Repair and Upgrading of Dams

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Editors
Sam Johansson
Malte Cederström
Sensitive monitoring of embankment dams

Surveillance sensitive des barrages en remblai

J. Dornstädter, GTC Kappelmeyer GmbH
Haid-und-Neu-Straße 7, D-76131 Karlsruhe
Phone: +49 721 60008 Fax: +49 721 60009

Summary

The failure of embankment dams is very often caused by internal erosion processes. One of the major goals in the field of the embankment dams inspection is the detection and localization of seepage zones in an early stage of development. Further investigations are concerned with the determination of the pore flow velocity and the risk assessment of starting internal erosion processes. Therefore continuous monitoring with reliable indications of any changes in the dams parameters is essential.

The application of temperature measurements to examine earthfilled dams started in the 1950’s. During the last ten years this method has been developed further. In Germany temperature measurements inside dams are now a standard tool for the sensitive monitoring of embankments. Some case studies are presented and some new ideas regarding the continuous temperature monitoring of embankments and the in situ proof of transport of fines are lined out. Further, comparisons to other geophysical and geochemical methods are made.

Résumé


Figure 1: Left - Annual temperature-depth variation in a non-percolated dam. Right - Annual temperature variation in a non-percolated dam compared to the water temperature of a waterway. 1 - water temp.; 2, 3, 4 - temp. of embankment at 2 m, 6 m and 16 m respectively.

3. TEMPERATURE MEASURING TECHNIQUE

As stated earlier, temperature measurement is a sensitive tool for the detection of seepage. Beside the well known possibility of measuring temperatures within piezometers (Armbruster, 1983) a new method has been developed in 1990 by the author (Dornstädt, 1991). This new technique allows temperature measurements up to several meters of depths, at a high reliability and at low cost in regions where no piezometers exist.

A hollow pipe with a diameter of 22 mm consisting of several threaded sections is rammed into the ground. Depending on grain size distribution, compactation and dam construction 20 to 25 meter can be reached easily. Thereafter, a chain of temperature sensors is inserted into the pipe. The temperature sensors consisting of temperature dependent resistors are equally spaced (usually at 1m distance) and connected with an electric cable. Field tests and modeling results have shown, that after installation of the pipes into the ground, the equipment needs an average of about 15-20 minutes to recover thermal equilibrium with the ground temperature within the range of about ± 0.1 °C. In order to insure a reliable seepage detection a dense grid of temperature measurements has to be carried out. Usually a profile parallel to the dam axis with a lateral grid of 20 m is sufficient.

Due to the high sensitiveness of the measuring method, even leaks, which could not - or only unsatisfactorily - be detected with other common measuring methods (e.g., water level measurements in dam substance of middle to high permeability, geoelectrical measurements) can be detected and localized untimely. Therefore controlling surveys can be started on time and can be narrowed down on the actual affected area. Necessary repair works can be planned and done more systematically and the successful realization can be verified.
Absolute temperature within the embankment.

Temperature difference to a temperature - depth profile in a non-percolated dam.

Figure 3: Temperature distribution along a partly percolated earthfill dam with an impervious core. The anomalies at km 40.620 and at km 40.650 indicate seepage through the foundation. At km 40.700 the 'impervious' core is percolated.

Another example of seepage underneath the dam's body is the one from a section of an embankment dam. Measurements were performed in late fall when water temperatures were already decreasing. Figure 4 shows a temperature contour plot together with a schematic cross section of the dam. A clear underflow could be detected along the entire stretch. The abnormal high temperature values of the dam's body are due to the warm underflow during the summer when the water temperature was over 20 °C. Hence, there is no significant leak in the sealing system of the dam. Only the nonexistence of a sealing element in the foundation of the dam is responsible for the underflow. The safety of the dam could be endangered by the underflow if due to insufficient filter stability internal erosion processes or additional external stresses e.g. earthquakes occur. Therefore a careful monitoring of the dam and an evaluation of the risks mentioned above seems to be necessary.

The fourth example is a verification of a dam after introducing a grout curtain. Five years after the grouting measurements show new seepage zones in the dam. A temperature contour plot of the measurements would look very similar to the one in Figure 3. The most likely explanation why the grout curtain failed, is that grouting was done too late when the flow velocity was already too high for the selected injection material. To avoid faulty grouting a verification whether it was successful could be performed with temperature measurements after the grouting procedure as soon as the dam is in thermal equilibrium.
Only small temperature differences - no significant leak

The temperature drop of about 2°C in the upper part of joint 11 is indicating the development of a small fissure in sealing element 11.

Figure 5: Continuous monitoring of the sealing elements of a lock chamber with temperature measurements. The sealing joints are numbered from J1 to J12. In each of the two graphs the temperature changes within 12 hours are shown.

Figure 6 shows two curves with different temperature adaptation processes for different flow velocities as a function of time. By comparing measured curves to calculated ones, the pore velocity can be determined (Wegmann & Dornstädt, 1996). Compared to a long term temperature measurement over several months, which can be used also for the determination of the flow velocity, with the heat pulse method only a single measurement over a time interval of 6-12 hour is needed.

Figure 6: Determination of flow velocity using the heat pulse method. The two curves show the different temperature adaptation processes for different flow velocities as a function of time. By comparing measured to calculated curves the in situ percolation velocity can be determined.

1- flow velocity = 1*10⁴ m/s
2- flow velocity = 5*10⁶ m/s

5. ONGOING RESEARCH

Subject of ongoing research is the simplification of long-term temperature monitoring in constructions i.e., embankment dams and specially to develop an on line monitoring system
the surface (Günther et. al., 1977). Detection of temperature anomalies caused by seepage is restricted to locations where large amounts of seepage water flows directly to the dam surface. Therefore this method is restricted to applications where inspection work can be performed only by plane and small scale damages are negligible.

Subsurface temperatures can be measured either in standpipe piezometers or by using the method described in chapter 2. Temperature measurements in standpipes usually deliver good quality data. The only problem is that standpipe piezometers are only very locally extant and the building of such is rather expensive.

6.2 Electromagnetic measurements

One of the most common electromagnetic applications in civil engineering and applied geophysics is the georadar. The use of the instrument is very simple and straight forward and the soil suffers no impact at all. For dam inspection however, the use of georadar is not ideal because the instrument delivers only reliable data up to a couple of meters depth. The georadar has a penetration depth of more than two meters, but data from greater depths are difficult to interpret, and especially in heterogeneous soil prone to misinterpretation.

6.3 Geoelectrical measurements

A number of geoelectrical methods such as spontaneous potential measurements, geoelectric profiling and Mise-à-la-masse are quite common in applied geophysics and dam investigations. They constitute excellent methods to determine the geologic structure of a dam and with additional material parameters of the dam, not always available, they can be used for leak detection. The methods are based on the interpretation of the electrical resistivity of the dam. A leak in the dam will have an influence on the electrical resistivity, but a number of other material parameters as well. Hence, without the exact knowledge of the material parameters data interpretation can be very ambiguous. In the past measurements lead sometimes to misinterpretations and unsatisfactory results. Nevertheless, recent experiments showed promising results and in near future geoelectrical methods might become a more reliable tool for the investigation of embankment dams.

6.4 Geochemical tracer methods

For the application of fluorescence, salt or radioactive tracers permissions of environmental authorities are unavoidable and sometimes the injection of tracers at a well defined place is impossible. To detect the arrival of tracers downstream sampling points are needed. Normally piezometer standpipes are used as sampling point. The flow velocity can be estimated accurately but the lateral extension can not be determined. The number of piezometers is limited and allows therefore only a confined resolution. The method is in general not easily applicable.