

Earth dam – steady state seepage analysis

Program: FEM – Water Flow

File: Demo_manual_32.gmk

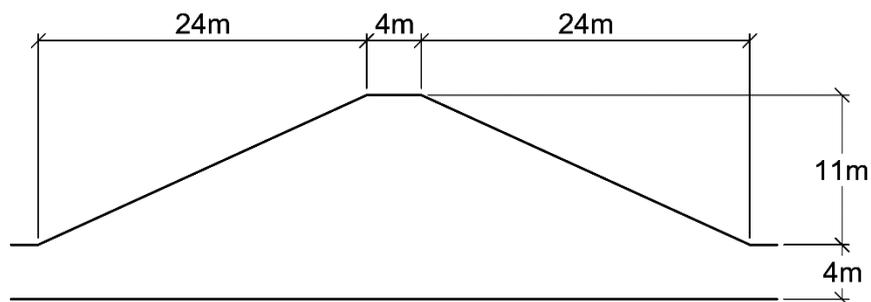
Introduction

This example illustrates an application of the GEO5 FEM module – Water Flow to analyze seepage through a homogeneous earth dam. The objective is to locate a ground water table (phreatic line) within the dam. This problem falls into the category of an unconfined water flow. The task requires specifying the dam geometry, material properties of the soil and hydraulic boundary conditions. The analysis provides the location of ground water table within the dam body, the distribution of pore pressures below the ground water table and the distribution of water flow velocities. Above the ground water table, the program also allows for plotting the negative pore pressures (suction). A total discharge through permeable boundaries is also provided.

Task input

The dam height is set equal to 11 m, the projected length along both the upstream and downstream face is assumed equal to 24 m and the dam crest is set equal to 4 m. Impermeable subsoil is found 4 m below the terrain surface and the water table at the downstream face is found 1 m below the terrain surface. The soil within the entire domain is considered homogeneous and isotropic with the same hydraulic properties in both the vertical and horizontal direction. The chosen soil was classified as sandy silt based on the USDA classification system.

The task is to determine the location of phreatic line by considering the water table in the reservoir 2 m, 9 m, and 10.8 m above the terrain surface, respectively. Apart from that, we should also check whether the water discharge at the foot of the downstream face will take place.



Transversal cut through a homogeneous earth dam – geometrical details

Analysis – entering input data

The basic setting of the project, geometry of the computational model and material parameters are specified in the topology regime [Topo]. Therein, also the finite element mesh is generated. The hydraulic boundary conditions are introduced subsequently in individual calculation stages [1], [2] and [3].

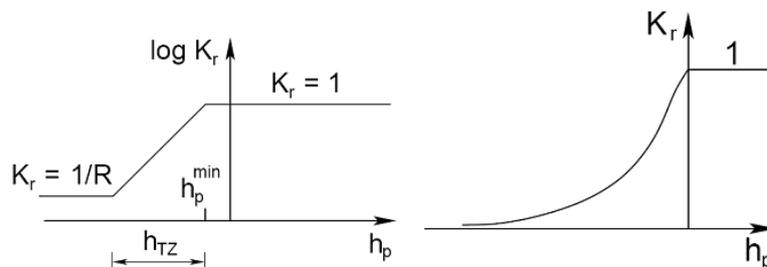
Material

The required material parameters of the soil should be provided by laboratory measurements. However, in case of our illustrative example such measurements were not available. Therefore, we adopted approximate values corresponding to sandy silt.

If choosing the van Genuchten model the typical values of model parameters corresponding to sandy silt are: $k_{x,sat} = k_{z,sat} = 1.06 \text{ m/day}$, $\alpha = 7.5$ and $n = 1.89$. The associated void ratio for this type of soil is: $e_0 = 0.7$. For further details, see the program help¹.

Material parameters are specified in the “Edit soil parameters” form

Note: The soil permeability in the unsaturated or partially saturated soil above the phreatic line is expressed as a multiple of the coefficient of permeability in a fully saturated soil K_{sat} and the coefficient of relative permeability K_r . The latter follows from the transition zone model. This model specifies how the coefficient of relative permeability K_r evolves with the pressure head (h_p) (pore pressure). Such dependency is schematically plotted for the Log-linear and van Genuchten models in the subsequent figure.



