# GeoStudio Example File Verification - Sandbox problem

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# Introduction

Many studies have shown that an understanding of pore-water pressure distributions within a landscape is required when conducting slope stability analyses. Generally, these analyses are conducted using simple two-dimensional, homogeneous and isotropic assumptions. Rulon and Freeze (1985) conducted a laboratory experiment of a layered sandbox with multiple seepage faces to gain a better understanding of the pore-water pressure distributions and their influence on slope stability analyses. The objective of this example is to demonstrate the use of SEEP/W to simulate these layered slope systems in order to understand the pore-water pressure distributions, as observed in the laboratory and numerical analyses completed by Rulon and Freeze (1985).

# Background

Rulon and Freeze (1985) have studied the development of multiple seepage faces on earth slopes due to a layered soil system. To verify their theory, a physical model was constructed in the laboratory. Figure 1 below shows a schematic diagram of the physical model. Water was sprinkled on the upper crest to simulate rain and instruments were installed to measure the pore-water pressure distribution and the total seepage outflow. Two seepage exit points were observed along the slope of the laboratory model. In addition, Rulon and Freeze (1985) conducted a finite element analysis of the laboratory slope to verify the numerical solution of the observed layered slope system. The simulated results compared favorably with the observed pore-water pressure distribution, seepage face locations and total outflow rates.

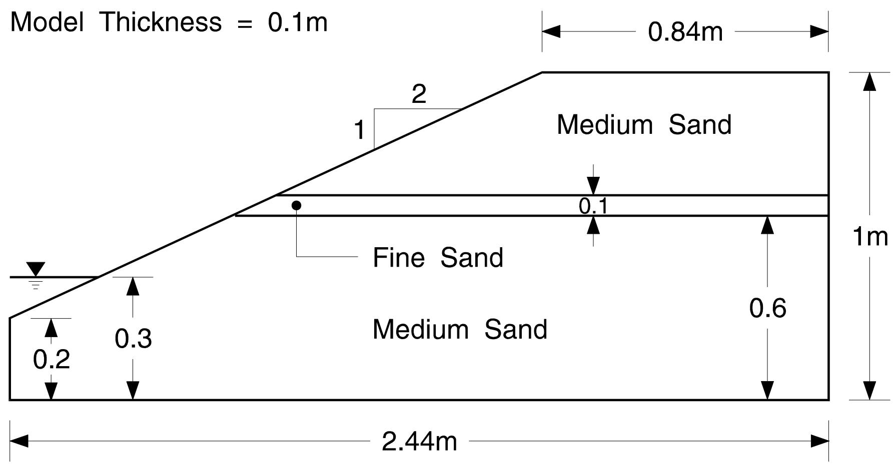


Figure 1. Laboratory model geometry used by Rulon and Freeze (1985).

# Numerical Simulation

A similar geometry was developed in SEEP/W using the domain extents used in the laboratory experiment (Figure 2). The artificial rainfall along the crest was simulated using the unit flux boundary condition with a rate of 2.1 x $10^{-4}$ $m^3/sec/m^2$. The water level along the toe of the slope was simulated using a total head boundary condition of 0.3 m and a potential seepage face boundary condition was placed along the remainder of the slope. The laboratory model developed by Rulon and Freeze (1985) was only 0.1 m in thickness, but the default of 1 m in SEEP/W was used for the illustrative purpose of this example.

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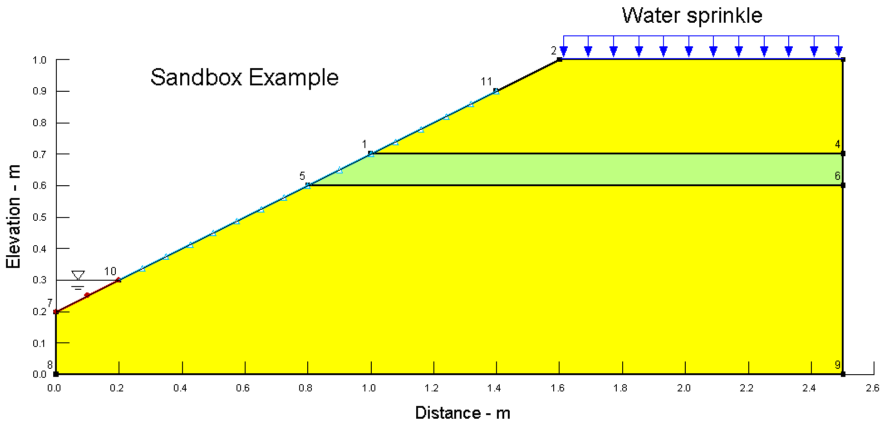


**Figure 2. Problem configuration.**

Volumetric water content (VWC) functions for silt and sand were selected from the SEEP/W sample functions to represent the medium and fine sands used in the physical model by Rulon and Freeze (1985). A saturated water content of 0.35 and 0.40 were used to define the medium and fine sand VWC functions, respectively (Figure 3). Since the example uses a steady-state analysis, the VWC functions are not required, but they are used to estimate the hydraulic conductivity functions, together with the Ksat values defined by Rulon and Freeze (1985).

