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Detection of Internal Erosion and Seepage Evaluation Using Resistivity Monitoring

By Pontus Sjö Dahl,
Torleif Dahlin and
Sam Johansson

The resistivity method is well suited for dam monitoring as it is non-destructive and easily adapted for long-term monitoring. Measurements detect changes of material properties as well as anomalous variations, which may relate to internal erosion and seepage. However, applying the resistivity method on embankment dams can be challenging. This paper contends with practical use of the resistivity method on embankment dams, and presents two examples from Sweden.

1 Introduction

Resistivity surveying is a geophysical method widely used for a variety of engineering and environmental applications. In characterizing the subsurface the method makes use of the fact that earth materials have different ability to conduct electrical

current. Being non-destructive the method may be attractive for installations on existing dams and it has been found useful for status control in dam safety investigations. Another more ambitious and more powerful approach is using the method for long-term monitoring of dams. In that case additional information is received

from an analysis of the seasonal resistivity variations in the dam.

2 Fundamental principles

The resistivity in an embankment dam varies seasonally, and depends mainly on the temperature and the ion content of the seepage water. Both these parameters vary seasonally, and their variation in the dam depends on the seepage flow. Areas in the dam with larger seepage may stand out as areas with larger seasonal variation.

2.1 Seepage induced variations

Seasonal temperature variations in an embankment dam has since long successfully been used for seepage detection. Seepage flow rates can be evaluated from temperature measurements without knowledge of hydraulic conductivity in the dam [1]. This is a great achievement, as the true in-field hydraulic conductivity is a difficult parameter to estimate. In a similar way resistivity can be used to evaluate seepage. Seepage causes resistivity variations in the dam that may be recorded by repeated measurements. Johansson and Dahlin [2] did some initial test on repeated resistivity measurements from the Lövön dam. The basis for this principle is the relation between temperature and resistivity (Eq. 1), where the resistivities, ρ_T , at different temperatures, T , relates to the resistivity, ρ_{18} , at a temperature of 18°C. The temperature coefficient of resistivity, α , is empirically

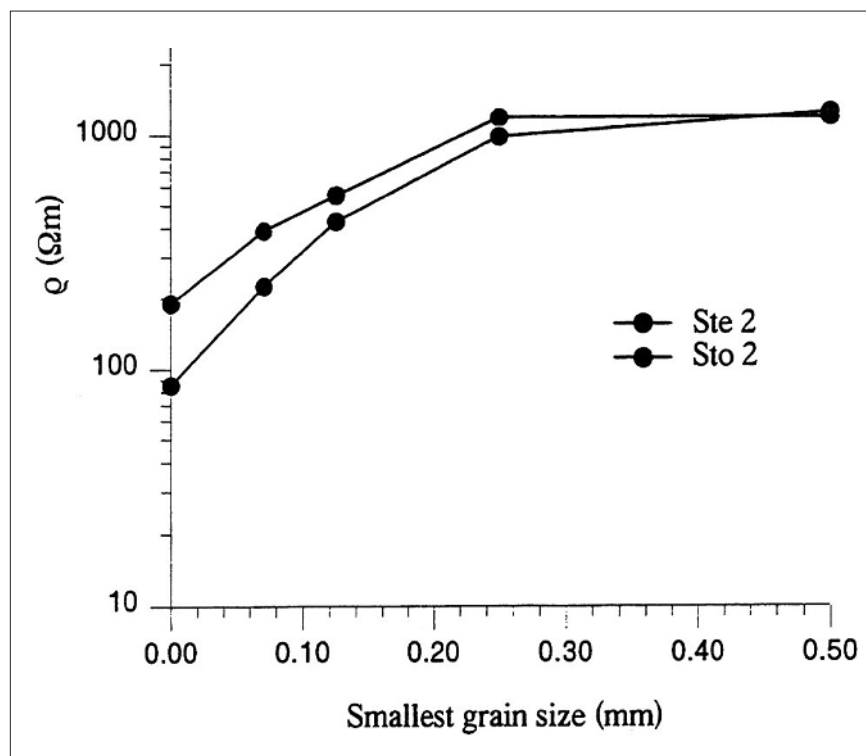


Figure 1: Importance of fines content on resistivity of soils. Results from an experiment simulating erosion in a glacial till used for sealing waste deposits, but similar to a dam core (Ste 2 and Sto 2 are named samples from two different sites) [1]

found to be approximately $0.025^{\circ}\text{C}^{-1}$, and valid for temperatures above the freezing point [3]:

$$\rho_T = \frac{\rho_{18}}{(1 + \alpha(T - 18))}$$

2.2 Effects from internal erosion

Internal erosion is the reason why weak zones can take the form of high-resistive anomalies. When internal erosion occurs, the fine particles of the soil are washed out from the core. This process affects the resistivity in two aspects, each working against the other. Firstly, the porosity of the core increases which leads to a decrease of the resistivity due to higher water content. Secondly the reduction of the fines content in itself increases the resistivity. In many fine-grained soils, the second aspect dominates. Laboratory test performed by Bergström [4] on some Swedish glacial tills used for sealing layers on waste deposits indicate a significant increase in resistivity when the fine content is removed (Figure 1).

