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. Specifically, an analysis is performed with the mobilized strength properties for the friction angle (φ') and cohesion (c'), followed by an incremental decrease of $tan\varphi'$ and c'. This results in stress states that violate the strength criteria, which are resolved by employing the same iterative stress update algorithm used in SIGMA/W for standard elastic-plastic analysis. This example verifies the Strength Reduction stability procedure in SIGMA/W by comparison to Dawson et al. (1999). 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 1h: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).

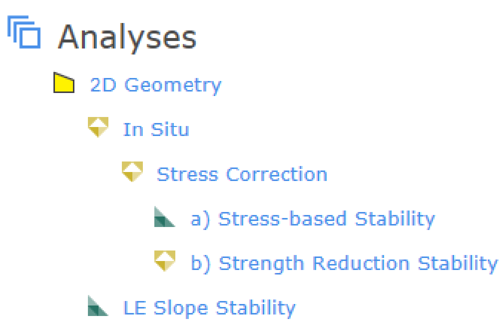

Figure 1. Analysis tree for the Project.

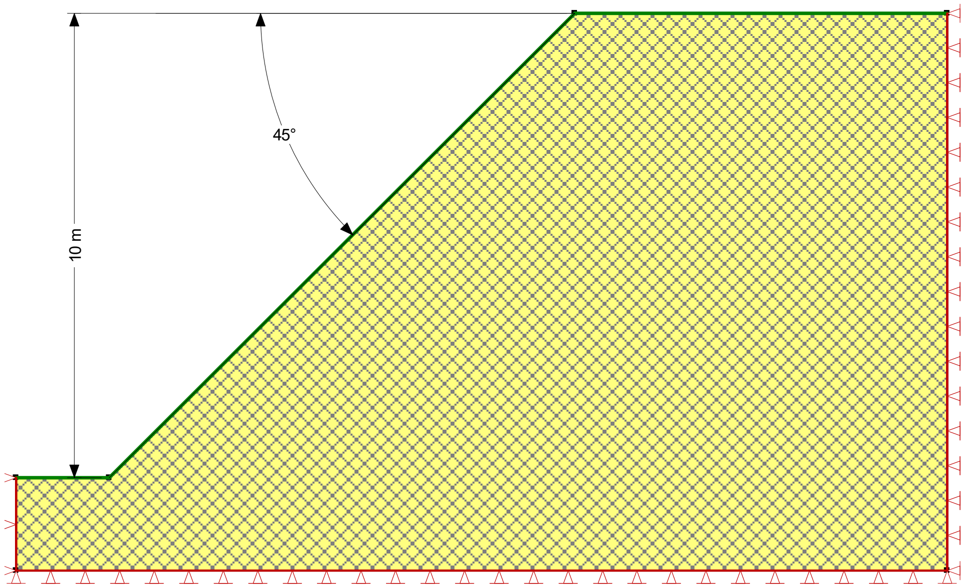

Figure 2. Problem configuration.

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 0.975 and 1.1, respectively, with the increment set to 0.025. The starting factor is less than 1.0 because it is known *a priori* that the Safety Factor is equal to 1.0. The soil has a friction angle and cohesion of 20° and 12.38 kPa, respectively.

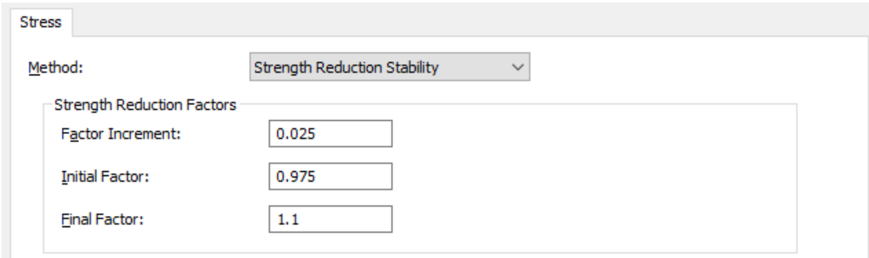

Figure 3. Strength reduction stability analysis settings.

