rocscience

Slide3, RS3, Slide2, RS2

3D Slope Stability

Verification Manual

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Introduction

This document contains a series of verification slope stability problems that have been analyzed using *Slide3*, *RS3*, *Slide2*, and *RS2*. The verification tests come from:

- Published examples found in reference material such as journal and conference proceedings.
- Other examples verified by comparing results from each program.

For all examples, a short statement of the problem is given first, followed by a presentation of the analysis results, using various limit equilibrium analysis methods for *Slide2* 7.0 and *Slide3*. Full references cited in the verification tests are found at the end of this document. The Bishop and Janbu methods are both simplified for all examples.

Each example is numbered, which is shown in the title, and will remain consistent across all verification documents relating to that model. As well, the folder that contains the models in each program will be titled 3D Verification [number of the model]. Each model also has a description under its title in the Table of Contents and in the body of the verification. The first part of its description will define its type as either 2D extruded, 2D swept, or 3D. This verification document contains only 3D models and has its own corresponding index. Both the verification and the index for 3D models are separate from the other two model types.

Generally, a 3D model is a model that cannot be classified as either a 2D extruded or 2D swept model. These models have mostly been created by lofting different 2D cross sections to each other, so their cross sections are not consistent throughout the model, which is what differentiates these models from the other two model types. Models with more complex geometries, such as open pits, have also been included in this index.

1. 3D Verification #1

1.1. 3D valley, (4) materials, water table, ellipsoidal with SA

1.1.1. Introduction

This example is a model of a 3D valley with a water table. It was modeled in both *Slide3* and *RS3*.

1.1.2. Problem Description

The slope geometry for the valley in the XZ plane is given as Figure 1.1 and Figure 1.2 is the top view of the valley. The water table extends across the entire valley, and can be seen better in Figure 1.3, which is the ZY plane. Material properties are shown in Table 1.1. The ellipsoidal slip surface is found using a cuckoo search with surface altering optimization.

1.1.3. Geometry and Properties

Table 1.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Material 1 (Drained)	35	35	18.15
Material 2	150	45	21.58
Material 3	35	15	18.15
Material 4	10	35	18.15
Material 1 (Undrained)	70	0	18.15

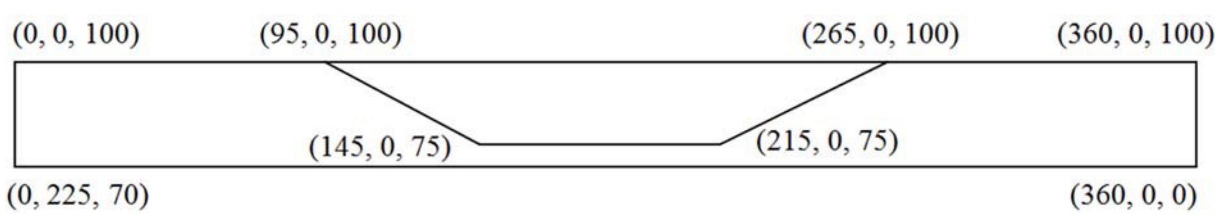

Figure 1.1

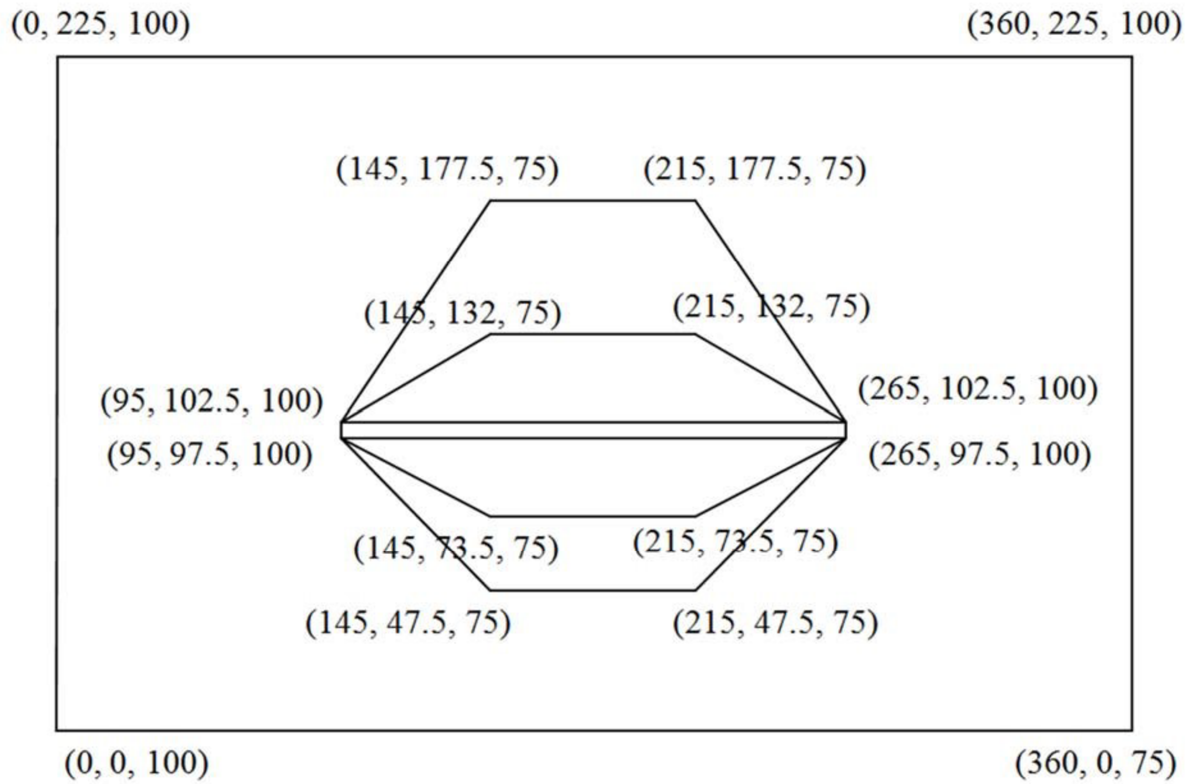

Figure 1.2

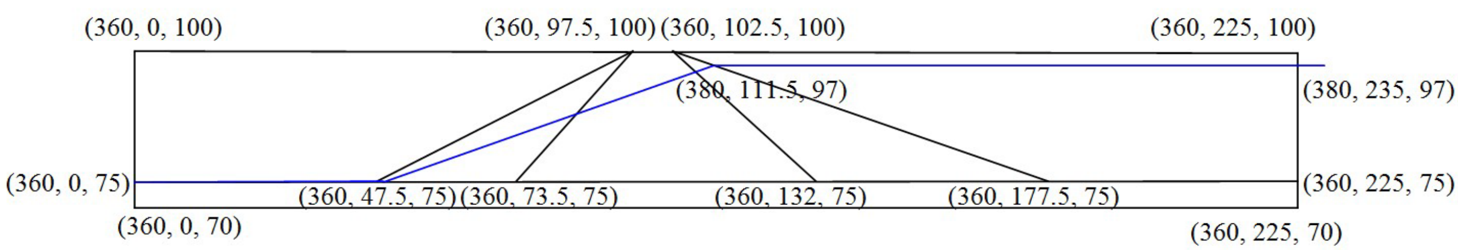

Figure 1.3

1.1.4. Results

Table 1.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.25</td><td>1.14</td><td rowspan="4">1.34</td><td rowspan="4">1.18</td></tr>
<tr><td>GLE</td><td>1.336</td><td>1.24</td></tr>
<tr><td>Janbu</td><td>1.217</td><td>1.08</td></tr>
<tr><td>Spencer</td><td>1.327</td><td>1.23</td></tr>
</table>

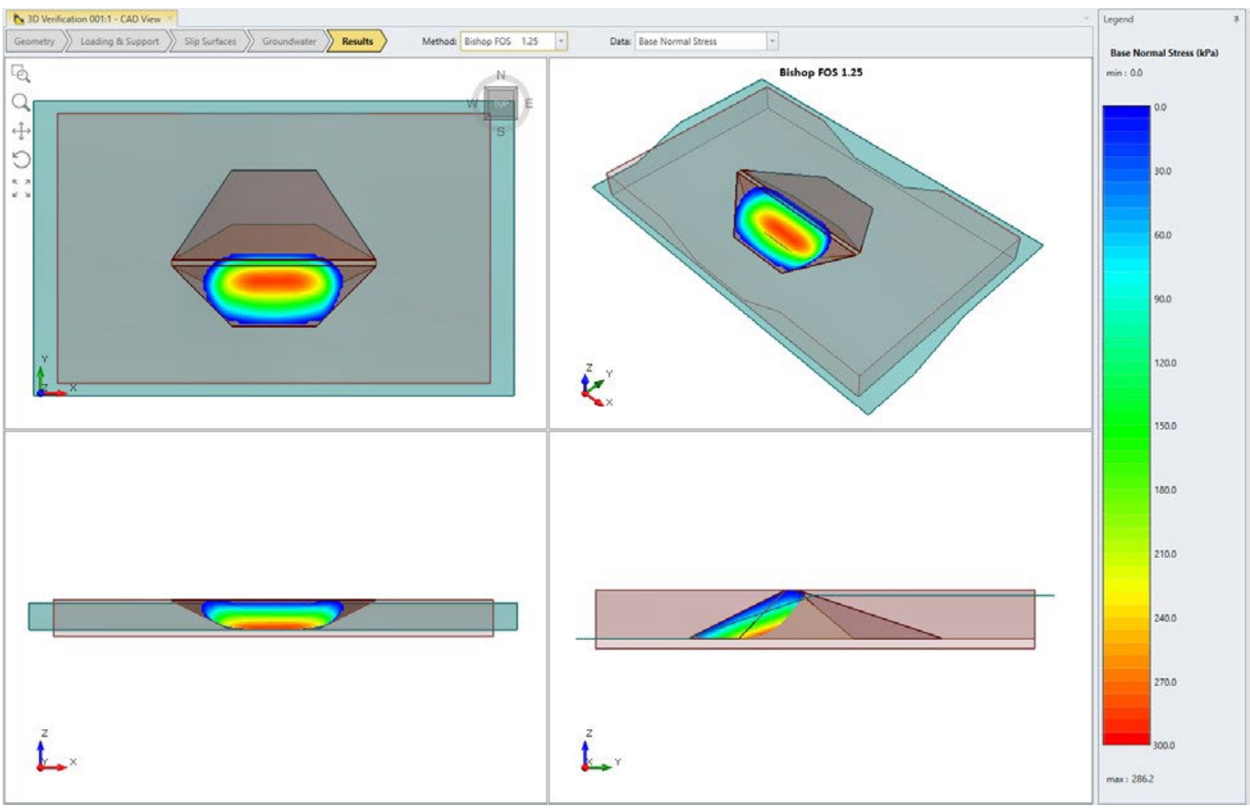

Figure 1.4 – *Slide3* Base Normal Stress Contour on Slip Surface Found Using the Bishop Method

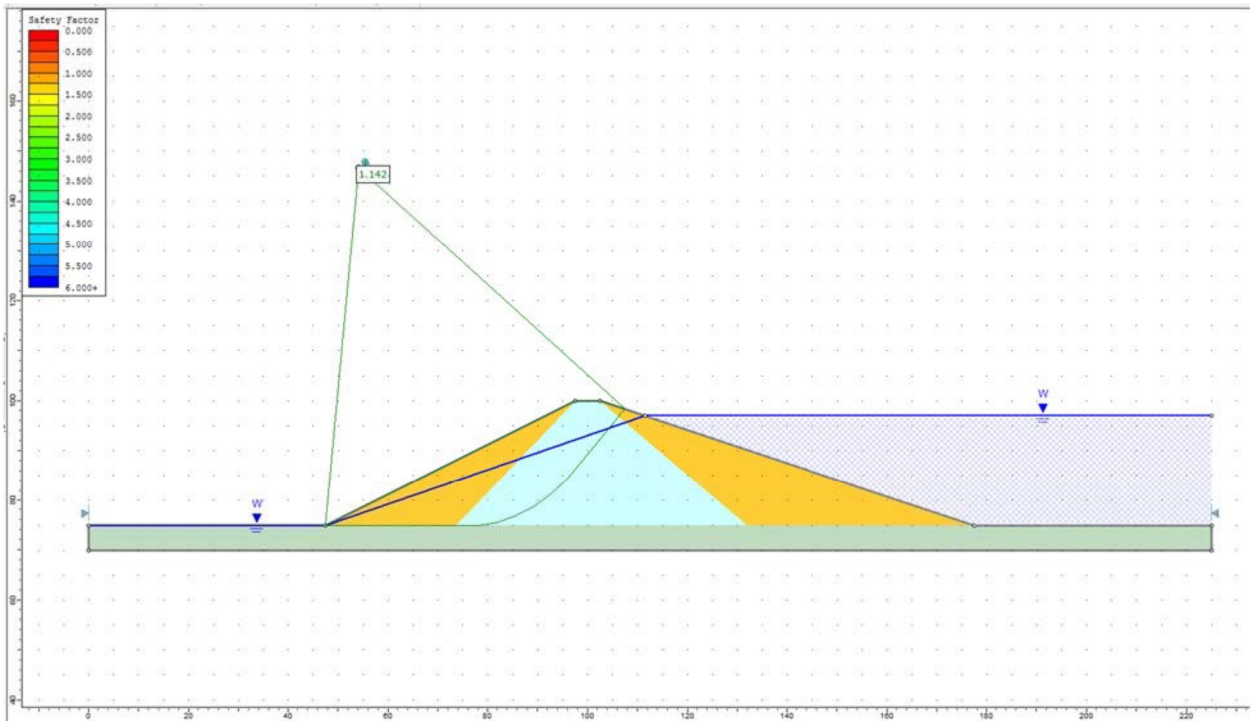

Figure 1.5 – *Slide2* Solution Using the Bishop Method

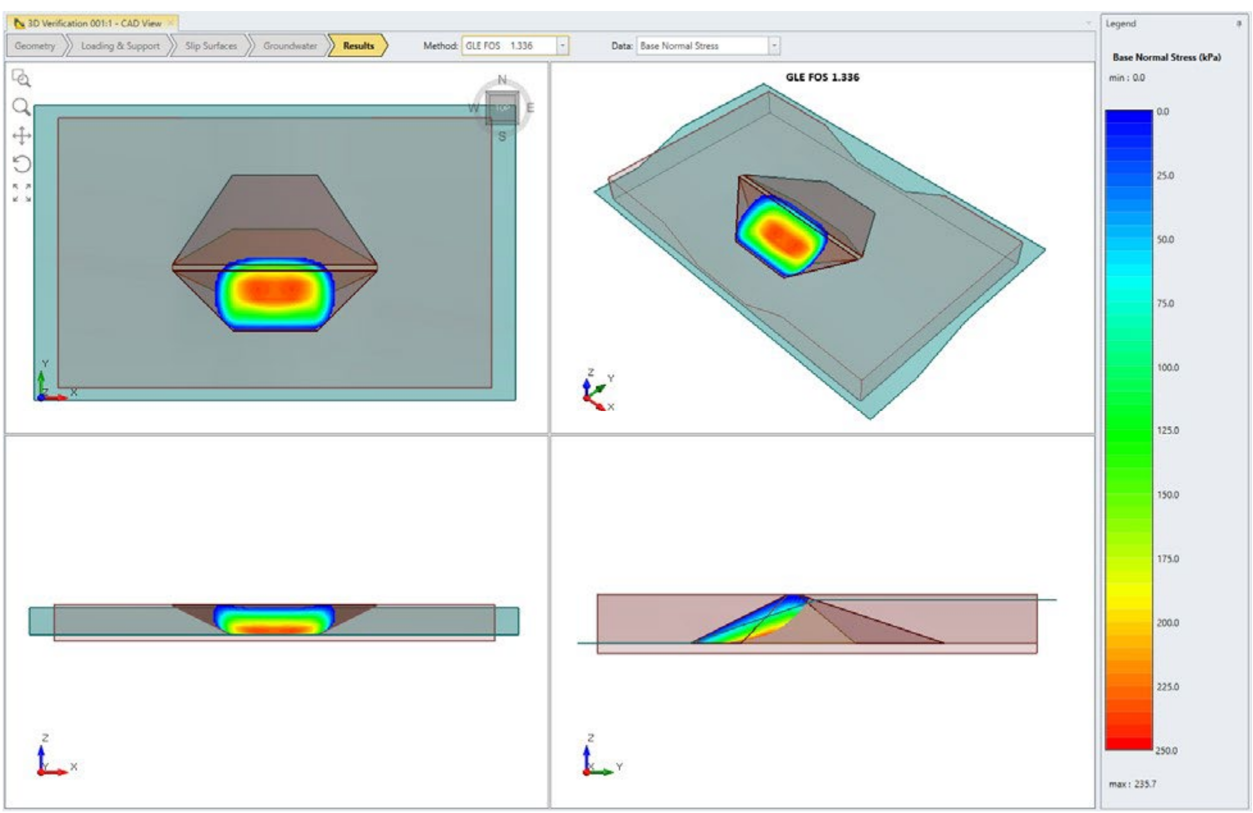

Figure 1.6 – *Slide3* Base Normal Stress Contour on Slip Surface Found Using the GLE Method

