GeoStudio Example File
Strength Reduction Stability

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Introduction

Stability by strength reduction is a procedure where the factor of safety is obtained by weakening the soil in steps in an elastic-plastic finite element analysis until the slope fails. The factor of safety is deemed to be the factor by which the soil strength needs to be reduced to reach failure (Dawson et al., 1999; Griffiths and Lane, 1999). This example illustrates how a Strength Reduction stability analysis can be done with SIGMA/W. In addition, the results are discussed in the context of an alternate procedure known as a stress-based stability analysis.

Numerical Simulation

Figure 1 shows the analysis tree for the project. An *In Situ* Gravity Activation analysis is used to establish the state of stress in a 2h:1v 10 m high slope (Figure 2). The specified soil stiffness is arbitrary for an *In Situ* analysis because the displacements are inconsequential. Poisson's ratio governs the amount of stress that transfers into the horizontal direction when using Gravity Activation (vs the K0 Procedure).

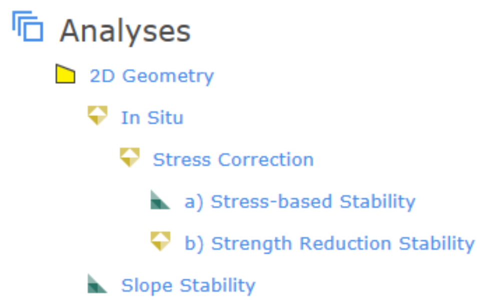

Figure 1. Analysis tree for the Project.

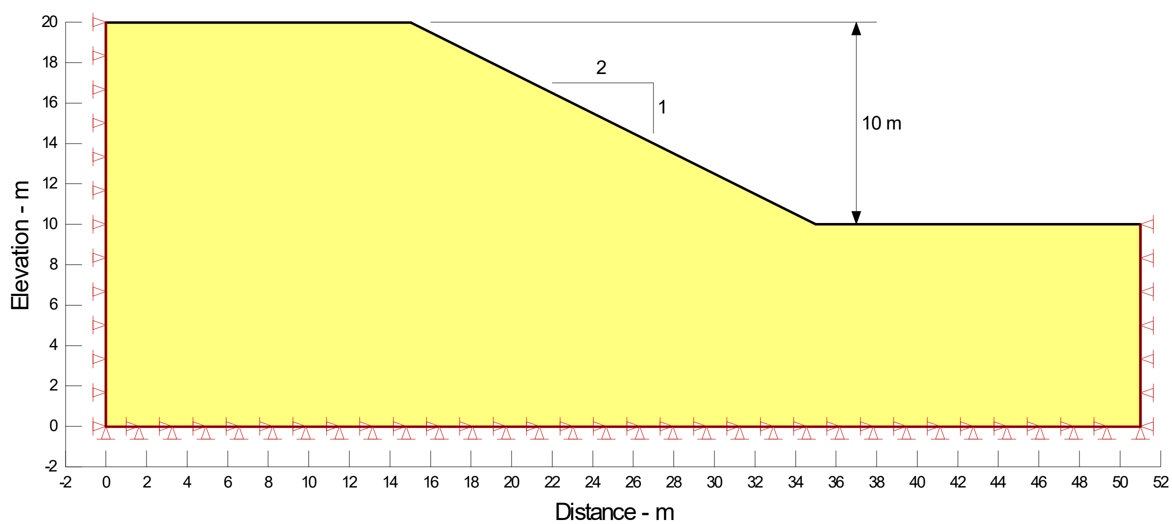

Figure 2. Problem configuration.

The Stress Correction analysis ensures that all stress states start within legal stress space; that is, on or below the Mohr-Coulomb failure surface. The Stress Correction analysis forms the Parent for the subsequent finite element (FE) stress based and strength reduction stability (SRS) analyses (Figure 1). The FE stress approach calculates a safety factor by integrating the SIGMA/W shear stress and shear strength along the slip surface (see SLOPE/W Reference Book):

$$FS = \frac{\sum_{i=1}^{n} \left(\tau_{f(i)} l_i\right)}{\sum_{i=1}^{n} \left(\tau_{m(i)} l_i\right)}$$

where i is the number of slices, $\tau_{f(i)}$ shear resistance at the base of the slice, $\tau_{m(i)}$ mobilized shear stress at the base of the slice, and l_i is the base length of the slice. A Limit Equilibrium (LE) stability analysis is also used for comparison purposes (Figure 1).