Results and Discussion

Figure 4 shows the displacement contours and vectors generated by the stress correction. The strength properties were carefully selected by Dawson et al. (1999) to produce a configuration that was at state of limiting equilibrium (i.e. failure). The stress correction analysis – by way of correcting returning illegal stresses onto the failure surface - reveals that the slope has collapsed. Ironically, a SRS analysis is not actually required to deduce the strength reduction factor (i.e. factor of safety).

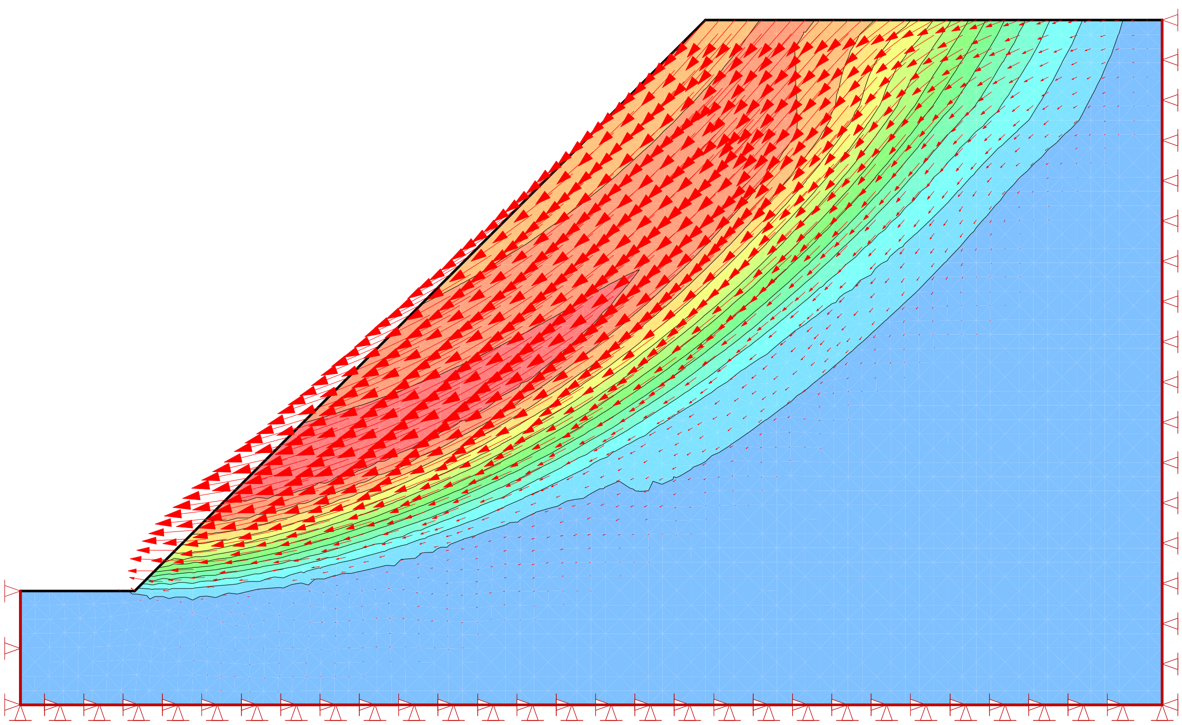

Figure 4. Displacement contours and vectors generated by the stress correction analysis.

The SLOPE/W FE Stress stability factor is 1.044 as shown in Figure 5, which confirms that the slope has failed. Figure 6 presents the distribution of the resistance and driving or mobilized shear along the slip surface. Note that the shear resistance is essentially equal to the mobilized shear along the entire slip surface. As shown in Figure 7, the factor of safety obtained by a limit equilibrium slope stability analysis (i.e., 0.996) is almost identical to the FE Stress stability factor.