Evolution of the coefficient of relative permeability as a function of pressure head for Log-linear and van Genuchten models of transition zone

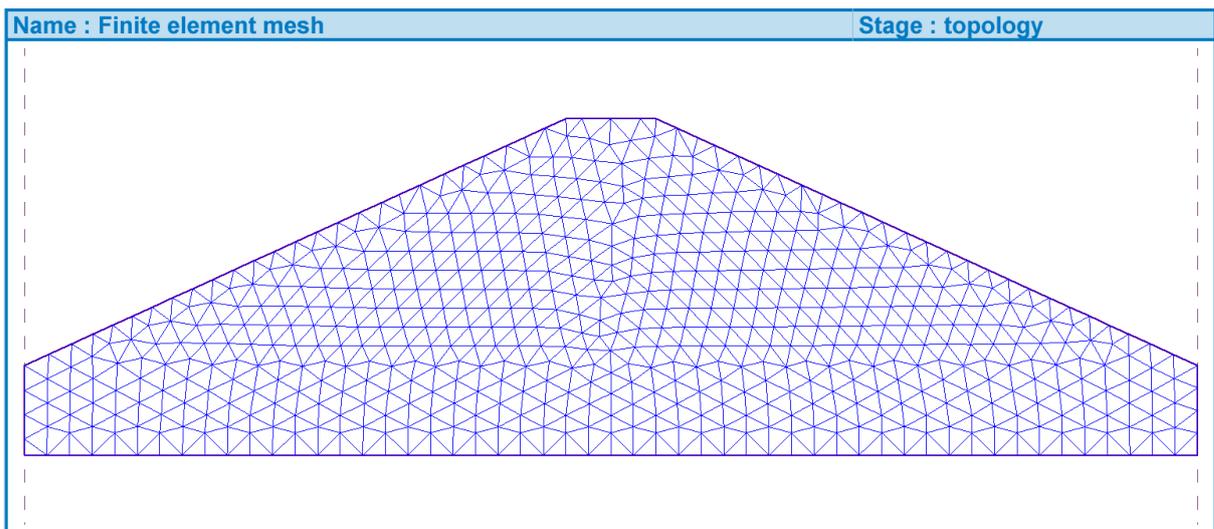
¹ <http://www.finesoftware.eu/help/geo5/en/material-models-in-flow-analysis-01/>

It is evident that for a positive pressure head – thus for the region below the phreatic line – the coefficient of relative permeability is always constant and equal to 1. The transition zone model thus does not influence the water flow below the phreatic line in the fully saturated zone. In the region with a negative pressure head (above the phreatic line) the degree of saturation decreases. This suggests the reduction of actual hydraulic permeability as only the saturated part of the pores contributes to the water flow.

Finite element mesh

The analysis adopts 3-node triangular elements as a default option assumed in the GEO5 FEM – Water flow program. Regarding the model dimension elements with their average edge length of 1 m appears sufficient. Given the present geometry and homogeneous soil requires no particular mesh refinement.

Note: The mesh refinement becomes important once considering more detailed geometrical model containing relatively small structural elements, e.g. sealing curtain or drains. The Advanced input option would further allow for the application of hybrid mesh (combination of triangular and quadrilateral mesh).



