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Geoelectric, thermic field measurements for dam control

Mesures géoélectriques, thermométriques à l'inspection des barrages

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SYNOPSIS Procedures of geoelectric and thermic field measurements, serving the purpose of timely detecting leakages in dams and dikes, are under development as yet. Within the scope of a pilot project and supported by work within some research projects, field measurements were carried out and evaluated in an effort to test the applicability of both subject procedures. The present contribution is reporting first results, and is giving hints indicating further ways of proceeding toward this objective.

INTRODUCTION

Failure of two dams in the Seventies, and the enhanced engineering activities in using water resources for energy-production and waterway purposes, have called for an improvement of dam control. This involves less the short dams transverse to a river, as such easy to keep under control; it rather concerns the long side dams within the dwatering system of canals and rivers; these side dams in many instances are not at all provided with any system of control, even though they may be just a few years old.

The measuring procedure endeavored, therefore, should be space-covering and should not necessitate operative measures immediately in the existing dam itself, at the same time observing the demand of economic reasoning.

The present paper introduces to the reader, field measurements carried out at dams within cooperative efforts of the Bundesanstalt für Wasserbau and the University of Karlsruhe upon initiation by the Administration of Waterways and Navigation of the Federal Republic of Germany. The present report explains the two different measuring procedures and compares their respective results.

PRINCIPLES OF THE GEOELECTRIC MEASUREMENTS

The determination of electric properties of the undisturbed geological subsoil or of the fill body is attributed to that branch of geophysics one can define as geoelectrics.

Data on the electric characteristics, in particular of the apparent resistivity, serve as a very valuable criterion in judging the geological subsoil or the structure of a fill body.

Data on the electric self-potentials as to magnitude and sign, make it possible to determine flow processes and their changes in the subsoil, even through such changes may be of relatively short endurance.

Advantages of geoelectric measurements are envisioned in their accuracy, their wide range of application, and their rapid conductability over dam sites of a major length.

Resistivity Methods

In the geoelectric resistivity methods, artificial direct- or alternate-current fiels were superposed on the ground. The apparent specific electric resistivity, i.e., the structure of the subsoil is determined independent upon the measuring procedure utilized. Variation of the electrode spacing or, respectively, the outlay, provides for information about the deeper parts of the dam.

In an effort to identify the latitudinal extent of the subsoil stratigraphy, the investigations presented here especially included geoelectric mapping (according to Wenner). This method gives information concering the latitudinal and depth distribution of the apparent specific resistivity rates and, at the same time, about the existance of water-saturated zones within the subsoil.

Self-Potential (SP) Measurements

Electric potentials occur during the movement of aqueous solutions (electrolytes) in porous or fissured media. Flow processes within the subsoil or within the building structure lead to filtration- or flow-potentials, respectively. The electric potentials are measured at the surface by means of a highly sensitive voltmeter, via non-polarisable electrodes. The physical interpretation of the measured electric filtration-potentials indicates processes of intensive seepage for minus potentials, and ascendent flow of water for positive potentials (Armbruster et al., 1982, 1984; Merkler et al., 1984).

Processes of oxydation and reduction generated within the subsoil, however, also raise electric potentials which are disturbingly superposed on the filtration-potentials. This complicates quantification of the in-situ SP measurements substantially; in addition to this, the inhomogeneity of the subsoil is here of no minor importance. On account of these circumstances, successful determination of water-flow quantities on the basis of the measured differences of electric potentials so far has been achieved only in model tests with homogeneous material (Armbruster et al., 1981, 1983; Merkler et al., 1984). For the exam-

ples, two measuring methods have been applied: As to the potential method, the electric potential is measured between a fixed nonpolarisable electrode (porous vessel bearing saturated $CuSO_4$-solution) and another appropriate electrode which is moved within a geometrical scanning pattern along profiles on the air-exposed side of the dam slope.
As to the gradient method, the electric potentials along the profiles are each measured between two electrodes moved with equidistant spacing.

