Rock Joint and Rock Mass Shear Strength

GEO-SLOPE International Ltd. | www.geo-slope.com

1200, 700 - 6th Ave SW, Calgary, AB, Canada T2P 0T8
Main: +1 403 269 2002 | Fax: +1 888 463 2239

Introduction

SLOPE/W can be used to model the stability of rock slopes using various strength models such as the Barton and Choubey (1977) and Miller (1988) for rock joints or the anisotropic function to model rock mass with linearly anisotropic strength. Linear anisotropy refers to the Mohr-Coulomb criterion with the coefficient of friction and cohesion varying linearly from bedding to cross-bedding direction. This example demonstrates how a shear-normal function can be used to accommodate the rock joint strength models along with the Generalized Hoek Brown model. The Anisotropic Function material model is also highlighted.

Background

The formula by Barton and Choubey (1977) represents a smooth shear-normal curve and can be expressed as:

$$\tau = \sigma_n^{'} \, tan\left(\emptyset_r + JRC \log_{10}\left(\frac{JCS}{\sigma_n^{'}}\right)\right) \qquad \text{Equation 1}$$

where $\emptyset_r$ is the residual friction angle, JRC is the joint roughness coefficient, and JCS is the joint wall compressive strength. Note that the second term in the bracket of Equation 1 cannot be negative (i.e. $\log_{10}\left(\frac{JCS}{\sigma_n^{'}}\right) \geq 0$).

Miller (1988) proposed the following formula to represent the shear strength at low normal stresses in rock:

$$\tau = a(\sigma_n^{'} + d)^b + c + \sigma_n^{'} \tan(\theta_w) \qquad \text{Equation 2}$$

where $a, b, c, and\ d$ are curve parameters, and θ_w is the "waviness angle" when the formula is used to model the shear strength of a rock joint.

Numerical Simulation

Figure 1 presents the geometry of the numerical model. The domain was divided into two regions for the convenience of modeling rock joint. There are three analyses in the GeoStudio Project. In the first analysis, the top region is modeled using a Generalized Hoek-Brown material model, while the lower region is defined using a Barton and Choubey (1977) function. The second analysis makes use of Miller (1988) to model the jointed rock, while the third analysis applies an Anisotropic Function to the entire domain.

