GeoStudio Example File

SHANSEP – Stress History and Normalized Soil Engineering Property

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Introduction

Efforts have been directed at defining the undrained strength of a soil as a function of the effective overburden stress. The undrained strength (S_u) often increases in direct proportion to the effective overburden stress (σ_v'). This relationship is represented using a ratio of shear strength to vertical effective stress (τ/σ_v'). Ladd and Foott (1974) suggested that the ratio can be refined to reflect the stress history of the soil, as defined by the over-consolidation ratio (OCR). They developed a special testing procedure to capture this phenomenon and called it the SHANSEP method (Stress History and Normalized Soil Engineering Property). This examples discusses the use of the SHANSEP undrained strength model in SLOPE/W, with a particular emphasis on ensuring that the effective stress regime is consistent with the stress state used for testing.

Numerical Simulation

The analyses in the GeoStudio project file considers a 1 m thick overconsolidated crust overlying a soft, weak soil (Figure 1). The water table is located at the base of the crust and is defined using a piezometric line. The intention is to construct a 4-m high embankment with a 4:1 slope at this site. The embankment is considered to be a free draining material (i.e., sand). The undrained strength of the soft soil is to be represented by the SHANSEP material model. Research has demonstrated that the undrained strength of normally consolidated clay soils can be represented by a constant strength ratio defined as $S_u/\sigma_v' = constant$. The undrained strength is normalized with respect to the vertical effective overburden stress.

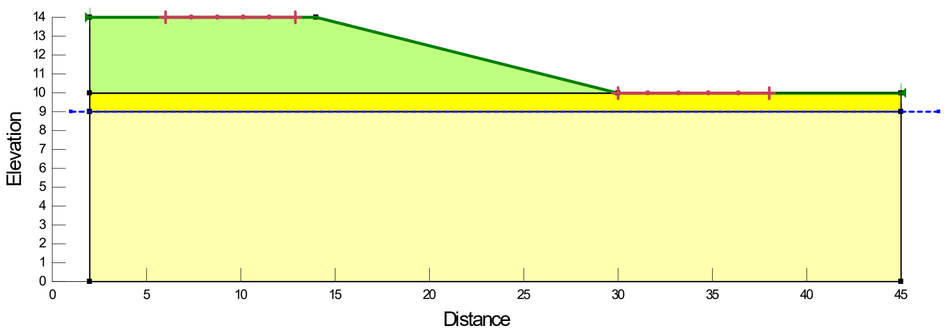

Figure 1 Problem configuration

For this illustrative example, the ratio has been selected to 0.3.

The undrained shear strength is then computed as

$$S_u = 0.3\,\sigma_v' \qquad \text{Equation 1}$$

Overconsolidation increases the undrained strength. When the overconsolidation ratio (OCR) is greater than 1.0, the undrained shear strength can be computed as:

$$S_u = 0.3\,\sigma_v'\,OCR^n \qquad \text{Equation 2}$$

where *n* is an experimentally determined exponent.

Using the SHANSEP soil model requires considerable care to make sure that the strength is referenced to the correct vertical effective stress. For example, in this illustrative example the short term undrained strength needs to be referenced to the effective stress conditions before the embankment is in place. The simulation therefore needs to be done in such a way that rapid placement of the embankment does not alter the effective stress in the foundation. The embankment weight will increase the pore-pressure, but if the excess pore pressure equals the embankment weight then the effective stress will not change. Two different techniques are illustrated here to correctly control the effective stress and in turn obtain the correct desired undrained strength.

SHANSEP options

GeoStudio allows for three different ways of specifying the SHANSEP undrained strength (Figure 2).

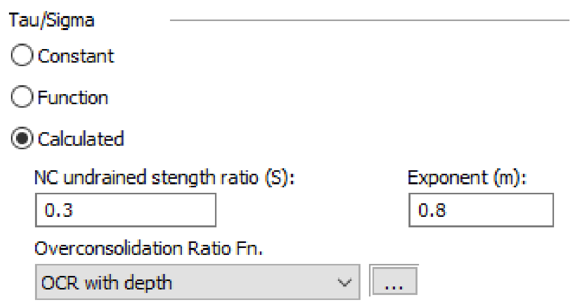

Figure 2 SHANSEP option

The Tau/Sigma ratio can be specified as a constant. Alternatively, the undrained strength can be specified directly as a function of the vertical effective stress. Finally, the Tau/Sigma ratio can be calculated from a closed form relationship that considers the spatial variability in the OCR. Each of these options are illustrated below.