PRINCIPLE OF THE THERMIC FIELD MEASUREMENTS

In the evaluation of measured values it is a prerequisite that the variable to be measured (temperature) is actually affected at all by the leaks searched for in the sealing system of a dam. The pilot project performed in 1981 rendered qualitative evidence of the temperature dependencies within the dam and at the surface of the dam.

Contact Measurements

This type of measurement is based on energy exchange due to thermal conduction between the medium to be measured (ground) and the temperature-sensitive element of minor mass (sensor). The sensor is placed into the medium or must at least contact it, not allowing any change to the existing temperature field thereby. For measurements within the dam, therefore, the sensor has to be installed during construction activities, or must be placed in lateron. In both instances, disturbance of the homogeneity of the dam is inevitable, all of the measured values render interpretable information for a point or for a line only (for instance in observation tubes). Temperatures are measured by means of resistance thermometers, thermo-elements, or thermo-sensors on the basis of semi-conductors. In the water-saturated ground, the soil measurement can be replaced by the measurement of water temperature. This makes it possible in existing gauge system; to gain interpretable information easily and fast (a few seconds only) concerning the temperature gradient down to the lower end of the observation tube. For measurements above the water level one needs either built-in sensors or portable ground thermometers, the latter assuming the existing temperature only after approximately 45 minutes subsequent to their placement in the dam. Surface-temperature measurements by means of thermo-sensors are possible, they are, however, not recommendable for reasons of inaccuracy.

Non-contact Measurements

In the non-contact measurement of the surface temperature the energy exchange takes place due to thermal radiation within the medium infrared range. The radiating body (surface) can be located at a larger distance to the thermal measurement device, or can also be in relative movement to the instrument (passive remote scanning). The device measuring the temperature is an infrared scanner that should be sensitive within the 8-to-14 μm-wavelenth range to which the atmosphere is penetrable, because of the relatively low temperatures.
The measurements at dams were made with a multispectral scanner, which also records the visible light (0.4 to 0.7 μm) and the adjacent near infrared (0.7 to 0.8 μm). The scanner is installed in a plane, including an aerial camera. All of the scanner's measuring data are recorded on magnetic tape and processed by means of computers (Armbruster, et al., 1985).

MEASUREMENTS EXAMPLES

Geoelectric measurements at dams revealed qualitative interpretable information on flow processes in the subsoil; also, the pilot project started in 1981 showed that thermal measurements admit qualitative interpretation both space-covering (infrared images) and point-wise (ground measurements). Thereupon, preparations started for model measurements in laboratory channels, at model dams, and defined hydraulic fields.

Measurements at Dams

Example 1: At the lateral dam of a canal, wet spots had occured which gave rise to the conclusion that the Hydraton (clay) sealing was leaking. In an effort to determine location and extent of the leakage, SP and resistivity measurements were carried out at the air-exposed side of the dam, furthermore temperature measurements and an infrared image taken on a sunny day in April. Results of the SP measurements on three different days with varying water levels in the canal are illustrated in Figure 1.