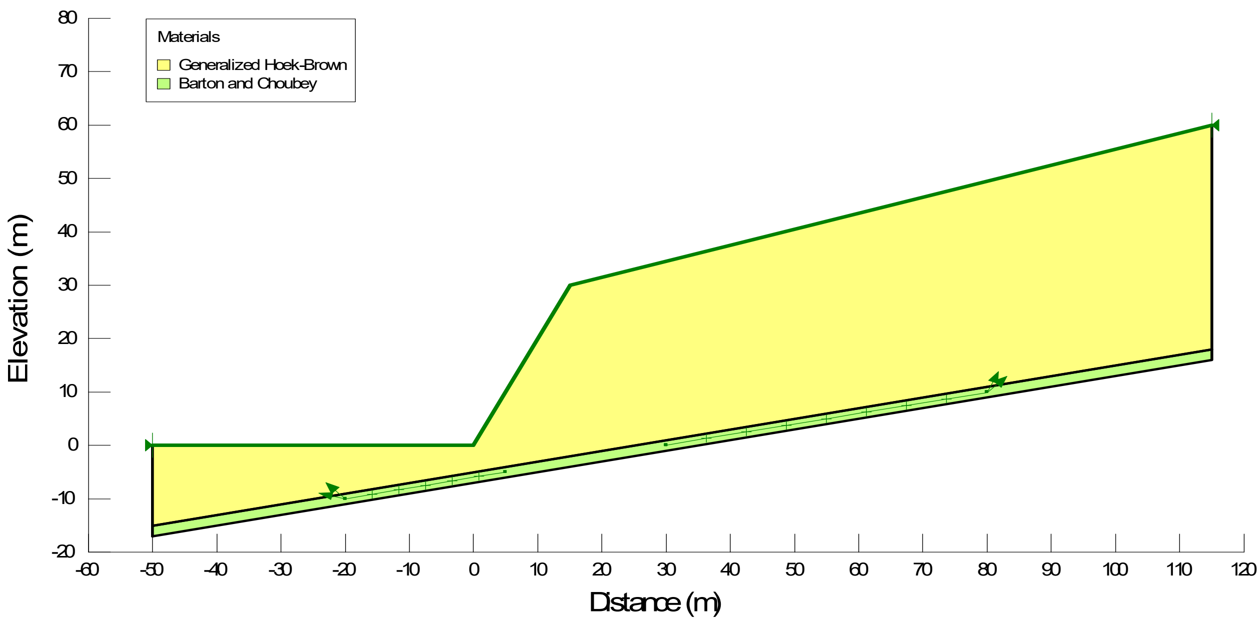

Figure 1. The geometry of the rock slope.

Pairs of shear and normal stresses were generated in an Excel spreadsheet based on Equation 1. The data points were copied from Excel and pasted into the Define Shear/Normal Strength Function window of SLOPE/W (Figure 2). The procedure of using Miller's formula was the same as for the Barton- Choubey model described above.

