SEEQUENT

GeoStudio Example File
Rapid Drawdown

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Introduction

When an earth embankment has retained a reservoir with a fairly constant water surface elevation for a long time, the seepage conditions within the embankment will likely reached a steady-state. If it is necessary to drain the reservoir quickly, the pore-water pressures within the embankment may remain relatively high while the stabilizing effect of the reservoir's weight along the upstream side of the embankment is removed. This process is typically referred to as 'rapid drawdown' and can cause instability of the upstream face of the embankment.

A SEEP/W water transfer analysis can be used to evaluate changing pore-water pressure conditions after the reservoir has been drained. In the worst case, it is assumed that the reservoir has been drained instantaneously. More realistically, the reservoir will be drained over a period of time. This example illustrates how these conditions, modeled with a water transfer analysis, can be used in SLOPE/W to determine the influence of instantaneous or gradual drawdown on slope stability.

Numerical Simulation

The analysis involves an embankment that is approximately 44 m wide at the base and 10 m high (Figure 1). The embankment has a drain located at the toe to prevent water from exiting along the downstream slope face. The head in the reservoir before drawdown is 8 m.

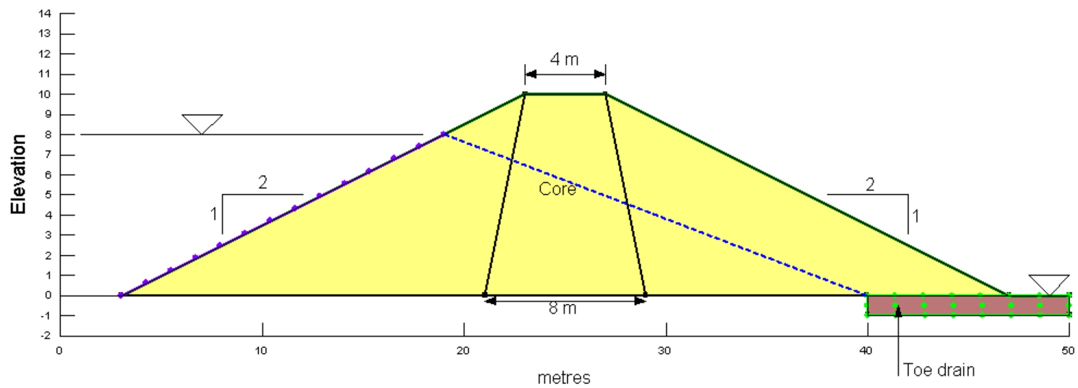

Figure 1. The problem configuration.

There are a total of 5 analyses in the Analysis Tree (Figure 2), with a steady-state water transfer analysis acting as the Parent to the remaining analyses. The first water transfer analysis represents the steady-state conditions within the embankment given the presence of the reservoir for a long period. The initial water table is drawn from the reservoir to the toe drain, and a constant head boundary condition (8 m) is applied to the upstream face of the embankment, representing the initial water level within the reservoir. The toe drain is simulated using a zero pressure head boundary condition applied to the toe drain region. The results from this Parent Analysis act as the initial conditions for the two scenarios: 'Instantaneous drawdown', and 'Slow drawdown'.

Figure 2. Analysis Tree for the Project.

After the water in the reservoir is drained, the relatively high pore water pressures within the embankment will cause groundwater movement out of the embankment, creating a seepage face along the upstream side of the embankment. The size and position of the seepage face are not known. Moreover, the seepage face will change with time after the drawdown occurs. A SEEP/W analysis can incorporate the seepage face along the upstream side of the embankment using the ‘Potential Seepage Face Review’ water rate boundary condition.

The second water transfer analysis is a transient simulation of the reservoir undergoing instantaneous drawdown, with the level of the reservoir changing from 8 m to 0 m. The instantaneous drawdown is simulated using a zero pressure head boundary condition at the toe of the upstream slope and a potential seepage face boundary condition along the upstream slope to the height of the original reservoir level.