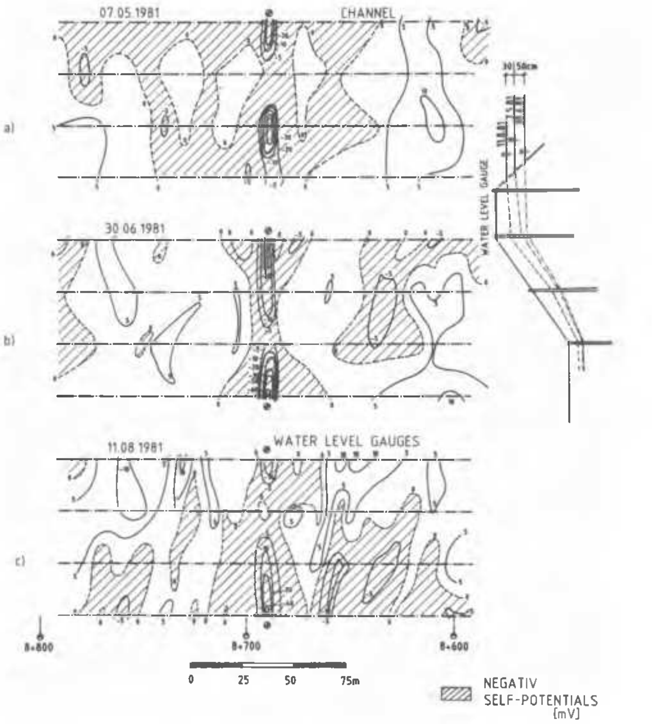

Fig. 1: SP fields at a canal dam in various points of time

The diagram makes extended minus-anomalies visible of laminar shape and uninterrupted from the crest of the dam down to the dam toe. The high negative values (⩾ 30 mV), preferably occurring along the gauge line, can be traced back to leaks in the Hydraton sealing or to seepage processes in the sense of descendent water flow. The magnitude of the space-covering minus anomalies is seen related to the head of water in the canal, this means that a larger area of the dam or, respectively, a broader space of the dam is percolated when the

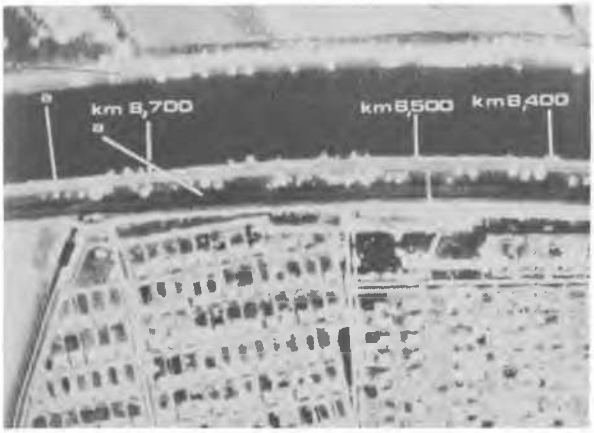

Fig. 2: Infrared image (2 Apr.81) of the dam shown in Figure 1

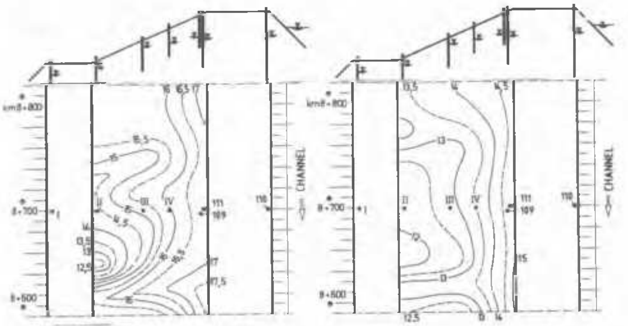

Fig. 3: Ground temperatures (4 Aug.81) 1m, respectively, 2m below upper edge of the dam face

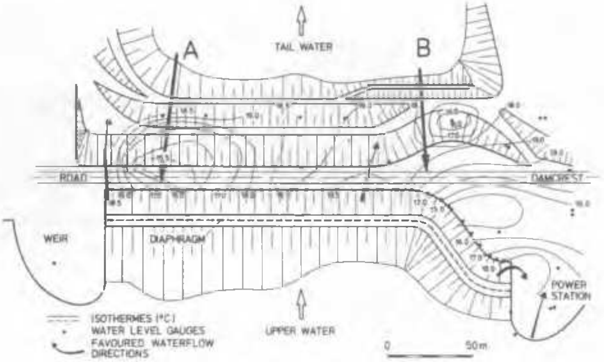

Fig. 4: Ground temperatures, 0,2 m below the free surface of a transverse dam, measured in water level gauges