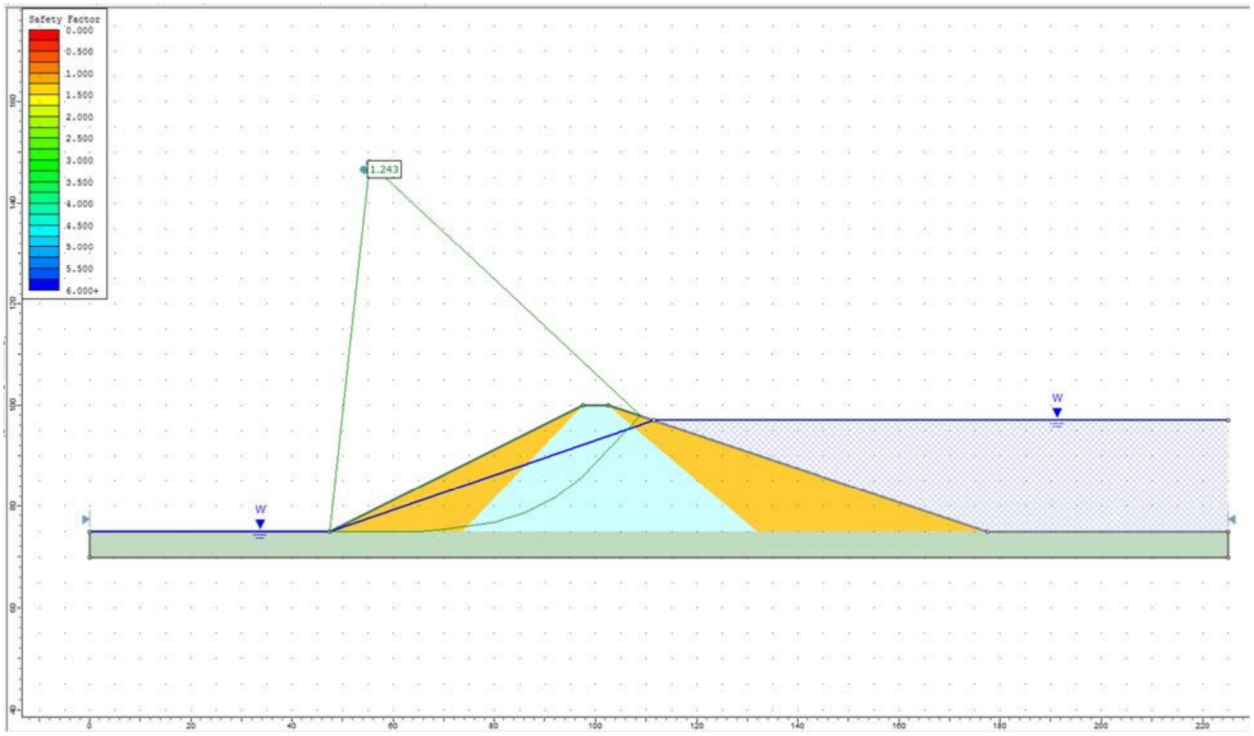

Figure 1.7 – *Slide2* Solution Using the GLE Method

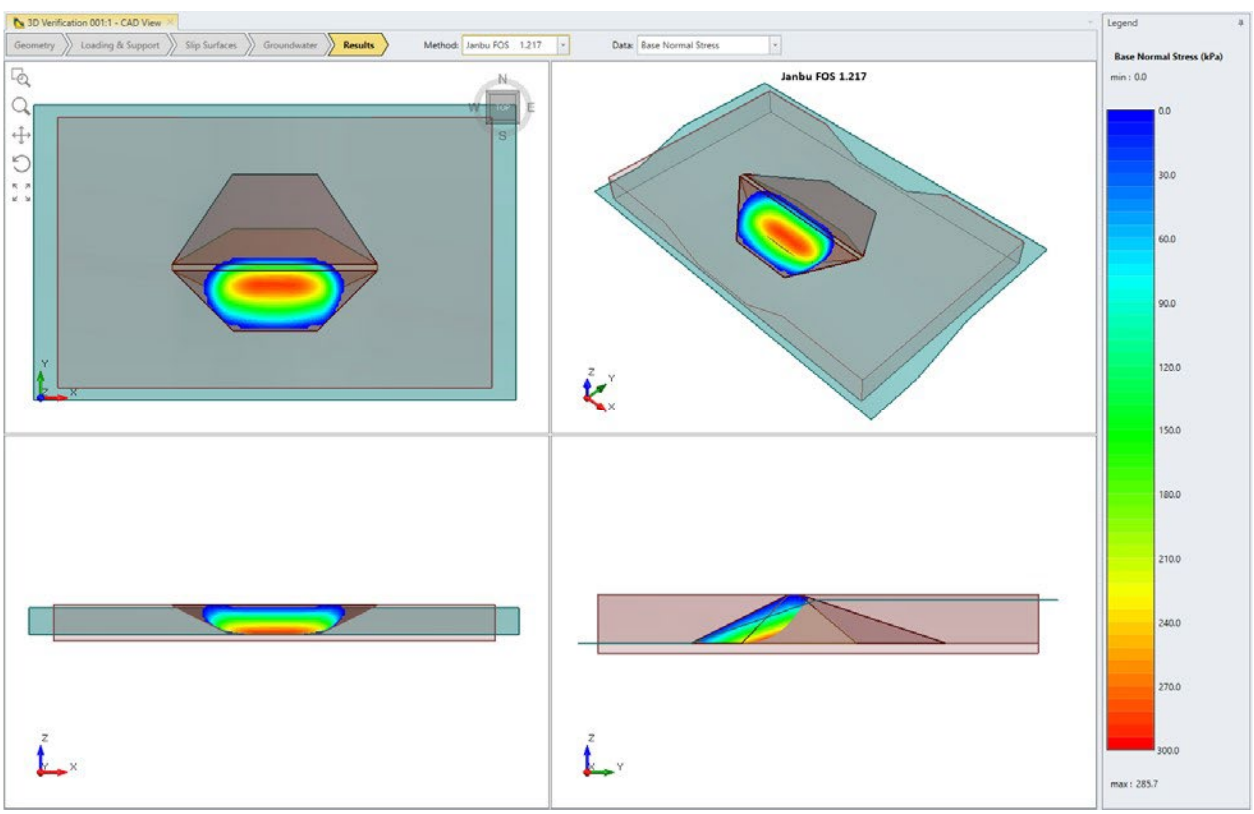

Figure 1.8 – *Slide3* Base Normal Stress Contour on Slip Surface Found Using the Janbu Method

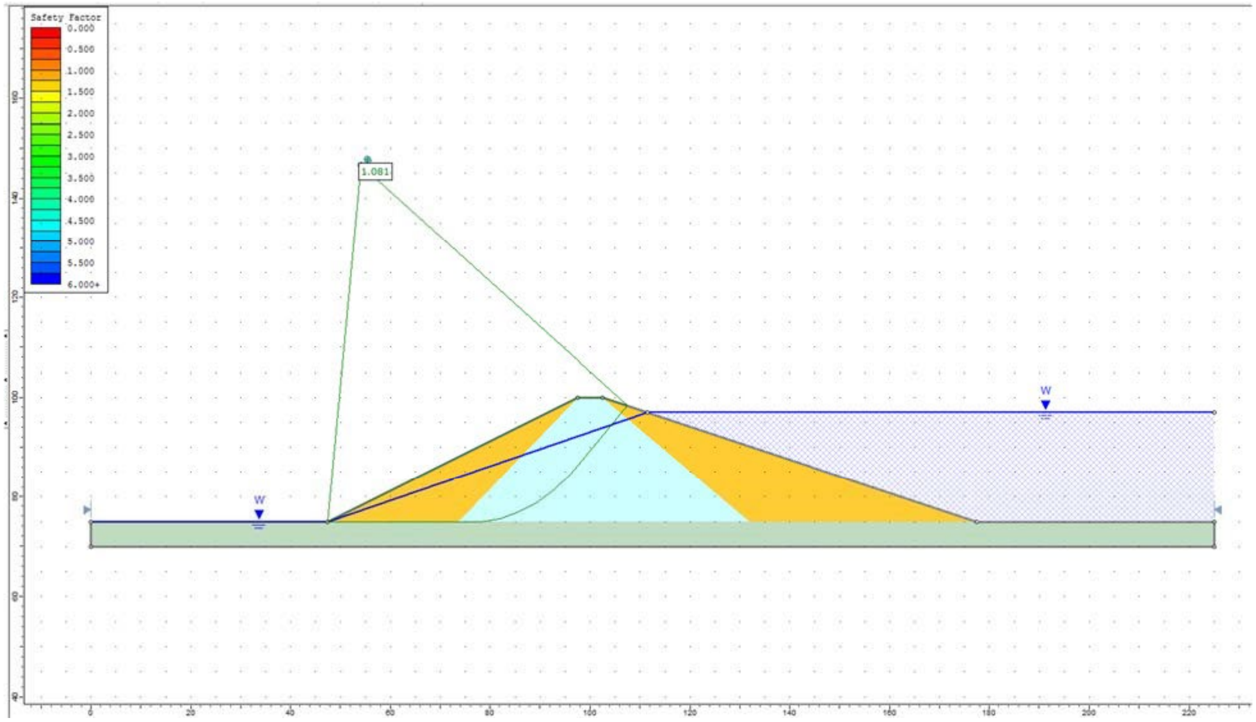

Figure 1.9 – *Slide2* Solution Using the Janbu Method

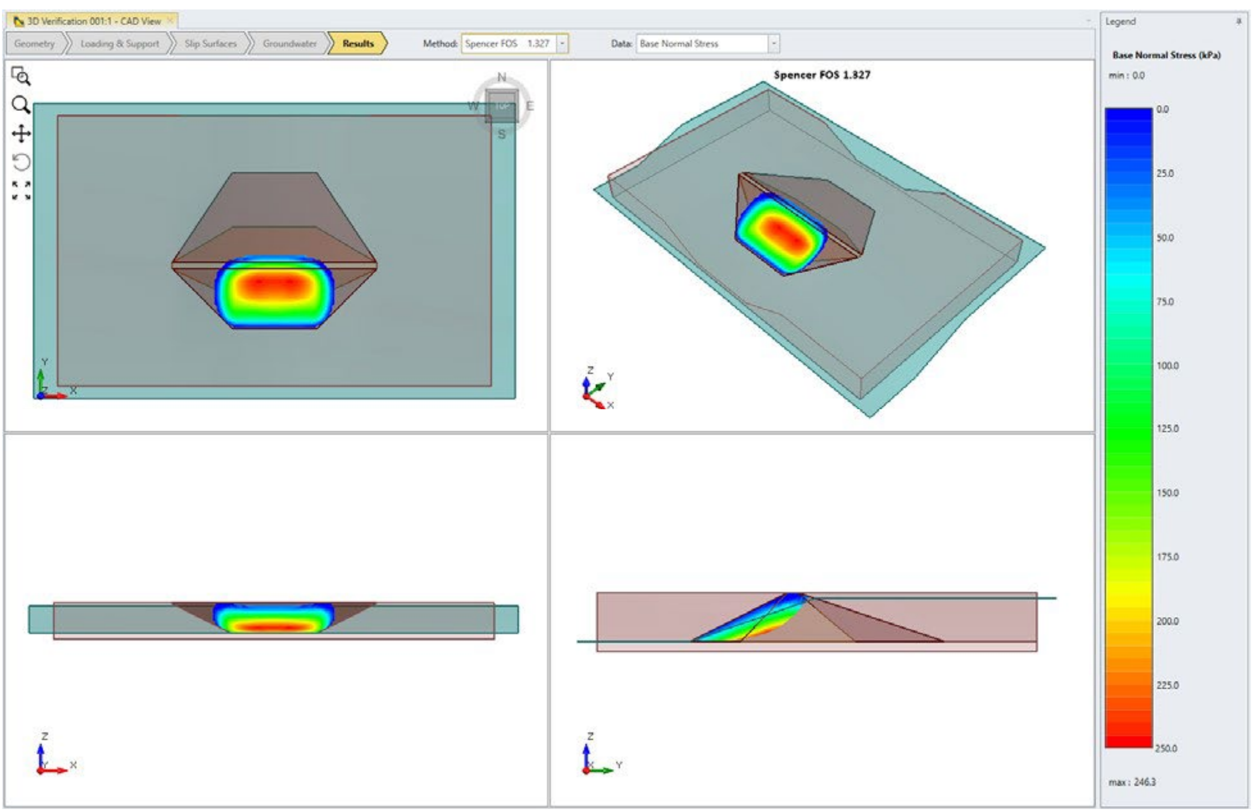

Figure 1.10 – *Slide3* Base Normal Stress Contour on Slip Surface Found Using the Spencer Method

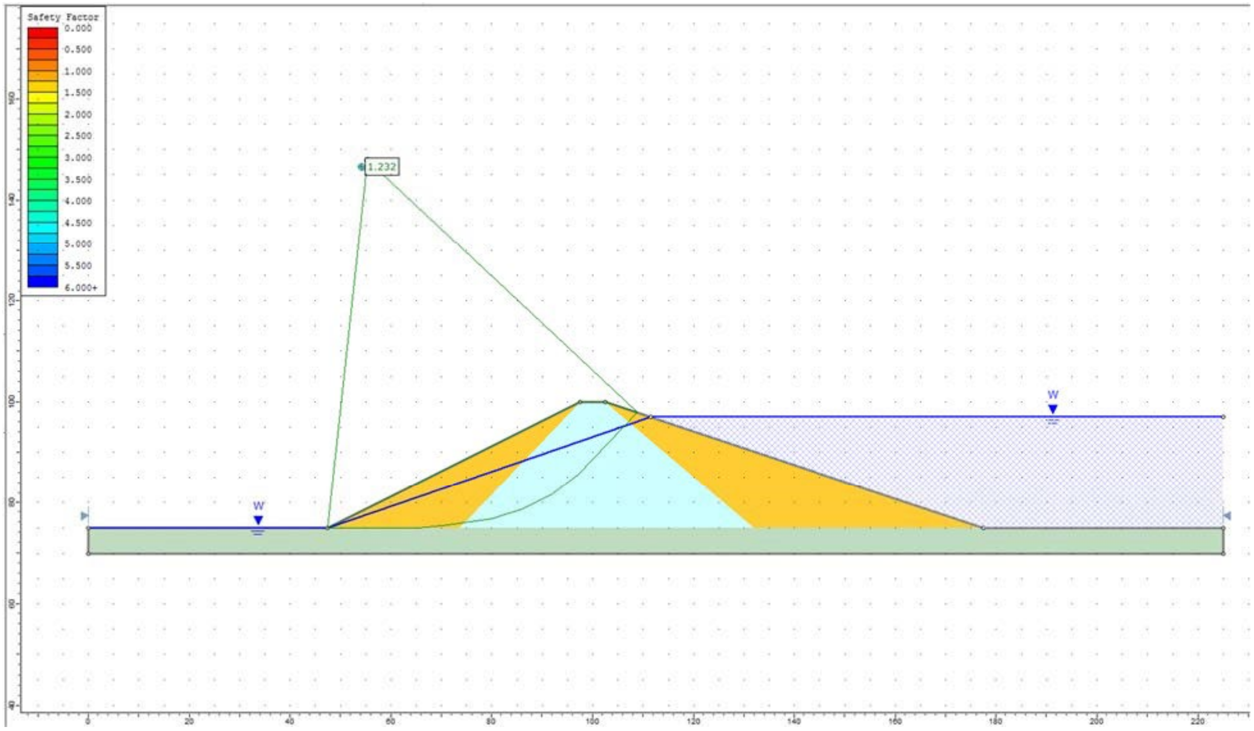

Figure 1.11 – *Slide2* Solution Using the Spencer Method

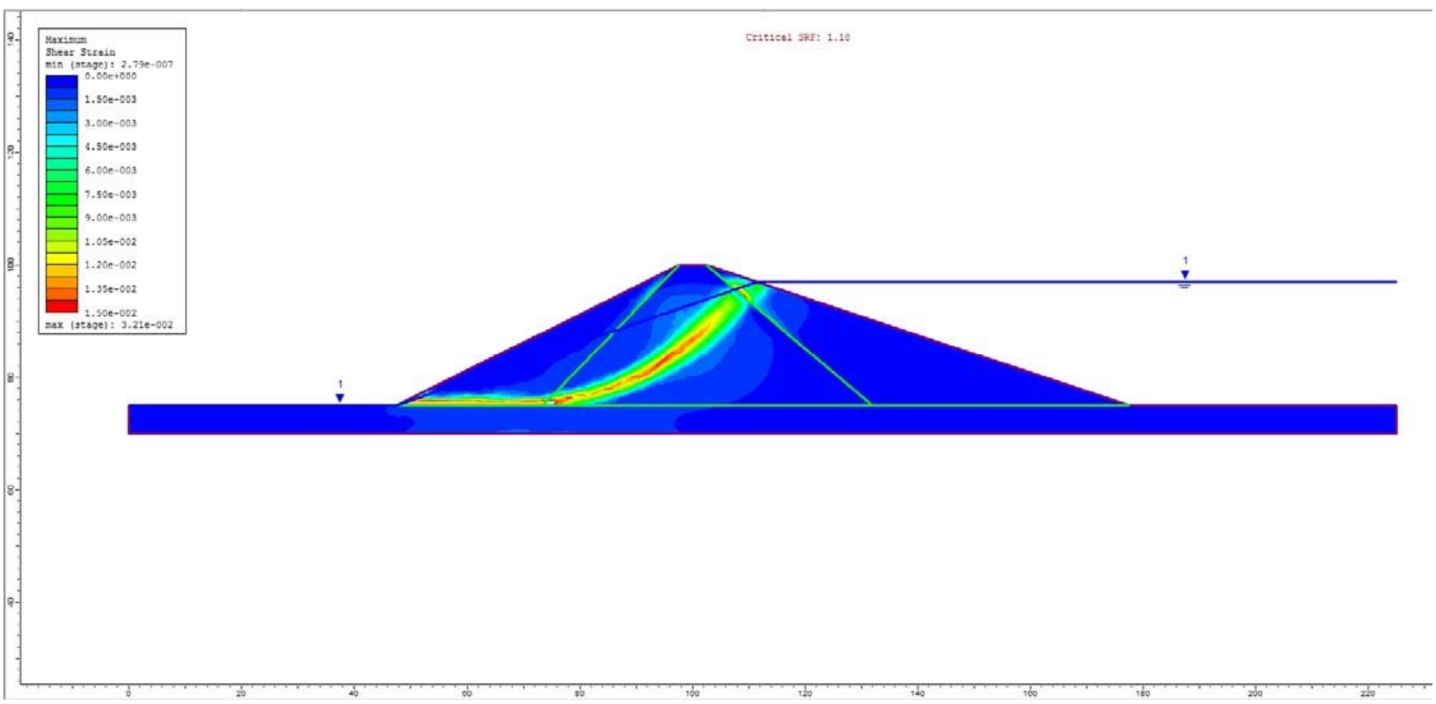

Figure 1.12 – *RS2* Maximum Shear Strain Contour

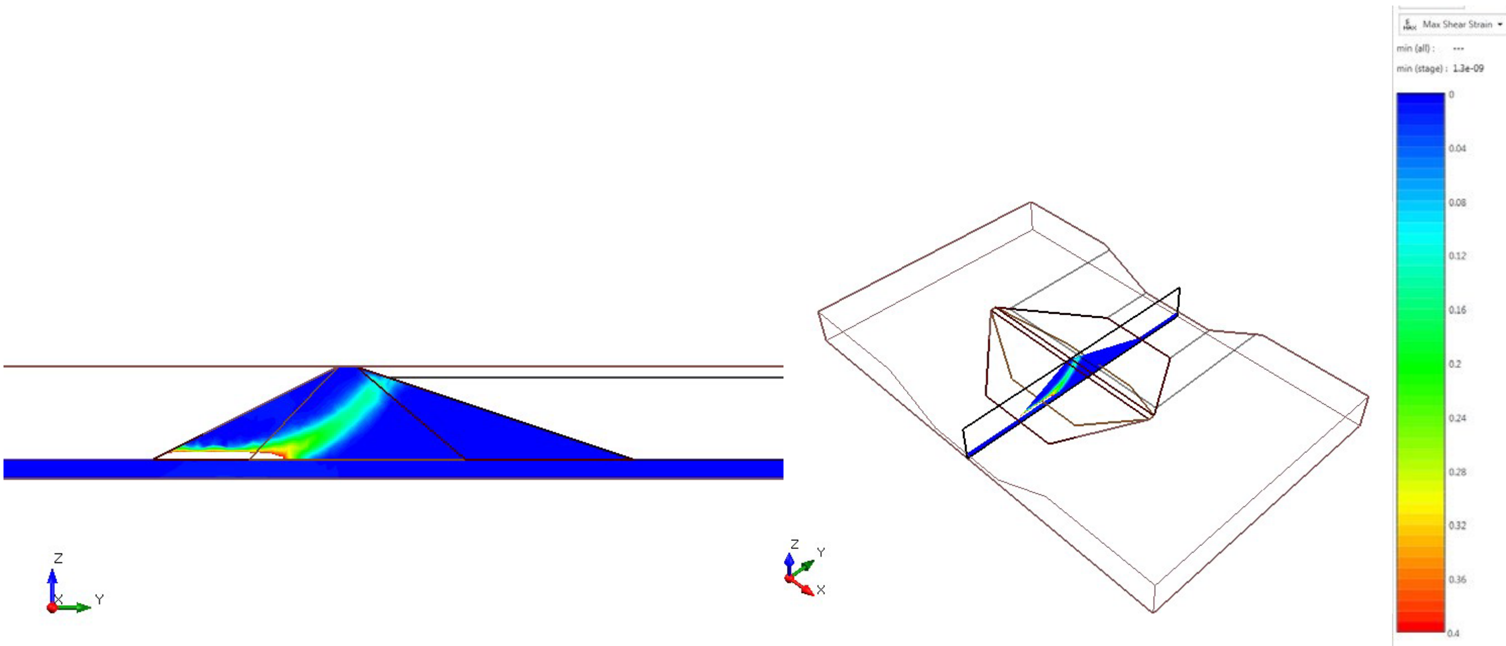

Figure 1.13 – *RS3* Maximum Shear Strain Contour

2. 3D Verification #2

2.1. 3D landfill, weak plane defined slip surface

2.1.1. Introduction

This example is taken from Chang (1992). The model is the Kettleman Hills landfill, which failed along the lining of the landfill material, changing the shape of the slip surface.

