GeoStudio Example File

The Effect of Pore-Air Pressure on Stability

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Introduction

The development of excess pore-air pressure, although not often considered in practice, can be influential for a certain class of problem. For example, the relatively fast construction of earth fill dams or embankments can result in an undrained response of both the compacted material and foundation soil. The pore-air pressure in the unsaturated zone will equal atmospheric pressure or it could be positive and in excess of atmospheric conditions, while the pore-water pressure remains negative. The effective stress and therefore factor of safety of the earth structure is altered. SLOPE/W has been formulated to handle both saturated and unsaturated soil conditions, so the effect of both pore-water and pore-air pressures can be modeled.

Background

The undrained loading response of an unsaturated soil is outside the scope of this example and has been discussed by others (Hilf, 1998; Wilson et al., 1998). The shear strength (s) for unsaturated soil is given by:

$$s = c' + (\sigma - u_a)\tan\phi' + (u_a - u_w)\left[\frac{\theta_w - \theta_r}{\theta_s - \theta_r}\right]\tan\phi' \qquad \text{Equation 1}$$

where c' is the effective cohesion of soil, σ is the normal stress, u_a is the pore-air pressure, ϕ' is the effective angle of friction, u_w is the pore-water pressure, θ_w is the water content, θ_s is the saturated water content, and θ_r is the residual water content. The second term represents the shear strength derived from the total mechanical load acting on the system, while the third term represents the unsaturated component to shear strength (see SLOPE/W Engineering Book and other examples). An increase in pore-air pressure has an opposing effect on the shear strength components: it decreases the effective stress strength and increases the suction strength. The overall effect therefore depends on the suction strength definition.

Numerical Simulation

Figure 1 presents the model domain for the analysis. For illustrative purposes, assume that some temporary positive air pressure developed in the core material during the construction of the clay core and subsequent compression due its self-weight. The objective is to determine the effect of the air pressure on the factor of safety. There are three cases in the GeoStudio Project: 1) air pressure without suction strength; 2) no air pressure with suction strength; and, 3) air pressure and suction strength. For simplicity, the clay core material is using an unsaturated strength friction angle (phi B) of 15° for both cases 2 and 3. In case 1 and 3, the clay core material is assigned a pore-air pressure of 30 kPa under Define Pore-air pressure.

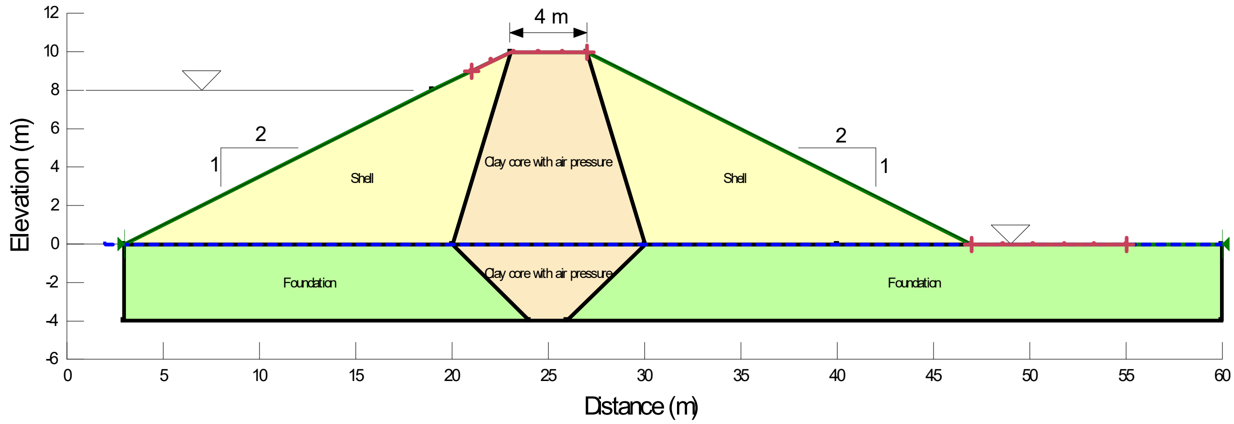

Figure 1. Illustrative example configuration.

Results and Discussion

Figure 2 and Figure 3 present the critical factor of safety for case 1 and 2, respectively. Figure 4 shows the pore-air pressure distribution along the slip surface for Case 1. The air pressure is 30 kPa as specified for all slices with the base in the core material and within the unsaturated zone. The factor of safety is about 1.2 for Case 1 because the net effective stress component of the shear strength is reduced by the pore-air pressure without any additional suction strength. Case 2 shows that the addition of suction strength increases the factor of safety to 1.32 (pore-air pressure is excluded).