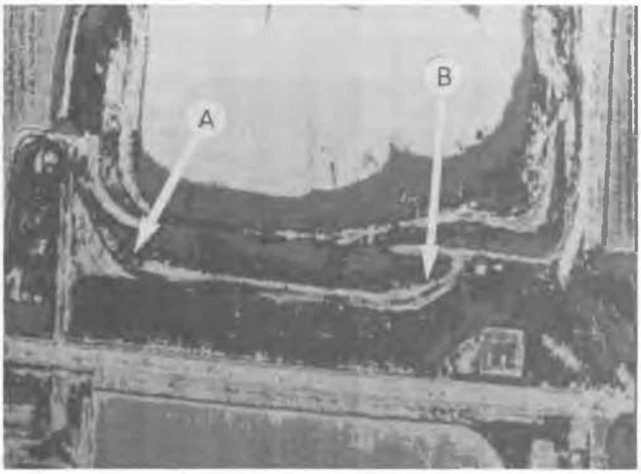

Fig. 5: Infrared image of the transverse dam shown in Fig. 4

Water level is high. Results of the resistivity measurements based on the relatively uniform distribution of resistivity values, admit the conclusion that the dam is homogeneously structed. The low resistivity values measured within the lower part of the dam are seen to result from the higher water level in this part of the dam. The mating infrared image made during the noon flight (Fig. 2) shows very clearly the wettened areas (dark spots (a) in the image) extending over an area of 200 meters (Fig. 2). The scanner record of the short range of infrared (not illustrated) also shows high vitality of growth at strong radiation intesity within this range, indicating moisture in the vicinity of this vegetation.

The ground temperatures measured at 1m and 2m depths (Fig. 3) can be interpreted only as a result of the respective water level, which at the dam toe is about 0.9 meters, and at the crest of the dam about 2.3 meters below the surface, the water level of the channel having been raised a few days ahead of the measurements after an extended period of drawdown. The measurement range with the exception of area 8 + 650 at the dam toe is within the area of inadequate sealing by which the warm channel water raised the dam temperature much faster than it did in unaffected parts of the dam. This interpretation can be derived also from the results of the SP measurements (Fig. 1).

Example 2: At the retaining wall of an impounded river, the temperatures measured just below the line of seepage in Summer (depth appr. 15 meters below crest of dam), indicate areas of pronounced percolation (Fig. 4). It can be clearly seen on the infrared image taken at the beginning of April that these areas in the tailwater ware marked by dark spots in the image due to the enhanced ascendent under flow (sections A,B). Measurements of the SP, too, shows the varying percolation of the dam. The positive potentials in the dam toe to the left (section A) indicate ascendent flow processes (left-hand side arrow of the temperature measurement). Within Section B there occur positive potentials, too, yet they (Fig. 6) are not so pronounced.

Measurements on Models

The anisotropy and inhomogeneity of dams give rise to electric disturbance potentials leading to substantial difficulties in the quantitative interpretation of the SP measurements. Therefore, model tests were expected to clarify the relationships between the seepage flow in the dam and the variables to be measured at the surface of the dam. At first, the seepage processes with self-potentials were measured at a homogeneous model dam in a small laboratory channel (1.40 x 0.75 x 0.55 m)(Fig. 7). It could be clearly evidenced that the SP values depend upon the seepage flow as caused by the head of the impounded water. Based on the SP values (Fig. 8), the seepage water was quantified by computation, and these quan-