Finite element mesh

Calculation stage No. 1 – water table at 2 m above the terrain on upstream face

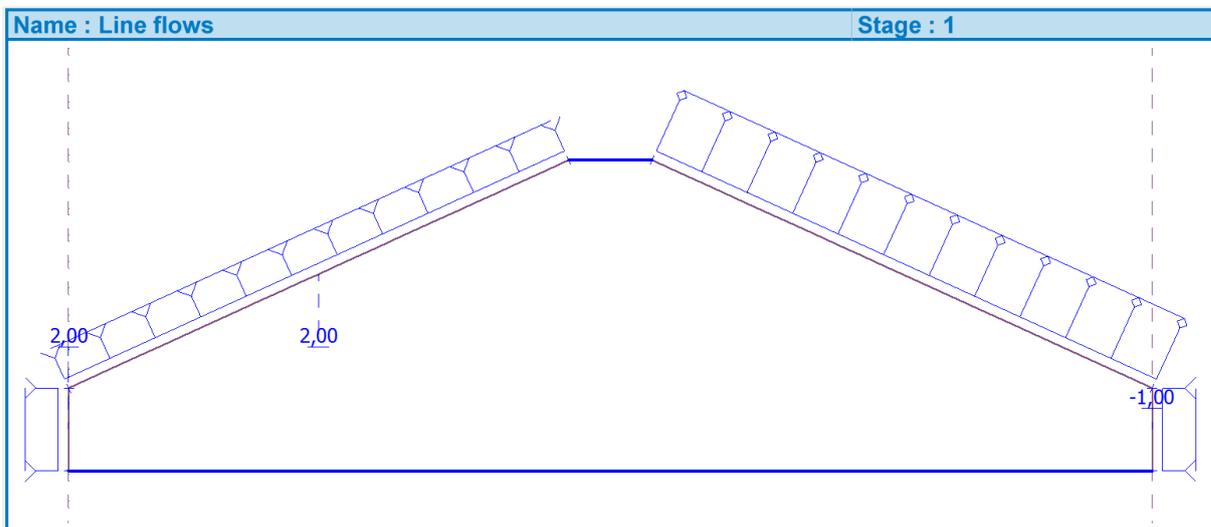
At each calculation, prior to running the analysis, it is necessary to input the hydraulic boundary conditions. These boundary conditions are in the program denoted as point or line flow.

Note: By default, all external boundaries are considered as impermeable. The calculation – the finite element analysis – thus requires prescribing pore pressures either along a portion of the external boundary (lines or points on the external boundary) or at points inside the domain.

