GeoStudio Example File
Verification – Kisch clay liner problem

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Introduction

A common technique for reducing the seepage loss from a reservoir is to line the reservoir with a clay blanket. Alternately, a compacted cap layer near the ground surface can limit infiltration into underlying waste material. If the waste is coarser in nature relative to the cap material, a capillary break phenomenon often results.

The problem is challenging to analyze because of the sharp contrast in the saturated hydraulic conductivity of the compacted material and that of the underlying material. As well, the underlying material is often sandy, with a very steep hydraulic conductivity function that requires a robust, iterative numerical solution.

The objective of this example is to compare the computed steady-state water transfer solutions completed in SEEP/W for fully unsaturated flow with a known solution. In addition, it will be shown that flow across a capillary break depends on the pore-water pressure profile established below the break location.

Background

Kisch (1959) studied the issues surrounding the leakage from clay-blanketed reservoirs, where the ground underneath the liner is unsaturated. Based on semi-analytical solutions, he concluded that the steady-state pore-water pressure profile looks something like in Figure 1. The pore-water pressures are negative throughout the profile except at the top and bottom boundaries; that is, the seepage flow is through unsaturated soil. This being the case, the flow regime is controlled by the contrasting hydraulic conductivity functions for the two soils.

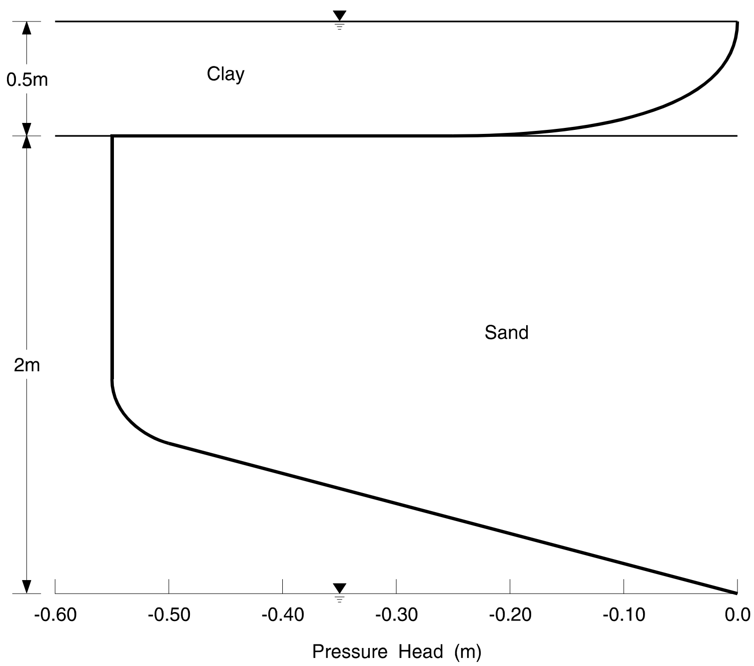

Figure 1. Conceptual solution to the Kisch (1959) problem.

Numerical Simulation

The one-dimensional model domain is shown in Figure 2. The one-dimensional line is 2.5 m in height, with a compacted clay material of 0.5 m thickness overlying a 2 m layer of coarse sand. Two analyses will be conducted in this example. In the first analysis, the top and bottom of the model are set to have a zero pressure boundary condition. At this surface, this implied a thin film of free water which can infiltrate at a rate controlled by the soil properties. At the base, the water table location is implied. In the second analysis, the bottom boundary condition is replaced with a unit gradient condition, which implies the specific location of the water table is not known. This may be the case for percolation through a cap over waste.

Kisch (1959) developed hydraulic conductivity functions for a Yalo Light Clay and for a Superstition Sand. The saturated conductivity of the clay is about 1x10^{-7} m/sec and just over 2 orders of magnitude less than that of the sand at 1.1x10^{-5} m/sec. The resulting functions based on the information given by Kisch (1959) are shown in Figure 3.

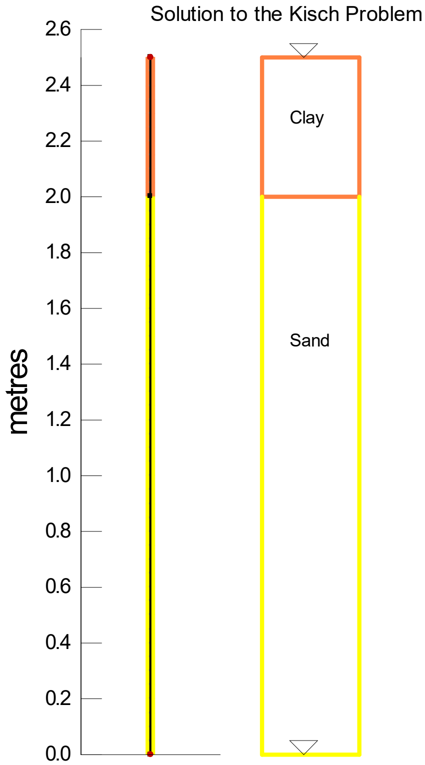

Figure 2. Problem configuration.