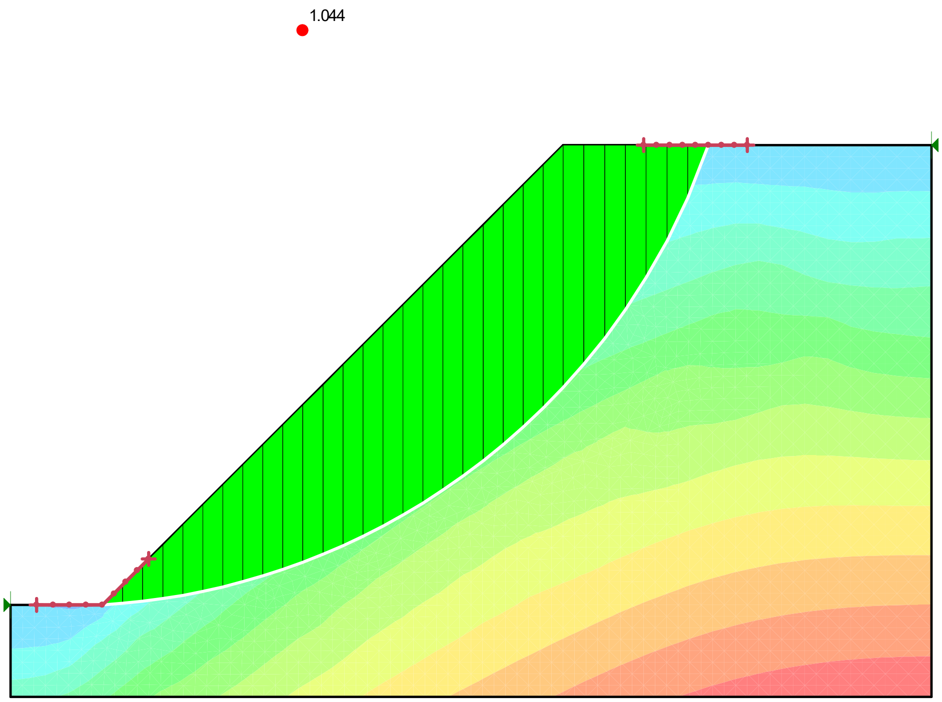

Figure 5. Factor of safety based on *in situ* stresses in Analysis 1.

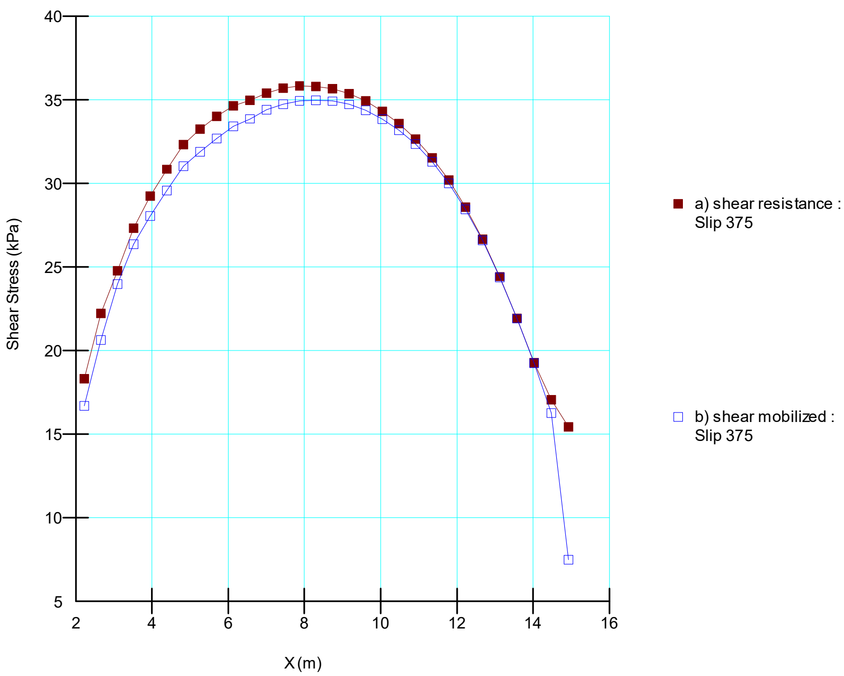

Figure 6. Shear strength and mobilized shear along the slip surface.