The SRS analysis defines the strength reduction factor (SRF) as:

$$SRF = \left(\frac{\tan \phi'}{\tan \phi'_f}\right) = \left(\frac{c'}{c'_f}\right) \qquad \text{Equation 1}$$

where ϕ'_f and c'_f are the effective stress strength parameters at failure. Figure 3 presents the settings for the SRS analysis. The initial and final factors are set to 1.3 and 1.75, respectively, with the increment set to 0.025. The starting factor is greater than 1.0 because it is known *a priori* that the Safety Factor is greater than 1.3.

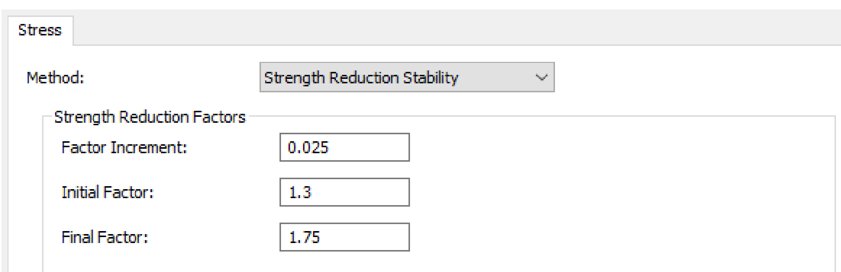

Figure 3. Strength reduction stability analysis settings.

Results and Discussion

The SLOPE/W FE Stress stability factor is 1.51 as shown in Figure 4. Figure 5 presents the distribution of the resistance and driving or mobilized shear along the slip surface. Note that the shear resistance is greater than the mobilized shear along the entire slip surface. As shown in Figure 6, the factor of safety obtained by a limit equilibrium stability analysis in SLOPE/W is 1.49.

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	In Situ Soil	Mohr-Coulomb	20	5	28	0

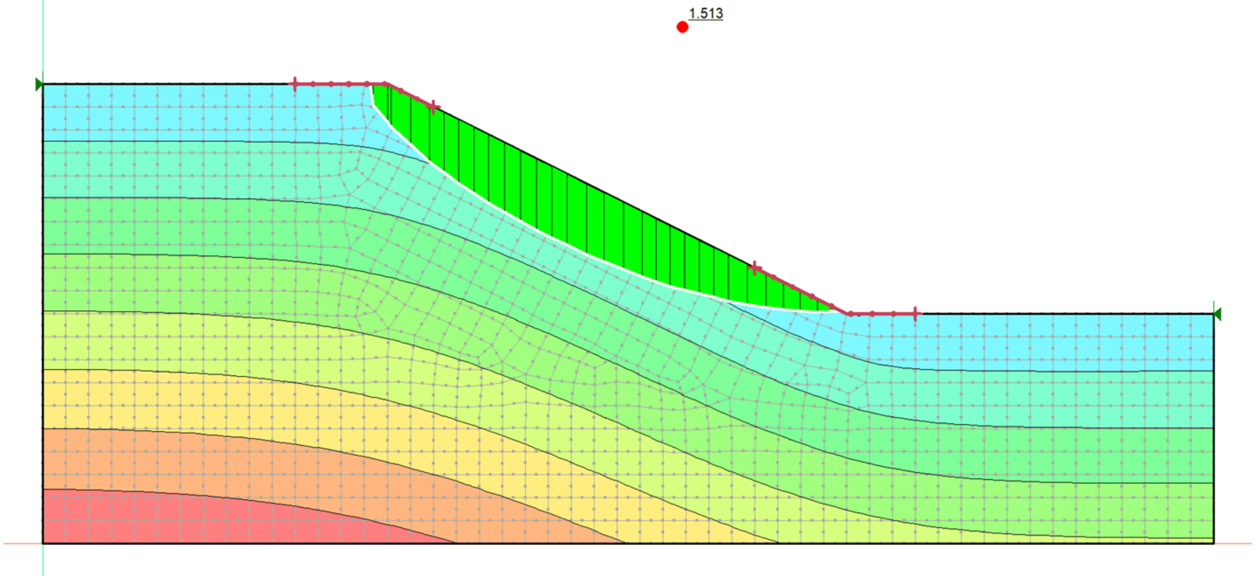

Figure 4. Factor of safety based on *in situ* stresses in Analysis (a).