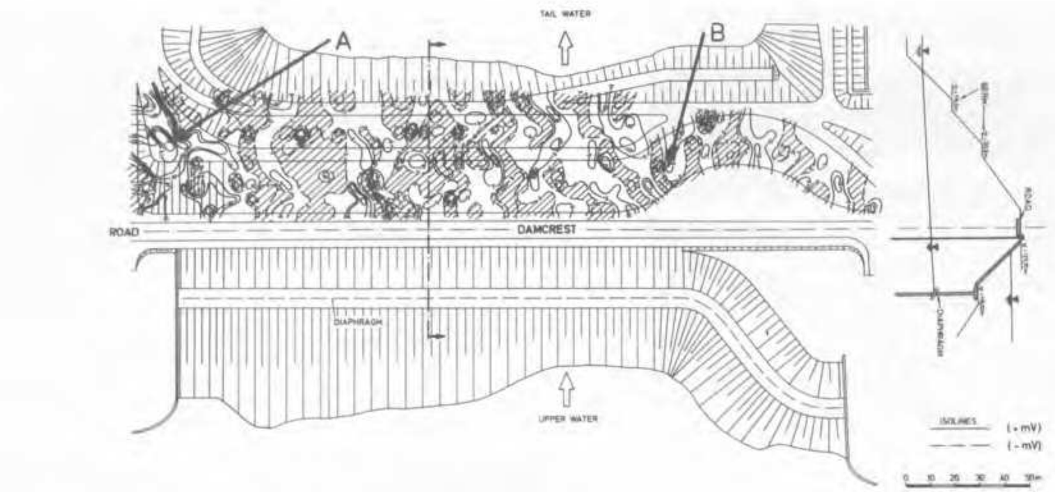

Fig. 6: Self-potentials at transverse dam shown in Fig. 4 measured by gradient method

Fig. 7: Model of the small laboratory dam

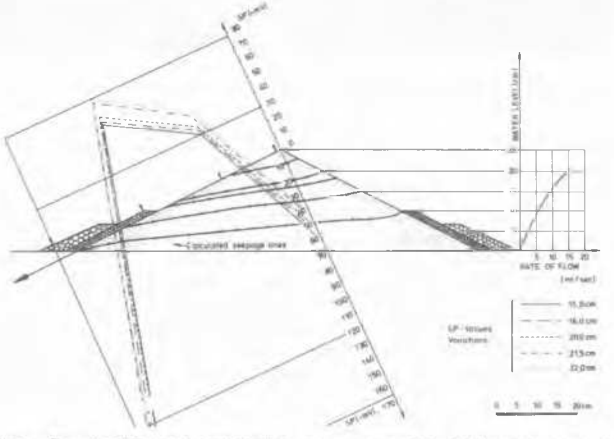

Fig. 8: Self-potentials at a small laboratory dam

tities deviate no more than 4 percent from the measured quantities (Merkler et al., 1984, Armbruster/Merkler, 1983). With the background of positive results in the small model, first experiments are started in a larger laboratory channel at the present time (Jul 84; sized 6.00 x 2.00 x 1.50 meters); in these tests both the geoelectric and the thermal fields occurring under seepage flow are to be measured. Furthermore, there is a model dam under construction at the home site of the BAW. With its height of 4 m and its length of 12 m, three-dimensional hydraulic fields can be generated. It is planned to derive the quantitative relationship between the hydraulic processes and the mating geoelectric and thermal fiels. This project will be jointly performed by four institutes.

CONCLUSIONS

Investigations presented and discussed here were conducted within the restrictions of an interdisciplinary application of geophysical and thermic measurements. Parallel measurements within identical dam sections on the one hand provided a chance of comparing both methods, and on the other hand, made it possible to determine leakages at the site.
It has been revealed that these methods fulfill the important prerequisites to localising leaking spots at dams. They can be applied in a space-covering and economically reasonable way without any aggravating disturbances to the dam.
As far as the problem of seepage water quantification, and the establishment of doubtless relationships between the hydraulic-potential field in the dam and the geoelectric- and thermal-potential fields in the dam and at the surface are concerned, additional model tests and in-situ experiments are needed. Based on the appreciated support by the Volkswagenwerk Foundation, by the Federal Ministry of Transport and by the Federal German Administration of Waterways and Navigation, these tests are presently under preparation, or have been started. Results of these additional experiments will be presented at some later time.

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