GeoStudio Example File
Verification – Infiltration into dry soil

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Introduction

Infiltration into unsaturated soil is a problem of great interest in the fields of hydrology, soil science, agricultural science, and geotechnical engineering. Some typical examples of practical problems include water movement in pavement sections, contaminant transport through the unsaturated zone, soil cover design, and irrigation and drainage studies. Interestingly, finite element solutions to infiltration problems involving dry soil can exhibit numerical problems (e.g. oscillation), mass balance errors, and can converge to the wrong solution. This deceptively simple problem is complicated by highly nonlinear hydraulic properties and relatively large pressure head gradients across the wetting front.

The objective of this example file is to benchmark SEEP/W against a semi-analytical solution for one-dimensional infiltration in unsaturated soil developed by Warrick et al. (1985). Details of the solution can be found in the original publication.

Background

Flow of water in the unsaturated zone is typically analyzed using the Richard's equation. These analyses are often complex and require specified hydraulic functions, such as the volumetric water content and the hydraulic conductivity functions. Warrick et al. (1985) presented a method of solving Richard's equation using scaled forms of the hydraulic functions to create a numerical solution that requires minimal calculations. The Richard's equation is defined as:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial\theta}{\partial x}\right) - \frac{\partial K}{\partial x}$$ Equation 1

where θ is the volumetric water content, t is time, x is depth, D is the soil water diffusivity, and K is the unsaturated hydraulic conductivity. Warrick et al. (1985) used dimensionless forms to substitute into the Richard's equation, as well as for use in the calculation of the wetting front. These dimensionless forms include:

$$W = \frac{(\theta - \theta_r)}{(\theta_s - \theta_r)}$$ Equation 2

$$T = \frac{\alpha K_s t}{(\theta_s - \theta_r)}$$ Equation 3

$$X = \alpha X$$ Equation 4

$$K^* = \frac{K}{K_s}$$ Equation 5

$$h^* = \alpha h$$ Equation 6

where α is a positive scaling factor, h is the pressure head, θ_s and θ_r are the saturated and residual water contents, respectively, and K_s is the saturated hydraulic conductivity.

The Richard's equation then becomes:

$$\frac{\partial W}{\partial T}=\frac{\partial}{\partial X}\left(D^*\frac{\partial W}{\partial X}\right)-\frac{\partial K^*}{\partial X}$$ Equation 7

where the dimensionless form of D^* was defined as:

$$D^*=K^*\frac{dh^*}{dW}=\frac{\alpha D(\theta_s-\theta_r)}{K_s}$$ Equation 8

Numerical Simulation

The one-dimensional model domain comprises a 1 m high column that has an initial pressure head of -8 m (Figure 1). The initial pore water pressure for the soil is established using the ‘Activation PWP’ feature under the Define | Materials dialogue box. This initial condition starts the soil from a dry state with a volumetric water content nearing residual (refer to the volumetric water content function). For the transient analysis, a zero pressure head is imposed at the top of the column, while the pressure head is maintained at – 8 m at the bottom. These boundary conditions simulate the infiltration condition as the negative pore water pressure at the top of the column is reduced to zero as soon as infiltration begins.

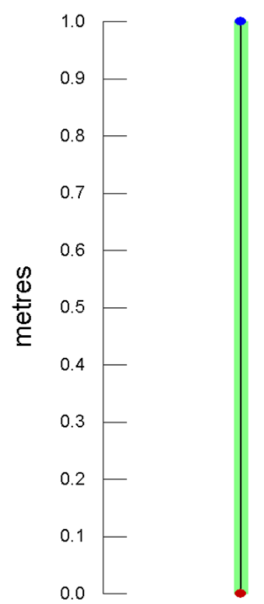

Figure 1. Model configuration.

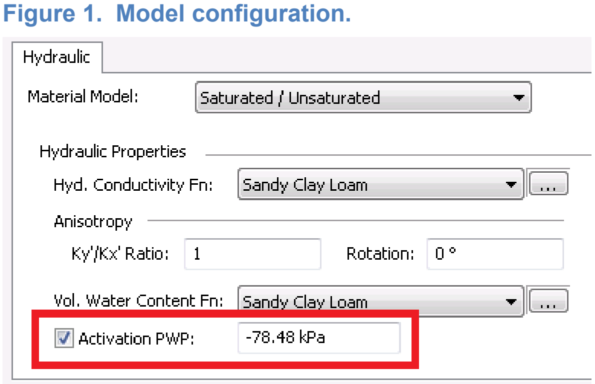

Figure 2. **Activation PWP option in the Define Materials window.**

The volumetric water content function for the soil used in the analysis was generated using the van Genuchten soil model. The key parameters are presented in Table 1 and are typical of a sandy clay loam. The hydraulic conductivity function was generated using the 'estimate' feature under Define Hydraulic Conductivity Functions using a saturated hydraulic conductivity (K_{sat}) of 1×10^{-6} m/s with the sandy clay loam volumetric water content function.

Table 1. Material properties used for the soil.

Parameter	Value	Units
Saturated volumetric water content (θ_s)	0.363	
Residual volumetric water content (θ_r)	0.186	
α	9.81	1/kPa
n	1.53	
Sat. Hydraulic Conductivity (K_{sat})	1×10^{-6}	m/s

The problem was modeled using two mesh and time step discretization. The coarse and fine mesh discretization of 0.05 m and 0.01 m, respectively, were used. The total time duration for the analysis was 46,800 seconds, with 10 and 100 time steps for the coarse and fine discretization, respectively.

Figure 3 presents the convergence settings for the analysis.