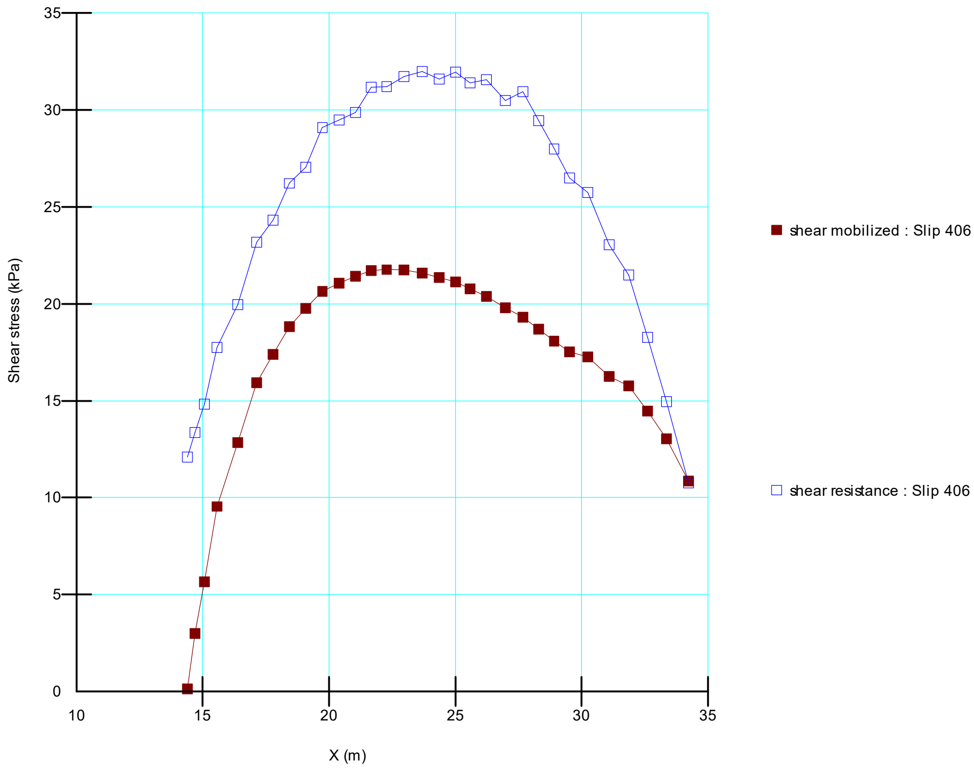

Figure 5. Shear strength and mobilized shear along the slip surface.

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)
	In Situ Soil	Mohr-Coulomb	20	5	28	0

