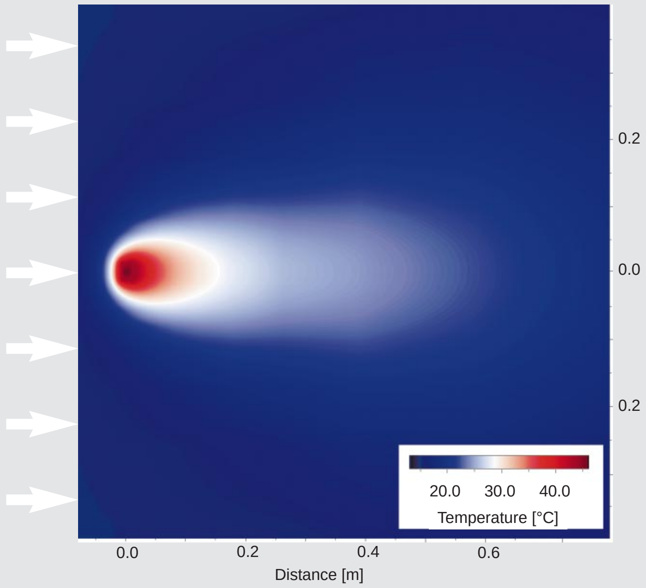
IN SITU MEASUREMENT OF SEEPAGE FLOW VELOCITY

Heat Pulse Method · Internal erosion is one of the most frequent causes of failure and deterioration of embankment dams. Internal erosion is controlled by construction properties, e.g. filter and drain design, grain and pore geometry, and by the hydrodynamic conditions within the dam itself. Construction properties are usually well known, but in most cases very poor information on the actual local hydrodynamic situation inside the embankment is available. Hydrodynamic parameters vary strongly from point to point due to local inhomogeneities like construction defects and weaknesses and the local deformation and stress conditions. The most critical hydrodynamic parameter for material transportation phenomena by seeping water is the local pore velocity. Regions with high pore velocities are most likely prone to internal erosion.

Up to now, critical pore velocities for the onset of internal erosion have been determined theoretically by using particle size distributions and measured hydraulic gradients. Both parameters are usually sampled over a rather large area and therefore do not take effects of the above mentioned inhomogeneities into account. Thus the applicability of theoretically calculated pore velocities is rather limited and in most cases questionable.



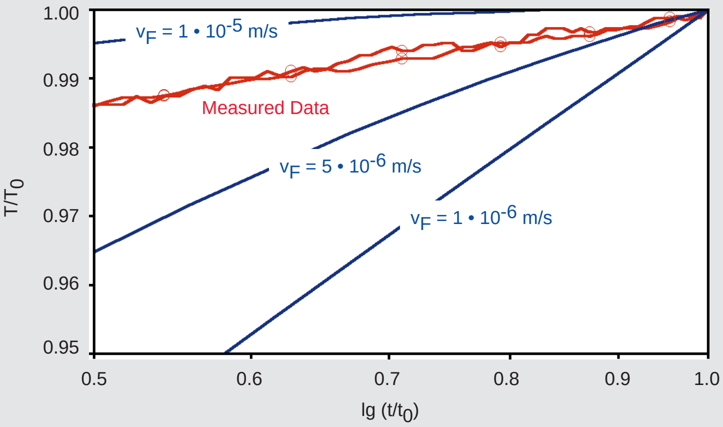
Horizontal plane view of a numerically calculated temperature field in the vicinity of a heat source after 12 hours of heating. The vertical line source is located at the origin of the coordinate system and has a source strength of 150 W/m. The surrounding soil has a porosity of 10% and a heat conductivity of 1.2 W/m/K. On the left hand side water with an initial temperature of 17.3°C enters the model area with a filter velocity of 10^{-5} *m/s.*

During the last years GTC developed a patented temperature based method – the heat pulse method (HPM) – for measuring the local pore velocity of seeping water in situ. With the HPM it is possible to determine pore velocities in the range from 10^{-7} m/s up to 10^{-3} m/s. Thus, allowing the in situ determination of this important hydrodynamical parameter for the first time.

Seepage flow is inevitably coupled with an advective heat transport (forced convection) that exceeds the conductive part already at flow velocities as small as 10^{-7} m/s (~ 1 cm/day). With a line heat source, a well defined heat disturbance is generated within the dam. Depending on the local heat conductivity and the flow velocity of the percolating fluid a specific temperature increase over time within the source will be obtained. By measuring this temperature increase as a function of time and comparing it to numerically calculated temperature-time curves the velocity of the percolating fluid can be determined.

To bring the line heat source and the temperature sensors into the embankment they are inserted in a hollow pipe with a small diameter that has been rammed into the dam before (Pat.No.: DE 41 27 646). Depending on grain size distribution, compactivity and dam construction 25 to 30 meter can be reached easily.

After the heat source is switched on the temperature within the heat source rises quickly and tends after a considerable time towards some asymptotic value – the equilibrium temperature. At this point as much energy as is produced within the heat source is transported away by the material surrounding the source. If no fluid flow in the vicinity of the probe exists the equilibrium temperature is rather high and will only be reached after a long time. With increasing fluid flow velocity the energy transport from the heat source will become more and more efficient, thereby lowering the equilibrium temperature and shortening the time necessary to reach it. By switching off the heat source a similar phenomena can be observed. With no fluid flow the cooling process is slow and the undisturbed temperature is only reached after a long time. High flow rates lead to a much faster adaptation to the undisturbed temperature.



Comparison between calculated temperature-time curves (blue lines) and temperatures measured in the ground in 10 meters depth (red lines). Temperatures are normalized with the finally reached temperature T_0 and are plotted versus time normalized with total heating time t_0. Note the logarithmic scale of the abscissa. Temperature-time curves for three different filter velocities v_F have been calculated. The measured temperature-time curves indicate a filter velocity of 8×10^{-6} m/s.

Both temperature adaptation processes (heating and relaxation) can be modelled numerically for a variety of material parameters (heat conductivity, heat capacity), flow velocities and source strengths. By comparing the measured temperature-time curves to the calculated ones it is then possible to determine the actual pore velocity in the vicinity of the probe. The penetration depth of the HPM depends on heating time, source strength and pore velocity. With a heating power of several tens to several hundreds of W/m and a heating time interval of 6 to 12 hours a depth of investigation of about 0.5 m can be reached with this method.

Beside soundings the HPM can also be applied by fibre optical temperature measuring systems using a hybrid fibre optical cable (Pat.No.: DE 198 25 500). By injecting liquid CO2 into the hollow pipe of a temperature sounding the HPM can be inverted. This procedure is called Frost-Pulse-Method (Patent Nr. DE 101 04 534) and leads to similar results as HPM.

Installation of a hybrid fibre optical cable in the double layered asphaltic facing of the Ohratalsperre, a rockfill dam in Thuringia, Germany, for leakage detction