Controlling the pore pressure response

As already noted above, for a short term rapid type of analysis the objective is to not alter the effective stress in the foundation. This can be done by defining a piezometric line together with a B-bar ($\overline{B}$) constant. This option is selected in the Define Analyses dialog box as shown in Figure 3.

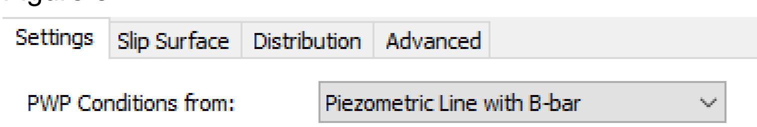

Figure 3 Selecting the pore pressure option

The next step is to flag the materials to which the piezometric line applies. The piezometric line is not applied to the embankment material and the upper overconsolidated crust. The No selections are shown in Figure 4

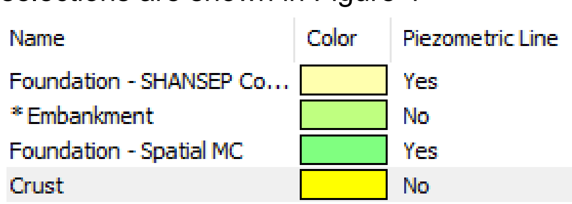

Figure 4 Material piezometric line application

The next step is to flag which material(s) generate excess pore pressure and which material(s) 'add weight'. As shown in Figure 5, B-bar is one for the foundation material but only the embankment is flagged as adding weight; that is, is the source of the excess pore-water pressure.

Materials:

Name	Color	B-bar	Add Weight
Foundation - SHANSEP C...		1	No
Embankment		0	Yes
Foundation - Spatial MC		0	No
Crust		0	No
Foundation - SHANSEP F...		1	No
Foundation - SHANSEP C...		1	No

Figure 5 Definition of B-bar and material weigh to include

These options need to be set specifically for each Analysis.

Since B-bar is 1.0, the excess pore pressure will equal the change in vertical total stress caused by adding the fill; consequently, the effective stress in the foundation remains unchanged from the condition that existed prior to fill placement.

1 - SHANSEP Constant

Analysis 1 defines the undrained strength with a SHANSEP constant of 0.3. The Factor of Safety for this case is 1.085 as shown in Figure 6. The shear strength along the slip surface in the foundation is shown in Figure 7. The strength is the lowest at the top of the foundation layer and increases as the slip surface passes deeper into the foundation where the initial effective stress was higher.

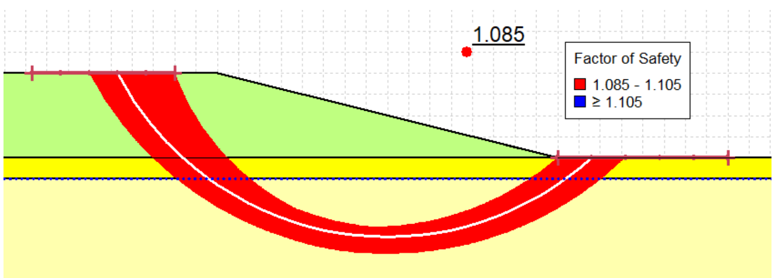

Figure 6 Short term SHANSEP constant

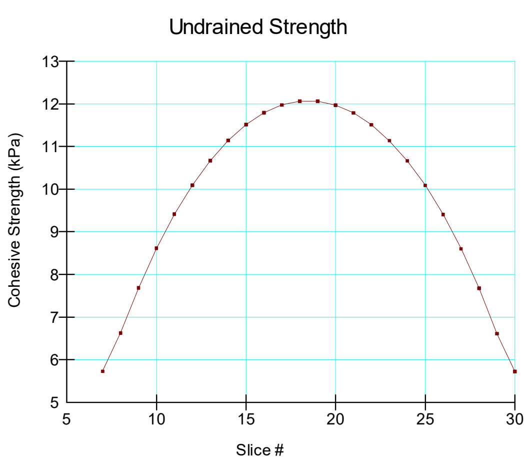

Figure 7 Short term SHANSEP constant

2 - SHANSEP function

Say that shear strength testing data is available at various depths within the foundation clay. Such data could be used to create a function like the one in Figure 8. At σ'_y = 18 kPa, S_u is 14 kPa. At σ'_y = 35 kPa, S_u is 10.3 kPa. The higher strengths near the top of the profile is a reflection of overconsolidation.

