MUSKAT PROBLEM

This document verifies that groundwater flow principles are correctly implemented in PLAXIS. Unconfined groundwater flow within a homogeneous earth dam underlain by an impervious base is studied (Figure 1). Such a problem is known as the 'Muskat problem', in which the free phreatic surface and the seepage face are unknown, leading to a set of nonlinear equations.

Used version:

- PLAXIS 2D - Version 2015.02
- PLAXIS 3D - Anniversary edition (AE.01)

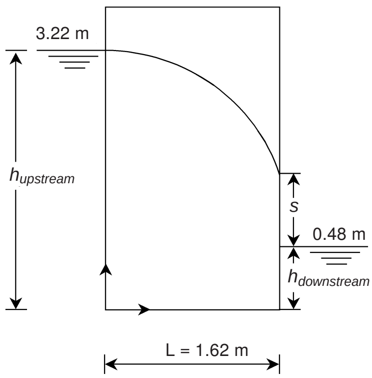

Figure 1 Dam with vertical faces (Muskat problem)

Geometry: As illustrated in Figure 1, the upstream head is set equal to 3.22 m while the downstream head equals 0.48 m. Dam width *L* equals 1.62 m. The seepage face is denoted as *s*. In PLAXIS 2D, a plane strain model is used with 15-noded triangular elements. The bottom groundwater flow boundary is set to closed while every other is set to be open (seepage). The considered model geometry and the adopted groundwater flow boundary conditions are presented in Figure 2.

In PLAXIS 3D, the same model as described above is used and it is extended by 1 m in the y-direction. Both groundwater flow boundaries in y-direction are set to be closed. Figure 3 illustrates the model geometry and the adopted groundwater flow boundary conditions.

In addition to the global model conditions, an inclined water level is used to generate the hydraulic head of 3.22 at the left side and 0.48m at the right side. The internal part of this water level has no meaning and it will be overwritten by the results of the groundwater flow analysis.

Materials: The soil is modeled as *Drained*, *Linear elastic*. The *Hypres* hydraulic model (*Van Genuchten*) is used to model the unsaturated flow conditions above the phreatic level. The *Top soil* option is selected, assuming *Coarse* soil type. Permeability equals 1 m/day in every direction. The adopted material parameters are:

Soil: Linear elastic Drained E' = 1 kN/m^2 k = 1 m/day

Meshing: In PLAXIS 2D, the *Fine* option is selected for the *Element distribution*. The

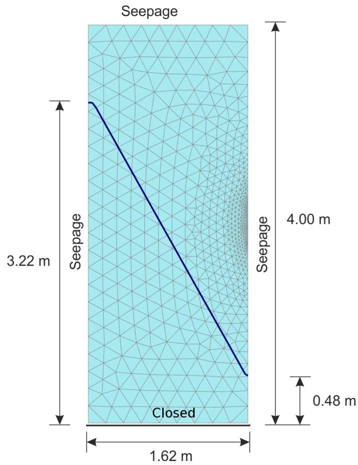

Figure 2 Model geometry, generated mesh and groundwater flow boundary conditions (PLAXIS 2D)

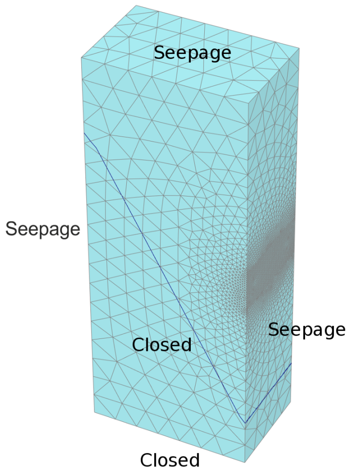

Figure 3 Model geometry, generated mesh and groundwater flow boundary conditions (PLAXIS 3D)

right model boundary is refined around the expected height of the seepage face. The mesh is locally refined by a *Coarseness factor* of 0.075. The generated mesh is illustrated in Figure 2.

In PLAXIS 3D, the *Medium* option is selected for the *Element distribution* while the mesh is locally refined by a *Coarseness factor* of 0.1 at the right model boundary, as described above. The generated mesh is illustrated in Figure 3.

Calculations: The calculations are performed using the *Flow only* calculation type in the Initial Phase.

Output: The groundwater flow field and the computed phreatic line are presented in Figure 4 for PLAXIS 2D. The active pore pressures and the seepage face at the end of the analysis are illustrated as well. In Figure 5 the corresponding results are plot for PLAXIS 3D.