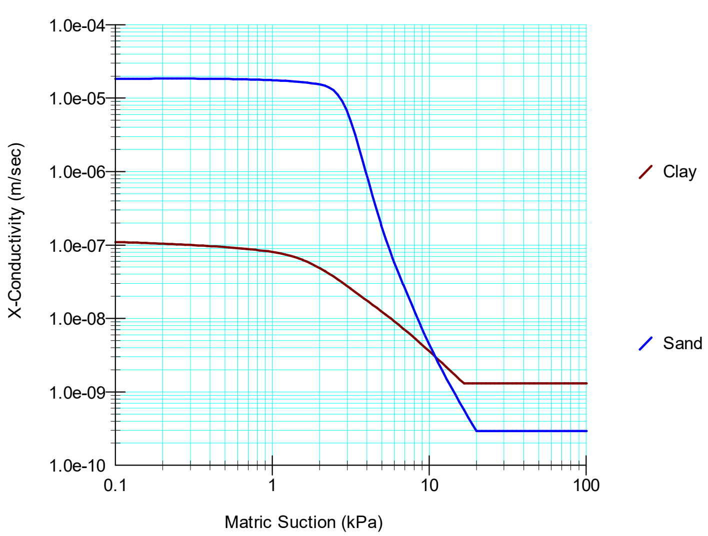

Figure 3. Hydraulic conductivity functions.

The volumetric water content functions were estimated using the internal estimation algorithms for clay and sand. The saturated water content for the clay and sand functions were set to 0.5 and 0.35, respectively (Figure 4). The global element mesh size was set to 0.05 m.

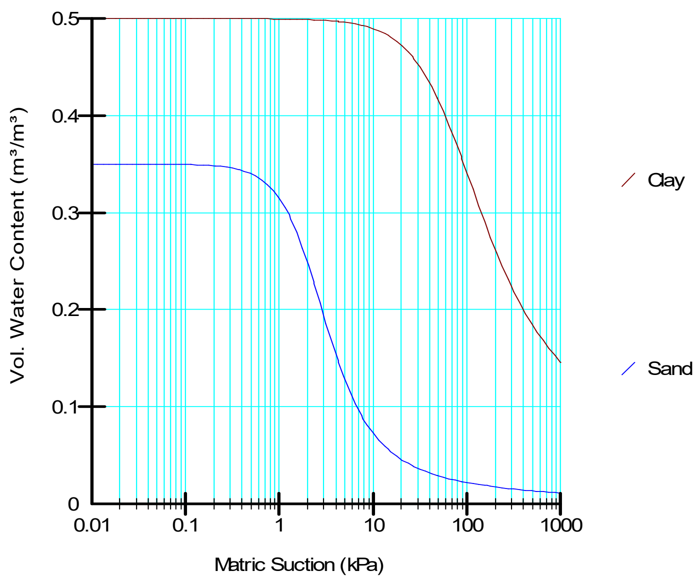

Figure 4. Volumetric water content functions.

Results and Discussion

Figure 5 shows the SEEP/W computed pore-pressure profile for the first analysis, where the flow system is assumed to be a clay liner at the base of a pond that is some elevation above a water table. As expected, it has the same form as presented by Kisch (1959). At the bottom of the profile, the pore-water pressure distribution is negatively hydrostatic; that is, it is a straight line at an angle. This represents, in part, the tension-saturated capillary zone. From the end of the hydrostatic portion, the pore-water pressure profile bends and becomes vertical. When the pore-water pressure profile is a constant vertical line, it means the vertical gradient (i) in this zone is a constant 1.

The vertical portion of the pore-water pressure profile is at -5.22 kPa. Referring back to Figure 3, the hydraulic conductivity (K) at a suction of 5.22 kPa is around 1.3x10^{-7} m/sec. The flow rate (Q) is:

$$Q = iKA \quad \textbf{Equation 1}$$

where A is the cross-sectional area. The cross-sectional area for the one-dimensional analysis is 1 m^2. Therefore, Q = 1 * 1.3e-7 * 1 = 1.3x10^{-7} m^3/sec.