The advantage of this option is that the strength function can have any shape that reflects test data. This could be useful in cases where there are different layers with different composition and a different stress history.

The result for this case is shown in Figure 9 and Figure 10. The Factor of Safety is 1.193, which is higher than for the previous SHANSEP constant case. This is due to the higher strength at the top of the foundation layer as specified in the strength function. This effect can be seen in the strength along the slip surface as depicted in Figure 10.

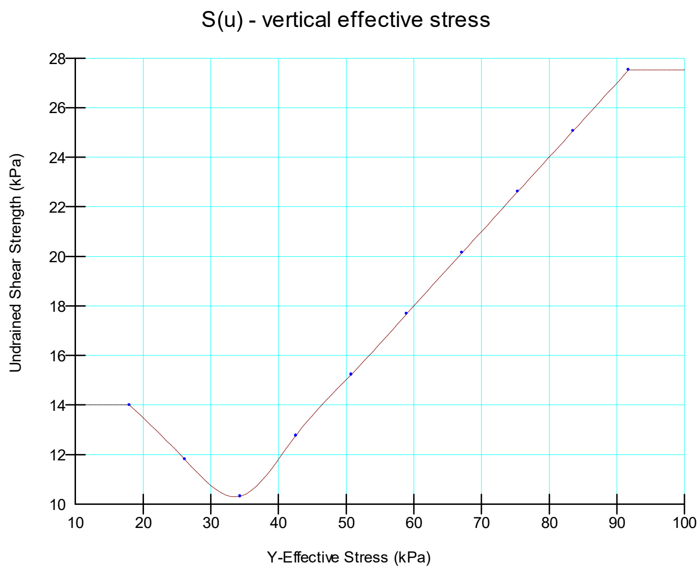

Figure 8 SHANSEP strength function

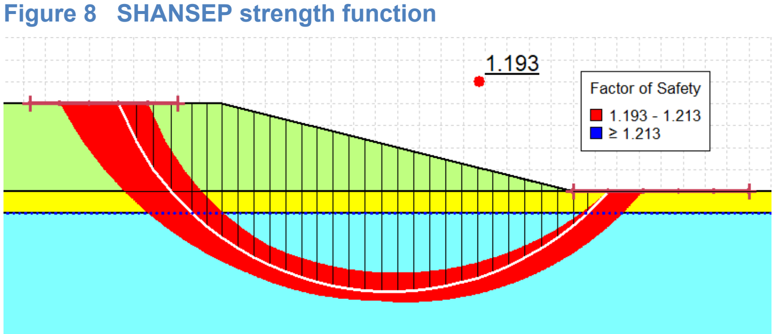

Figure 9 Short Term SHANSEP function

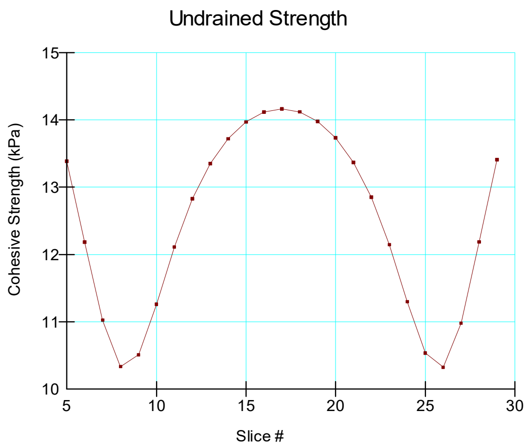

Figure 10 Short Term SHANSEP function

3 - SHANSEP Calculated

Say that a series of odometer tests have be done and that it is possible to define OCR at various depths within the foundation clay. GeoStudio allows for the specification of an OCR function y-coordinate (Figure 11). The OCR is three at the top of the soft layer (i.e. El. 9 m), transitioning nonlinearly to 1.0 at depth, which reflects normal consolidation.