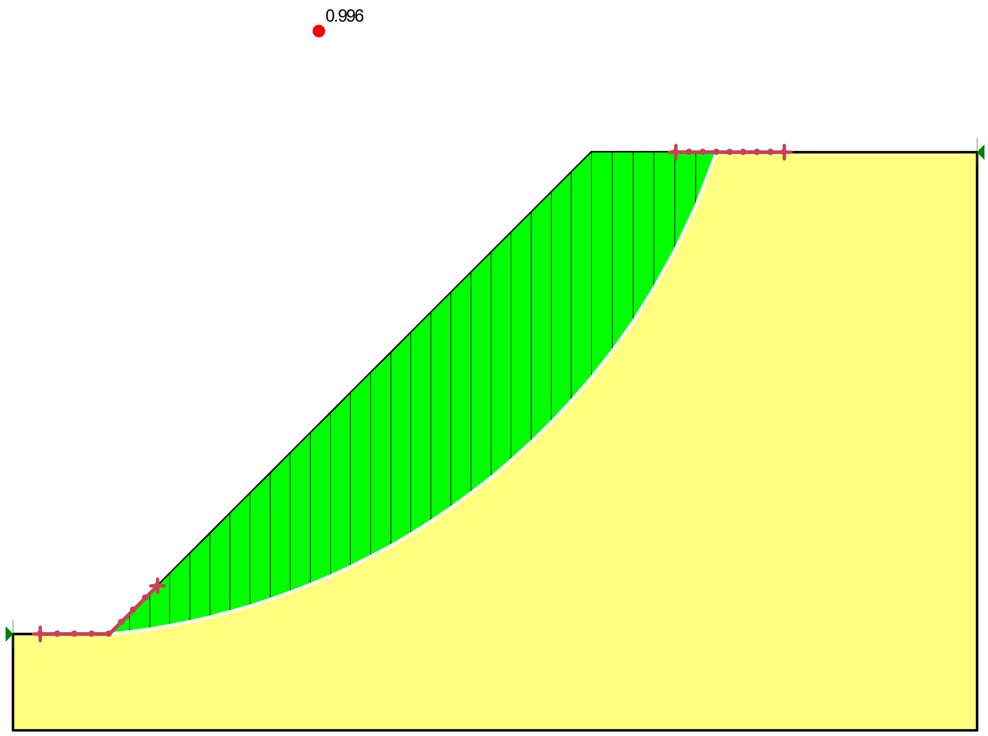

Figure 7. Factor of safety based on *Limit Equilibrium* slope stability Analysis.

Figure 8 to Figure 11 present the SRS results. Unlike the FE Stability and Limit Equilibrium methods, the factor of safety is not calculated directly via the SRS method. The safety factor must be interpreted. The accumulated displacements and strains are reset at the onset of the SRS analysis; consequently, there are no simulated displacements when the SRF is incremented from 0.975 to 1.0 because the stress correction ensure that all stresses are on the failure surface (i.e. SRF = 1.0). The increment to 1.025, however, confirms that the slope is failed. The plastic states and displacement contours clearly reveal a global rupture zone propagating from the toe to the crest. (Figure 8). The deviatoric strain contours more clearly defined the location of the global rupture zone (Figure 9). The Stress Iteration Count and the Relative Displacement Error both increase precipitously at a reduction factor of 1.025 (Figure 10 and Figure 11). Figure 11 also indicates a change in the displacement pattern of the crest for strength reduction factors greater than 1. The SRS safety factor is therefore 1.0, which is in-keeping with the FE Stability safety factor and the results presented by Dawson et al. (1999).