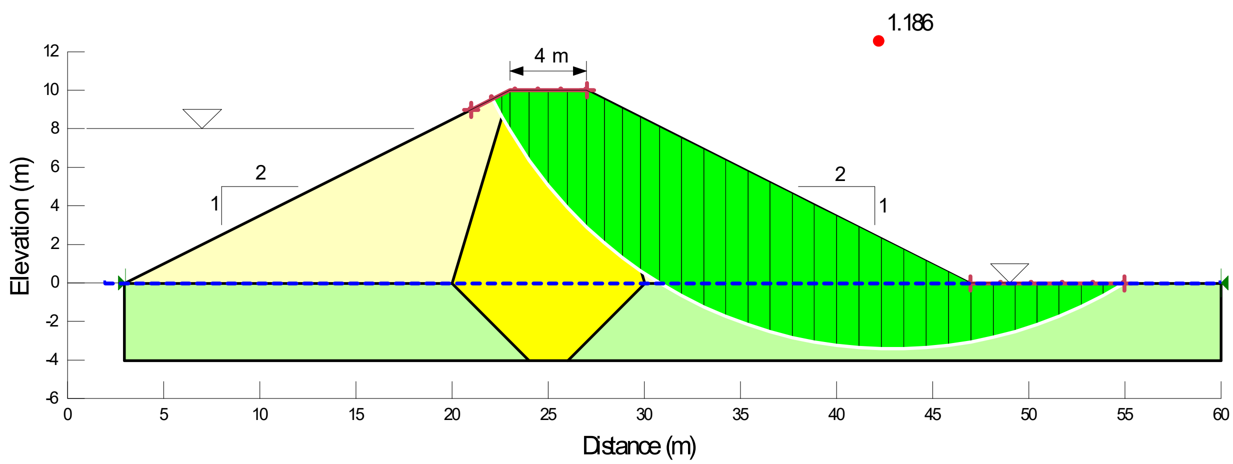

Figure 2. Case 1 factor of safety.

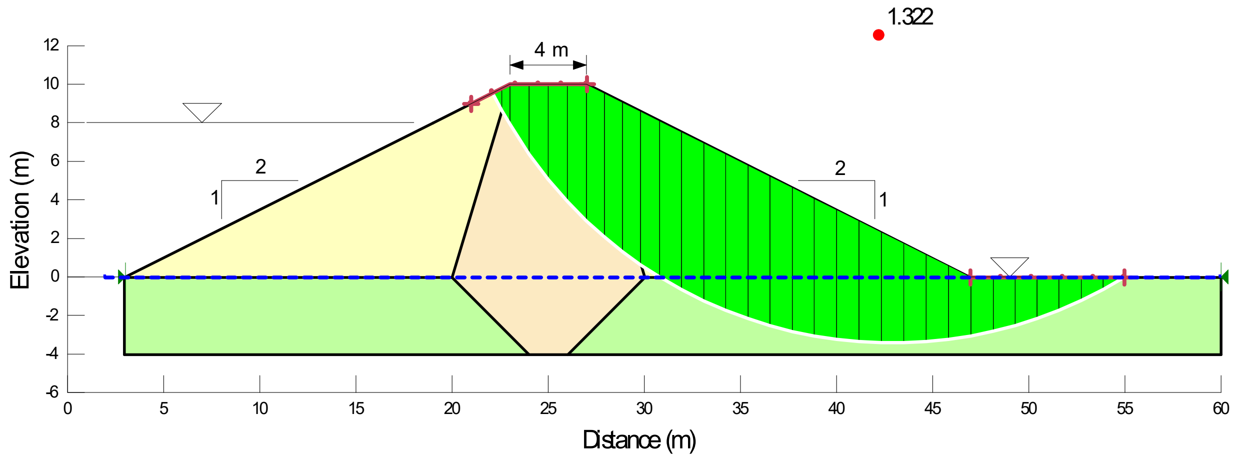

Figure 3. Case 2 factor of safety.

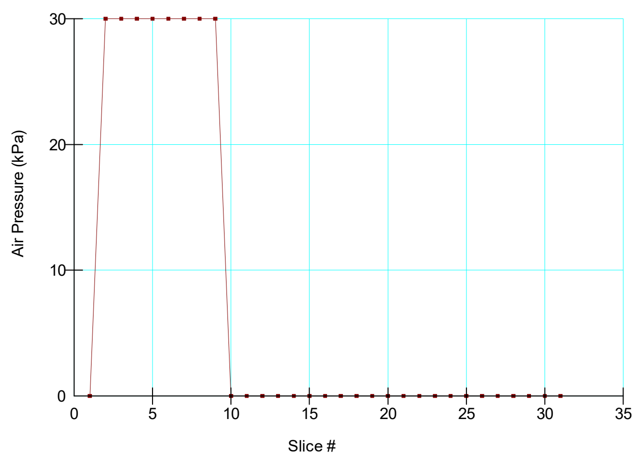

Figure 4. Pore-air distribution for Case 1 and 3.