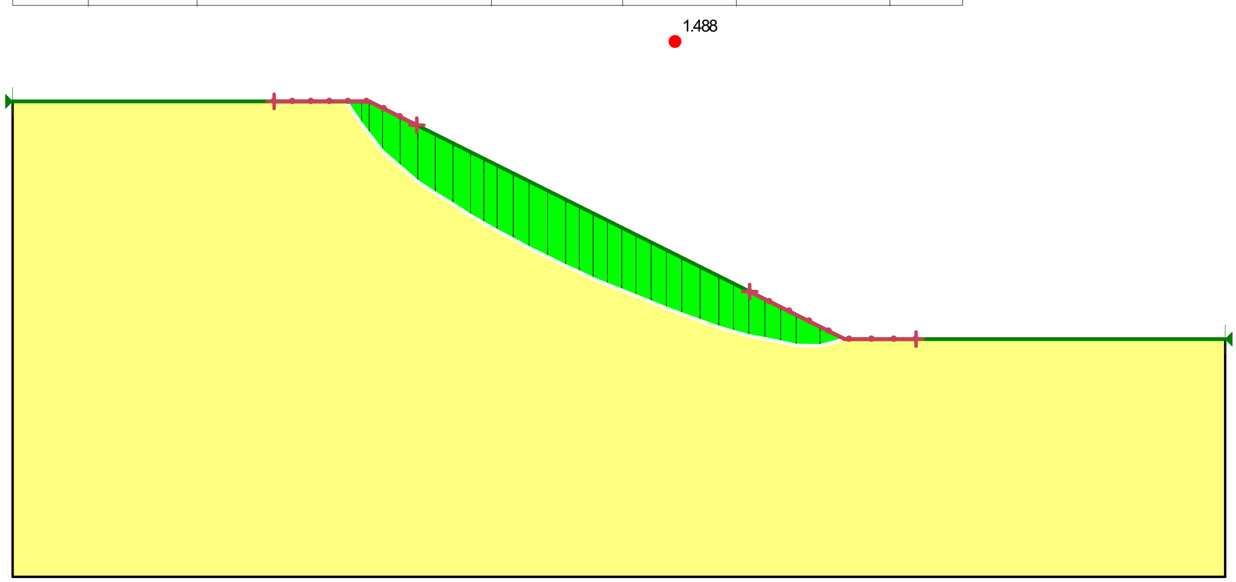

Figure 6. Factor of safety based on *Limit Equilibrium* stability Analysis.

Figure 7 to Figure 8 present the SRS results. Unlike the FE Stability and Limit Equilibrium methods, the factor of safety is not calculated directly via the SRS method, rather it must be interpreted from graphs and other information. Figure 7 shows the plastic states – that is, gauss regions with stress states on the failure surface – and the deviatoric strain contours at a strength reduction factor of 1.45. A global rupture zone has fully developed. The Relative Displacement Error (Figure 8) starts to increase and the iteration count reaches the maximum at an SRF of 1.4 (Figure 9). The crest displacement vs SRF (Figure 10) also shows a demarcation in the rate of change at an SRF of 1.4. The SRS safety factor is therefore around 1.4, which is less than the FE and LE Stability safety factors, thereby confirming that a more critical mode of failure might exist.

Color	Name	Stress Material Model	Initial Void Ratio	Unit Weight (kN/m³)	Effective Elastic Modulus (kPa)	Effective Poisson's Ratio	Effective Cohesion (kPa)	Effective Friction Angle (°)	Dilation Angle (°)	K0
	In Situ Soil	Mohr-Coulomb	0.5	20	50,000	0.334	5	28	0	0.5305

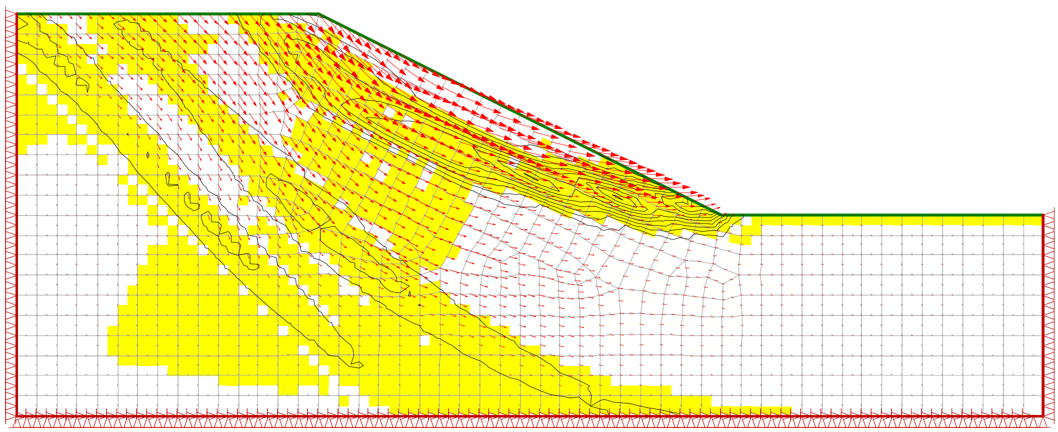

Figure 7. Plastic states (failure) when the safety factor is 1.45.

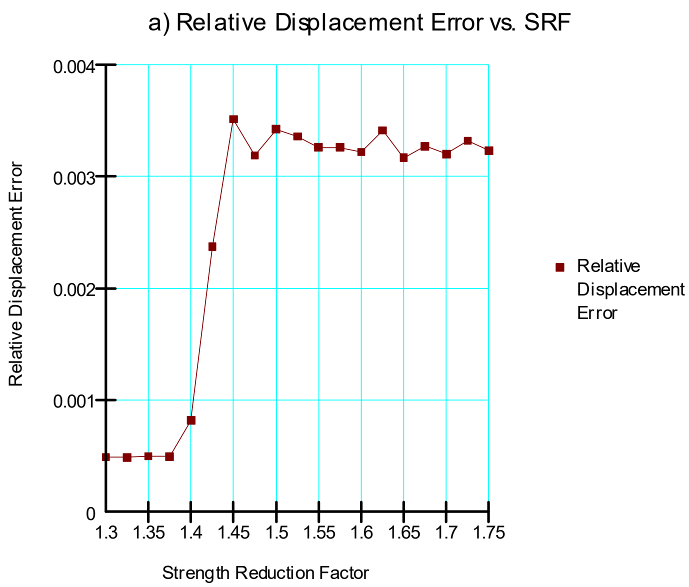

Figure 8. Relative displacement error vs strength reduction factor.