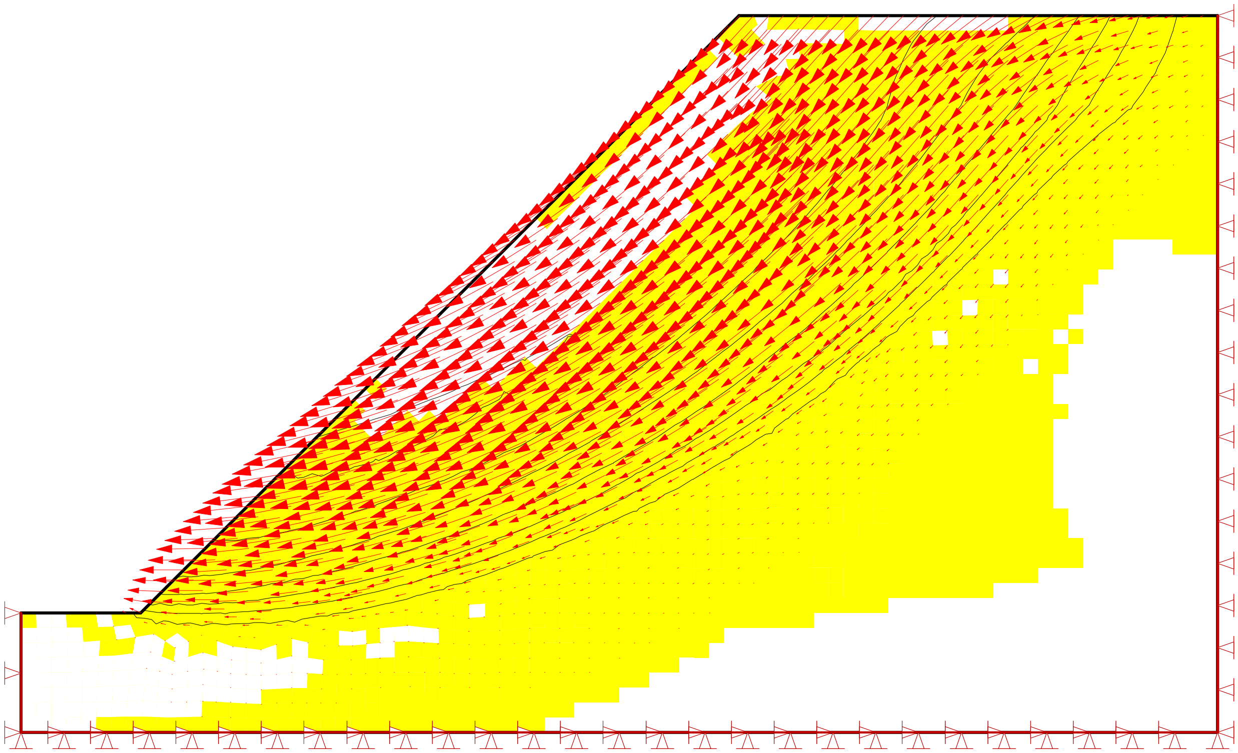

Figure 8. Plastic states (failure) and displacements when the strength reduction factor is 1.025.