The slope stability analysis child of this transient water transfer simulation helps determine the influence of this instantaneous change in the pore-water pressure conditions within the embankment on the factor of safety over a period of 30 days following drawdown. The pore-water pressure results from all time steps in this analysis are used in SLOPE/W by selecting all of the time steps in the water transfer analysis. This can be done by selecting (all) time steps from the Parent Analysis in the Time edit box as shown in Figure 3.

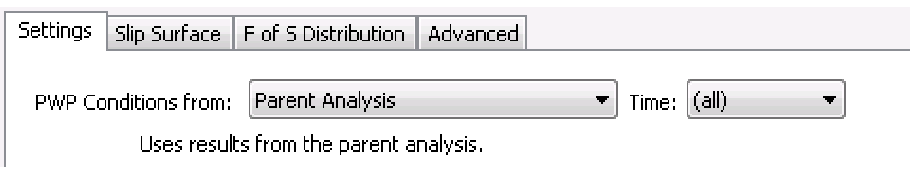

Figure 3. Selecting all time steps from the Parent Analysis.

The final water transfer analysis simulates gradual drawdown of the reservoir over a period of 5 days. The changing water level of the reservoir is defined using a head function boundary condition (Figure 4). This boundary condition is applied to the upstream slope of the embankment to the point representing the highest level of the reservoir. The potential seepage face review option is also activated to allow flow to leave the upstream side of the domain. As with the rapid drawdown scenario, the pore water pressures from the gradual drawdown water transfer analysis are used in SLOPE/W to determine the resulting factor of safety.

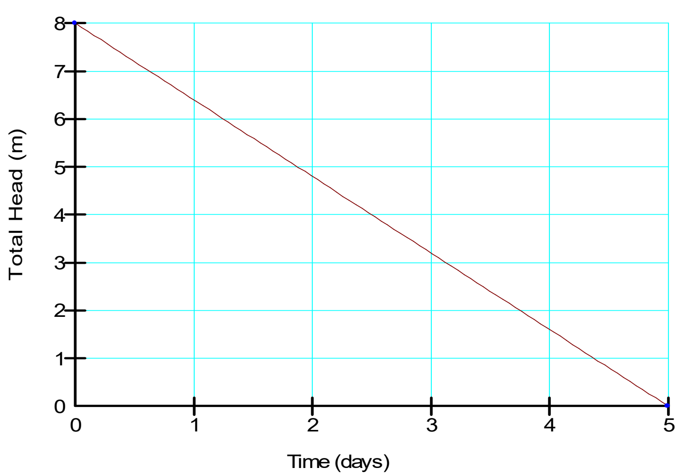

Figure 4. Reservoir drawdown with time for the slow drawdown analysis.

Both of the slope stability analyses use the Spencer analysis type, with the slip surface defined using the entry and exit method in the right to left direction. The potential entry location of the slip surface is defined at the top of the embankment core, with the exit defined along the lower toe of the slope (Figure 5).

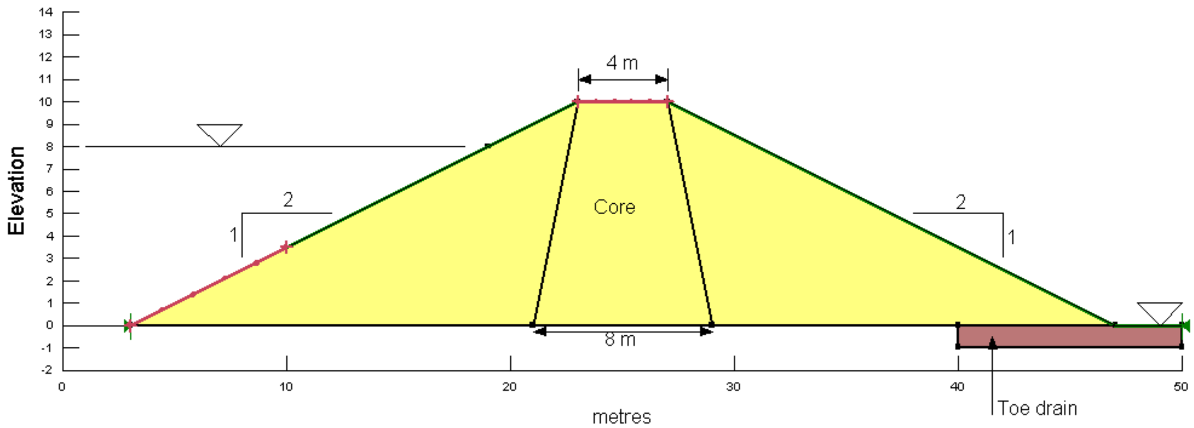

Figure 5. Entry and exit locations for the slope stability analyses.