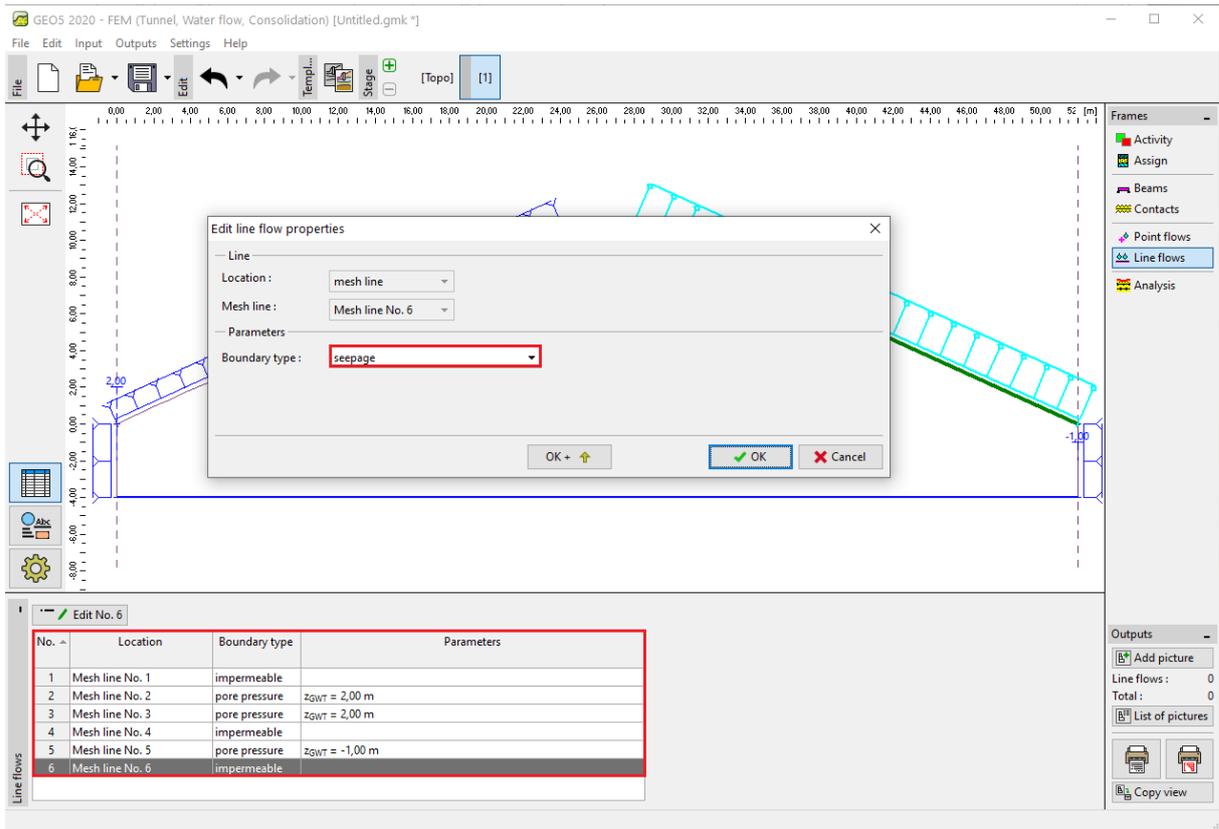
Boundary conditions - stage No. 1

In the calculation stage No. 1 we define the following boundary conditions

- I. On upstream face we prescribe the *pore pressure* type of boundary condition with the help of water table height set equal to 2 m above the terrain surface. Point out that along the part of the boundary above the water table, an impermeable surface is considered. Suction along the line, where the pore pressure boundary condition is specified, is thus not prescribed specifically but rather determined through the analysis.
- II. A *seepage* type of boundary condition is prescribed on downstream face.
- III. On the vertical surface at the foot of downstream face we define in this example the *pore pressure* type of boundary condition by locating the ground water table at a depth of -1 m. This condition suggests a confined water flow with a water table at this particular level.
- IV. At the bottom boundary of the domain and along the dam crest we maintain the *impermeable* type of boundary conditions. This boundary condition suggests no flow across the boundary.



Boundary conditions (flow – lines) in the calculation stage No. 1

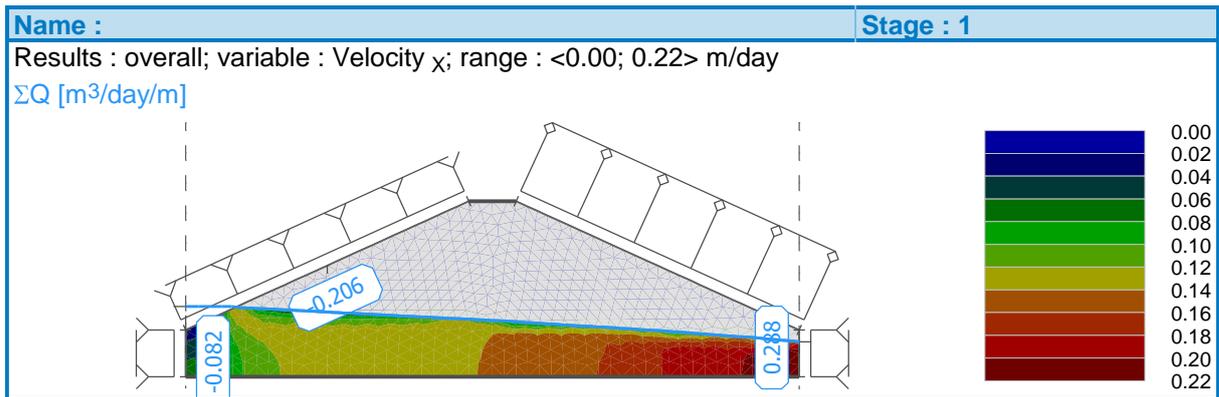


Specification of Line Flows (boundary conditions)

Note: The seepage type of boundary condition is used along segments of external boundaries where it is not known a priori whether the boundary will be located above or below the ground water table. The seepage boundary condition triggers an automatic search for a discharge (exit) point (a point on the seepage surface crossed by the phreatic line) and sets appropriate boundary conditions below (zero pore pressure) and above (zero flux) this point. This condition should be considered only at a boundary where a free water outflow may take place.

