SEEQUENT

GeoStudio Example File Verification - Consolidation

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Introduction

This example simulates a one-dimensional consolidation test using SIGMA/W and SEEP/W. The SIGMA/W formulation is verified by comparison to SEEP/W, because SEEP/W solves the rigorous groundwater flow equation, which includes changes in storage due to soil and water compressibility and flow due to gradients in pore-water pressure, water density, and gravitational flow. The Terzaghi 1D equation is not used for this comparison because the analytical solution excludes gravitational flow and water compressibility.

Numerical Simulation

Figure 1 shows the configuration for this example. Initially, the pore-water pressure is hydrostatic with depth, with zero pressure at the surface boundary. This makes the initial pressure at the base equal to 9.807 kPa (γ_w = 9.807 kN/m^3). There are three analyses included in the GeoStudio Project including: 1) a gravity action *In Situ* analysis to establish the initial stresses and pore-water pressures; 2) a consolidation analysis; and, 3) a transient SEEP/W analysis to confirm the results.

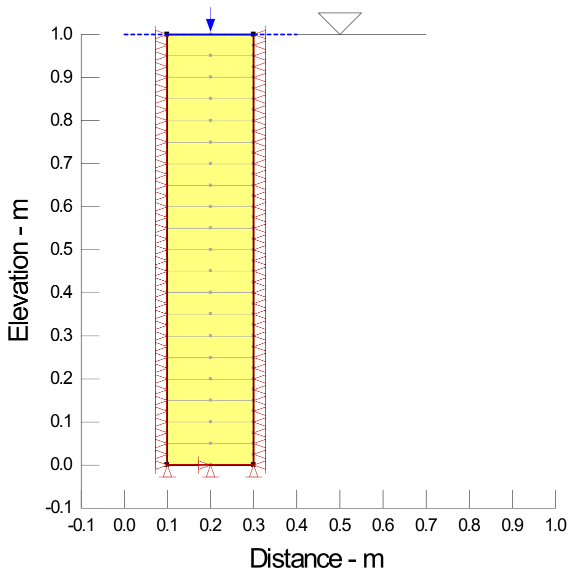

Figure 1. One-dimensional consolidation setup.

The pore-water pressures in this analysis will remain positive at all times, so the saturated-only material model is used to define the hydraulic properties. The saturated hydraulic conductivity (K_{sat}) is set to 1 x 10^{-6} m/sec. Changes in storage in the consolidation analysis are controlled by volumetric strain. The Poisson's ratio (v) and elastic modulus are set to 0.334 and 2000 kPa, respectively. The coefficient of volume compressibility (m_v) is only required for the SEEP/W transient analysis and it was back-calculated from the bulk modulus to be 3.325e-4 1/kPa.

In the consolidation analysis, a constant surface load cannot be applied during the dissipation stage because SIGMA/W is based on an incremental formulation. The surface load has to be applied only during the first time step, and then it has to be numerically removed for the remaining time steps. This can be accomplished with a step-function (Figure 2).

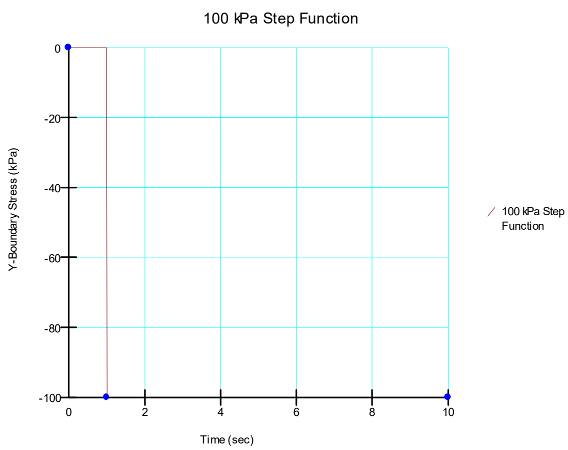

Figure 2. Surface load boundary function.