In the experiment conducted by Bergström, resistivity was measured on the same soil with different levels of fines removed, thereby simulating washout of fines as a result of internal erosion. The glacial till sample is similar to what is used in the cores of many Swedish dams. The resistivity rises approximately ten times after removal of fines smaller than 0.25 mm.

3 Materials and methods

3.1 System design

Installing electrodes along the crest has been the most practical design on existing dams. For zoned embankments with central cores it is most favourable to install the electrodes in the dam core. This secures good electrode contact and as the dam core is less resistive than the fill material, the current will have a channelling effect in the dam core, thereby focusing on the most interesting part of the dam [5]. Apart from these factors, dam geometry, material properties, water resistivity, error sources such as steel sheet piles or earthing cables, reservoir fluctuations, are examples of other factors influencing the choice of design.

3.2 Data acquisition

There is a variety of resistivity measuring instruments or packages of instruments on

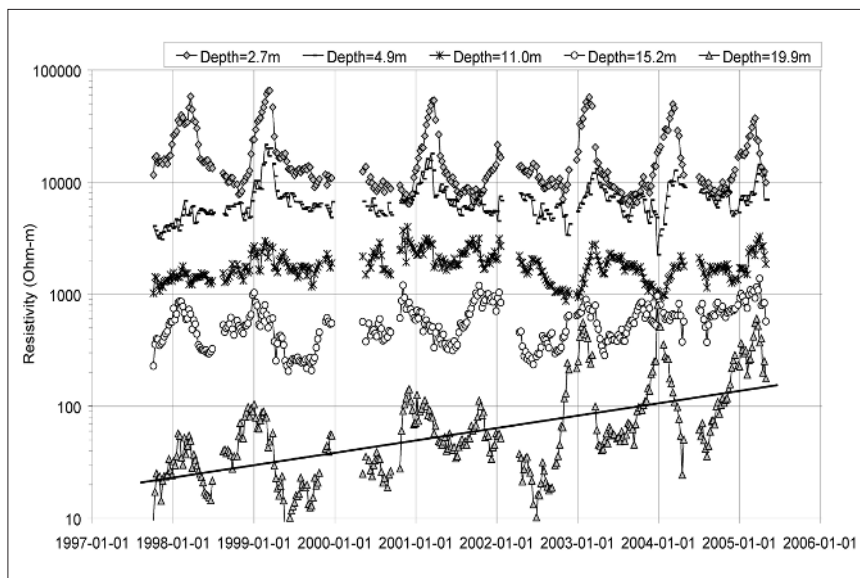


Figure 2: Resistivity at different depths in chainage – 43 m on Hällby dam

the market for field use. Such equipment typically consists of a resistivity instrument, a relay switch (electrode selector), multi-electrode cables, stainless steel electrodes and various connectors. Most modern instruments have a built-in computer that can handle the entire data acquisition process and memory capacity to store days of measured data. Systems used for permanent installations for dam monitoring have some specific requirements. An important addition is lightning protection that should be designed with individual protection for each electrode input connected to the system, as well as for power supply and possibly a modem telephone connection. It is fundamental to provide sufficiently good and stable electrode contact, as too high contact resistance between electrode and ground is a common source of data quality problems. If Self Potential is to be measured special non-polarisable electrodes should be used.

3.3 Data processing, inverse modelling and interpretation

Processing of resistivity data includes data quality assessment, inverse numerical modelling and presentation and analysis of the results. Checking data quality is usually performed by plotting the pseudosection. Checking of data also includes removal of apparently erroneous data points, and in some cases weighting of data in relation to reliability can also be performed. Subsequently, inverse numerical modelling is carried out on the data set, and the final model or alternative models are presented and analysed. For standard resistivity investigations this is usually made by hand in steps. However, for long-term monitoring it easily becomes too time-consuming and instead automatic routines are necessary. Such automatic routines need to be robust and simple but still have the ca-

Erfassung innerer Erosion und Ermittlung von Sickerwassermengen mittels Anwendung der Elektrischen Widerstandsmessung

von Pontus Sjö Dahl, Torleif Dahlin und Sam Johansson

Die Methode zur Messung des elektrischen Widerstandes ist zerstörungsfrei und aufgrund der einfachen Installation für die Dammüberwachung, auch über längere Zeiträume gut geeignet. Deren Messungen erfassen Änderungen von Materialeigenschaften sowie unregelmäßige Veränderungen, welche zu innerer Erosion und erhöhtem Sickerwasseraufkommen führen können. Allerdings kann die Anwendung dieser Methode sehr anspruchsvoll sein. Diese Abhandlung beschreibt den praktischen Gebrauch der Elektrischen Widerstandsmessmethode und stellt zwei Beispiele aus Schweden vor.

capacity to perform the individual steps of the data processing scheme.