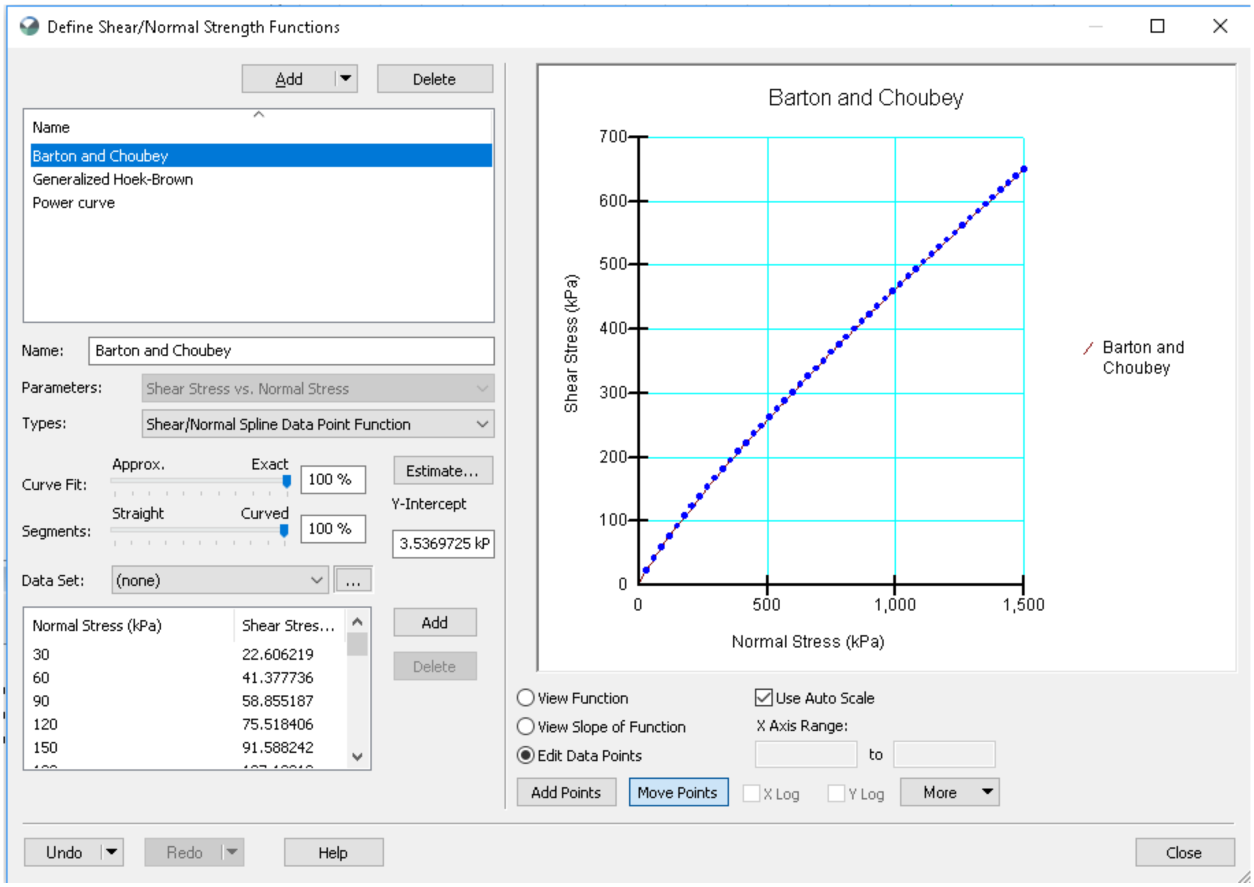

Figure 2. Barton and Choubey (1977) model (JRC = 8, JCS = 4000 kPa, ϕ_r = 20 deg) generated using Shear/Normal Function in SLOPE/W.

The linear anisotropy for Case 3 is illustrated in Figure 3. The bedding plane angle was assumed to be 11 degrees counter clockwise from horizontal. The cohesion and friction angle were assumed to be: $c = 30$ kPa and $\emptyset = 24$ degrees within ± 5 degrees of the bedding plane; and $c = 150$ kPa and $\emptyset = 36$ degrees within ± 75 degrees of the cross-bedding, respectively. Note that the coefficient of friction was assumed to be linearly anisotropic herein.

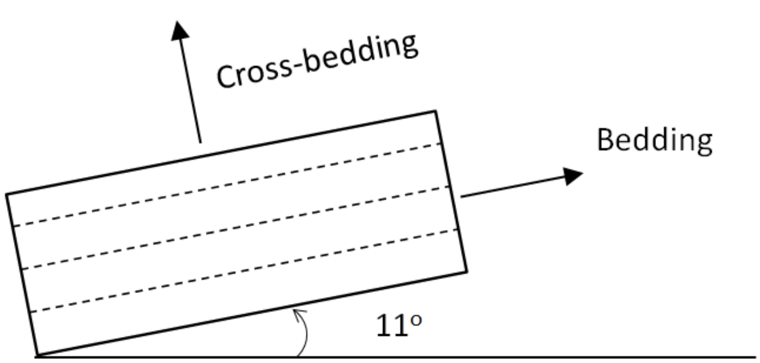

Figure 3. Assumed linearly anisotropic rock mass shear strength.

The Anisotropic Function curves that were created for SLOPE/W are presented in Figure 4. Note that in SLOPE/W, the Anisotropic Function is applied to friction angle (rather than coefficient of friction).