The results for this case are given in Figure 12 and Figure 13. Again, the higher strengths where the slip surface is close to the top of the layer are a reflection of the overconsolidation.

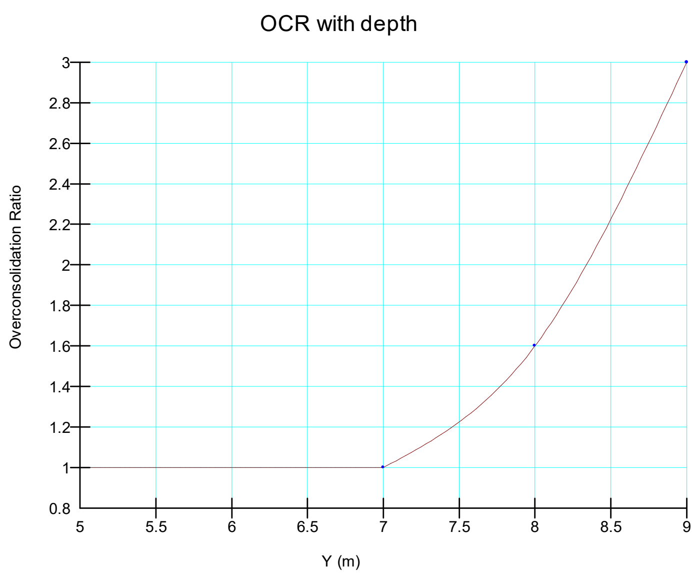

Figure 11 OCR function

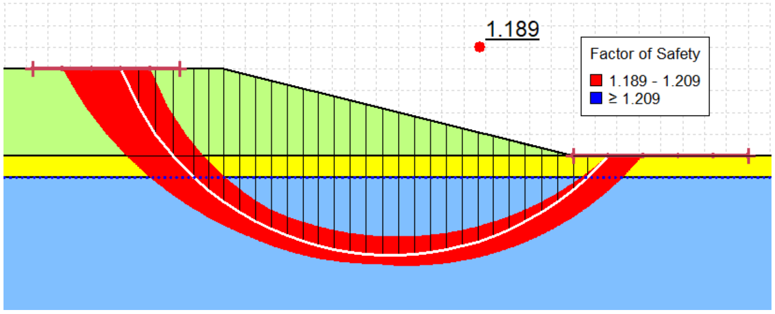

Figure 12 Short Term SHANSEP calculate

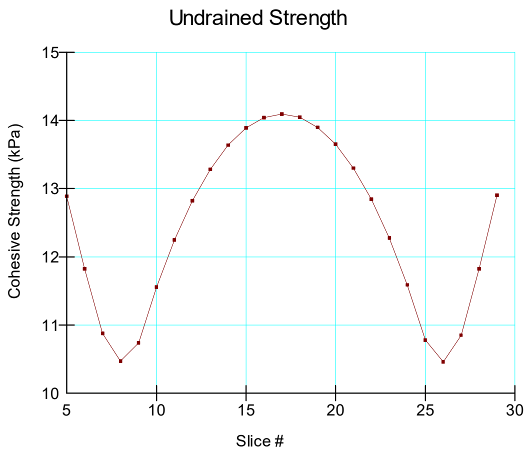

Figure 13 Short Term SHANSEP calculate

4 - Short Term with Spatial Function

The use of the SHANSEP model in combination with a piezometric line and B-bar can avoided by using a Spatial Function. Consider the aforementioned case involving a SHANSEP constant of 0.3.

The vertical effective stress at the water table is calculated as:

$$\sigma_v^{'} = \gamma_s z = 18\ kN/m^3 * 1m = 18\ kPa \qquad \text{Equation 3}$$

and the corresponding undrained strength as:.

$$S_u = 18\ kPa * 0.3 = 5.4\ kPa \qquad \text{Equation 4}$$

The effective vertical stress at the bottom of the foundation layer is calculated as:

$$\sigma_v^{'} = \left(18\ kN/m^3 * 10m\right) - (9.807 * 9m) = 91.737\ kPa \qquad \text{Equation 5}$$

where the unit weight of water is taken as 9.807 kN/m^3. The corresponding undrained strength is given by:

$$S_u = 91.737\ kPa * 0.3 = 27.52\ kPa \quad \text{Equation 6}$$

Figure 14 presents a graph of the undrained strength verses y-coordinate functional relationship used to define the cohesion for the Spatial Mohr-Coulomb material model. The friction angle (phi) is set to zero. Figure 15 shows a contour map of the undrained strength as created by the Spatial Function.