Verification: The solution of the Muskat equation for the seepage face *s* is compared

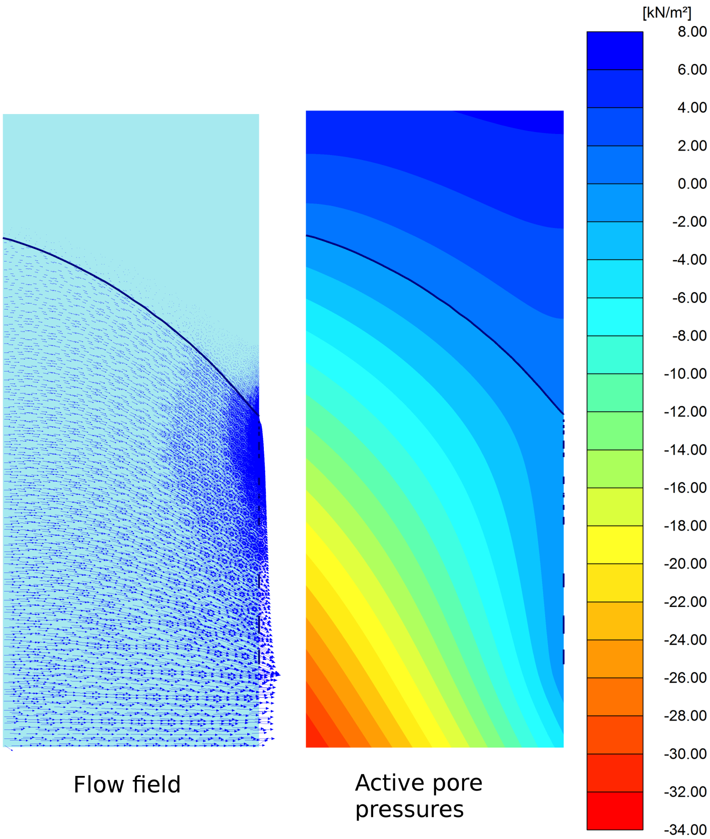

Figure 4 Flow field and active pore pressures obtained in PLAXIS 2D

with the non-linear solution of PLAXIS. With respect to the Muskat equation, graphs which describe the relationship between the geometry of the structure, the heads and the length of the seepage face s have been presented by many researchers. Herewith, the graph presented in Figure 6 is used (Kang-Kun & Leap, 1997).

The calculation results for the seepage surface s obtained from Figure 6 and PLAXIS are compared in Table 1. It is concluded that PLAXIS approaches well the analytical formulation.

Table 1 Comparison between analytical solution and PLAXIS results

Seepage face s (m)			Error	
Muskat	PLAXIS 2D	PLAXIS 3D	PLAXIS 2D	PLAXIS 3D
1.55	1.611	1.609	+ 4.2 %	+ 4.1 %

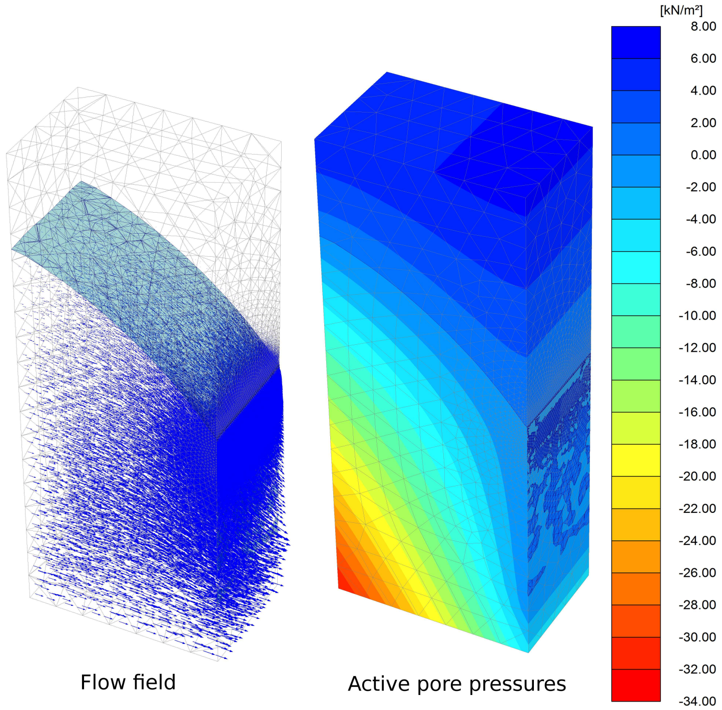

Figure 5 Flow field and active pore pressures obtained in PLAXIS 3D

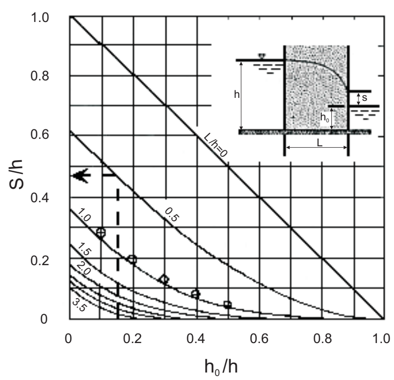

Figure 6 Graph for Muskat problem (Kang-Kun & Leap, 1997)

REFERENCES

[1] Kang-Kun, L., Leap, I.D. (1997). Simulation of a free-surface and seepage face using boundary-fitted coordinate system method. Journal of Hydrology, 196, 297–309.