The global element size has been set to 1 m. Within the embankment core, the mesh size was refined to 0.5 m for the water transfer analyses. The transient analyses have a total duration of 30 days, with 10 time steps increasing exponentially from an initial time step of 6 hours.

Results and Discussion

The long-term, steady-state conditions established using the Parent analysis are shown in Figure 6. After instantaneous drawdown, water stored within the embankment gradually drains from areas of high pore-water pressure. Thus, the piezometric line changes position over time, as illustrated Figure 7. This means that the seepage face also changes over time, gradually decreasing in size.

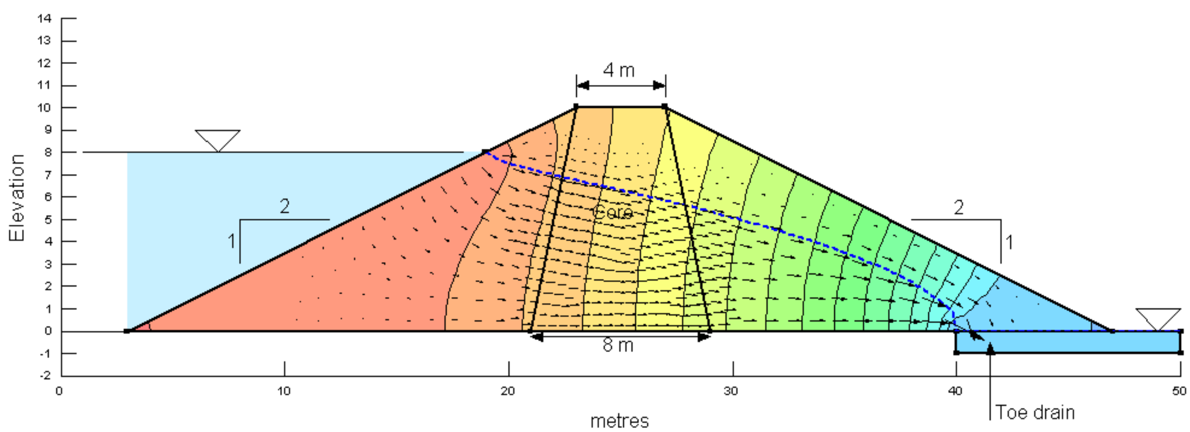

Figure 6. Steady-state initial conditions.

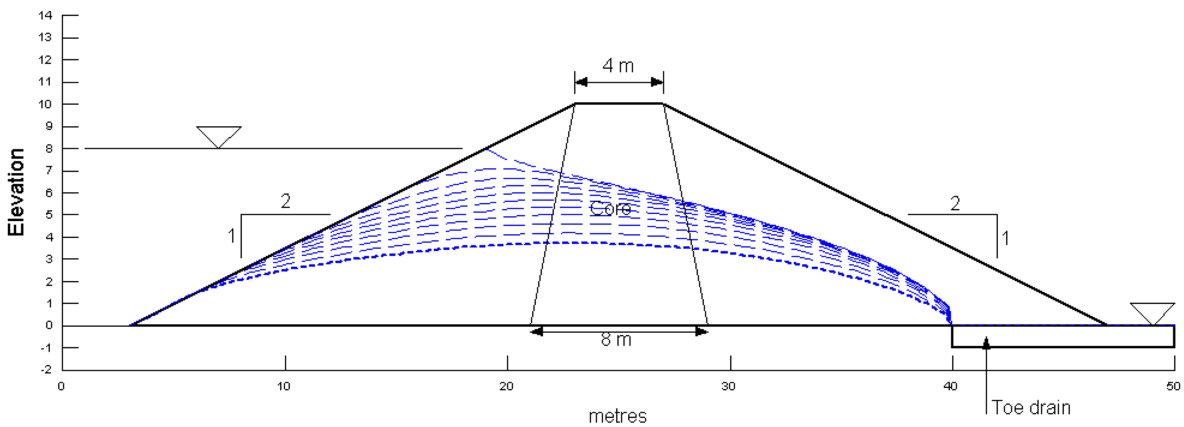

Figure 7. Changing positions of the piezometric line after instantaneous drawdown.