2.1.2. Problem Description

This problem used lofted 3D cross sections to create the geometry of the landfill, and weak planes to construct the slip surface, which simulates the lining in the landfill. The material properties of the fill material are shown in Table 2.1. This slope is homogenous; however each weak surface has its own properties, which better simulates the various properties of the lining material. It also helps simulate the wetting of the base of the landfill described in Chang et al. (2016), amongst other papers. The safety factor was calculated using the user defined weak planes.

2.1.3. Properties

Table 2.1: Material Properties

	c′ (psf)	φ′ (deg.)	γ (lbs/ft^3)
Fill Material	0	20	110
Discontinuity 1 (Base)	0	8	127
Discontinuity 2 (Landfill Side Lining)	0	8.5	127
Discontinuity 3 (Base)	900	0	127

2.1.4. Results

Table 2.2: Safety Factors Safety Factors Using *Slide3*

Method	Safety Factor *Slide3*
Bishop	1.123
GLE	1.137
Janbu	1.106
Spencer	1.143

Referee: FS 1.01 [Chang, 1992]

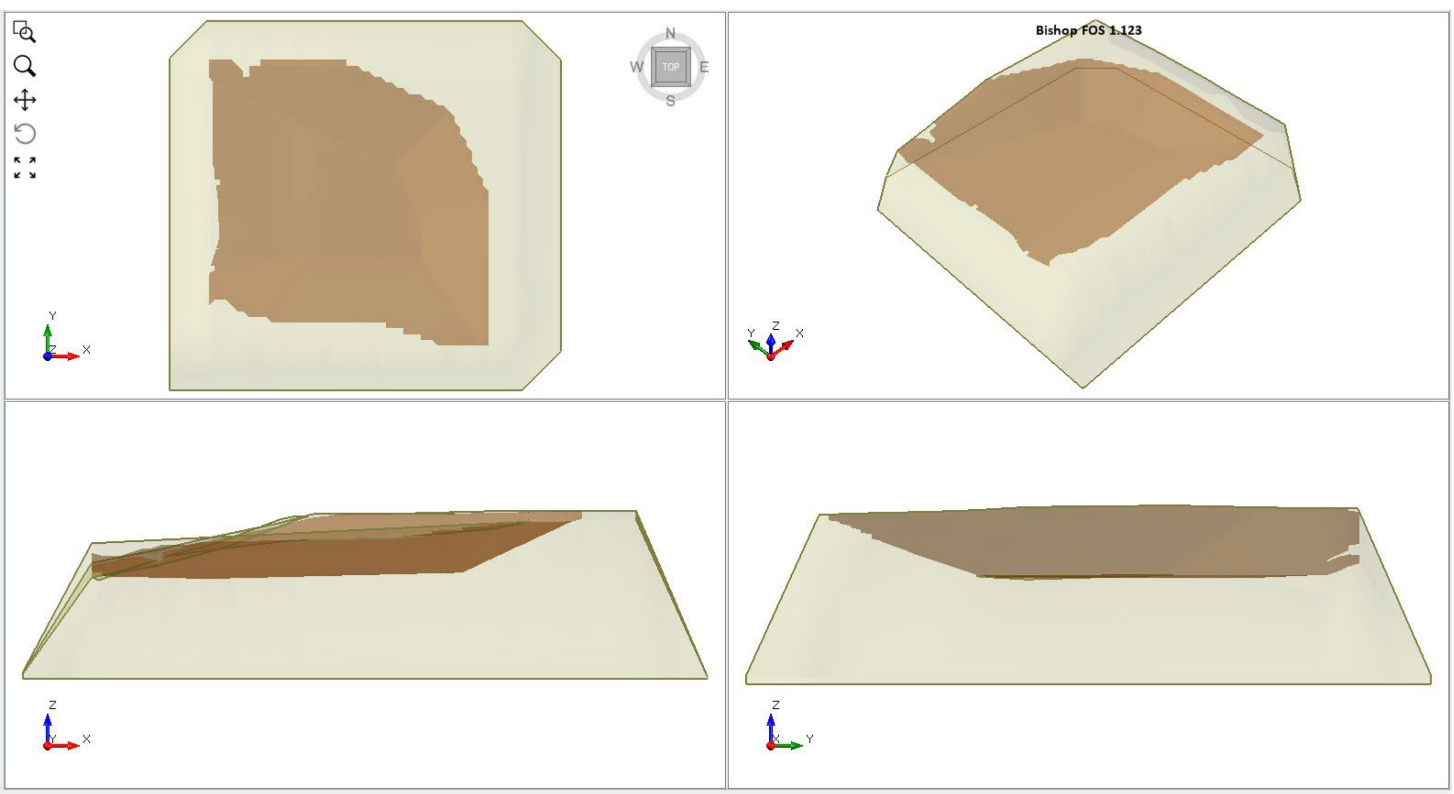

Figure 2.1 – *Slide3* Solution Using the Bishop Method

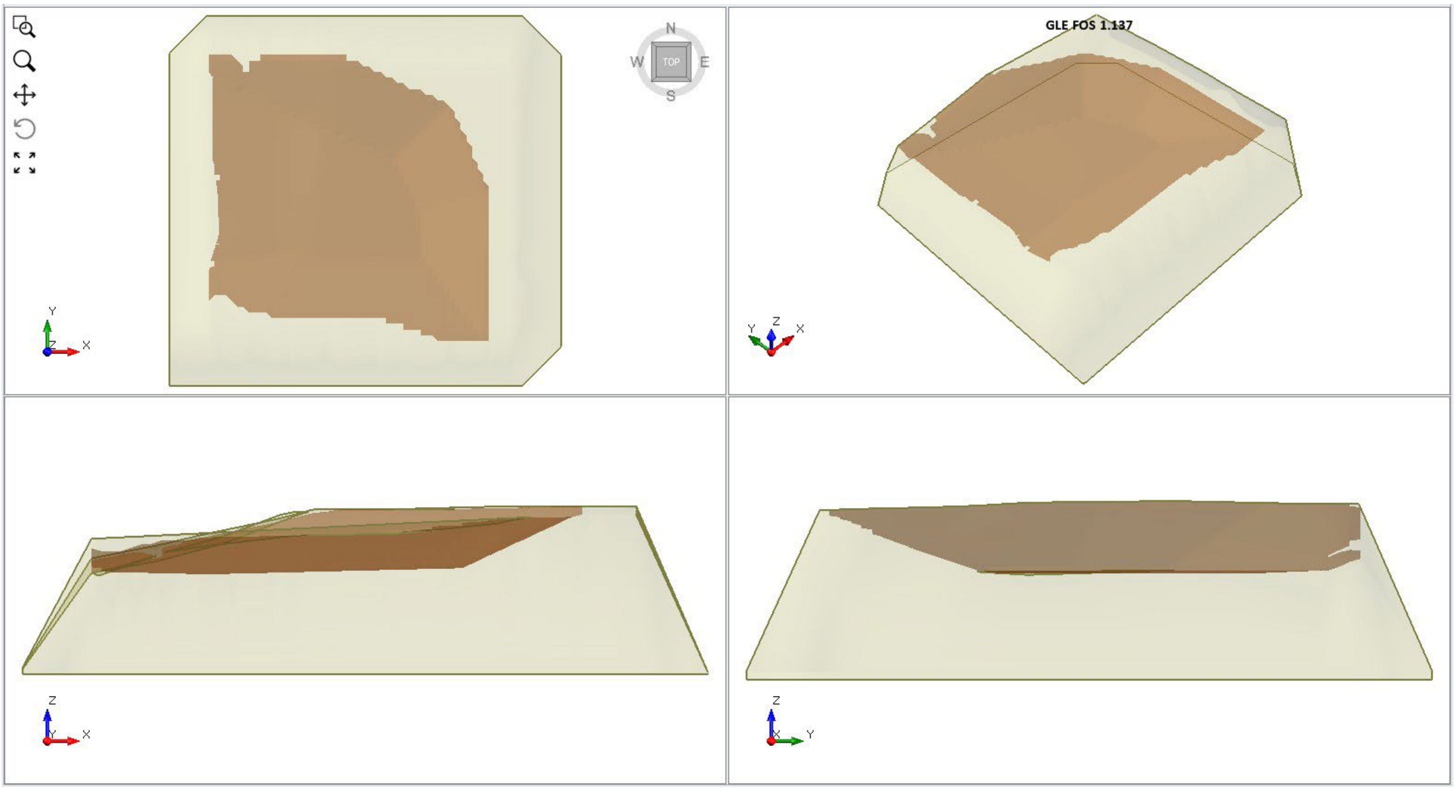

Figure 2.2 – *Slide3* Solution Using the GLE Method

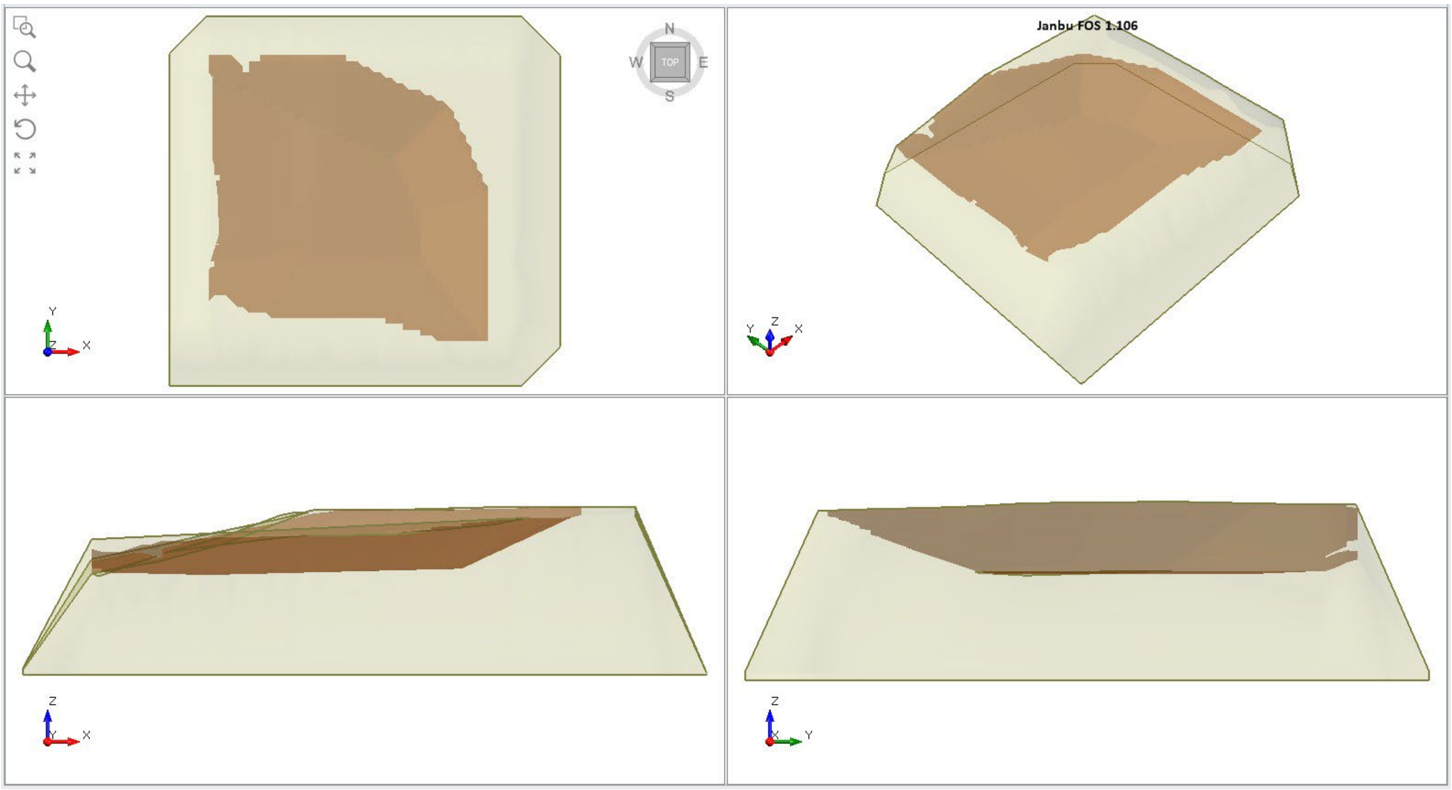

Figure 2.3 – *Slide3* Solution Using the Janbu Method

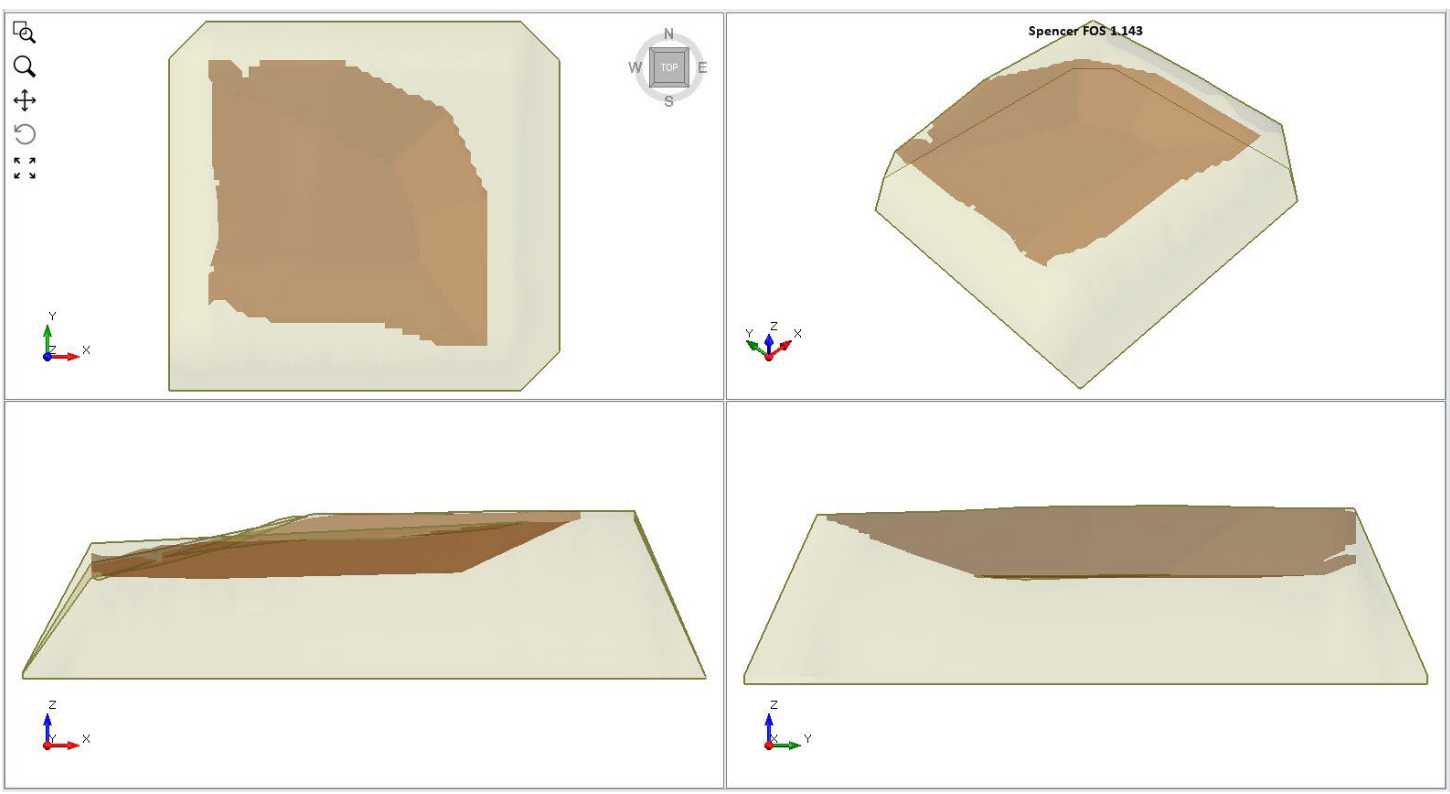

Figure 2.4 – *Slide3* Solution Using the Spencer Method

3. 3D Verification #3

3.1. 3D open pit mine, homogeneous, slope limits, ellipsoidal with SA

3.1.1. Introduction

This model is an open pit mine. It was done in two cases, each case with a different slope limit. This is case 1.

3.1.2. Problem Description

This model has complicated geometry, as it is meant to model a real open pit mine. The material properties of the mine are shown in Table 3.1. There is no pore pressure considered in this problem. The ellipsoidal slip surface was found using a cuckoo search. The slope limit volume is defined as a rectangular prism with the following vertices: (367.87, 1984.69, 876.94), (367.87, 1984.69, 1023.32), (204.21, 1984.69, 1023.32), (204.21, 1984.69, 876.94), (367.87, 2263.11, 876.94), (367.87, 2263.11, 876.94), (204.21, 2263.11, 876.94), (204.21, 2263.11, 1023.32). The *Slide2* cross section is in the XZ plane and taken at Y = 2200 m.