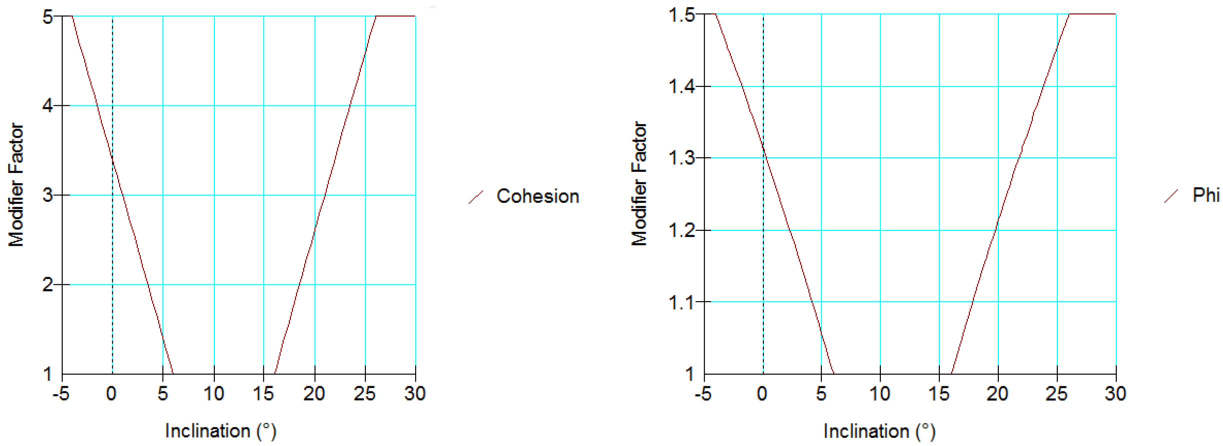

Figure 4. Cohesion and friction angle anisotropic Functions.

Results and Discussion

Figure 5 presents the factor of safety and critical slip surface for Case 1, in which the rock joint was defined using the Barton-Choubey model.

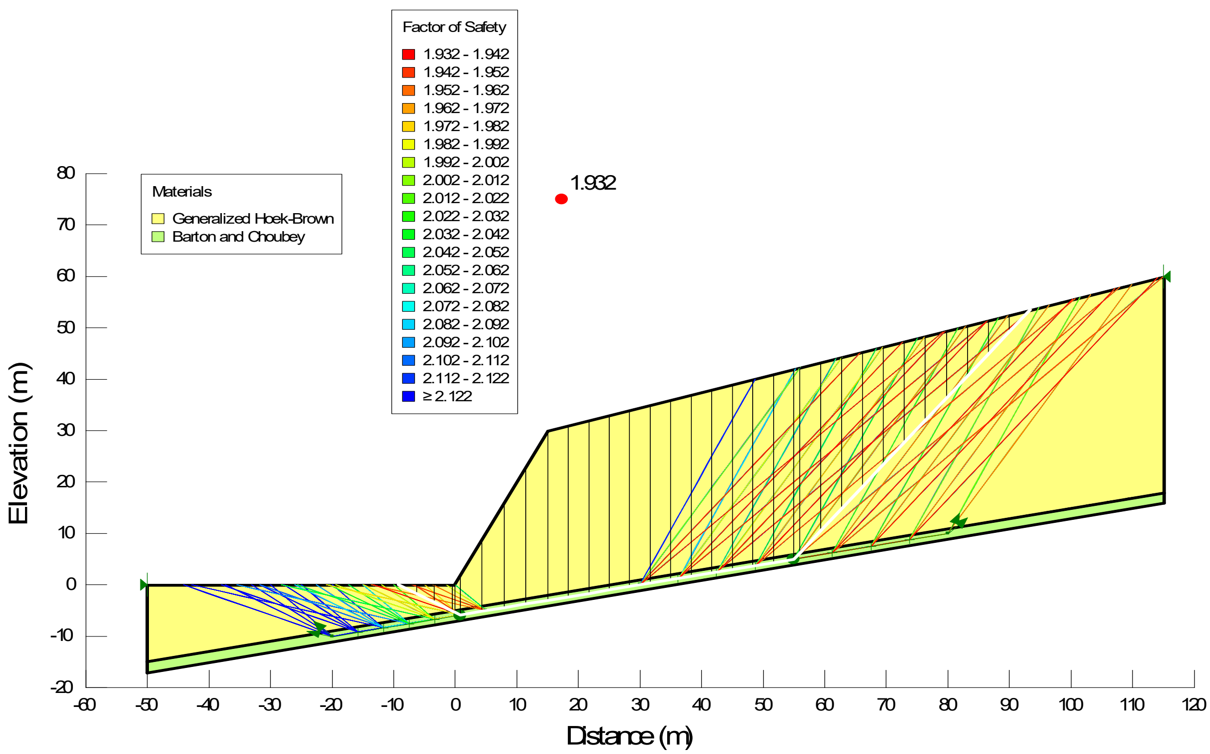

Figure 5. SLOPE/W calculated FOS using Barton and Choubey (1977).

