerning the location of leakages on the surface of the geomembrane. It becomes feasible to solve the inverse problems of complex models constructed in the evaluation of the data of not only geoelectric, but also of other geophysical methods. The parameter sensitivity testing method presented can also be used in solving the inverse problem. The electrode arrangement features and data evaluation methods applied can also be used for exploring other facilities with geomembrane insulation widely used in environmental protection. These include hydraulic walls, dams and various insulations constructed for the safe deposition of waste. It can be used for testing all enclosed spaces which were insulated using geomembranes with high resistivity, such as the insulation of tanks, pipes, salvage pools, irrigation canals in agriculture, rainwater tanks, and slurry, sludge and slag pools. The methods presented can be used for examining the external and internal surfaces of spaces closed by insulation, their geometrical and resistivity inhomogenities in terms of exploration and hydraulic dams constructed of electrically insulating materials. By using the iterative simultaneous successive approximation method developed, it becomes feasible to co-apply geophysical methods (operating on identical or different physical principles) in a wider range. The procedure makes use of the property of geophysical methods that they possess differing parameter sensitivities concerning the facility under examination. The iterative simultaneous successive approximation method can be used to improve the information contents of the data about the facility examined and to improve evaluation accuracy. Thus the evaluation of geological, hydrogeological and environment physical structures determined by a geophysical method becomes more reliable.

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