3.1.3. Properties

Table 3.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Rock	100	35	20

3.1.4. Results

Table 3.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS2*
Bishop	1.738	1.518	1.55
GLE	1.773	1.543	
Janbu	1.659	1.447	

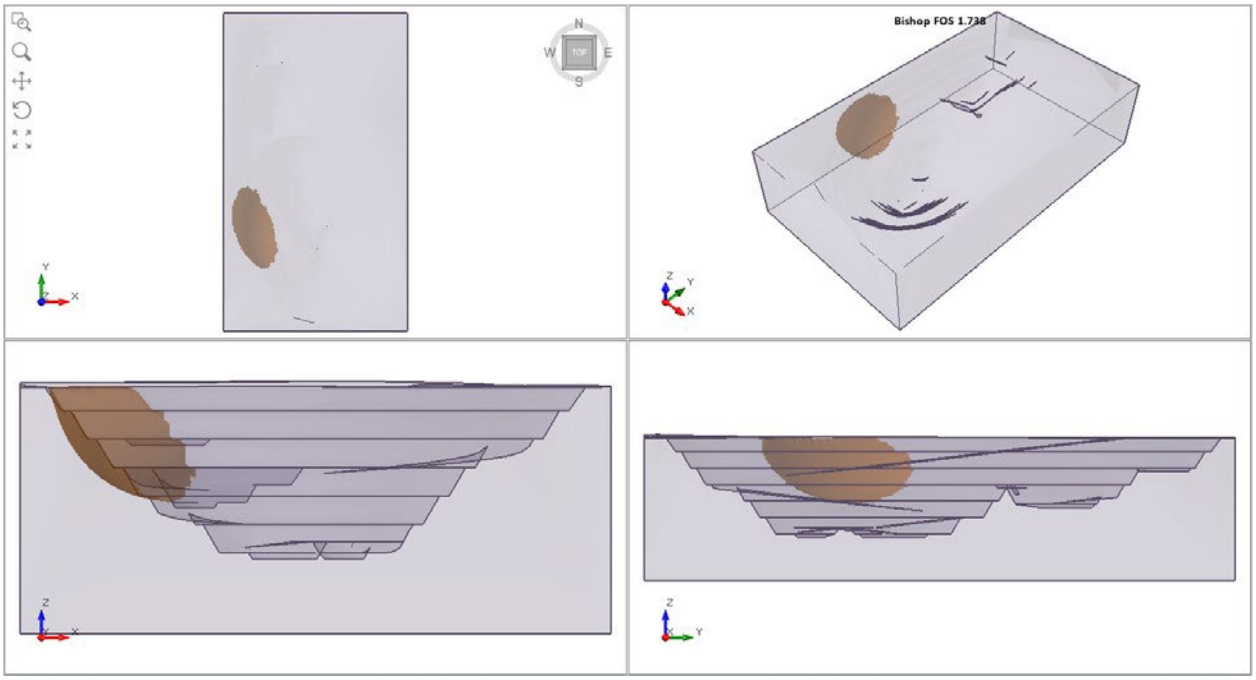

Figure 3.1 – *Slide3* Solution Using the Bishop Method

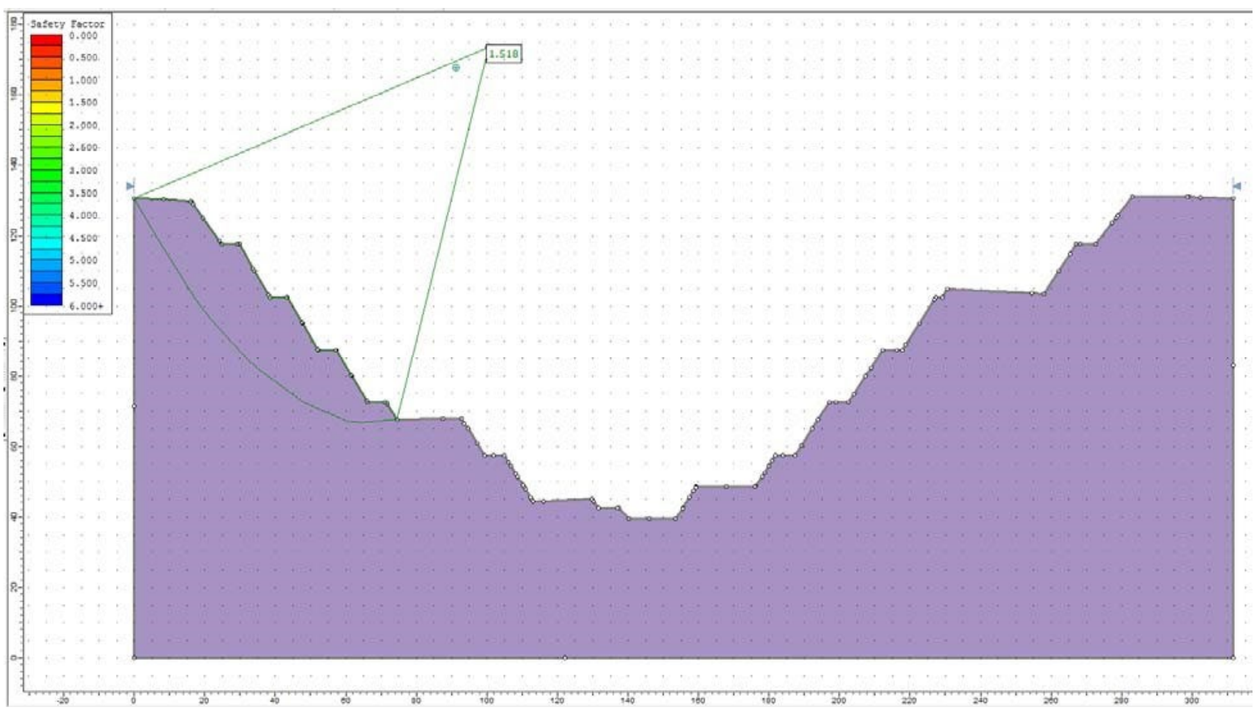

Figure 3.2 – *Slide2* Solution Using the Bishop Method

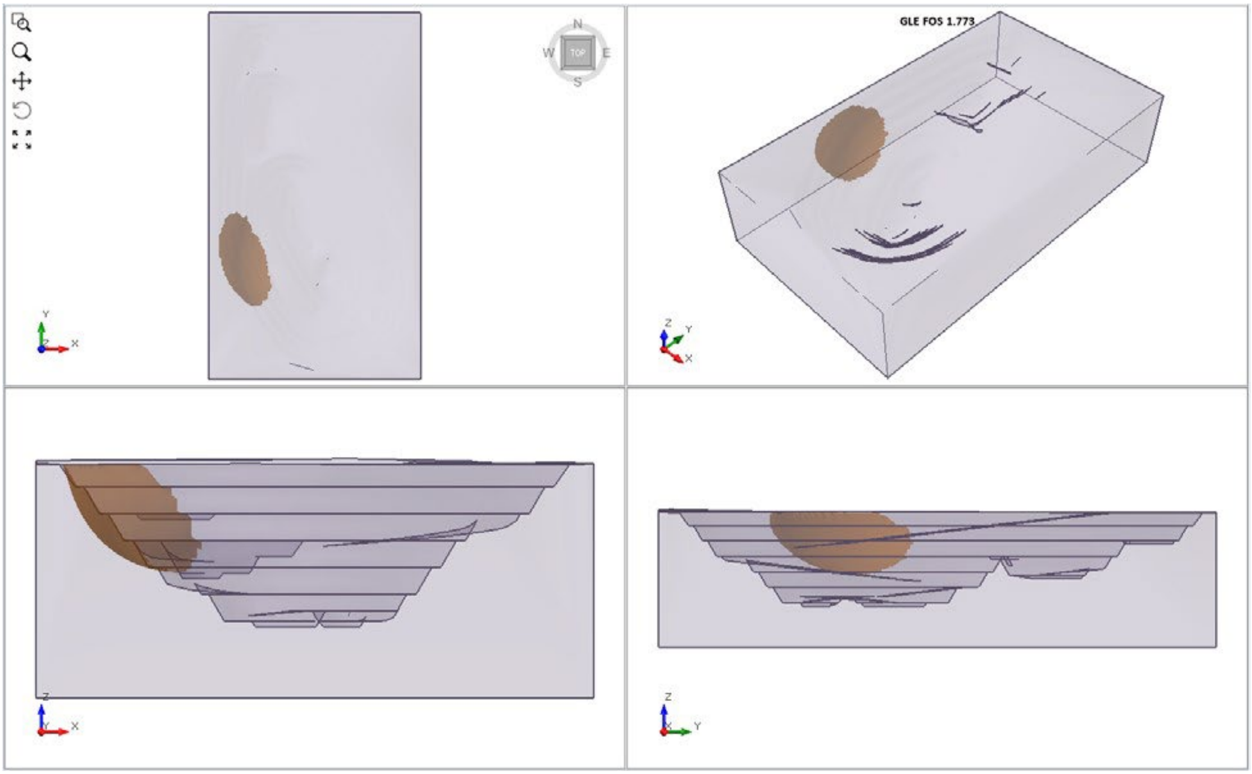

Figure 3.3 – *Slide3* Solution Using the GLE Method

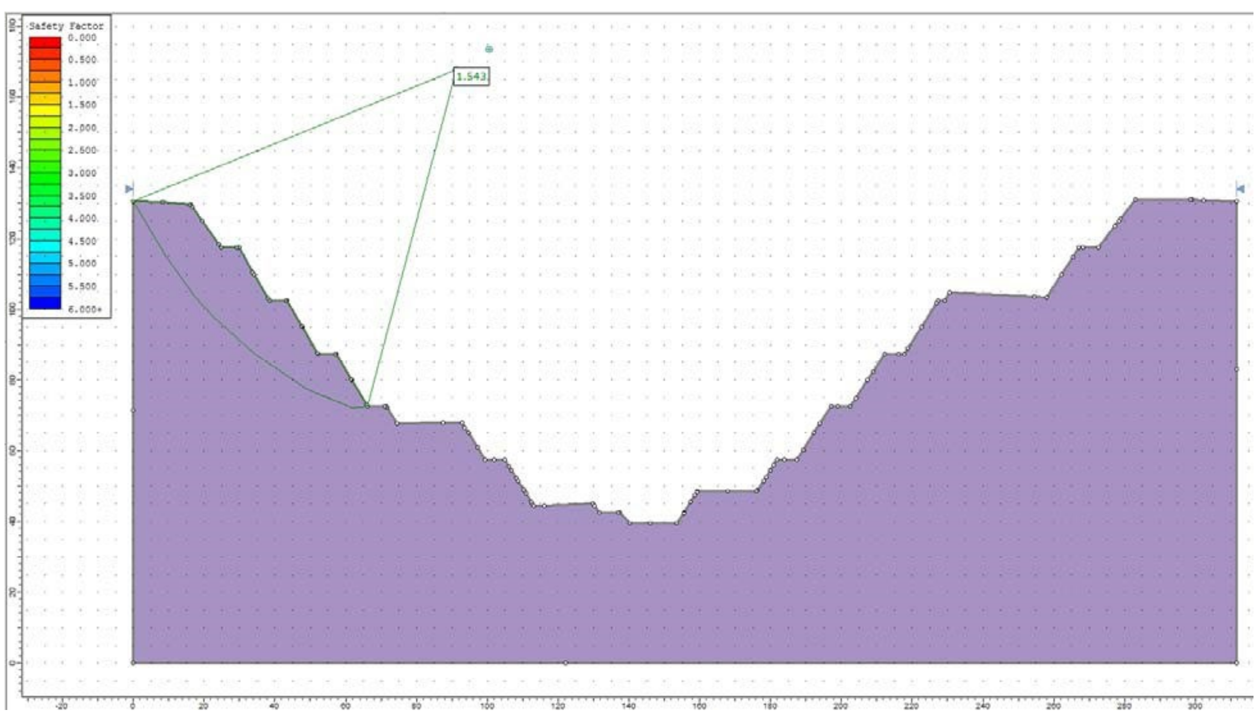

Figure 3.4 – *Slide2* Solution Using the GLE Method

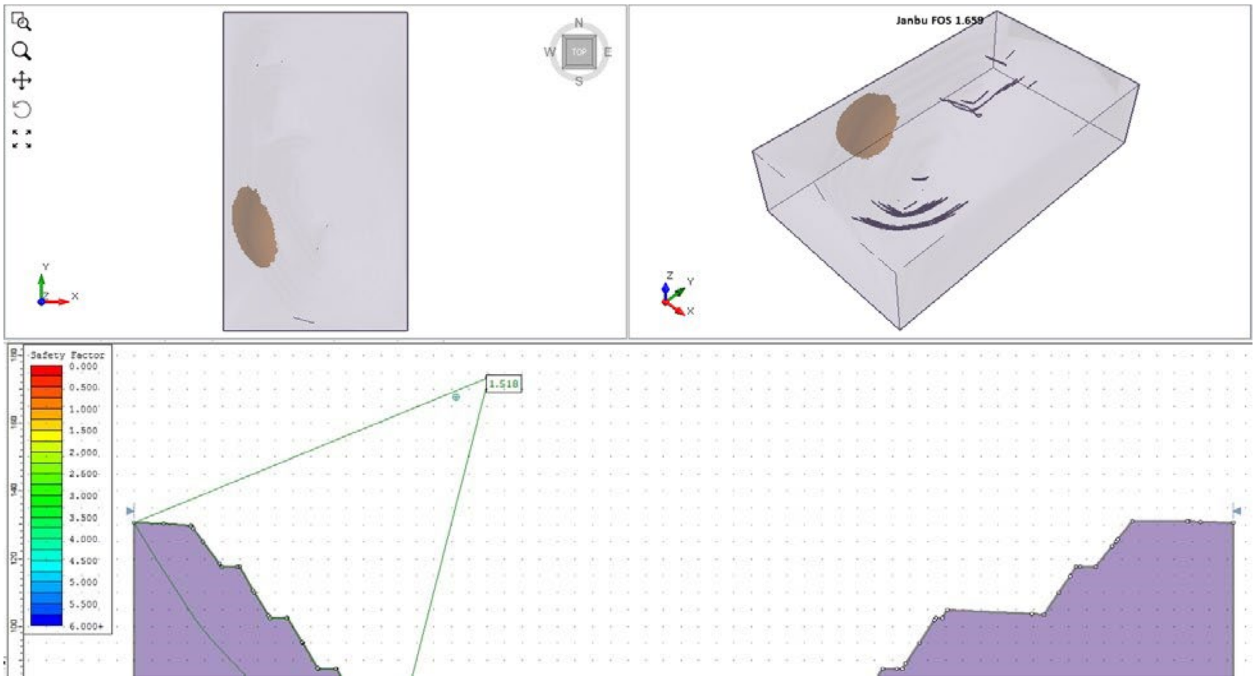

Figure 3.5 – *Slide3* Solution Using the Janbu Method

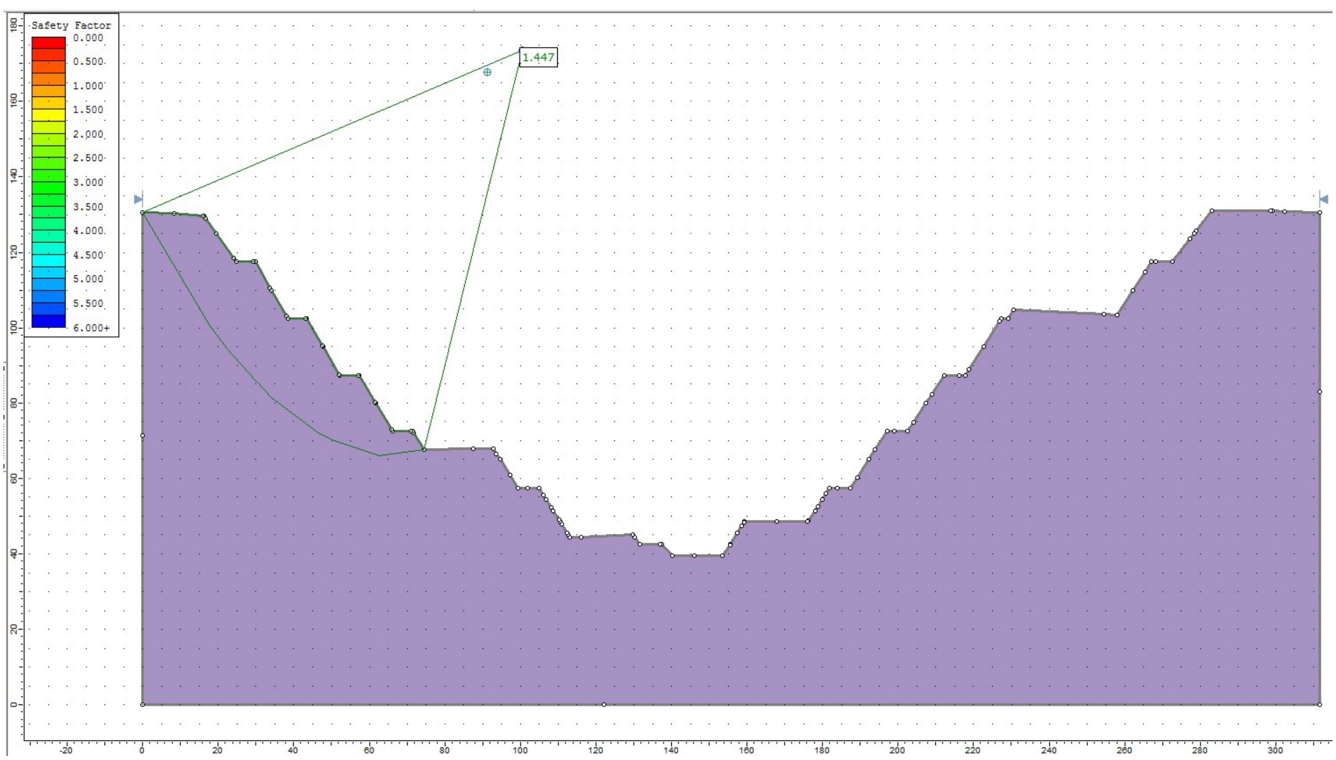

Figure 3.6 – *Slide2* Solution Using the Janbu Method

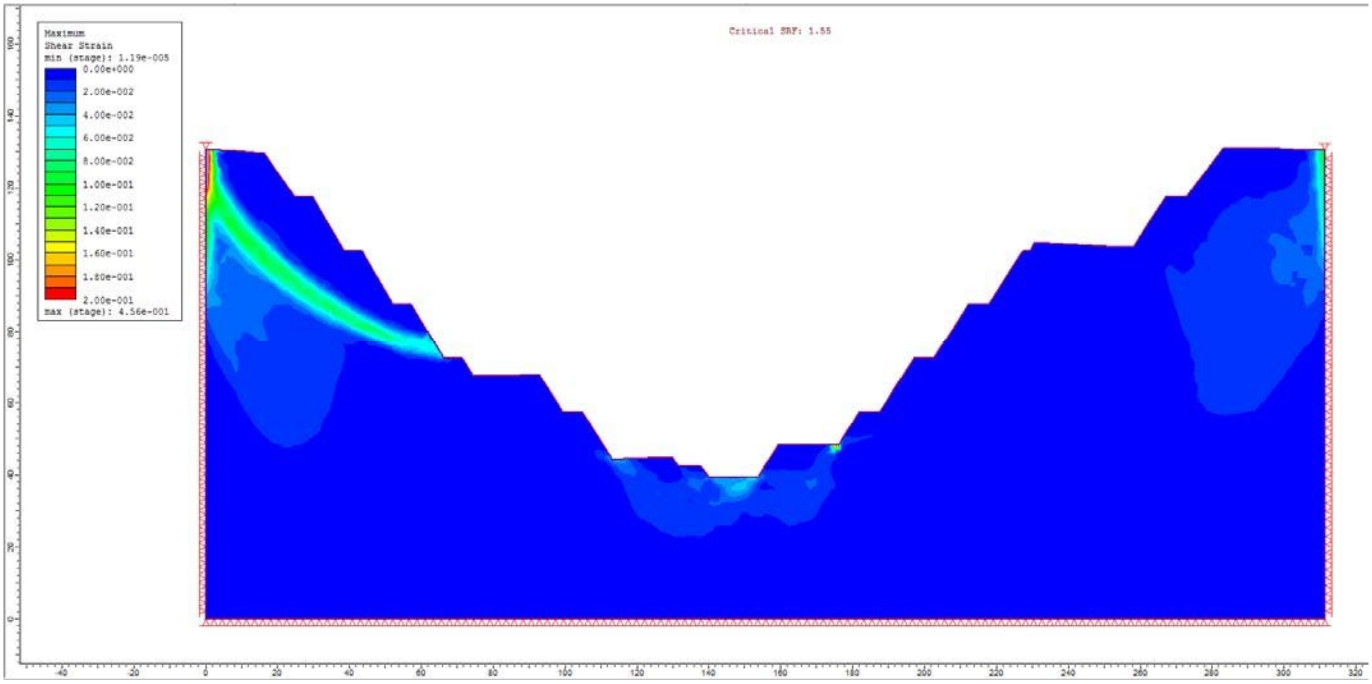

Figure 3.7 – *RS2* Maximum Shear Strain

4. 3D Verification #4

4.1. 3D open pit mine, homogeneous, slope limits, ellipsoidal with SA

4.1.1. Introduction

This model is an open pit mine. It was done in two cases, each case with a different slope limit. This is case 2.

