Flow Through Earth Embankments And Dams - A Comparison Of Numerical Approaches

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Abstract

Dams, levees, and dikes play a critical role in flood prevention. There can be simple earthen embankments or engineered designs with low permeable cores and/or drainage facilities. Unlike cement dams there is flow of water in earthen embankments. The latter are unsaturated in the upper part and saturated below. The flow of water through earth dams is of high practical importance for the stability of the structure in case of rising water levels in the stream or upstream reservoir. Of particular interest is the location of the water table separating the saturated from the unsaturated zone, and especially the position, where the water table meets the downstream surface. Rising outflow on that dam surface increases the risk of dam break. Models are an important tool for the estimation of the outflow and thus can indicate the risk. Models can be important already in the design phase of a dam project. They can also be used for real-time simulations using the varying water table as input parameter.

The problem of flow through an earth dam is a classical topic for modelling of porous media flow. Starting in the 19th century mathematicians and engineers developed analytical solutions for idealised 2D cross-sections concerning the geometry and geology. For the water table inside the embankment Di Nucci (2015) derived a 1D solution. For the construction of flow-nets there are graphical methods proposed. However, for complex real-world cases numerical methods are of higher importance. They have the advantage that specific factors and conditions, as anisotropy and inhomogeneity, can be taken into account, not only in 2D but also in 3D. Probably all types of numerical approaches have been applied: finite differences, finite volumes, finite elements, boundary elements and, most recently, natural elements.

Here I demonstrate the application of COMSOL Multiphysics using two approaches: fixed geometry and deformed geometry The former one takes the entire cross-section as model domain, the second restricts the domain to the saturated part. In the fixed geometry the parameter of hydraulic conductivity is modified to account for unsaturated conditions. In the deformed geometry the position of the water table is a free boundary that is a-priori unknown and has to be determined. Results for both cross-sections are depicted in the figures for flow from the high water table on the left to the right.

Figure 1 shows the result for a classical set-up obtained by the deformed geometry approach. The colormap represents the pressure head, increasing from atmospheric zero at the top to the bottom. Streamlines illustrate the flow direction and magnitude. The cyan line near the water table represents the di Nucci 1D solution.

Similarly Figure 2 depicts the flow through a realistic design with a core and drainage as output from a fixed geometry model. The lower conductivity of the core is the core for the buckles of the water table interface. Note that in this scenario the water table is almost touching the downstream surface of the embankment, which may change for altered core conductivity or drainage length.

Figures used in the abstract

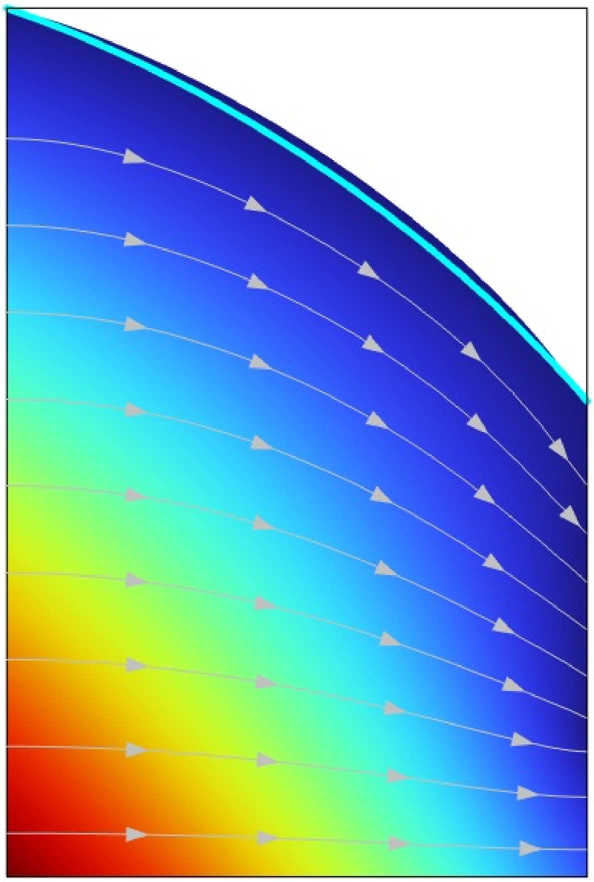

Figure 1 : Classical set-up, numerical result and 1D analytical solution

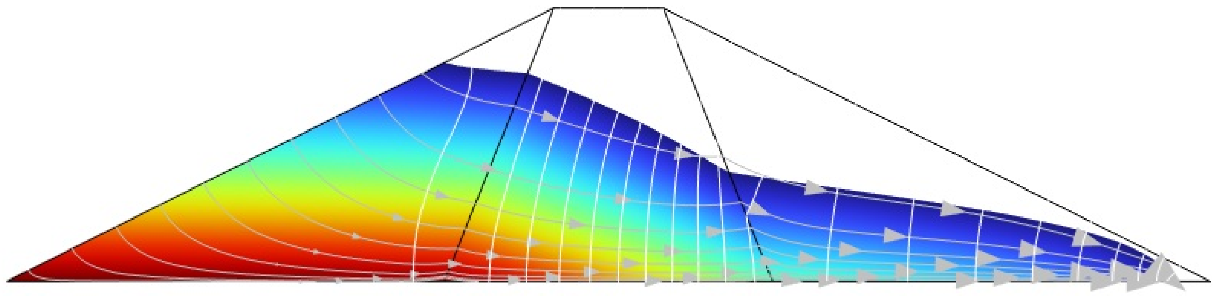

Figure 2 : Realistic design with core and drainage, numerical result