4 Case studies

4.1 Hällby

The embankment dams at Hällby have a total length of around 320 m. The maximum height is 30 m. The dams are constructed as zoned rockfill embankment dams with vertical central glacial till cores. Hällby was the first Swedish embankment to get a permanently installed monitoring system intended for resistivity measurements. Daily measurements started to take place in 1996, which make these long-term monitoring data unique. In 2004–2005 the monitoring temporarily halted as the dams were upgraded and the electrodes re-installed.

Resistivity in the dam varies seasonally (Figure 2). In general on the Hällby dam, the variation is high close to the crest, which is explained by extremely high winter resistivities due to ground freezing. The amplitude of the variation becomes lower at larger depths. This is consistent with theory as the impact from seasonal temperature variation in the reservoir or in the air decreases with distance from the reservoir. The data showed in Figure 2 is from an area adjacent to previously reported sinkholes. Here, contrary to the expectations, there are significant variations at large depths, which have not been seen elsewhere. Moreover, there are also signs of increas-

ing variations and increasing absolute resistivities on large depth.

4.2 Sädva

The Sädva dam is located in the Skellefteälven River just south of the Arctic Circle. The total length of the dam is 620 m, and the maximum height is 32 m. The dam is a rock fill embankment dam with a slightly inclined central glacial till core. The monitoring installation comprises full instrumentation for resistivity measurements. Permanent electrodes are installed inside the top of the dam core along the full length of the dam, and daily measurements have been carried out since 2001.

The seasonal variation is obvious also in the Sädva dam (Figure 3). Comparing with Hällby, the variations are generally smaller and also consistent along the length of the dam, which may be a sign of a healthier dam with lower seepage flow rates. The homogeneous conditions in the dam are evident. Moreover, freezing effects and electrode contact problems were avoided by improved installations.

5 Conclusions

The resistivity method is a non-destructive method suitable for long-term monitoring. The rapid development in the areas of data acquisition and data processing has supported the possibilities of constructively using the method for dam applications. Long-term monitoring with spatially

denser data points can now be achieved. This approach has been tried in two Swedish dams and similar installations are planned for another two dams.

Fundamental is the physical coupling between the resistivity parameter and seepage or seepage paths. The monitoring approach is based on two principal ideas, which both may be identified by studying time-series. Firstly, washout of fines due to internal erosion will affect the resistivity in the dam. Secondly, seasonal resistivity variations in the reservoir, originating from variations in temperature and ion content, will affect the resistivity in the dam as the seepage water propagates through the dam.

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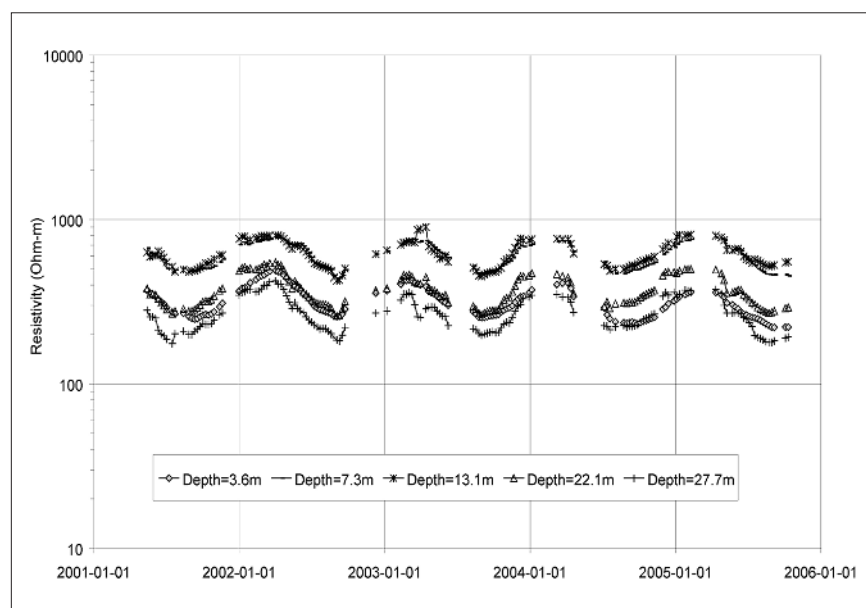


Figure 3: Resistivity at different depths in chainage 100 m on Sädva dam