4.1.2. Problem Description

This model has complicated geometry, as it is meant to model a real open pit mine. The material properties of the mine are shown in Table 4.1. There is no pore pressure considered in this problem. The ellipsoidal slip surface was found using a cuckoo search. The slope limit volume is defined as a rectangular prism with the following vertices: (208.99, 2439.25, 878.73), (208.99, 2439.25, 1021.74), (208.99, 2530.6, 878.73), (208.99, 2530.6, 1021.74), (526.03, 2439.25, 878.73), (526.03, 2439.25, 1021.74), (526.03, 2530.6, 878.73), (526.03, 2530.6, 1021.74). The *Slide2* cross section is in the XZ plane and taken at Y = 2477 m.

4.1.3. Properties

Table 4.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Rock	100	35	20

4.1.4. Results

Table 4.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS2*
Bishop	2.456	2.324	2.31
GLE	2.493	2.363	
Janbu	2.327	2.237	

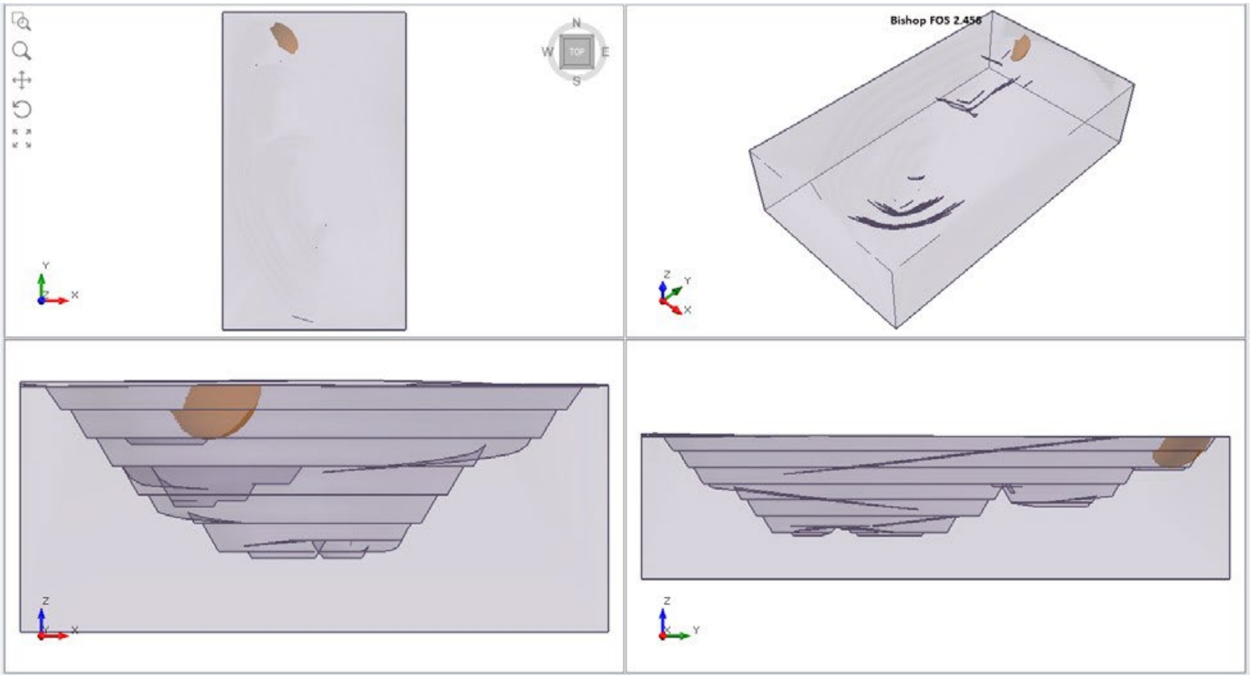

Figure 4.1 – *Slide3* Solution Using the Bishop Method

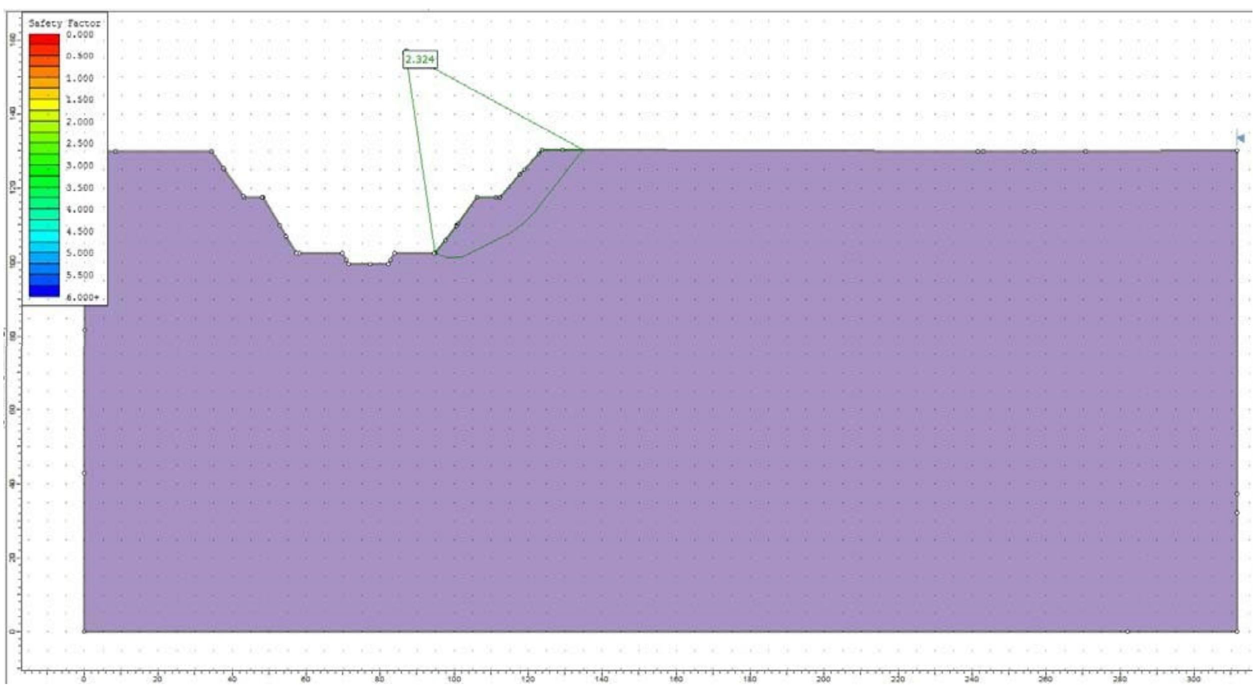

Figure 4.2 – *Slide2* Solution Using the Bishop Method

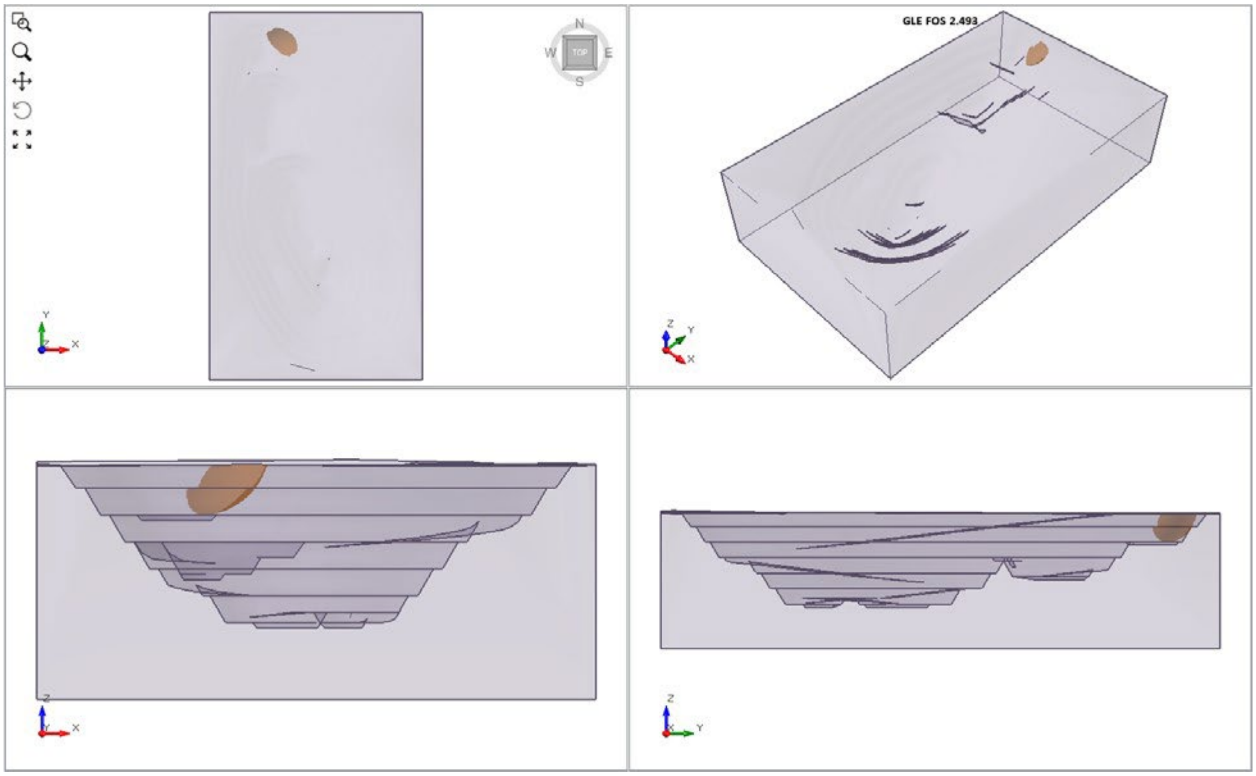

Figure 4.3 – *Slide3* Solution Using the GLE Method

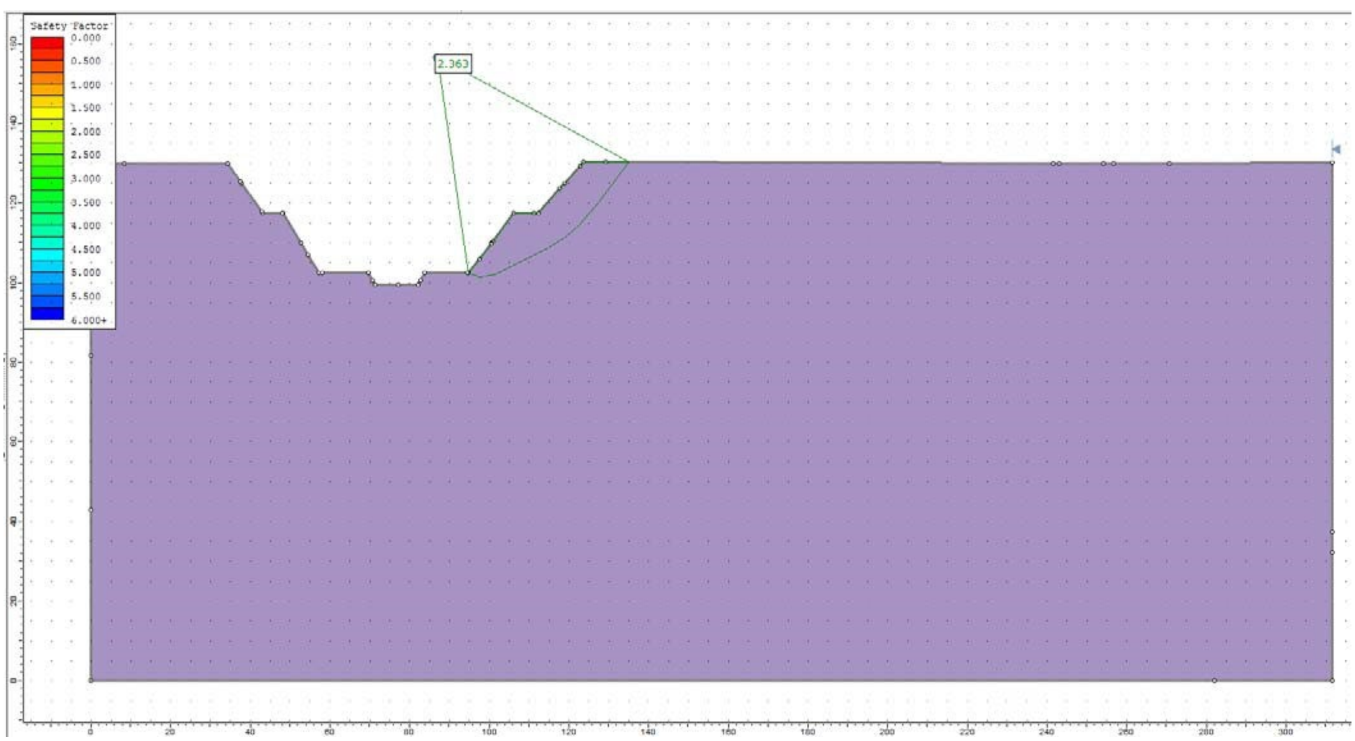

Figure 4.4 – *Slide2* Solution Using the GLE Method

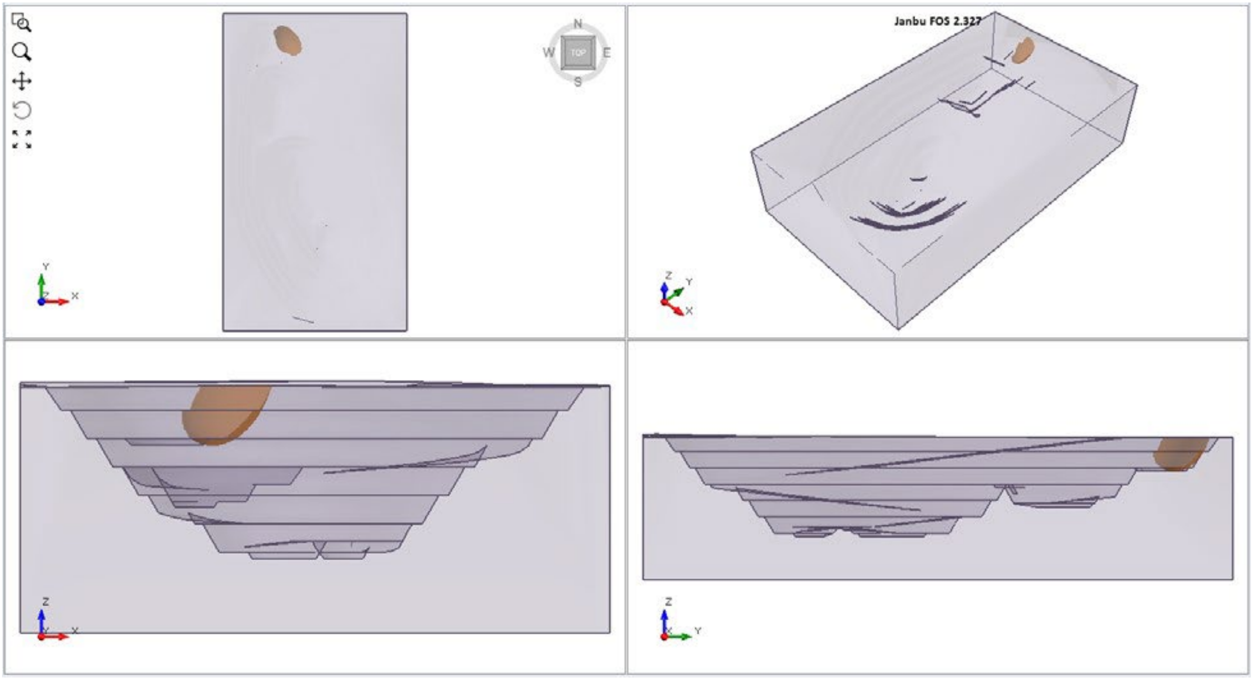

Figure 4.5 – *Slide3* Solution Using the Janbu Solution

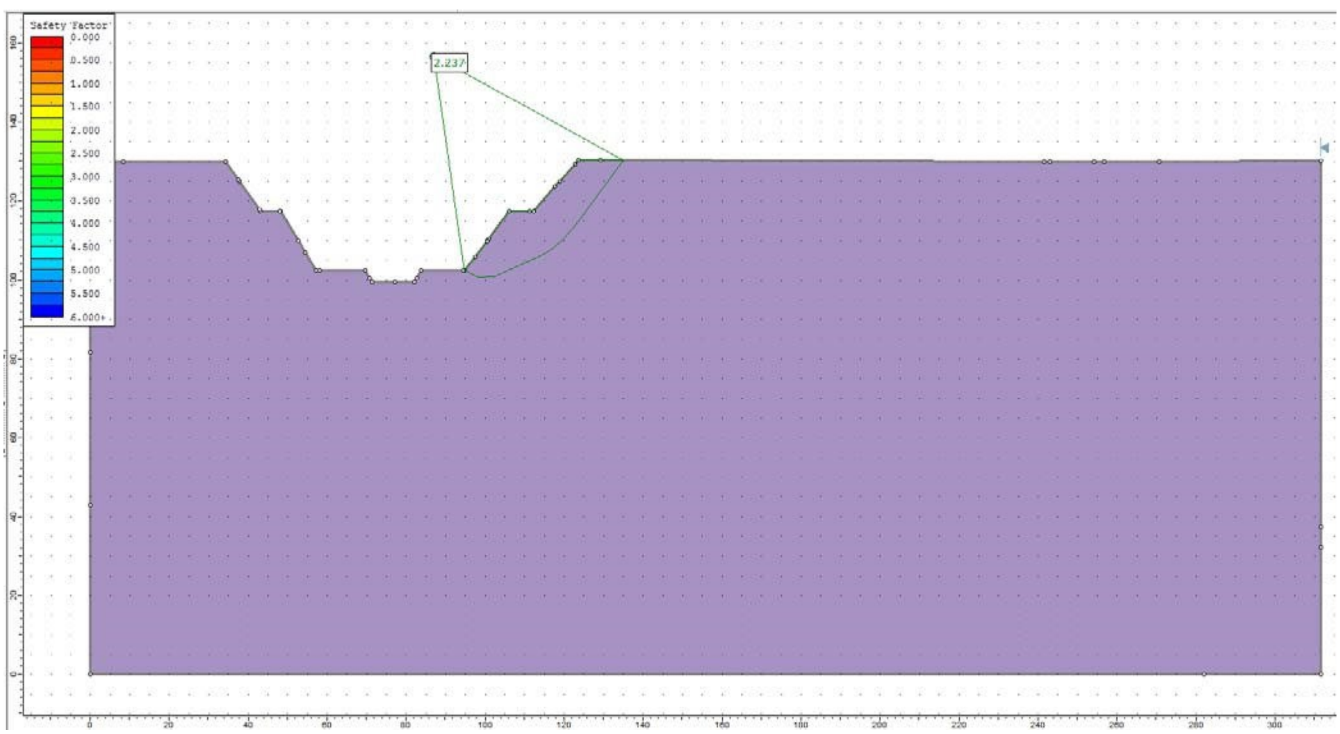

Figure 4.6 – *Slide2* Solution Using the Janbu Method

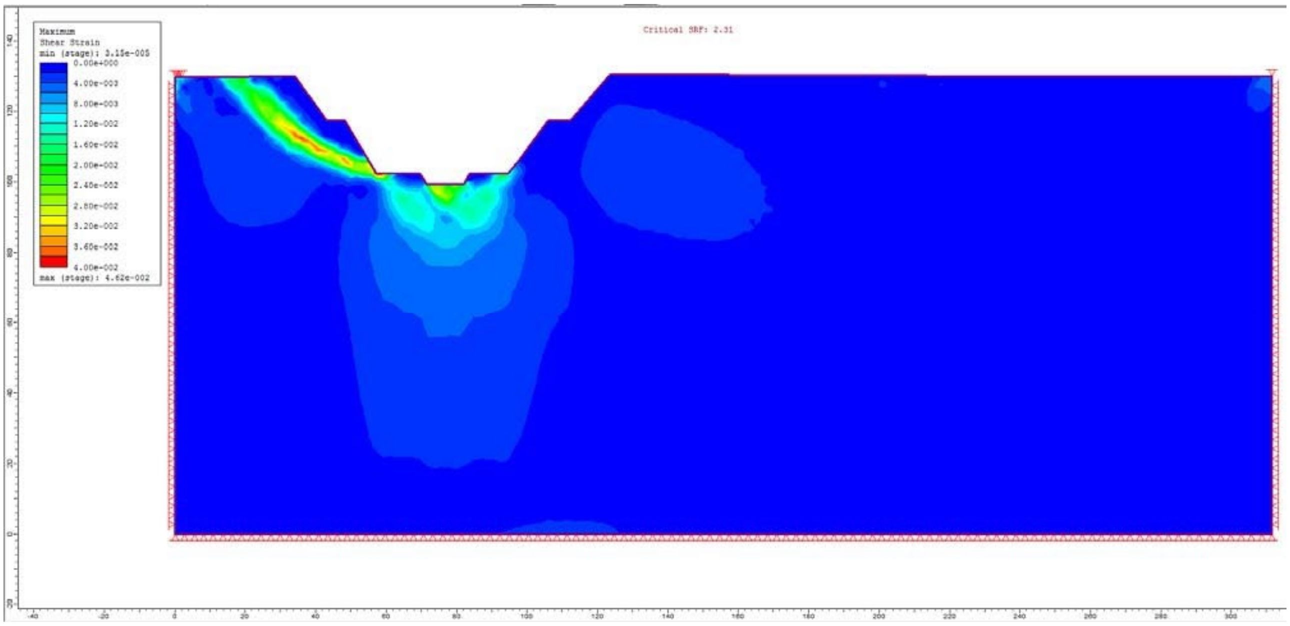

Figure 4.7 – *RS2* Maximum Shear Strain

5. 3D Extruded Verification #5

5.1. 3D coastal bluffs, (4) materials, spherical

5.1.1. Introduction

This example is taken from Brien and Reid (2007). It is a model of coastal bluffs in Seattle, Washington. Scoops3D was used to calculate the Bishop's circular slip surface and corresponding safety factor. The Scoops3D results will be compared with the *Slide3* results.

5.1.2. Problem Description

This example is a non-homogeneous model of the coastal bluffs. The material properties for all four layers can be found in Table 5.1. There is no groundwater in this problem. In the problem defined by Scoops3D, the minimum volume of the slip surface is 1.06e5; this minimum volume has also been implemented in *Slide3* to be constant with the problem defined by Scoops3D. The 2D cross section used to calculate the safety factor in *Slide2* 7.0 and *RS2* was taken in the XZ plane at Y = 218950 m. The spherical slip surface is required.

5.1.3. Properties

Table 5.1: Material Properties

	c´ (psf)	φ´ (deg.)	γ (pcf)
Advance Outwash Deposits	209	38	115
Lawton Clay Member	606	26	108
Beach Sands	0	34	115
Olympia Beds	397	34	115

5.1.4. Results

Table 5.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.16</td><td>1.154</td><td rowspan="4">1.3</td><td rowspan="4">1.23</td></tr>
<tr><td>GLE</td><td>1.162</td><td>1.153</td></tr>
<tr><td>Janbu</td><td>1.137</td><td>1.153</td></tr>
<tr><td>Spencer</td><td>1.163</td><td>1.153</td></tr>
</table>