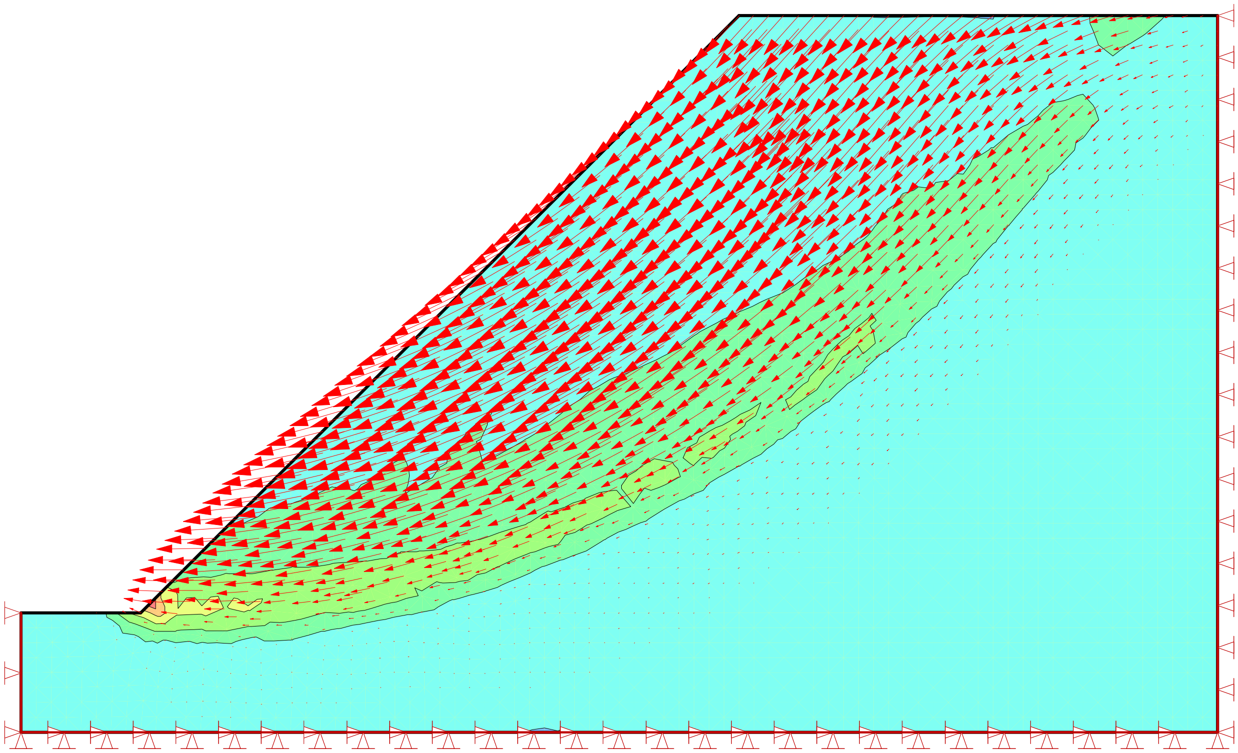

Figure 9. Deviatoric strain contours when the strength reduction factor is 1.025

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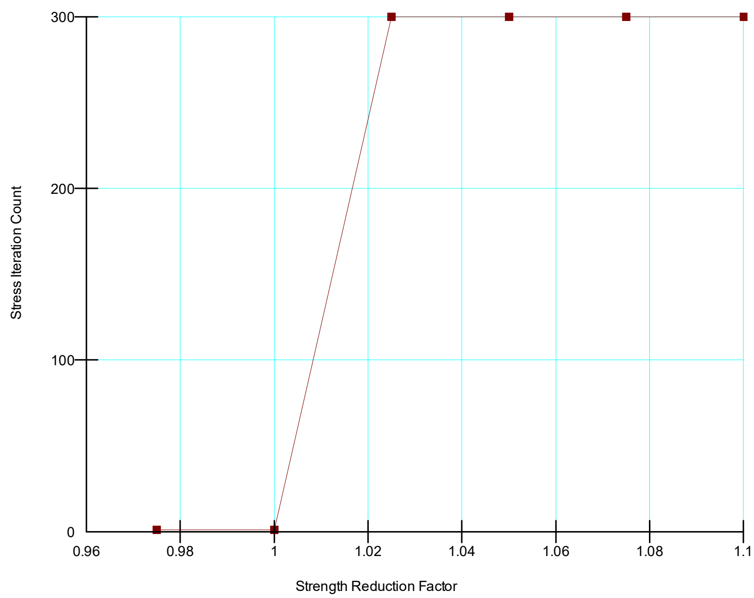

Figure 10. Stress iteration count vs strength reduction factor.