The initial step duration in the function is 1 sec. SIGMA/W obtains the function values at time *n* and (*n*-1). In this case, they are 60 and zero. The difference is 100 kPa, which is the surface load applied for the first time step. For all other time steps, the applied load increment is zero. For example, the function value at *t* = 1 is 100 and at *t* = 2 is also 100, and therefore the applied load increment is zero as intended.

The left and right boundaries of the domain are fixed in the x-direction. The bottom of the domain has been fixed in both the x- and y-direction so that no displacement can occur in either direction. The total duration of the analysis is set to 20,000 seconds, with time steps that increase exponentially over 20 time steps with an initial increment size of 60 second. The global element size has been set to 0.05 m, with single element width using the "Number of Divisions" constraint on the surface line of the domain.

The transient seepage analysis requires a boundary condition to replicate the instantaneous increase in pore-water pressure due to loading. For this reason, the initial pore-water pressure conditions are defined using a water table drawn at an elevation of 11.197 m. The pore-water pressure at the top of the column is therefore 100 kPa (9.807 x (11.197 – 1) = 100 kPa).

Results and Discussion

Figure 3 shows the pore-water pressure response to the applied 100 kPa and the subsequent dissipation. The form and shape is in-keeping with figures presented in classical soil mechanics textbooks. The increase is 100 kPa except right at the top, where there has been some dissipation during the first time step (60 seconds). At the bottom, the pore-water pressure increases from 10 kPa to 110 kPa due to the load.

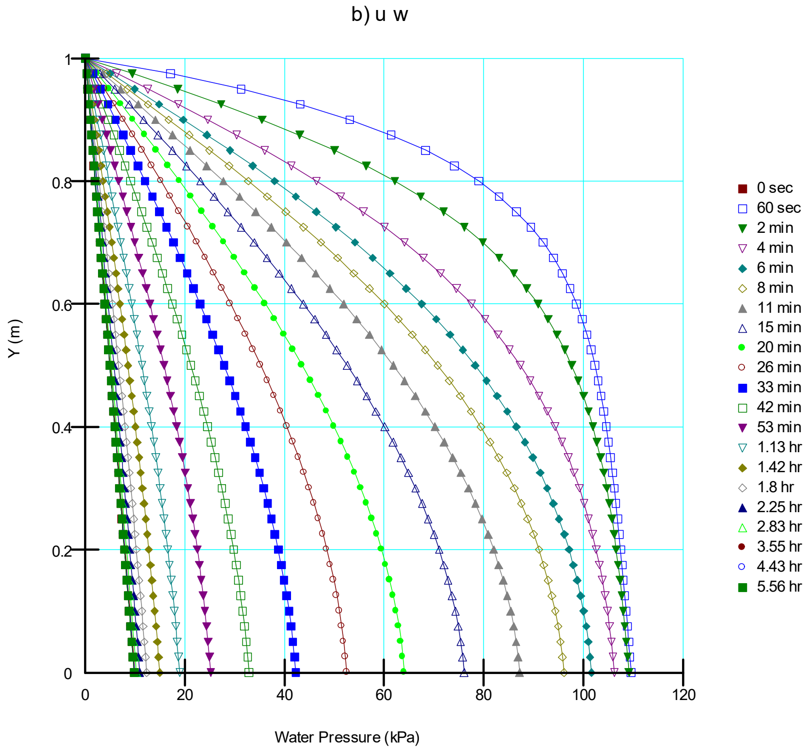

Figure 3. Pore-water pressure response and dissipation.

Figure 4 compares the SEEP/W and SIGMA/W pore-water pressure profile after 900 seconds of consolidation. SEEP/W and SIGMA/W produce the same result. This is important because SEEP/W solves the groundwater flow partial differential equation, which captures storage changes in the saturated zone via soil compressibility. In contrast, storage changes in the SIGMA/W coupled flow equation are governed by volumetric strain. The two formulations are theoretically equivalent for problems in which changes in effective stress are equal to changes in pore-water pressure, which is the case in this example.