Referee: FS 1.179 using the Bishop method calculated using Scoops3D

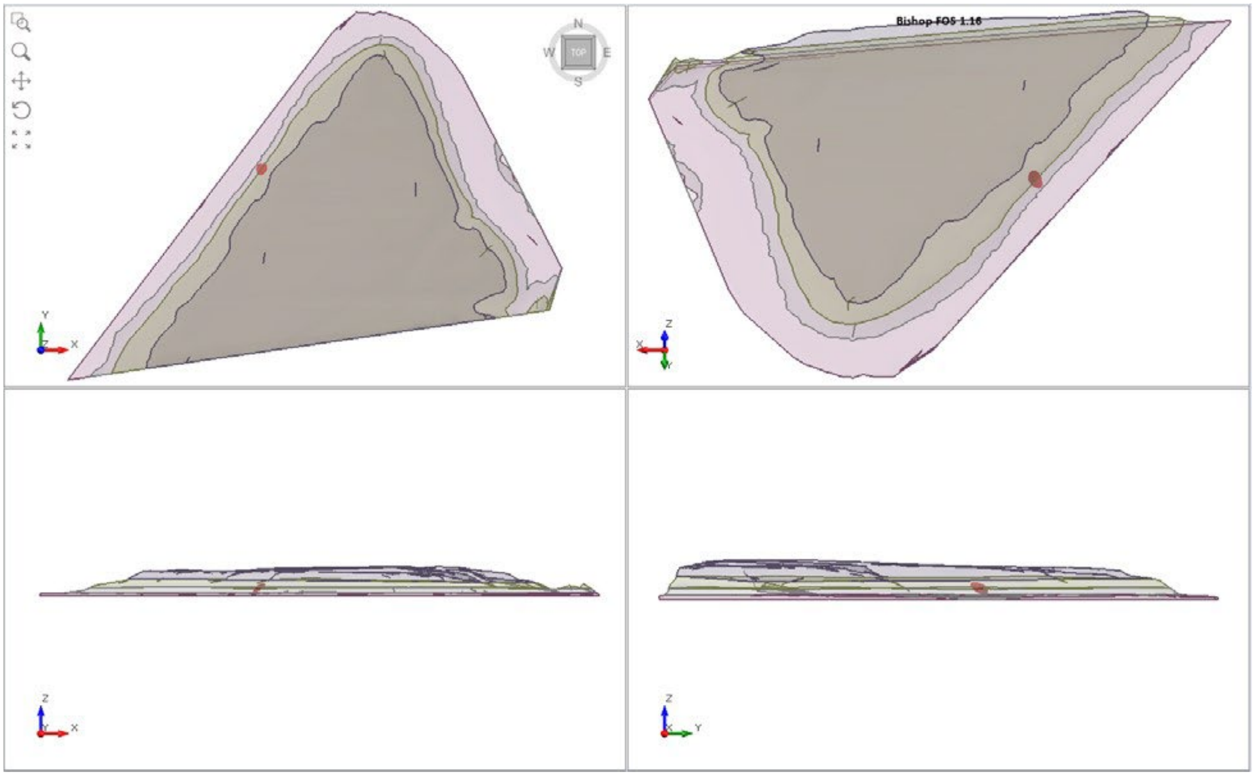

Figure 5.1 – *Slide3* Solution Using the Bishop Method

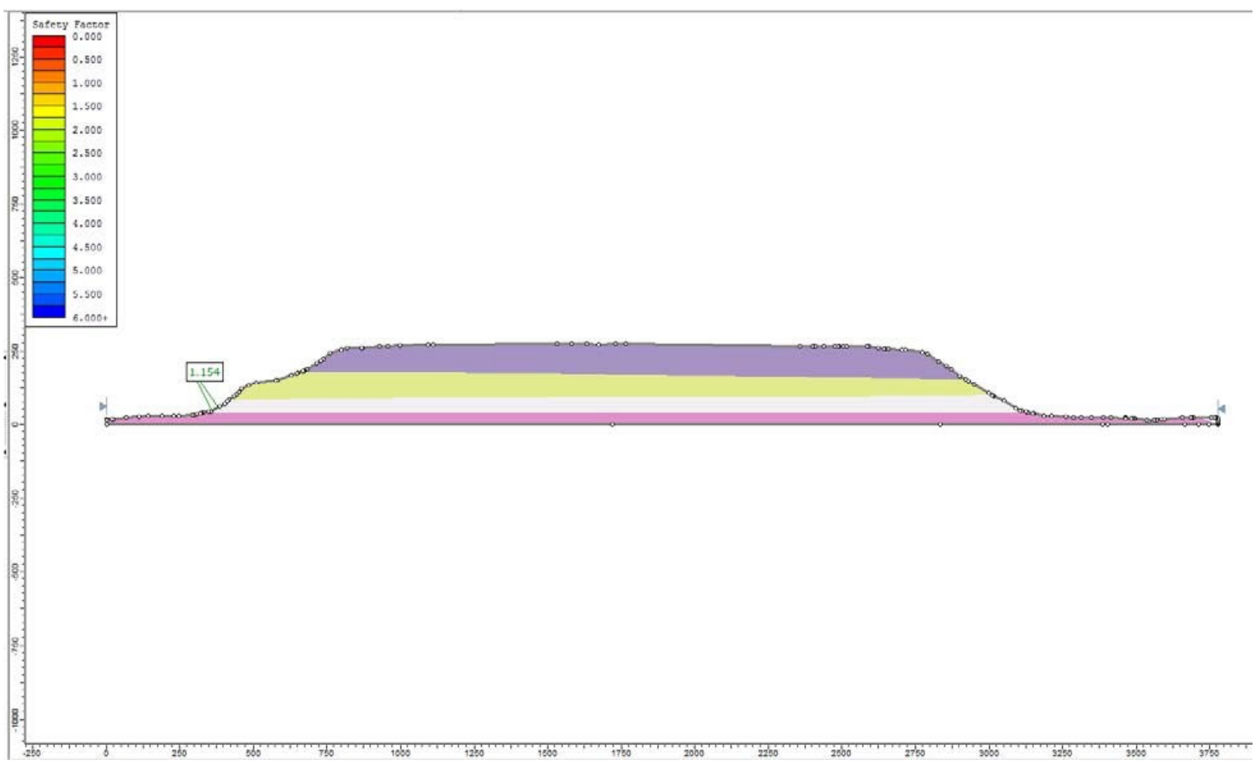

Figure 5.2 – *Slide2* Solution Using the Bishop Method

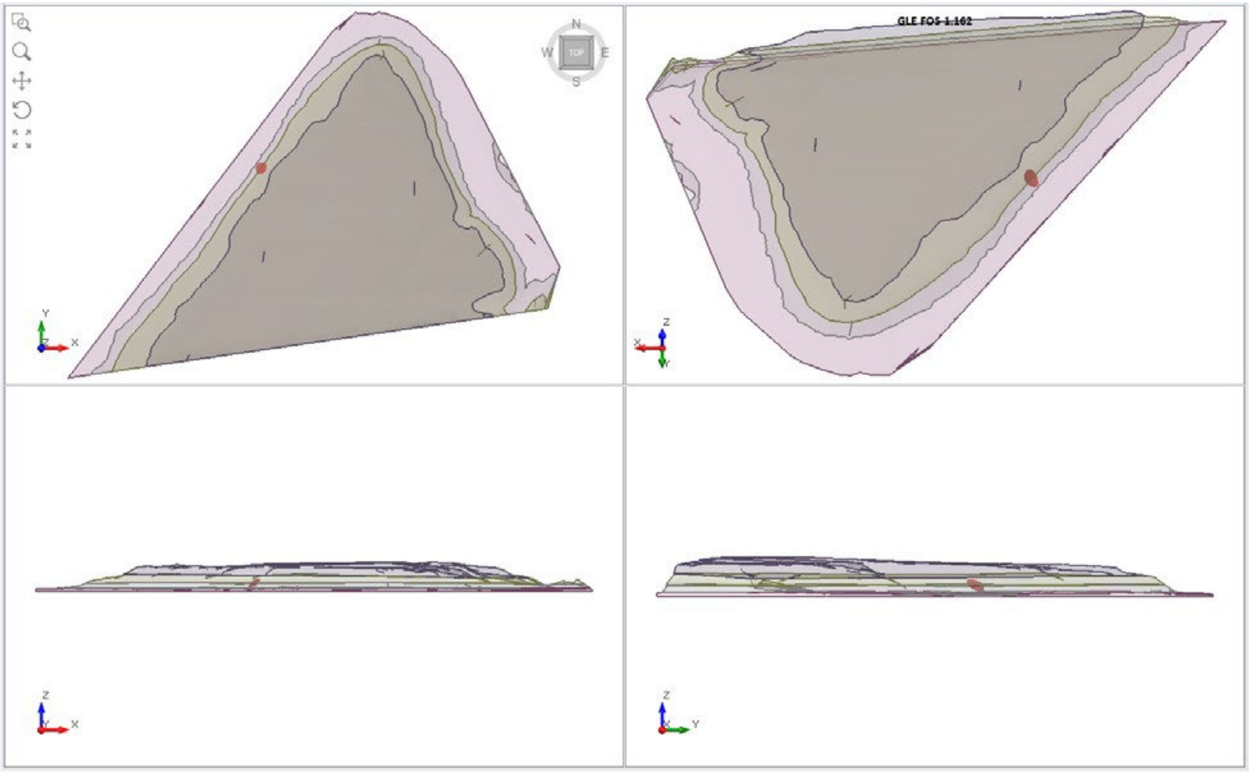

Figure 5.3 – *Slide3* Solution Using the GLE Method

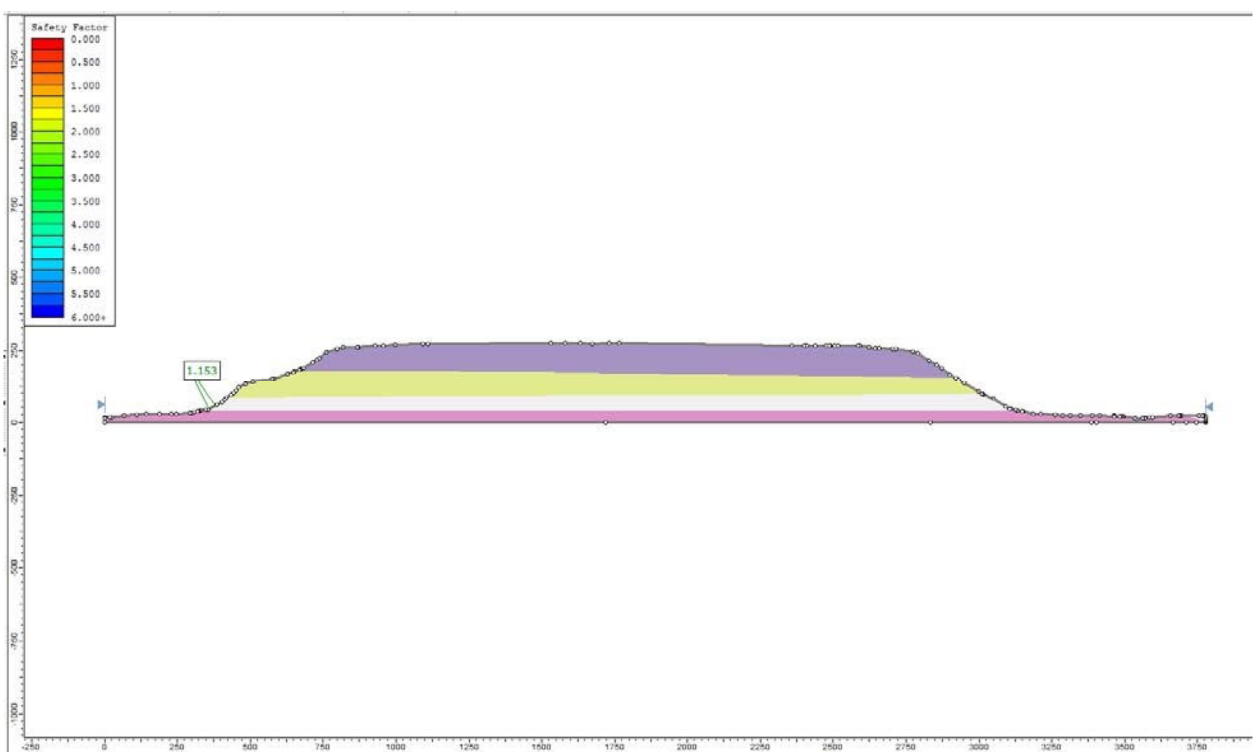

Figure 5.4 – *Slide2* Solution Using the GLE Method

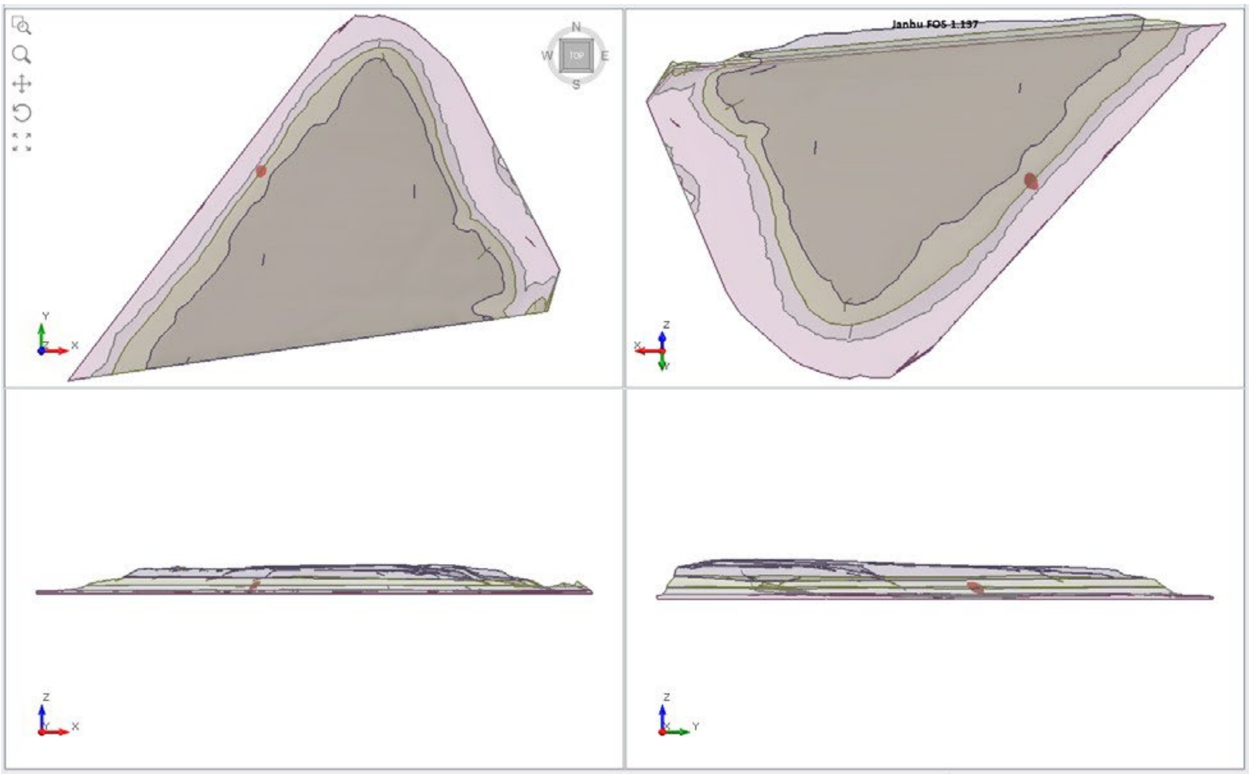

Figure 5.5 – *Slide3* Solution Using the Janbu Method

Figure 5.6 – *Slide2* Solution Using the Janbu Method

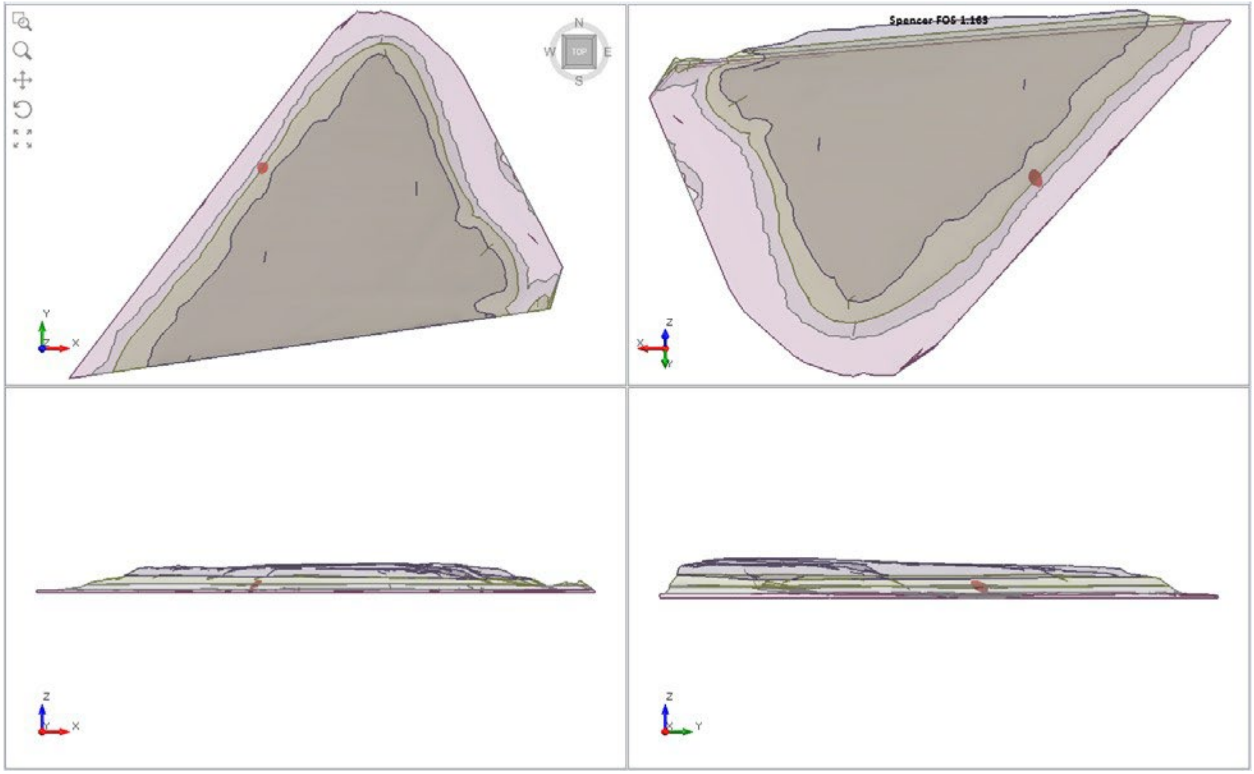

Figure 5.7 – *Slide3* Solution Using the Spencer Method

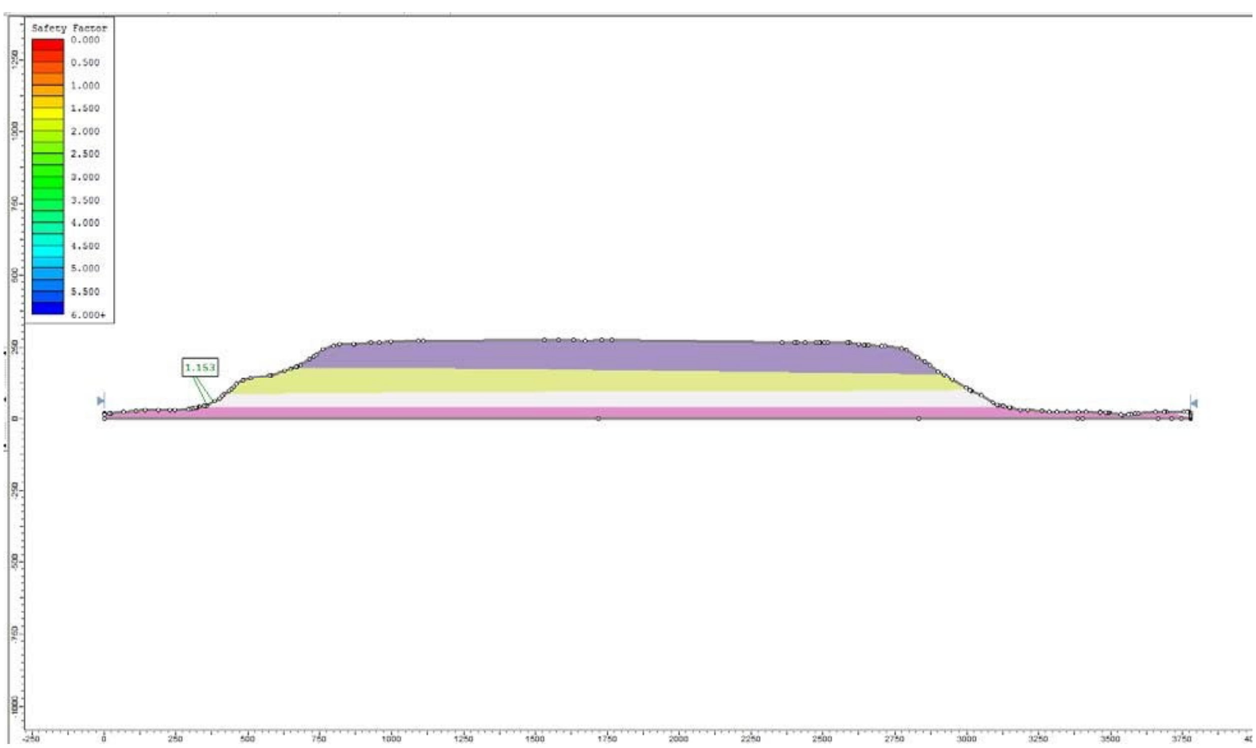

Figure 5.8 – *Slide2* Solution Using the Spencer Method

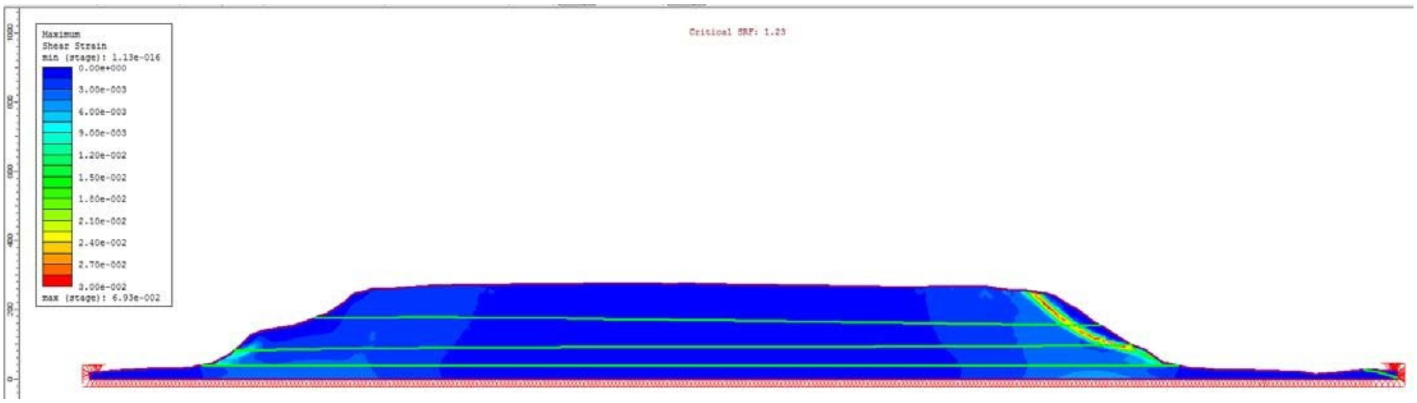

Figure 5.9 – *RS2* Maximum Shear Strain

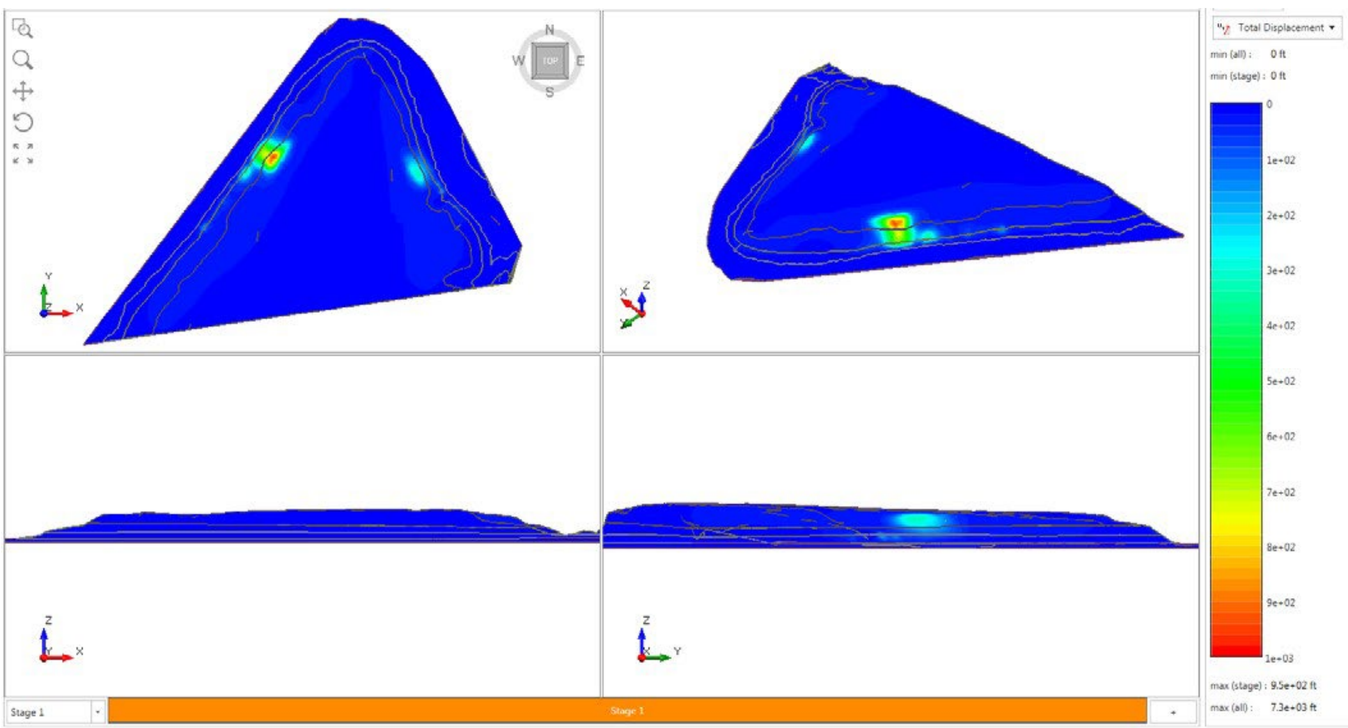

Figure 5.10 – *RS3* Maximum Shear Strain

6. 3D Verification #6

6.1. 3D lofted, weak surface with rock base, spherical

6.1.1. Introduction

This model is taken from Usluogullari et al.'s finite element analysis of different cross sections of a slope in Turkey (2015). The analysis by Usluogullari was originally done on the 2D extrusions of cross sections of the slope. However, this problem lofts the cross sections to create a 3D model that will be analyzed by *Slide3* and *RS3*.

6.1.2. Problem Description