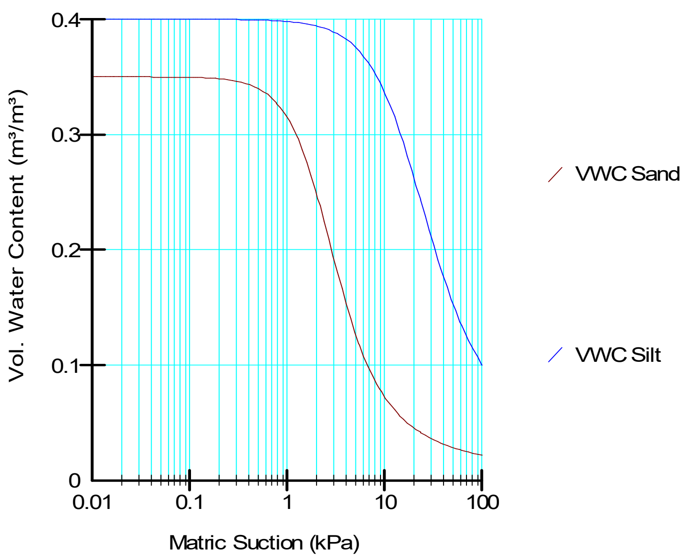


**Figure 3. Volumetric water content functions for the sand and silt sample types.**

Rulon and Freeze (1985) conducted laboratory testing to determine the saturated hydraulic conductivity for the medium and fine sands used in the physical model. The best-fit values were determined to be $1.4 \times 10^{-3}$ m/sec for the medium sand and $5.5 \times 10^{-5}$ m/sec for the fine sand. The resulting functions in SEEP/W using these values are shown in Figure 4. Notice that for suctions greater than 3 kPa, the hydraulic conductivity is less for the medium sand than for the fine sand.

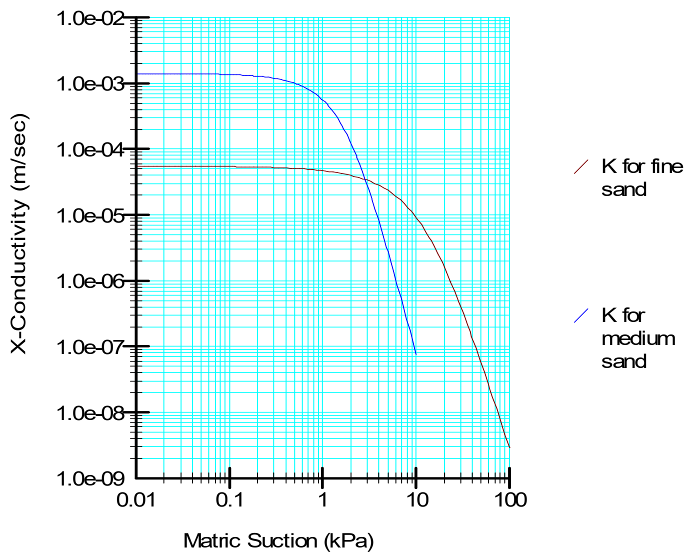


Figure 4. Hydraulic conductivity functions for the medium and fine sands.

The global element mesh size was set to 0.05 m, with finer discretization within the region representing the fine sand. The element size within this small layer was defined using the "Ratio of default size" option and set to a ratio of 0.75.

# Results and Discussion

Figure 5 shows the steady-state condition as published by Rulon and Freeze (1985). The result total head contours and phreatic surface reached in the SEEP/W analysis is shown in Figure 6. Very similar results are shown for both predicted analyses and the observed conditions in the laboratory.

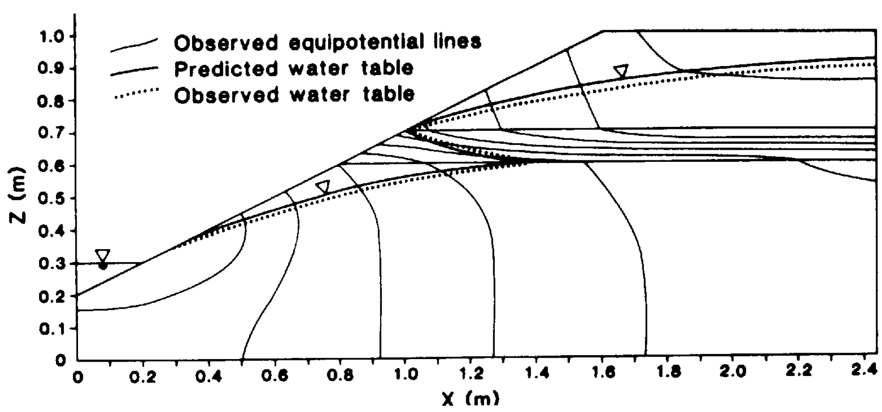


Figure 5. Rulon and Freeze (1985) published steady-state condition.