Using the View Results Information command on a node within this section of the profile shows that the SEEP/W computed Q is also approximately 1.3x10^{-7} m^3/sec.

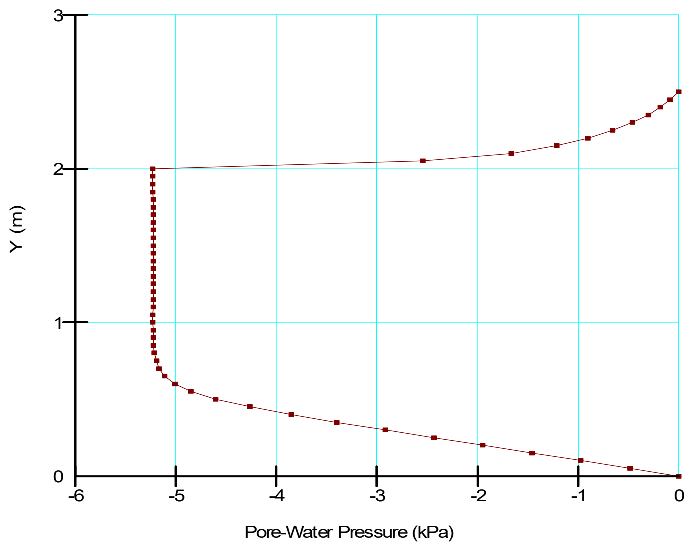

Figure 5. Pore-water pressure profile of the known water table analysis.

The pore-water pressure profile has to be continuous, even across a material boundary. This means that the pore-water pressure at the bottom of the clay is -5.22 kPa, the same as at the top of the sand. Under steady-state conditions, the flow rate in the clay is the same as in the sand. To meet these two requirements means that the gradient in the clay has to be fairly high. Just above the sand-clay contact, the gradient approaches a value of 5 (Figure 6).

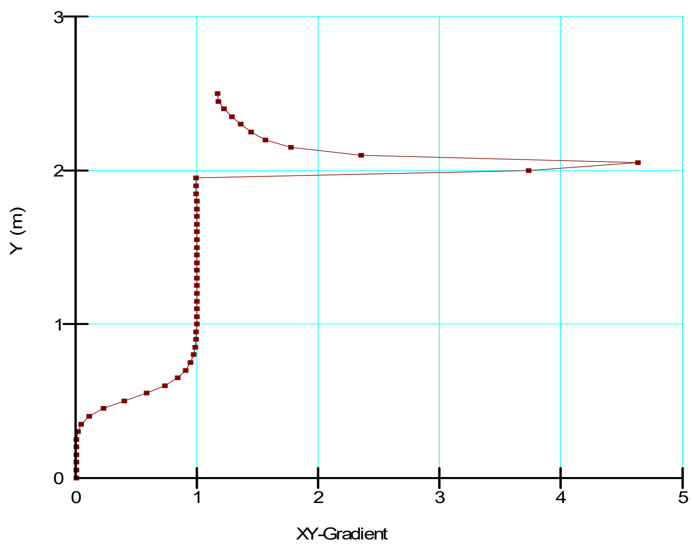

Figure 6. Vertical gradient of the profile overlying a water table.

It is often assumed that, for vertical infiltration into the ground, the gradient is 1.0 (Cedergren, 1967). The analysis here shows that this is only true for certain conditions.

Obtaining a converged solution can be difficult for a case like this with two widely different conductivity functions. Figure 7 For a converged solution, the conductivities corresponding with the SEEP/W computed pressures must lie on the specified conductivity function. Figure 7 shows that this is indeed the case, although it takes 122 iterations to achieve this result.