Figure 6.1, 6.2, and 6.3 show the three cross sections that are lofted together to form a model of the slope studied by Usluogullari. However, the 3D slope was not originally analyzed by Usluogullari, so Figure 6.3 has been extruded 50m in the Y direction to give a more accurate comparison between *Slide3*'s results and Usluogullari. To create the 3D loft, Figure 6.1 is in the XZ plane. Figure 6.2 and 6.3 are both originally in the XZ plane and have coordinates as shown in their respective figures before undergoing the following transformations to create the loft. Figure 6.2 is rotated -45° around the Z axis, with an origin at X = 180 m, and then translated from X = 180m to X = 230 m. Figure 6.3 is rotated -90° around the Z axis, with an origin at X = 165 m, and then translated from X = 165m to X = 230 m. Figure 41.3 is also used for the 2D analysis using *Slide2* 7.0 and *RS2*. Table 6.1 shows the material properties. The spherical slip surface is required in all cases.

6.1.3. Geometry and Properties

Table 6.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Weak Layer	2	25	19
Rock	6000	40	21

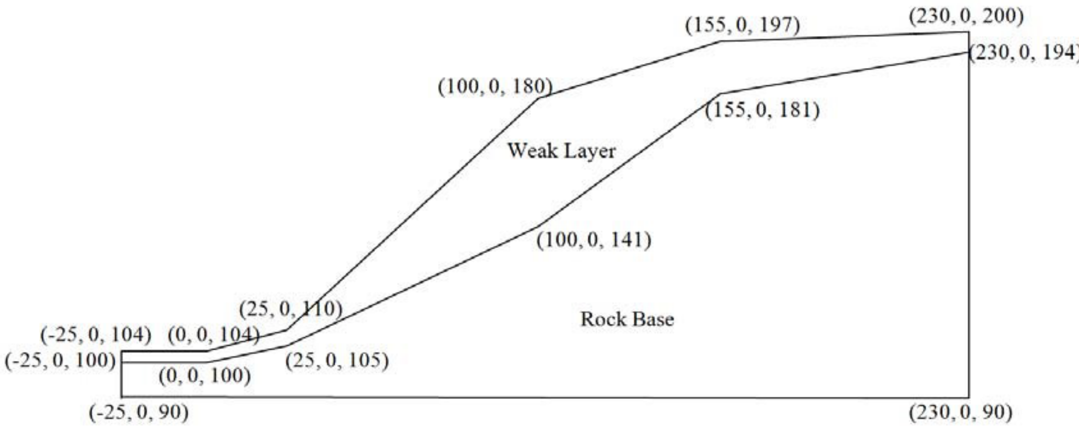

Figure 6.1

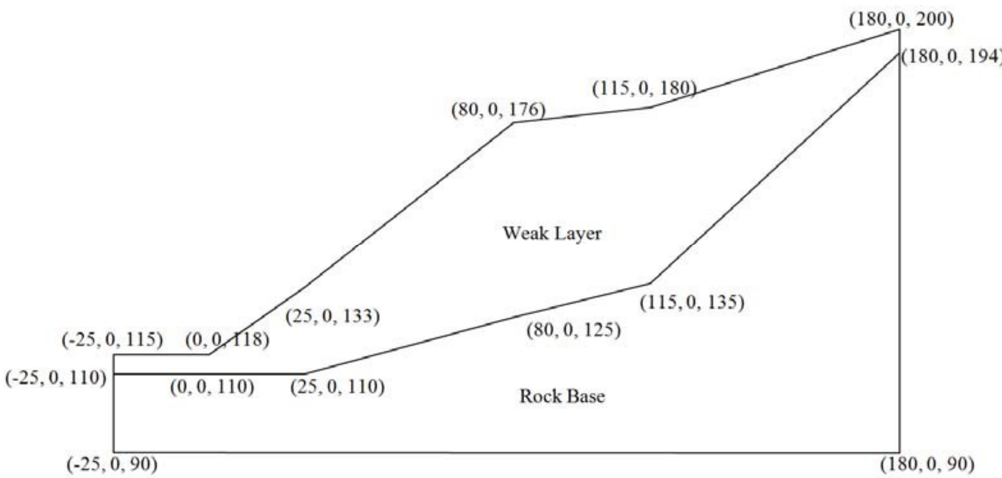

Figure 6.2

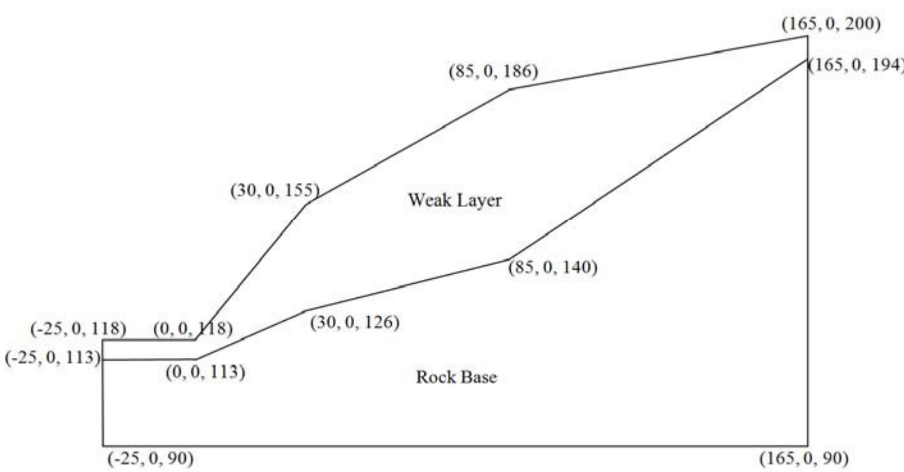

Figure 6.3

6.1.4. Results

Table 6.2: Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	0.512	0.465	0.51	0.46
GLE	0.515	0.462		
Janbu	0.481	0.450		
Spencer	0.511	0.463		

Referee: FS 1.073 [Usluogullari et al., 2015]