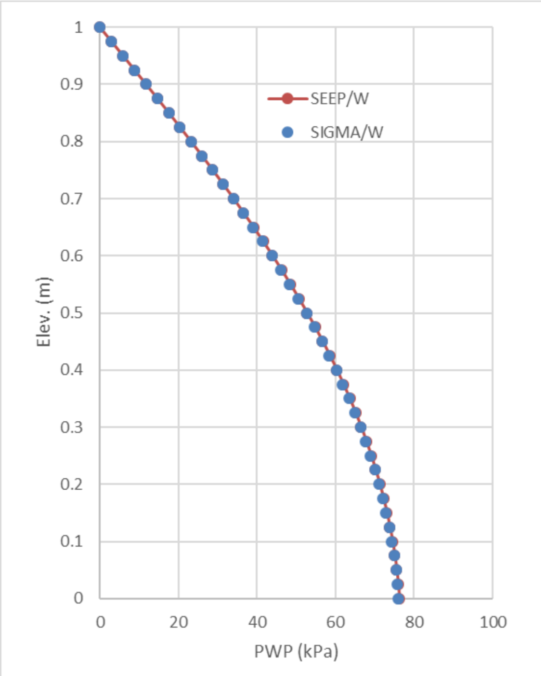

Figure 4. Pore-water pressure profile after 900 seconds.

A final verification of the SIGMA/W consolidation formulation is achieved by comparing the volume of water released from the column. Again, SEEP/W and SIGMA/W produce the same result. The volume of water released from the column is 0.00665 m^3. The volumetric strain throughout the column on the last time step is 0.00332. Given the column dimensions (0.2 m^3), the change in volume must therefore be 0.00332 x 0.2 m^3 = 0.00665 m^3. It should also be noted that both the SIGMA/W and SEEP/W formulations include the compressibility of water. Although pedantic, 3.51e-6 m^3 of water was actually released due to the compressibility of water.

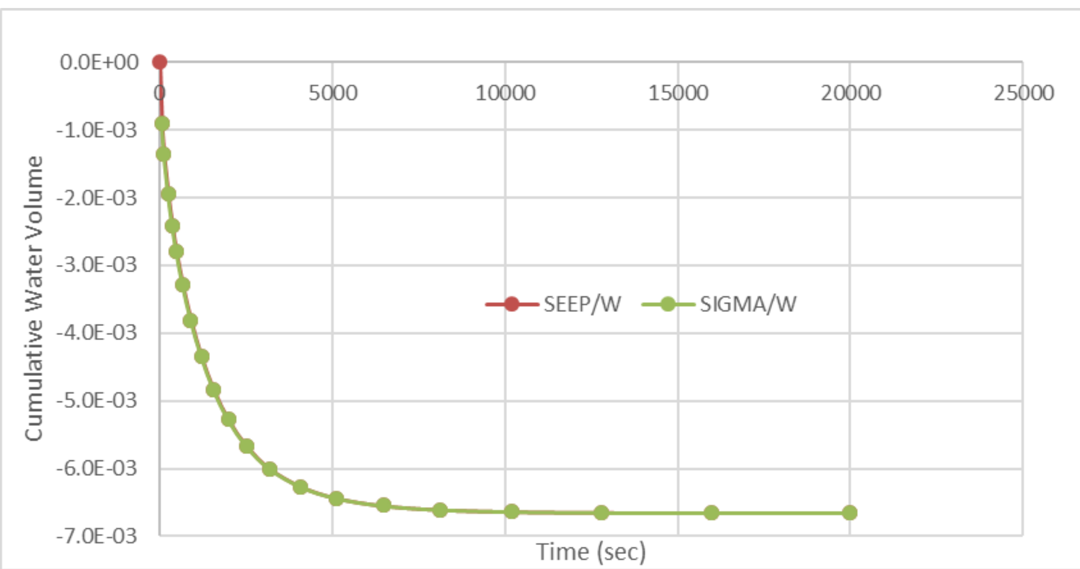

Figure 5. Cumulative water discharge from the top of the column.

Summary and Conclusions

This example models a 1D consolidation problem to verify the SIGMA/W consolidation formulation by comparison to SEEP/W. SEEP/W solves the rigorous groundwater flow partial differential equation, which includes both soil and water compressibility on the storage side of the equation. Both formulations produce the exact same result.