Figure 5 shows the factor of safety for Case 3. The addition of pore-air pressure reduces the factor of safety compared to Case 2 because the effective normal stress is reduced, but the addition of suction strength causes the FOS to be higher than Case 1. A plot of suction strength verses slice base is shown in Figure 6. The suction strength in the core is 8 kPa, compared to only 5 kPa for Case 2 (see graph in file). The key concept is the trade-off between suction strength and effective stress. The pore-air pressure reduces the effective stress, but simultaneously increases the matric suction. As such, the overall effect of changing the pore-air pressure depends on the suction strength definition.

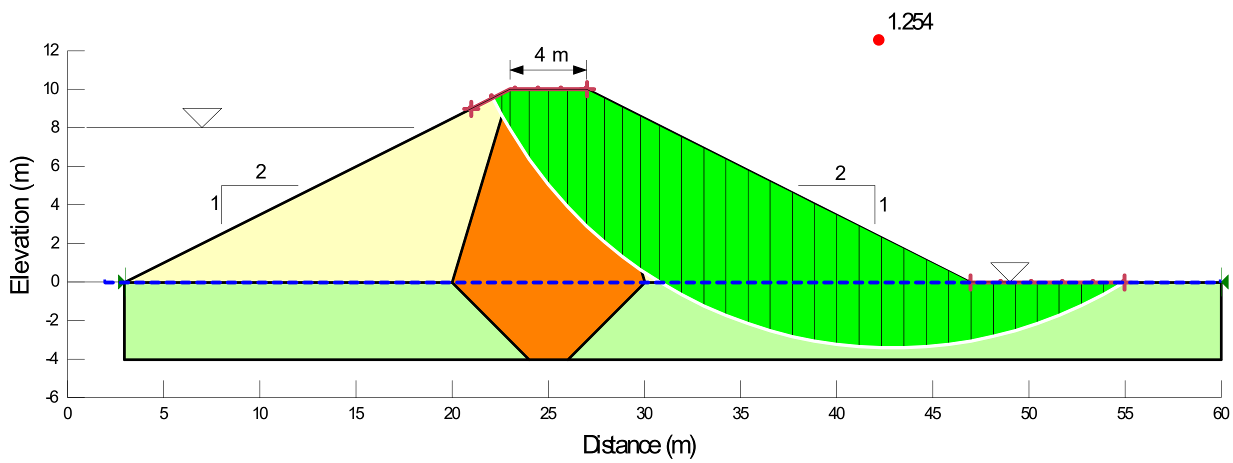

Figure 5. Case 3 factor of safety.

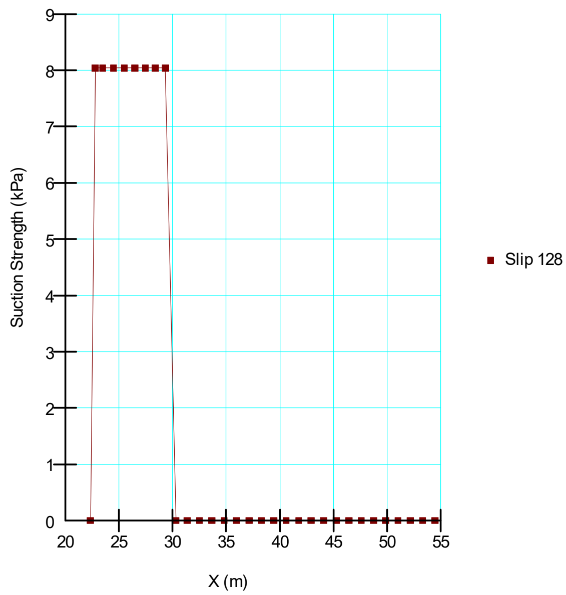

Figure 6. Suction strength for Case 3.

Summary and Conclusions

This example demonstrates that the effect of pore-air pressure on shear strength in the unsaturated zone must be interpreted in the context of the Mohr-coulomb strength equation for unsaturated soils. An increase in pore-air pressure reduces the effective stress, but also increases the matric suction. As such, the suction strength can offset the reduction in effective stress strength. However, this example used a simple PhiB definition for the unsaturated strength definition. The use of a volumetric water content function is more rigorous but complicates the interpretation because the suction strength depends on the characteristics of the volumetric water content function.

SLOPE/W can handle the suction strength and air-pressure simultaneously. However, SLOPE/W alone has no mechanism to make sure that there is a correct balance between the pore-air and pore-water pressures. So caution and care is required when making use of the pore-air feature in SLOPE/W. Generally, it is best to start with looking at the effect of air pressure alone to assess its relevance. If it does not have a great influence on the stability, it can therefore be ignored. If it is of significance, then a careful study of the interrelation between u_a and u_w is required. It is worth noting that SLOPE/W only recognizes the pore-air pressure where the pore-water pressure is negative.

References

Hilf, 1948. Estimating construction pore pressures in rolled earth dams. Proceedings, 2nd International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, The Netherlands. Vol. 3, pg. 234 – 240.

Wilson, G.A., Clifton, W., and S.L. Barbour, 1999. The Emergence of Unsaturated Soil Mechanics. NRC Press, Ottawa, Canada.