Figure 6 presents the information for Slice # 15, which is founded in the rock joint material. As can be seen in the figure, the base normal was 754.86 kPa and the shear strength at the base of the slice was computed as $751.06 \times tan\left(8 \times log_{10}\left(\frac{4000}{751.06}\right) + 20\right) = 363.26$ kPa (Equation 1).

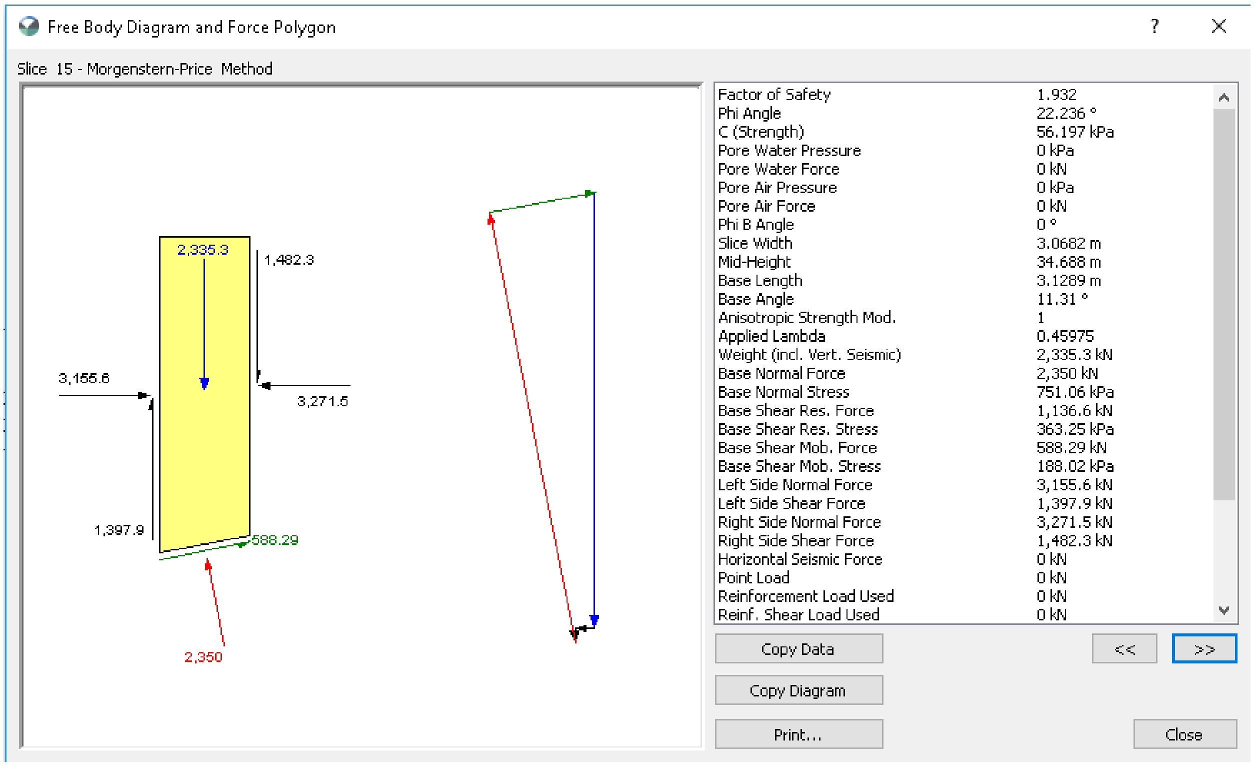

Figure 6. Slice information when Barton and Choubey's formula (1977) was used.

Figure 7 presents the information for Slice #15 for Case 2, which uses Miller's model. The base shear strength was correctly computed as $1.05 \times (746.41 + 0)^{0.86} + 5 + 746.41 \times tan(4^o) =$ 367.61 kPa (Equation 2).