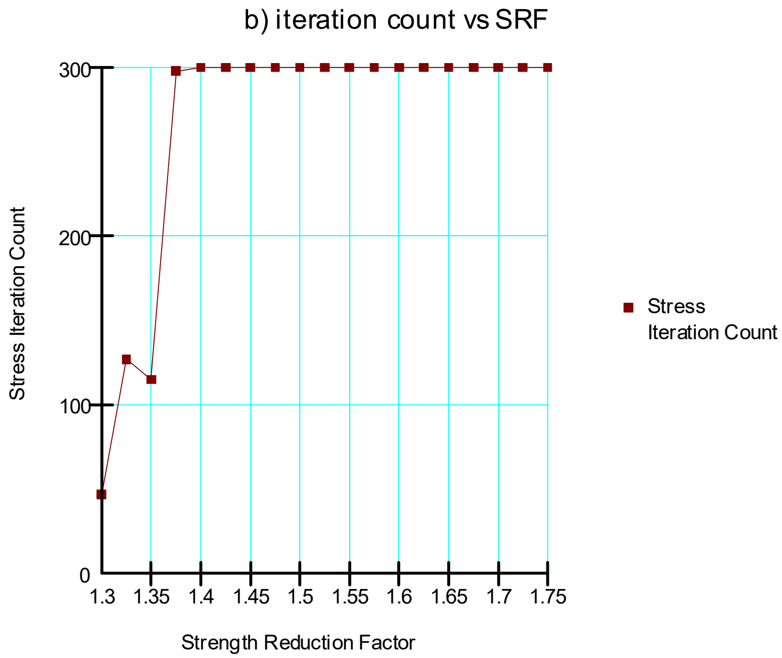

Figure 9. Iteration count vs strength reduction factor.

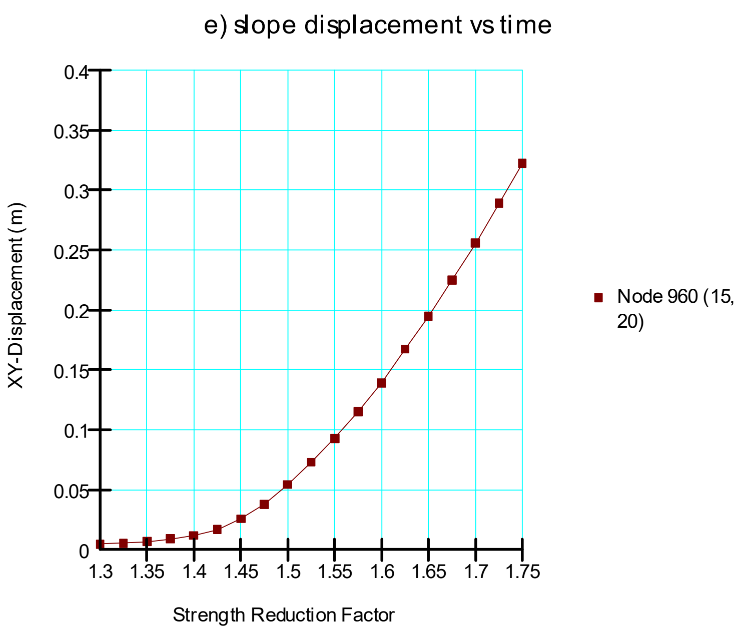

Figure 10. Crest displacement vs strength reduction factor.

Summary and Conclusions

This example demonstrates that SIGMA/W can be used to do a Strength Reduction method of stability analysis. A comparison of the FE and LE Stability with SRS techniques reveal that a key advantage of the SRS technique is that the mode of failure evolves naturally as the strength is reduced.

References

Dawson, E.M., Roth, W.H. and Drescher, A. (1999). Slope Stability Analysis by Strength Reduction, Geotechnique, 49(6), 835-840

Griffiths, D.V. and Lane, P.A. (1999). Slope Stability Analysis by Finite Elements, Geotechnique, 49(3), 387-403