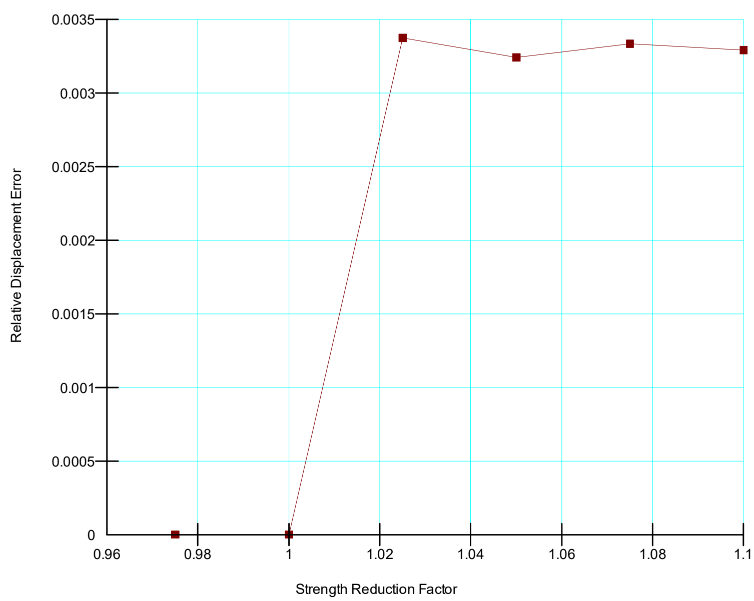

Figure 11. Relative displacement error vs strength reduction factor.

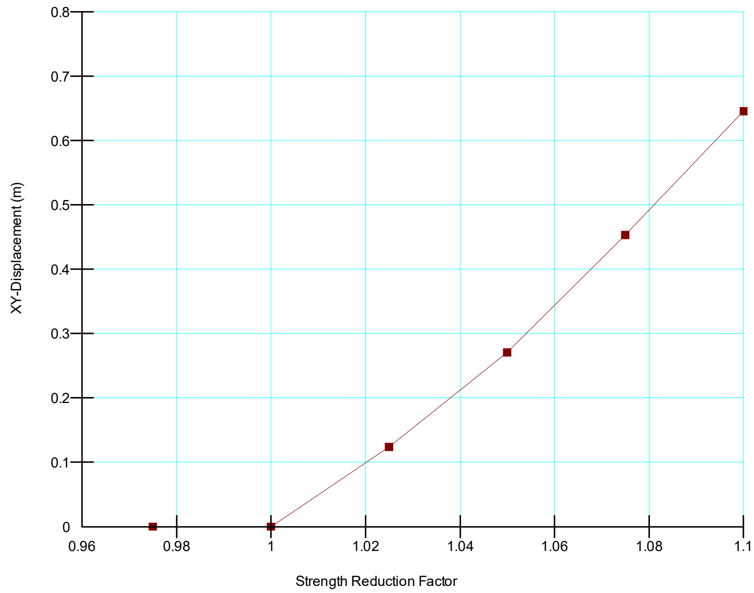

Figure 11. Crest displacement vs strength reduction factor.

Summary and Conclusions

This example verifies the SIGMA/W Strength Reduction method of stability analysis by comparison to Dawson et al. (1999) and SIGMA/W FE and LE Stability analyses.

References

Dawson, E.M., Roth, W.H. and Drescher, A. (1999). Slope stability analysis by strength reduction, Geotechnique, 49(6), 835-840.