Figure 8 shows the location of the piezometric line and velocity vectors at the end of day 1 from the instantaneous drawdown water transfer analysis. The colored circles on the upstream face show which nodes are H nodes (red) and which are Q nodes (blue). Water is flowing out of the bottom portion of the upstream face at the H nods (red). These will change with each time step.

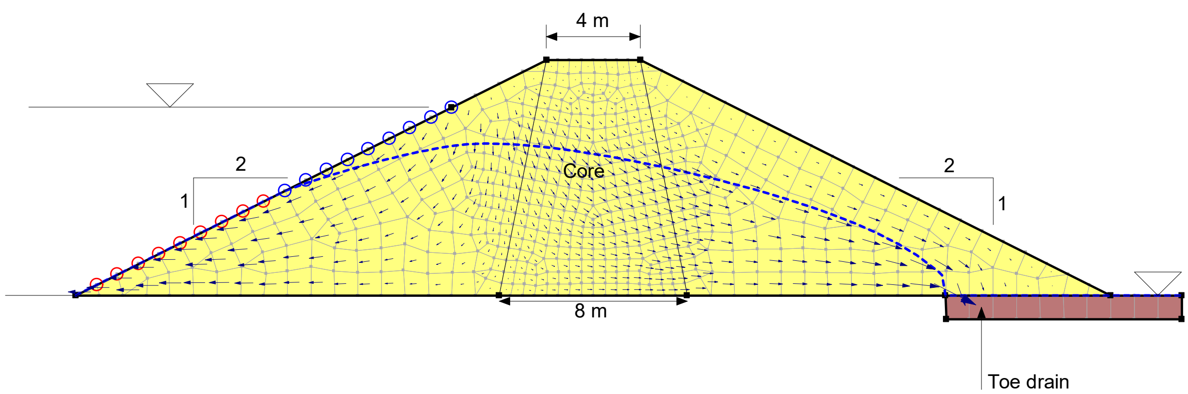

Figure 8. Piezometric line and velocity vectors at the end of day 1 from the instantaneous drawdown analysis.

Using The Draw Slip Surface command in SLOPE/W, we can create a plot of Factor of Safety versus time given instantaneous drainage of the reservoir (Figure 9). The factor of safety drops below 1.0 immediately following drawdown. However, the factor of safety recovers over time as the excess pore-water pressure within the embankment dissipates.

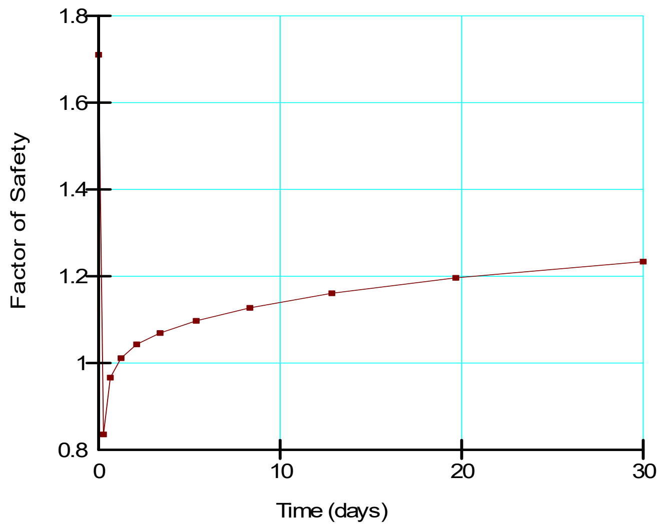

Figure 9. Factor of safety versus time after instantaneous drawdown.