Results – stage No. 1

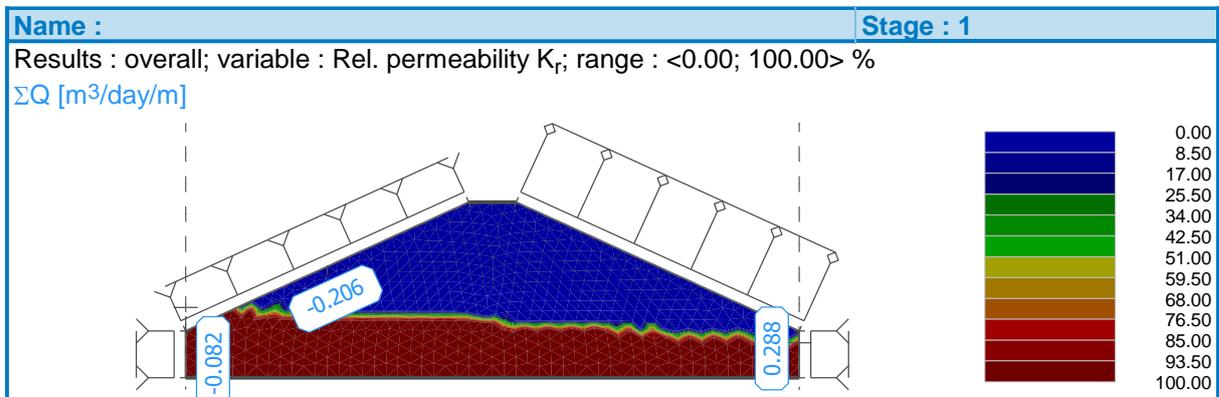
Setting the Detailed results option (Topo->Settings) allows us to visualize below the ground water table the distribution of pore pressure, horizontal and vertical components of the water flow velocity vector and the overall hydraulic height.



Distribution of horizontal component of water flow velocity

The program makes also possible to display the total flux across particular segments where the water flow takes place. A negative sign represents inflow of water into the model whereas a positive sign corresponds to flow of water out of the domain. It is clear from the figure that water enters the domain on upstream face and exits the domain below the foot of the dam only. The flux values are taken per 1 m run of the dam measured in the out of plane direction.

The figure below clearly shows that above the phreatic line the coefficient of relative permeability rapidly decreases. Most of the flow thus takes place below the phreatic line, so that in the fully saturated zone.