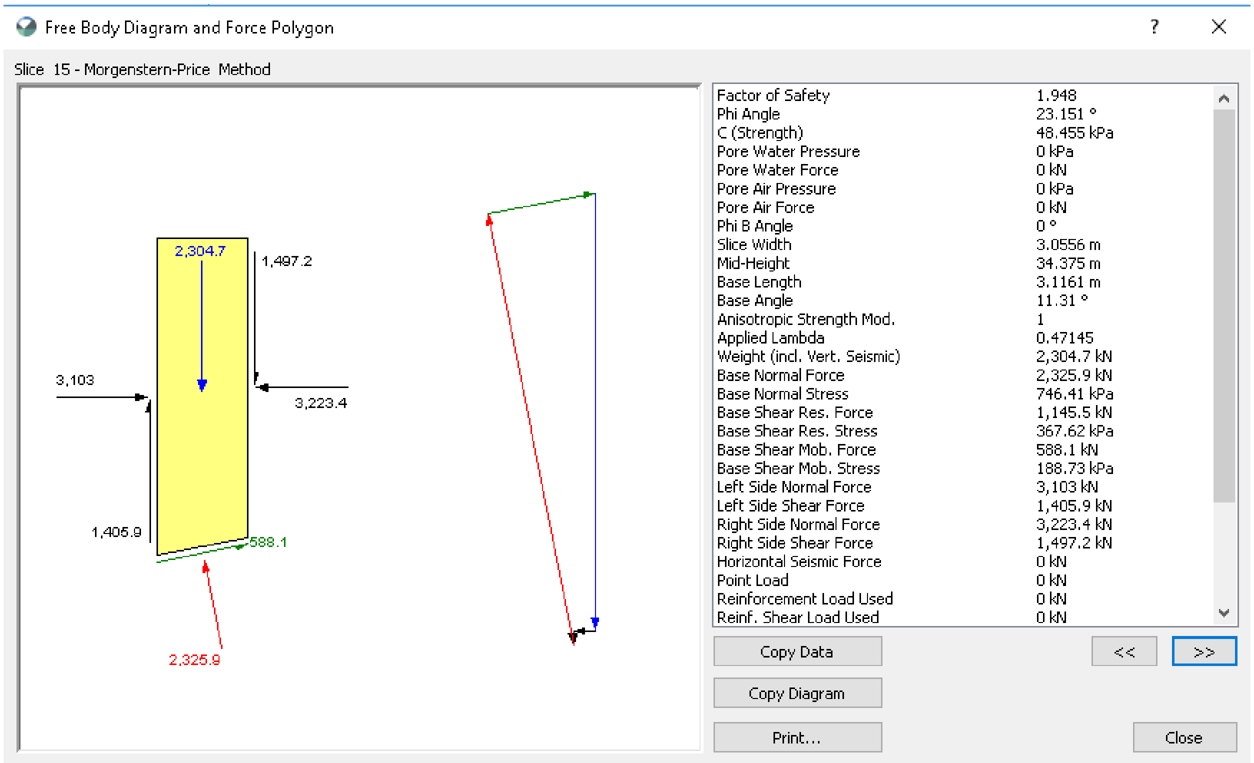

Figure 7. Slice information when Miller's formula (1988) was used ($a = 1.05$, $b = 0.86$, $c = 5$, $d = 0$, $\theta_w = 4$ degrees).

Figure 8 presents an example slice data (Slice # 10) for the linear anisotropy case. The base angle was 17.344 degrees and hence, as shown in the figure, the cohesion and friction angle were linearly interpolated as $\frac{(17.344 - 16)}{(26 - 16)} \times (150 - 30) + 30 = 46.128$ kPa and $tan^{-1}\left[\frac{(17.344 - 16)}{(26 - 16)} \times (\tan 36^o - \tan 24^o) + \tan 24^o\right] = 25.782$ degrees (with round-off error).

