GeoStudio Example File
Suction Strength

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Introduction

The shear strength of an unsaturated soil comprises three components: cohesion, frictional strength, and suction strength. Suction strength arises from the negative pore-water pressure acting on the soil grains, which increases the effective stress. This component is often ignored is geotechnical design, however, it can be important in certain classes of problems including rainfall-induced instability or back analysis of overly steepened slopes. This example describes how to include suction strength in a SLOPE/W analysis and the effect it has on the calculated factor of safety.

Background

There are a number of equations available in the literature to describe the shear strength of unsaturated soils. Vanapalli et al. (1996) suggested a non-linear shear strength equation that involved a normalization of the volumetric water content function given by:

$$\tau = c' + (\sigma_n - u_a)tan\phi' + (u_a - u_w)S_e tan\varphi'$$

Equation 1

where τ is the shear strength, c' the effective cohesion, $(\sigma_n - u_a)$ the net normal stress on the failure plane, σ_n the total normal stress; u_a the air pore-air pressure; u_w the pore-water pressure; $(u_a - u_w)$ the matric suction; ϕ' the friction angle; and, S_e is the effective degree of saturation given by:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

Equation 2

where θ is the volumetric water content and the subscripts r and s indicate residul and saturation, respectively. The suction strength is represented by the third term in Equation 1. The literature clearly demonstrates that the unsaturated shear strength can be related to the volumetric water content function. According to Equation 1, the shear strength of an unsaturated soil increases nearly proportionally with matric suction until the air entry value is reached. At higher matric suctions, the suction strength decreases non-linearly, and in accordance with the decrease in effective degree of saturation, reaching zero once the volumetric water content is equal to the residual value (i.e. θ = θ_r).

The relationship between suction strength and matric suction is soil type dependent via the relationship between volumetric water content and matric suction. Figure 1 presents the volumetric water content of a soil with a porosity of 0.5 and a residual water content of about 0.14. The corresponding suction strength was calculated using the third term in Equation 1 assuming a friction angle of 30°. The suction strength does not begin to increase markedly until the air entry value is exceeded.

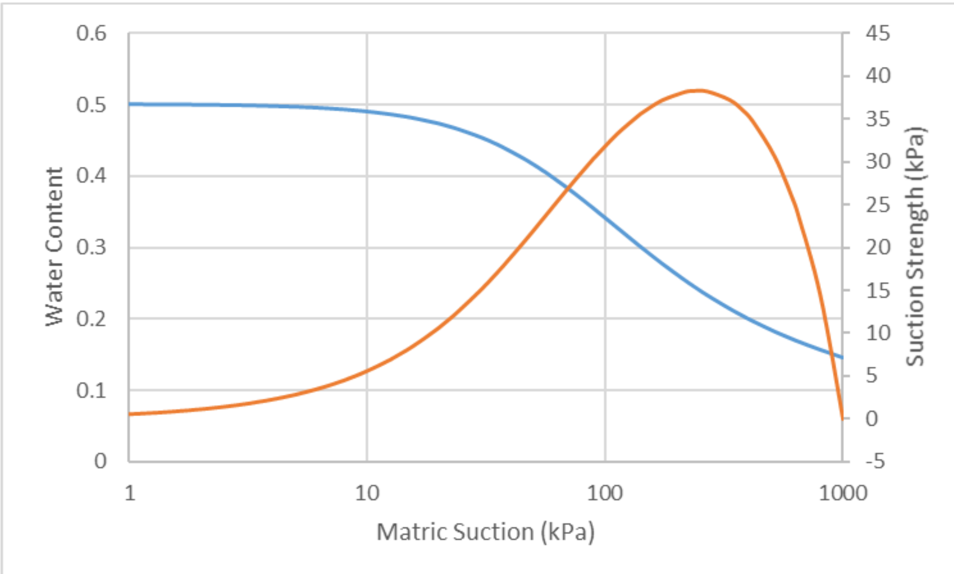

Figure 1. Example of a volumetric water content function.

Numerical Simulation

The effect of the suction strength is illustrated for a simple 2h:1v slope (Figure 2). The suction strength is defined by selecting a volumetric water content on the Suction Strength tab. By default, SLOPE/W does not include suction strength. GeoStudio includes sample VWC functions for a range of material textures. Each of these sample functions are used to illustrate the effect on shear strength in six slope stability analyses (Figure 3). The water table was defined using a piezometric line at the elevation of 10 m.

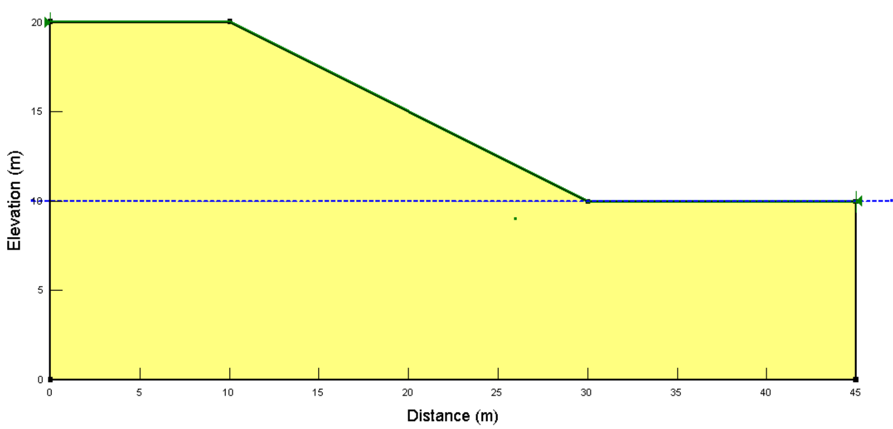

Figure 2. Problem configuration.