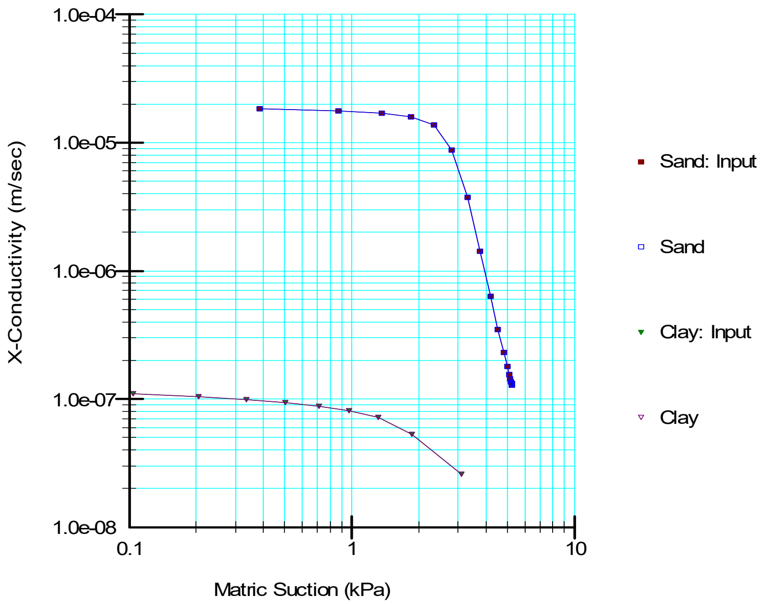

Figure 7. Converged conductivities in relation to the specified conductivity functions.

Sometimes the water table may be deep beyond the level of interest to the liner performance. From the above, it is evident that the vertical gradient is unity (1.0) in the sand for a distance between the liner-base and where the negatively, hydrostatic line from the water table intersect (Figure 6). This being the case, it is advantageous to simply specify a unit gradient type boundary at the base of the problem. The pore-water pressure profile solution to this second analysis is shown in Figure 8. The amount of leakage through the liner is identical for both cases. The suction where the gradient is 1.0 is also the same in both analyses, at approximately -5.22 kPa.

The resulting vertical gradient for this second analysis is shown in Figure 9. Note, the unit gradient boundary condition should only be used if it can be placed far enough below the controlling conductivity material, such that the presence of the boundary condition does not adversely affect the solution. Typical uses for the unit gradient boundary condition would be flow through a liner (as illustrated in this example) and flow through a soil cover system designed to limit infiltration into mine, municipal and hazardous waste dumps.

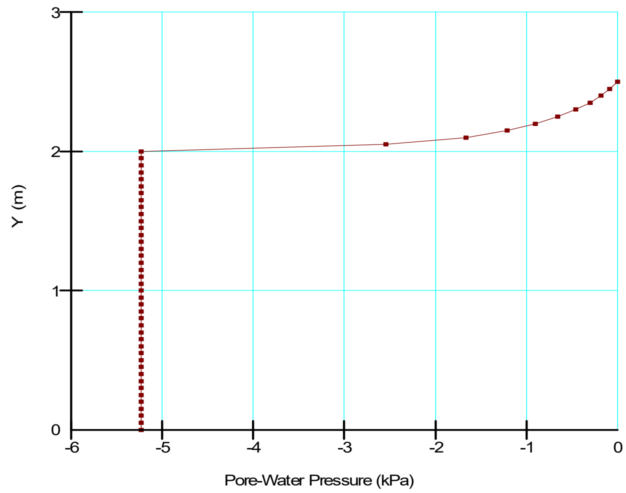

Figure 8. **Pore-water pressure profile of the analysis with a deep, unknown water table.**

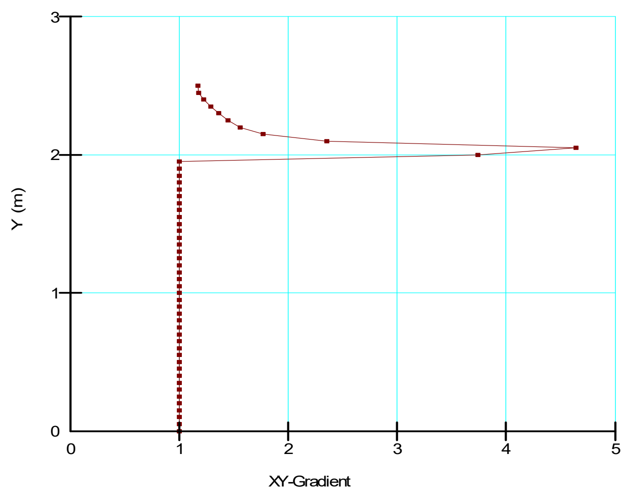

Figure 9. Vertical gradients with a deep water table represented by a unit gradient boundary.

Summary and Conclusions

This example illustrated the ability of SEEP/W to simulate similar results of an unsaturated flow problem when compared to a semi-analytical solution described by Kisch (1959). The use of unit gradient boundary conditions was also introduced for modeling scenarios where the location of deep water tables are unknown or do not have an influence on the performance of a liner or soil cover system.

References

Cedergren, H.R. 1967. *Seepage, Drainage and Flow Nets*, John Wiley & Sons, New York.

Kisch, M. 1959. The theory of seepage from clay-blanketed reservoirs. Géotechnique 9: 9-21.