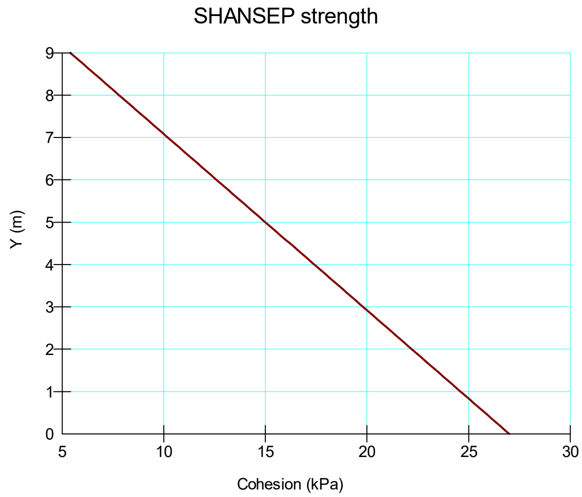

Figure 14. Undrained shear strength as function of elevation (y-coordinate) based on S_u/σ'_v = 0.3.

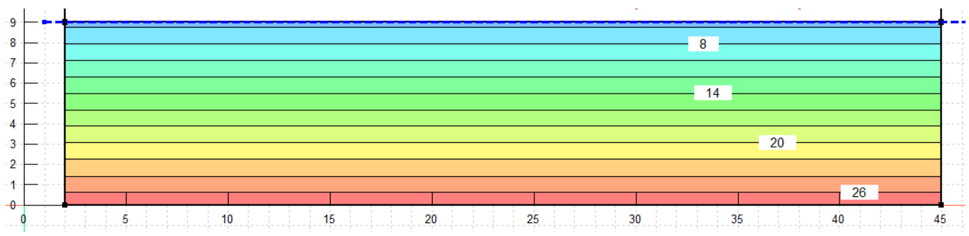

Figure 15 Undrained strength contour map from Spatial Function

Since the foundation soil is now described directly by undrained strength, a pore-water pressure definition is unnecessary.

The Spatial Function was created assuming a SHANSEP constant equal to 0.3. The results therefore should be identical to Analysis 1. Comparing Figure 16 with Figure 6 reveals that this is indeed the case. The Factors of Safety is 1.085 in both cases.

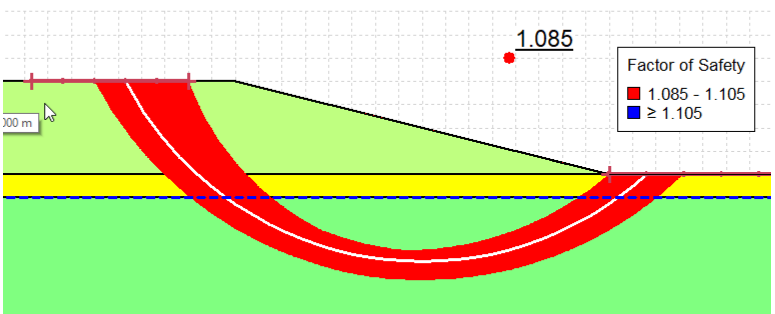

Figure 16 Short Term with Spatial Function

Figure 17 shows that the undrained strength for these two cases is identical.