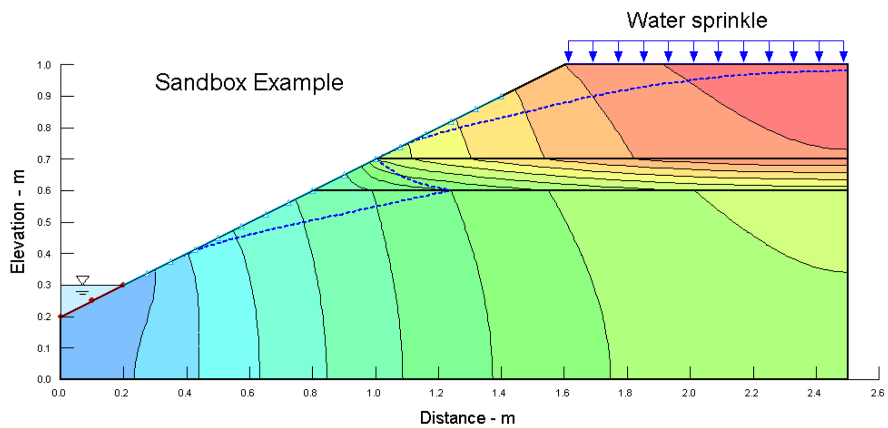


**Figure 6. SEEP/W steady-state condition.**

One of the purposes of the study was to explain the reason for localized wet areas on the cut slope. The results confirm that the reason for this observation is the stratigraphy. Layers of less permeable material impede the seepage flow at depth, which can lead to seepage exiting along the slope face.

The solution is dependent on the hydraulic conductivity contrast in the materials relative to the rate of infiltration. The total head contours (equipotential lines) are much closer together in the fine sand layer than in the medium sand. This is an indication of the higher energy loss in this layer due to the lower hydraulic conductivity.

Figure 7 shows the resulting flow directions, flow rates and locations of the exiting seepage. Water is exiting the section below the toe pond, on the slope face just above the pond and on the slope face just above the location where the fine sand daylights on the slope. The highest discharge rates are near the seepage exit locations.

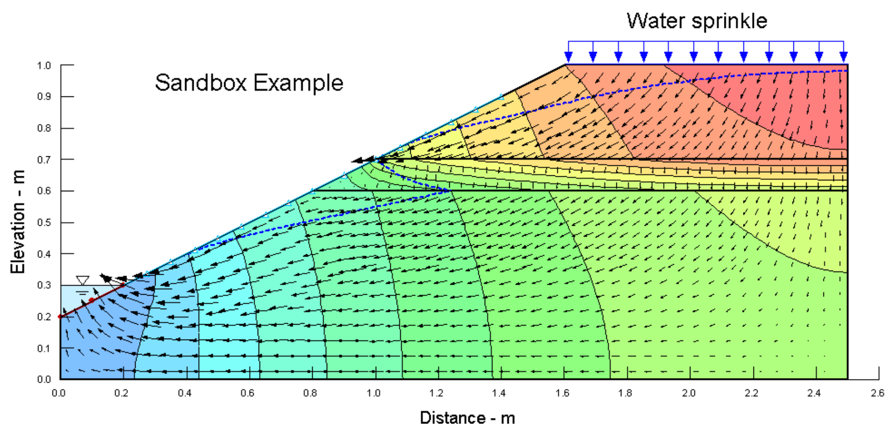


**Figure 7. Velocity vectors for the sandbox analysis.**

From the SEEP/W computations, the infiltration on the crest is +1.89e-4 $m^3$/sec (positive means water is flowing into the domain). The sum of the exiting seepage is the same, but of the opposite sign (minus means flow out of the domain). The specified infiltration rate is $2.1 \times 10^{-4}$ $m^3/sec/m^2$. Multiplying this by the crest area (0.9 m x 1 m = 0.9 $m^2$) gives 1.89e-4 $m^3$/sec, which is the same as computed by SEEP/W.

# Summary and Conclusions

The objective of this example was to illustrate the influence of layered materials on the pore-water pressure distributions and discharge locations along a slope. Without a saturatedunsaturated seepage formulation such as SEEP/W, it is not possible to numerically model a problem like this. A good agreement between the Rulon and Freeze (1985) numerical analysis, physical sandbox model and the SEEP/W results were reached.

# References

Rulon, J.J. and Freeze, R.A. (1985). Multiple Seepage Faces on Layered Slopes and their Implication for Slope Stability Analysis, Canadian Geotechnical Journal, Vol. 22