Figure 10 shows the piezometric line and velocity vectors at the end of day 1 from the slow drawdown water transfer analysis. Here the velocity vectors show that less water is leaving the domain via the upstream slope, and more of the water is flowing out of the toe drain, due to the continued presence of water in the reservoir. As the reservoir level decreases over time, flow from the upstream face increases.

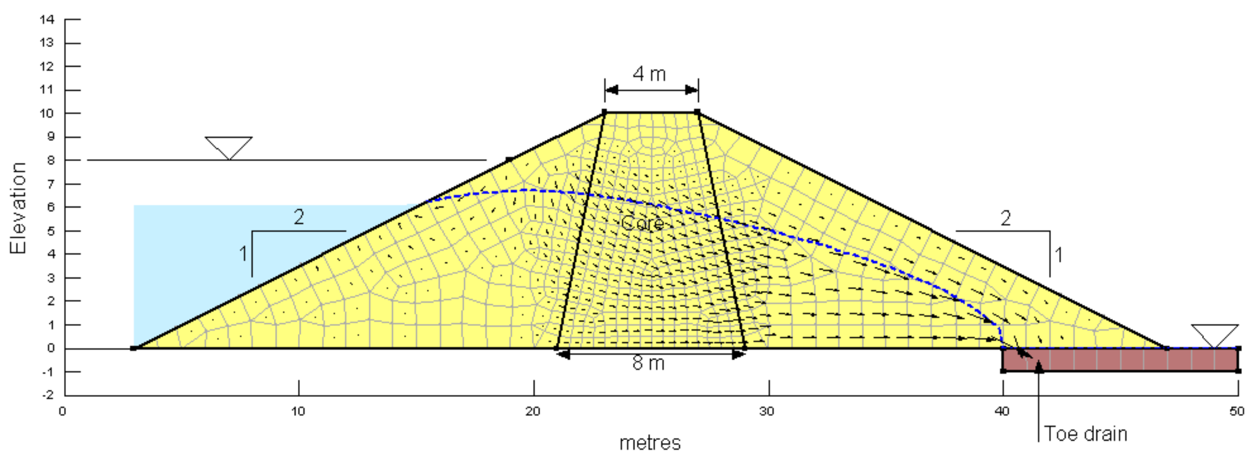

Figure 10. Piezometric line and velocity vectors at the end of day 1 from the slow drawdown analysis.

When the reservoir level is drawn down slowly instead of instantaneously, the stability of the embankment is substantially different (Figure 11). As with the instantaneous drawdown analysis, the factor of safety decreases when the reservoir is drawn down. However, the factor of safety for the slow drawdown analysis does not drop below 1.0.

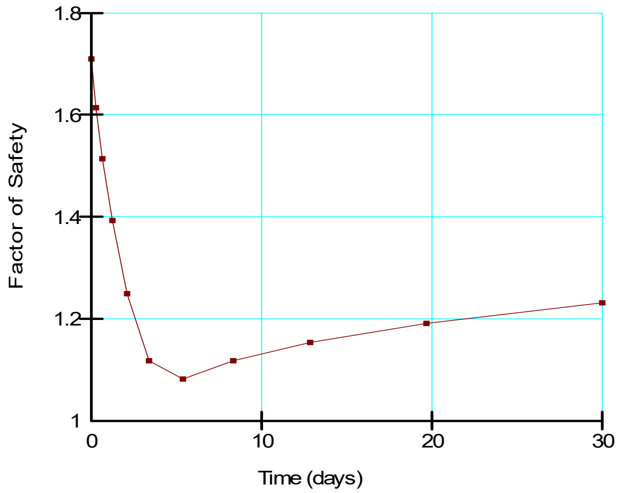

Figure 11. Factor of safety versus time from the slow drawdown stability analysis.

Summary and Conclusions

This example illustrates the power of GeoStudio product integration by using transient SEEP/W water transfer results in SLOPE/W to evaluate the change in factor of safety over time. The instantaneous drawdown scenario is a conservative approach for assessing stability of an embankment during reservoir drawdown; however, it likely represents unrealistic conditions as it is difficult to drain a reservoir over a very short period. The second scenario includes a gradual decline in the reservoir's water level so it is more realistic, and therefore, provides a more reasonable evaluation of the embankment's factor of safety during drawdown.