Analyses

- 1-clay
- 2-silty clay
- 3-silt
- 4-silty sand
- 5-sand
- 6-gravel

Figure 3. Analysis Tree for the Project.

All of the analyses use a Mohr-Coulomb material model with a soil unit weight of 20 kN/m^3, cohesion of 5 kPa, and friction angle of 20°. The volumetric water content functions were estimated using each of the sample types available in GeoStudio and a saturated volumetric water content of 0.5 (Figure 4).

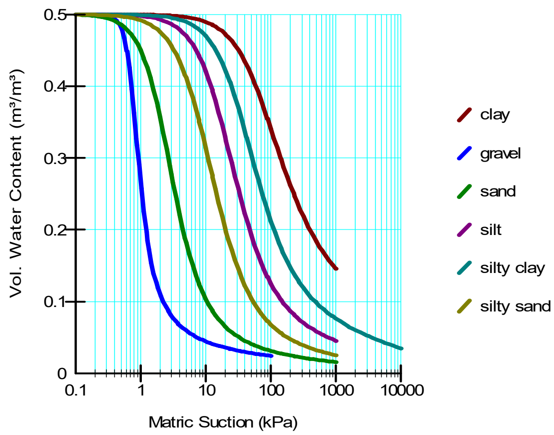

Figure 4. Volumetric water content functions used in each of the analyses.

Results and Discussion

Figure 5 presents the pore-water pressure and suction strength values for each slice of the critical slip surface for Analysis 2.   The suction strength increases as the pore-water pressure becomes negative, but then declines to zero as the pore-water pressure becomes large enough that the residual water content is reached. Also, the suction strength is zero when the pore-water pressure is positive.

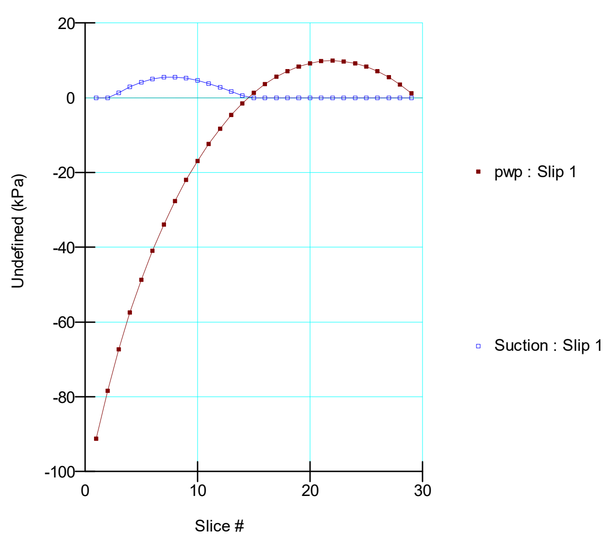

Figure 5.   Suction strength relative to the negative pore-water pressure (Analysis 2).

A plot of suction strength for all analyses is shown in Figure 6. Clay, being a fine grained soil, has a relatively high air entry value and a relatively flat VWC function. Consequently, the strength suction is a significant component of the overall shear strength. In contrast, sand has a relatively low air entry value and a steeper VWC function. The suction contributes very little to the shear strength.

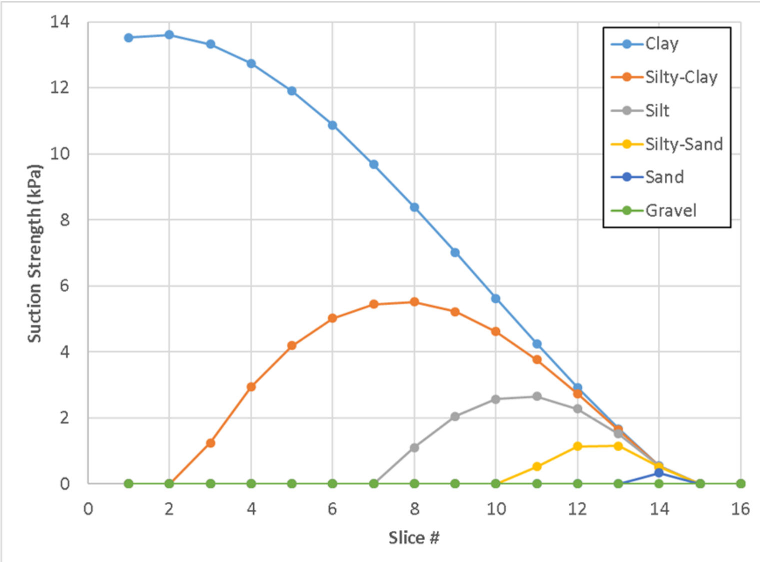

Figure 6. Suction strengths for various materials.

The safety factors for the various soils are in presented in Table 1. The suction strength can have a significant effect on stability. The factor of safety for the gravel slope represents the case in which suction strength is excluded. For a clay slope, the factor of safety rises to 1.342.

Table 1. Safety factors for various soils.

Soil type	Factor of safety
Clay	1.342
Silty-clay	1.226
Silt	1.183
Silty sand	1.171
Sand	1.167
Gravel	1.167

Summary and Conclusions

The shear strength that arises from negative pore-water pressures (i.e., matric suction), known as suction strength, can be included in SLOPE/W. This strength component is often related to the volumetric water content, producing a non-linear relationship. Although suction strength is generally not included in engineering design, it can be essential to analyze and understand many geotechnical problems such as rainfall-induced instability or unsupported vertical excavations that remain stable. It can also be included in back-analyses to produce a more conservative value for the friction angle.

References

Vanapalli, S.K., Fredlund, D.G., Pufhal, D.E. and Clifton, A.W. 1996. Model for the prediction of shear strength with respect to soil suction. Canadian Geotechnical Journal, Vol. 33 (3), 379 – 392.