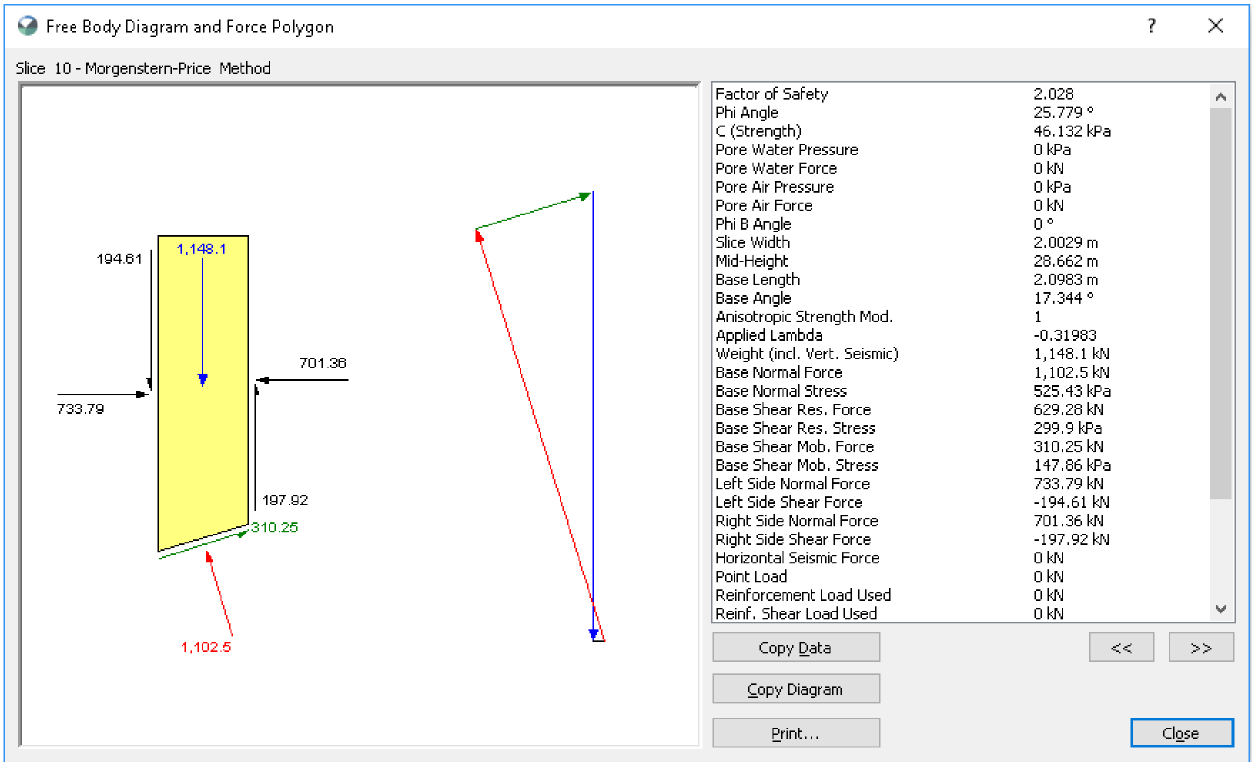

Figure 8. Slice information when rock mass strength was linearly anisotropic.

Summary

SLOPE/W can be used to model a variety of rock mass and rock joint shear strength material models. The formulas can easily be input into a spreadsheet and the data pasted into a shear-normal function. Other material models such as Generalized Hoek Brown or Anisotropic Function are available in the material drop-down list.

References

Barton, N.R. and Choubey, V., 1977. “The shear strength of rock joints in theory and practice”, Rock Mechanics, 10 (1-2), 1-54.

Miller, S.M., 1988. "Modeling Shear Strength at Low Normal Stresses for Enhanced Rock Slope Engineering", Proceedings of the 39th Annual Highway Geology Symposium, Salt Lake City, UT, USA, 346-356.