Fluid flow in highly compacted clays – laborative and numerical simulation

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Abstract

The fluid advancement in unsaturated highly compacted clay materials is determined by the hydration and swelling behaviour of the clay minerals as well as by the resulting capillary and permeability behaviour of the clay material.

Small-scale, technical experiments were performed in connection with the development of moisture detecting cable sensors for the investigation of fluid advancement within several compacted clay material /Kupfer et al., 2004/. Based on these investigations the processes of saturation and flow in compacted clays were analyzed and empirical approaches for the modeling of the main processes were developed. The resulting modeling concept allows the prediction of the fluid flow within clay based sealings and barriers in shafts and drifts.

Small-scale, technical experiments

In co-operation with the Department of Mining and Special civil engineering of the Freiberg University of Mining and Technology bentonite filled columns of a diameter up to 800 mm and a length up to 2000 mm were hydraulically tested in vertical direction. Figure 1 schematically shows the test configuration.

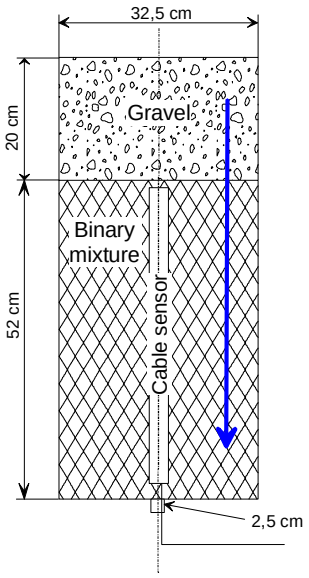

Fig. 1 Test configuration

The hydraulic tests were performed on bricks, granules and a binary mixture (pillows and granules) produced from MX-80 as well as Calcigel. Water and NaCl-solution were used as flow fluid. The clay materials were filled in with a defined clay bulk density. There was no confinement pressure applied to the columns. The hydraulic tests were performed at maximum fluid pressures of 10 MPa and a duration of maximal 150 days. Rate of flow, pressure, temperature and cumulative fluid volume were measured and recorded during the whole test. During some tests the swelling pressure were additionally recorded at different levels within the bentonite bodies. After testing the samples were dismanteled and the moisture distributions were determined within the clay bodies.

Process analysis and modelling

The fluid advancement within compacted clays is determined by:

- changes in the effective phase permeabilities as a result of the pore saturation,
- changes in the density / porosity of clay materials due to:
  - swelling of clay minerals – redistribution of the pore space,
  - secondary compaction and / or decompaction (axial displacement) of the clay body – changes in density,

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– reaching of an equilibrium between the moisture content or the pore saturation with fluid and the relative atmospheric humidity in the atmosphere or the pore gas.

The permeability of the saturated clay material is the highest possible permeability. Therefore, the flow within the saturated clay is determining the long-term flow within the whole sealing barrier.

Based on the knowledge about the properties of the used clay materials and test parameters as well as results from the test rebuilding a modelling concept was developed considering following processes:

– two phase flow in the unsaturated pore space,
– single phase flow in the saturated pore space,
– changes in the intrinsic permeability of clay materials due to swelling and consequently modifications of the pore structure ($n_{mobil} \rightarrow n_{immobil}$),
– changes in the intrinsic permeability caused by the secondary compaction and decompaction and consequently changes in density of the clay materials.

This modelling concept was taken to calibrate the model using the measured moisture distribution in the performed tests by the variation of the intrinsic permeability. Figure 2 shows an example for the calibration between the model and test results for a test with Calcigel (binary mixture) and water. As result of this it can be demonstrated that the developed modelling concept is capable to simulate flow and saturation processes in clay materials. Thus, it is possible to predict the moisture advancement in large-scale, clay based sealing systems by numerical modelling.

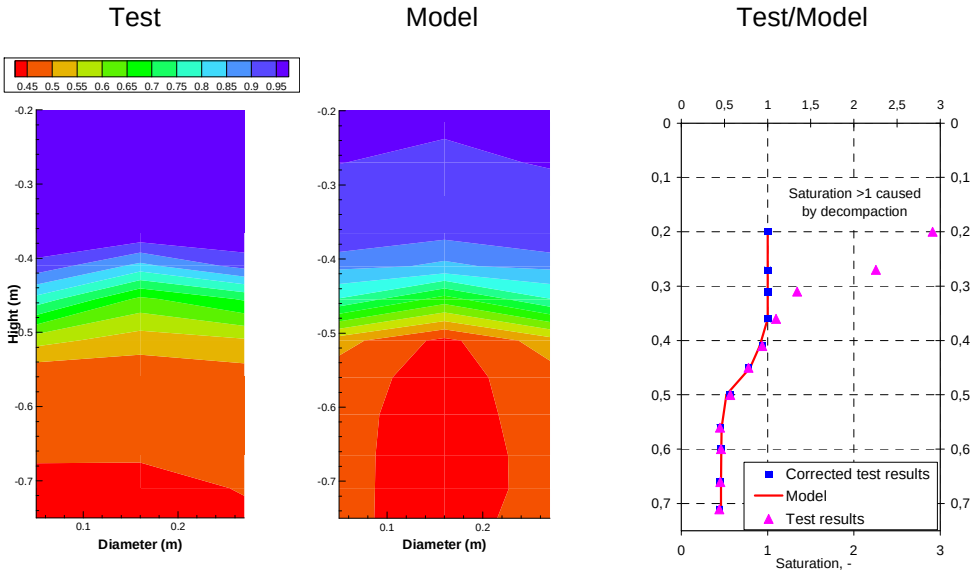

Fig. 2: Model results (clay material: calcigel, binary mixture; fluid: water)

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Kupfer et al., 2004: Entwicklung eines Messsystems zur Wassergehaltsbestimmung von Bentonit in salinarer Umgebung. BMBF-Förderkennzeichen: 02C0800, 2004