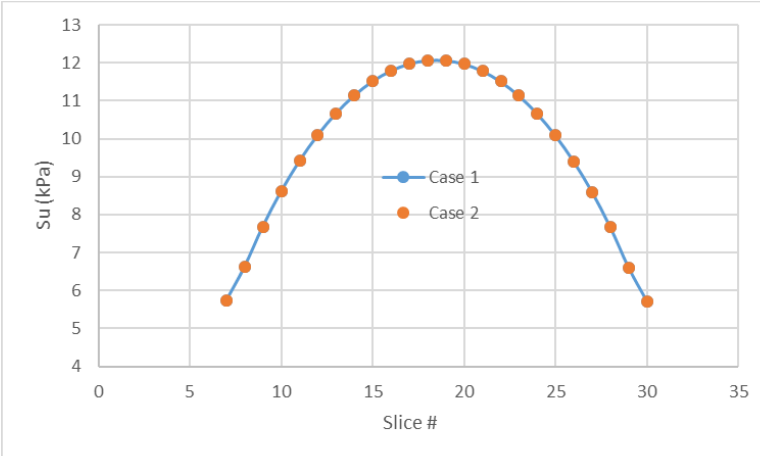

Figure 17. Undrained shear strength variation in the soft underlying soil for Case 1 and 4.

5 - Long Term with SHANSEP

With time the excess pore resulting from the embankment placement will dissipate and the effective stress will increase which will be reflected in higher undrained strengths.

This case can be modeled by ignoring any B-bar effects. The pore pressure conditions are define with a piezometric line as in Figure 18. Note that in reality the SHANSEP constant would likely have changed and/or the OCR profile from prior to construction would no longer be valid.

The Factor of Safety is much higher (Figure 19) because the undrained strength are much higher (Figure 20), particularly on the left where the embankment fil is the thickest.

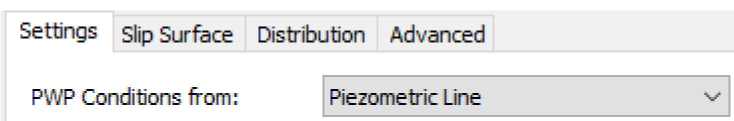

Figure 18 PWP option for long term conditions

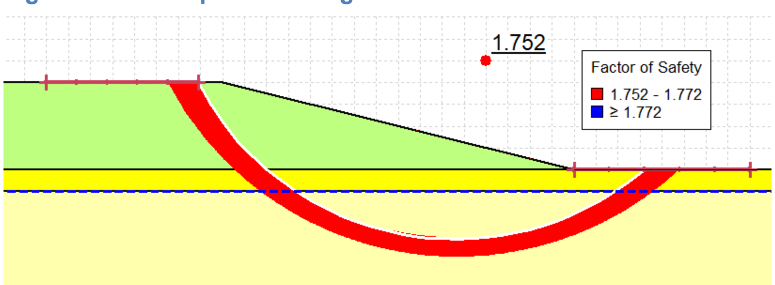

Figure 19 Long term Factor of Safety

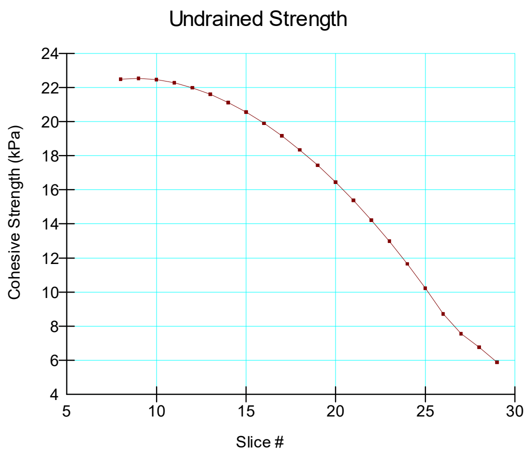

Figure 20 Long term strength after dissipation of the excess construction pore pressure

Summary and Conclusions

The SHANSEP material model defines the undrained shear strength as a function of effective vertical stress using a τ/σ'_v ratio. This parameter is often related to the over-consolidation ratio. A clear understanding of the stress and pore-water pressure conditions is necessary for using the SHANSEP model. When a simulation involves a fully-drained soil or long-term consolidation, this ratio can be used directly with the measured pore-water pressure conditions. When excess pore-water pressures due to surcharge loads are involved, the defined pore-water pressures must be consistent with the loading condition. This will ensure that the calculated undrained strength corresponds to the effective stresses before loading.

References

Ladd, C.C. and Foott, R. 1974. New design procedure for stability of soft clays. Journal of Geotechnical Engineering ASCE 100 (7): 763-786.