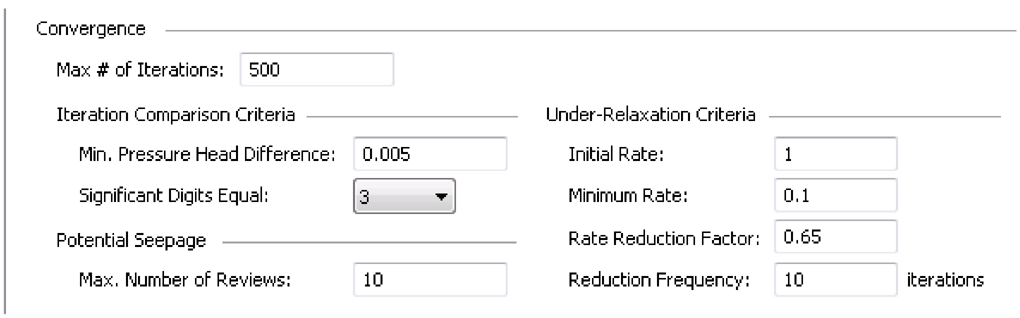

Figure 3. Convergence settings for analysis.

Figure 4 compares the actual K used at each Gauss integration point with the corresponding K from the specified K function. The two are the same, indicating that convergence was achieved.

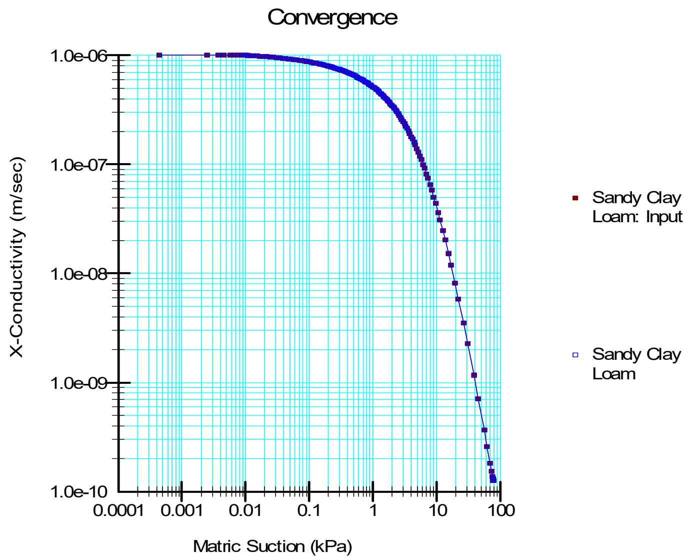

Figure 4. Actual K compared with the function K.

Results and Discussion

Figure 5 presents the modeled results using the fine and coarse discretization, along with the semi-analytical solution from Warrick et al. (1985). Both levels of discretization yield a correct solution, although the coarse discretization produces a wetting front that is more diffuse than the actual solution. Additional mesh and time step refinement cause the wetting front to rotate about the correct elevation.

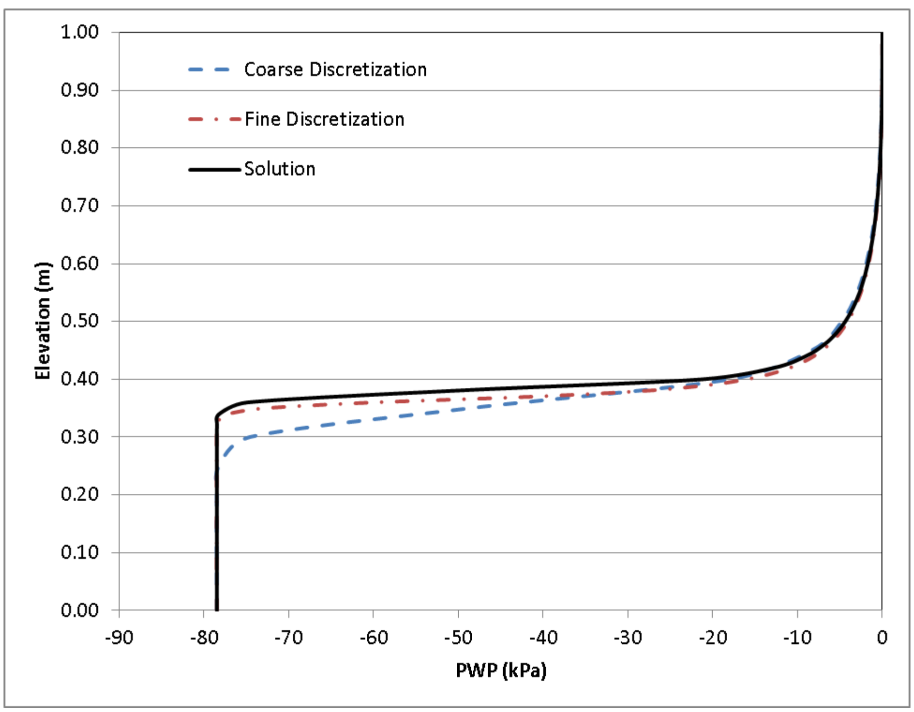

Figure 5. Vertical profiles of pore water pressure.

Summary and Conclusions

SEEP/W is capable of modeling infiltration into a dry soil, which can be a challenging problem due to non-linearity in the hydraulic functions and steep hydraulic gradients at the edge of the wetting front. The results demonstrate that a correct solution is produced even with fairly coarse discretization (spatial and temporal), although the accuracy of the wetting front elevation is improved with mesh and time step refinement.

References

Warrick, A.W., Lomen, D.O., and Yates, S.R. 1985. A generalized solution to infiltration. Soil Science Society of America Journal, 49: 34 – 38.