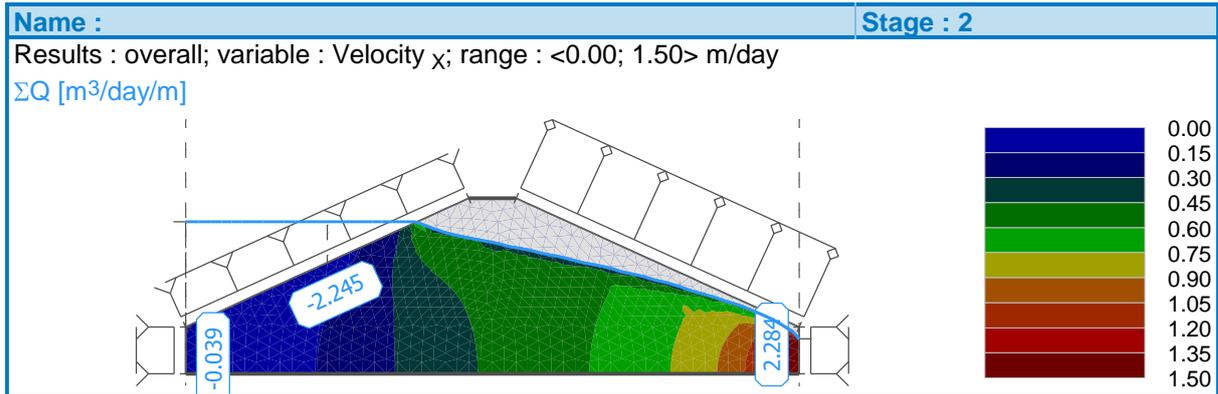


Distribution of coefficient of relative permeability

Calculation stage No. 2 – water table at 9 m above the terrain on upstream face

In this calculation stage we shall consider the water table in the reservoir at 9 m above the terrain on upstream face. The types of boundary conditions remain the same. Only the prescribed pressure head on the upstream face is changed (the vertical and inclined boundary on the left hand side of the model). The water table on these boundaries is raised from 2 to 9 m.

Upon performing the steady state flow analysis with the modified boundary conditions we arrive at rather different distributions of all relevant variables. By inspecting the figure below we notice that the phreatic line approaches the downstream face. Nevertheless, there is still no discharge of water at the seepage surface and all water flows out of the domain below the terrain surface.

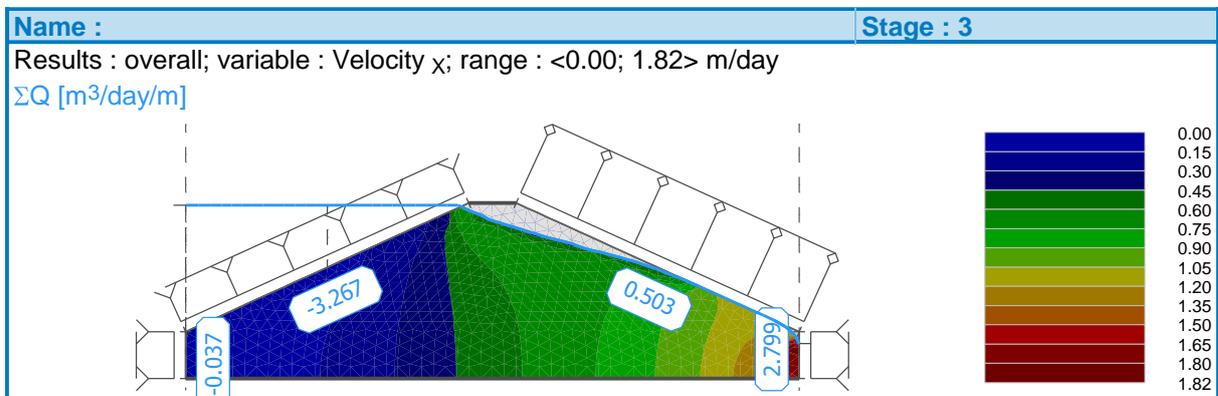


Distribution of horizontal component of velocity in stage No. 2

Calculation stage No. 3 – water table at 10.8 m above the terrain on upstream face

In this calculation stage the water table on the upstream face is raised by another 1.5m to reach the total height in the reservoir of 10.8 m. Again, only the two boundaries on the left were affected by adjusting the boundary conditions on the upstream face.

The analysis results show that in this case the phreatic line already touches the seepage surface and that there is a free water outflow along the downstream face. This is supported by a nonzero value of the water flux attached to the seepage surface. Point out that in case of steady state water flow the total amount of water entering the domain should be the same the amount of water leaving the domain.



Distribution of horizontal component of velocity in stage No. 3

Conclusion

Three analyses were carried to show the location and shape of the phreatic line for the level of water in reservoir at 2 m, 9 m and 10.8 m. For the first two cases the outflow takes place only bellow the terrain surface. When the water in reservoir is raised to 10.8 m the phreatic line touches the downstream face and the surface outflow occurs.

Note: The analysis also shows that the shape and position of phreatic line depends solely on the actual boundary conditions, geometry and material properties of soils. Unlike stress or transient flow

analysis the steady state flow analysis does not depend on initial conditions. Individual calculation stages do not follow each other and can be performed independently.