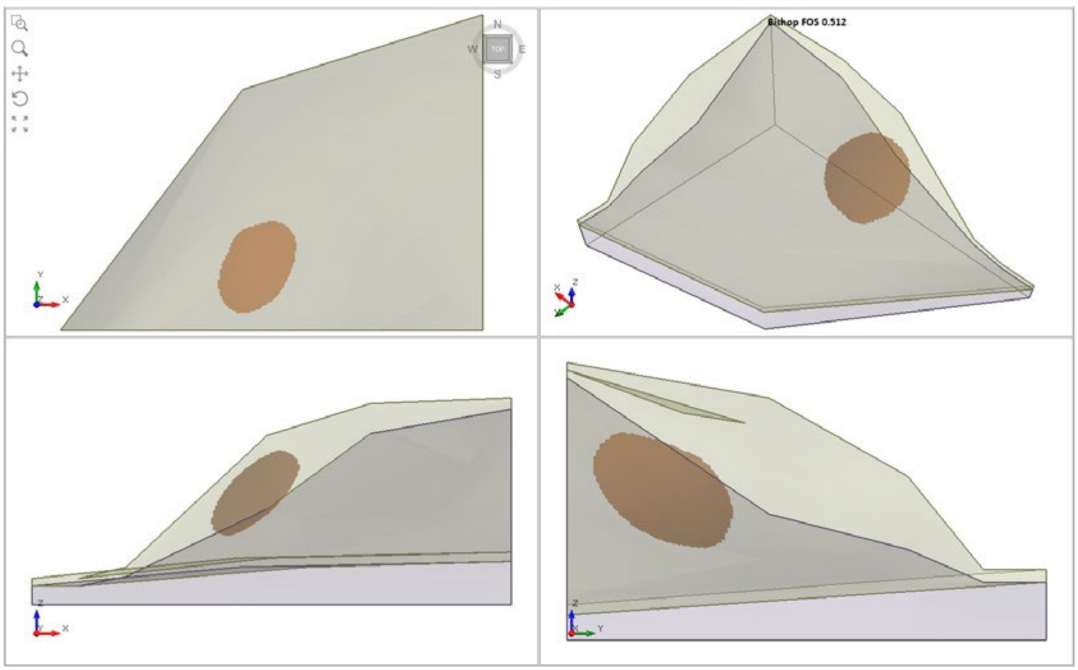

Figure 6.4 – *Slide3* Solution Using the Bishop Method

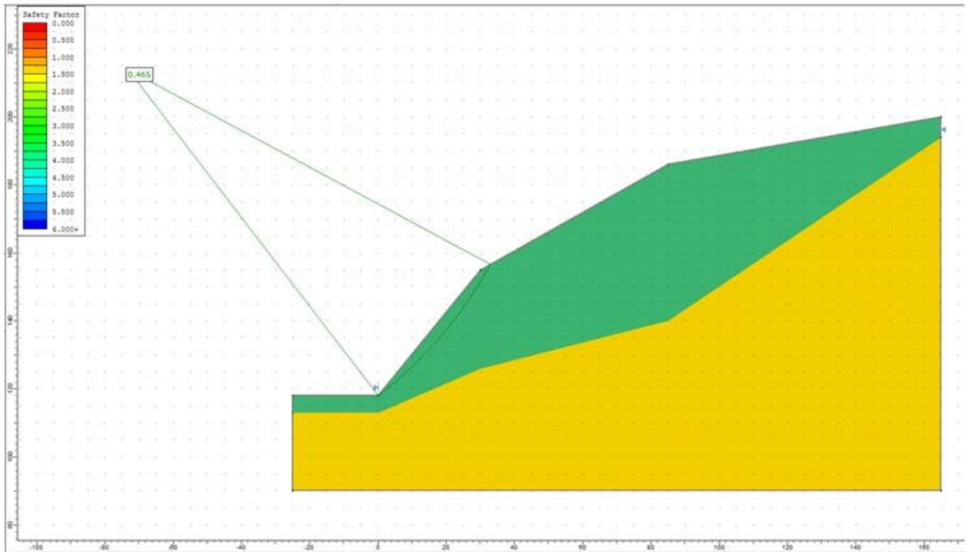

Figure 6.5 – *Slide2* Solution Using the Bishop Method

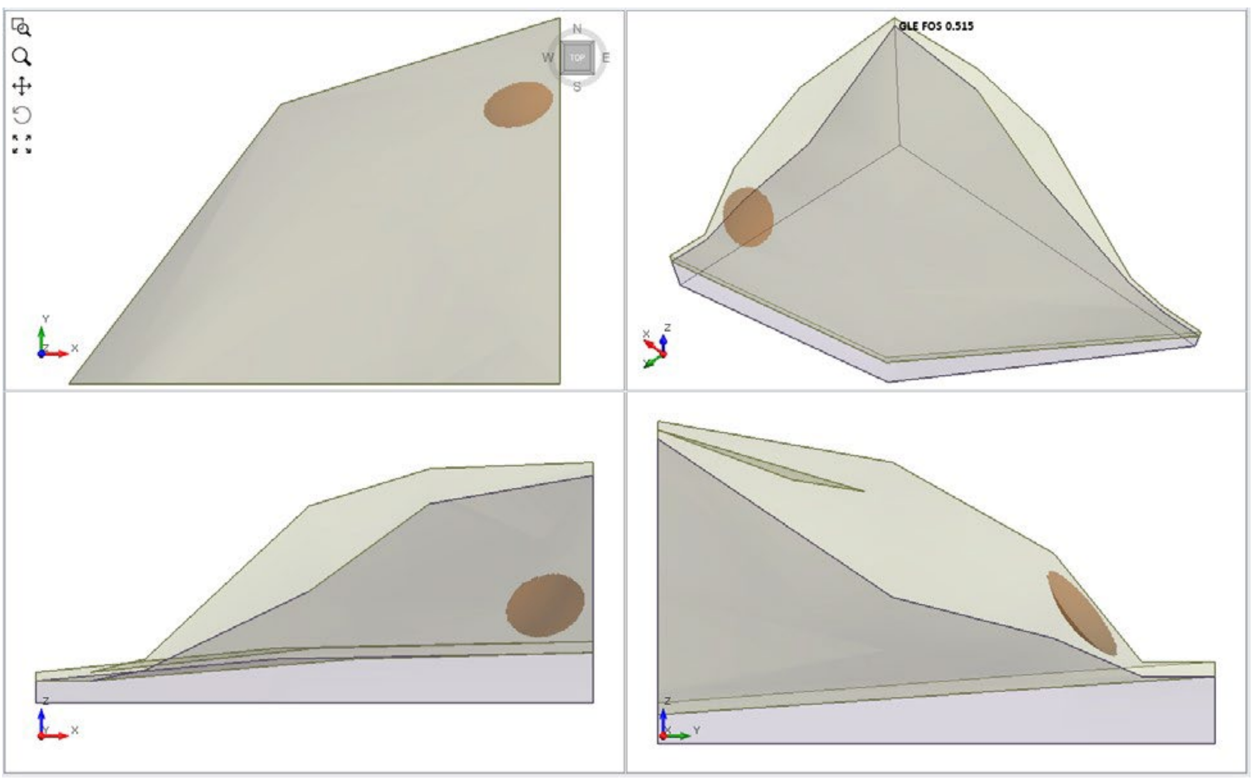

Figure 6.6 – *Slide3* Solution Using the GLE Method

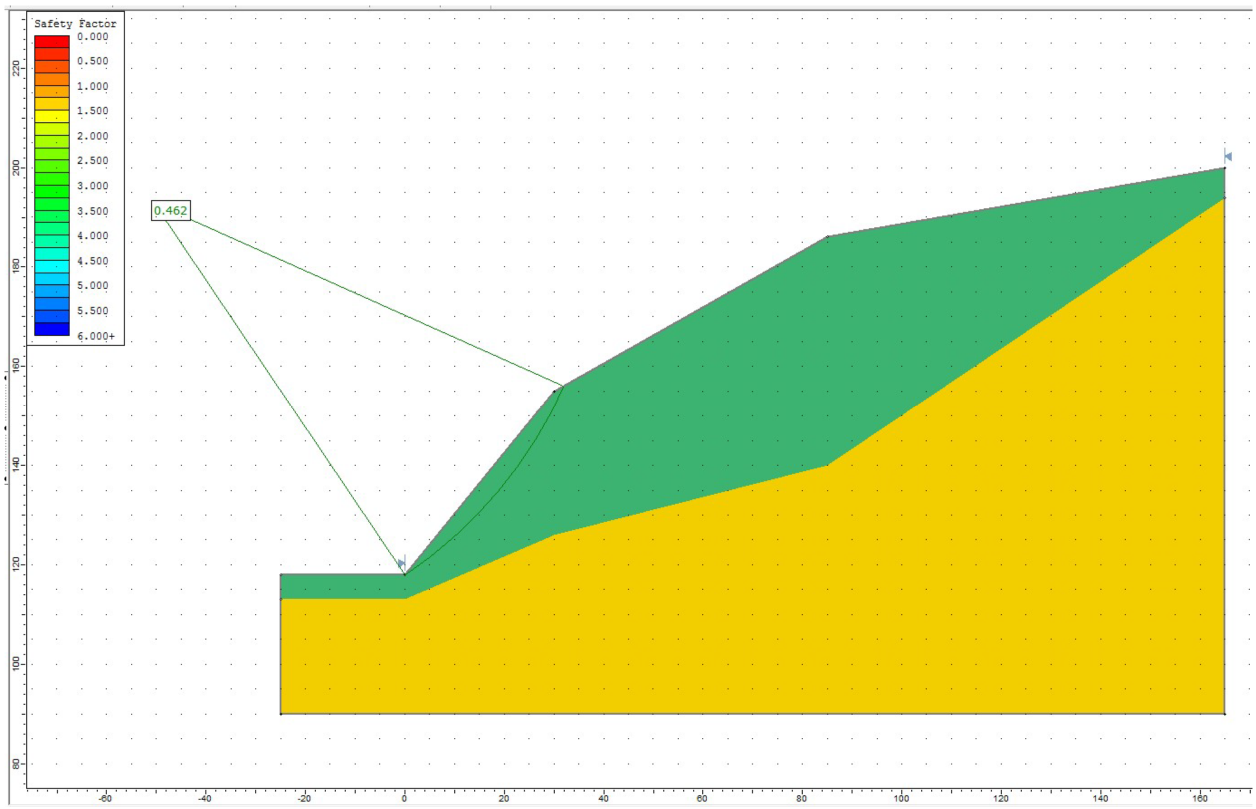

Figure 6.7 – *Slide2* Solution Using the GLE Method

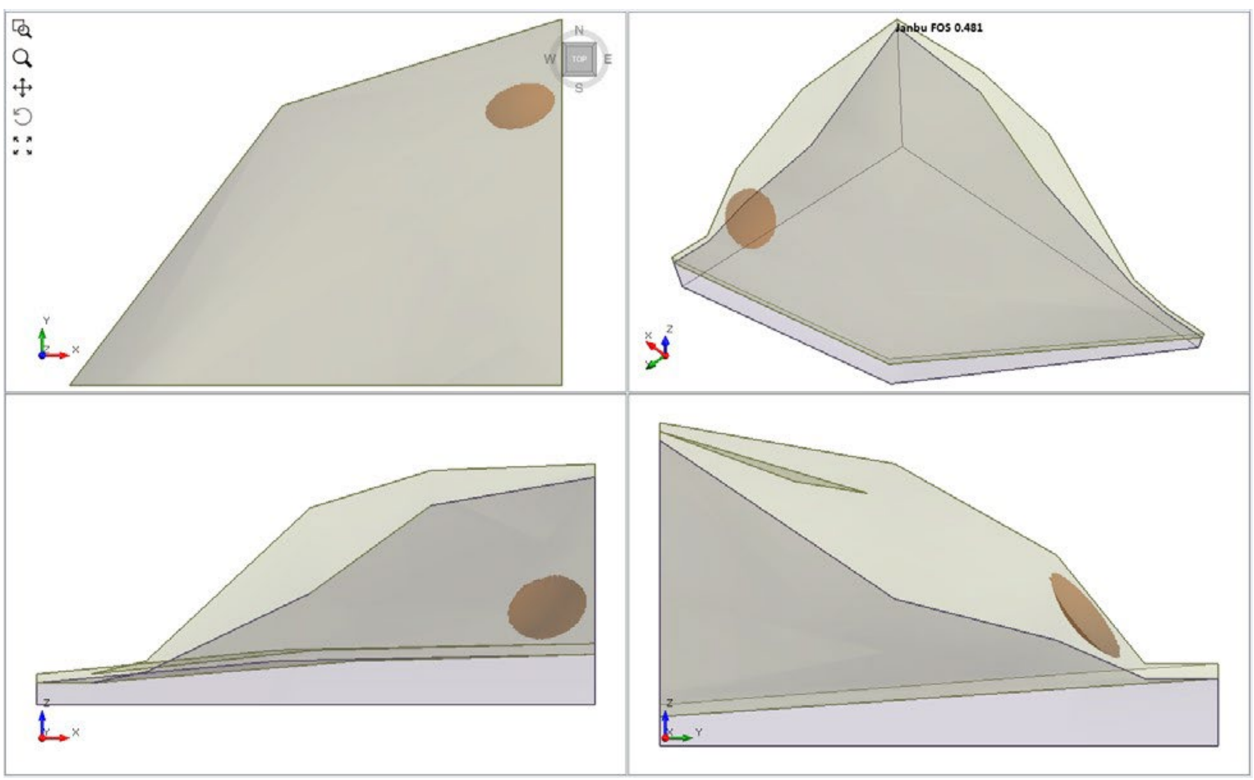

Figure 6.8 – *Slide3* Solution Using the Janbu Method

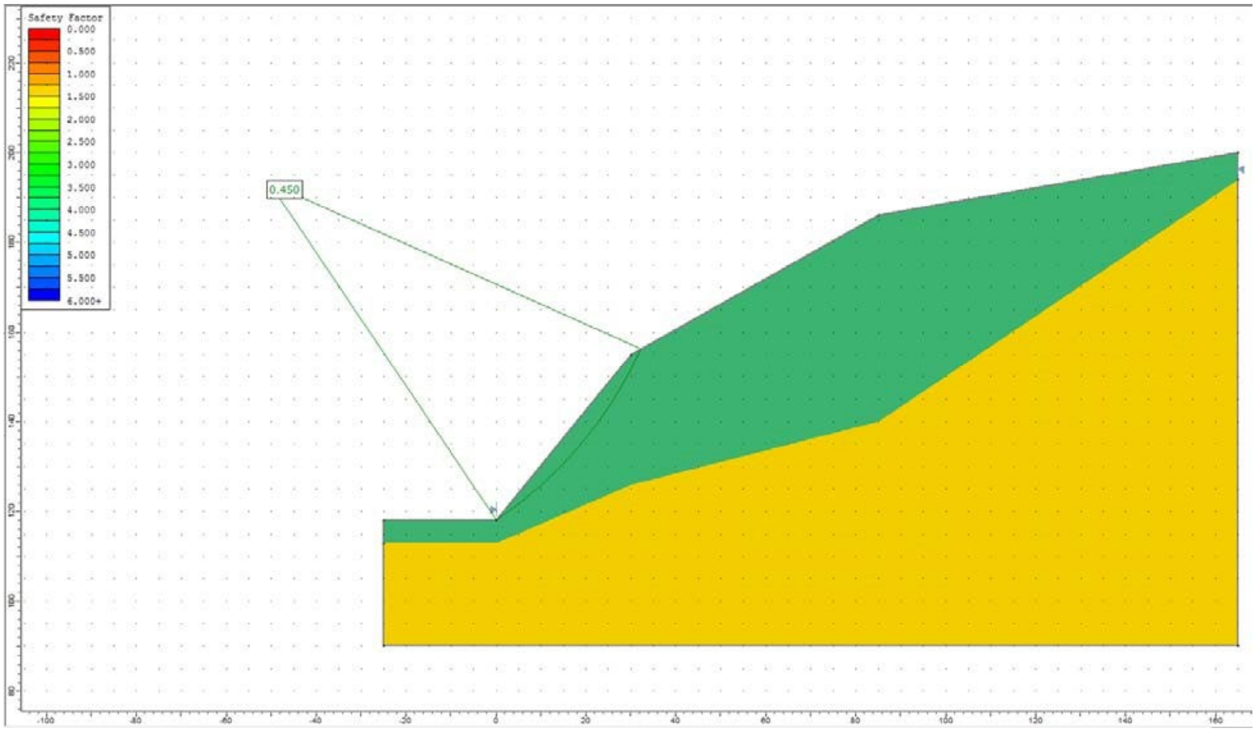

Figure 6.9 – *Slide2* Solution Using the Janbu Method

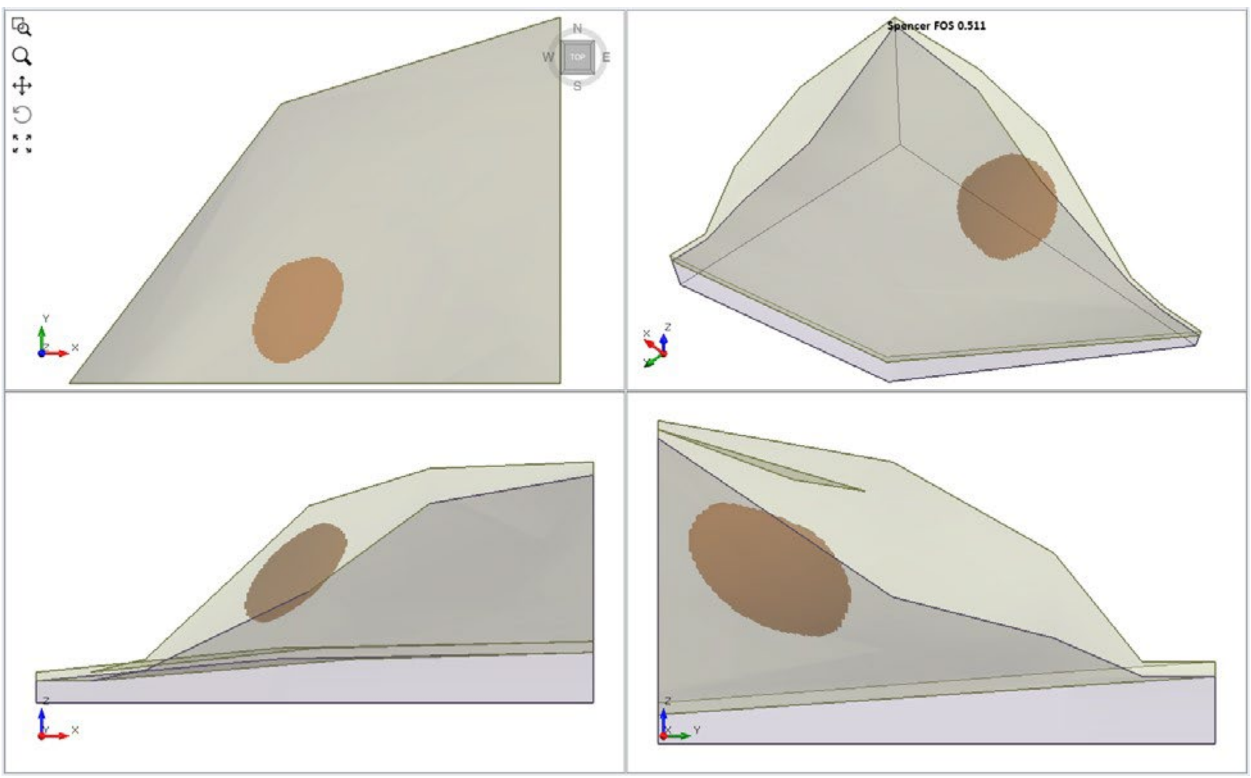

Figure 6.10 – *Slide3* Solution Using the Spencer Method

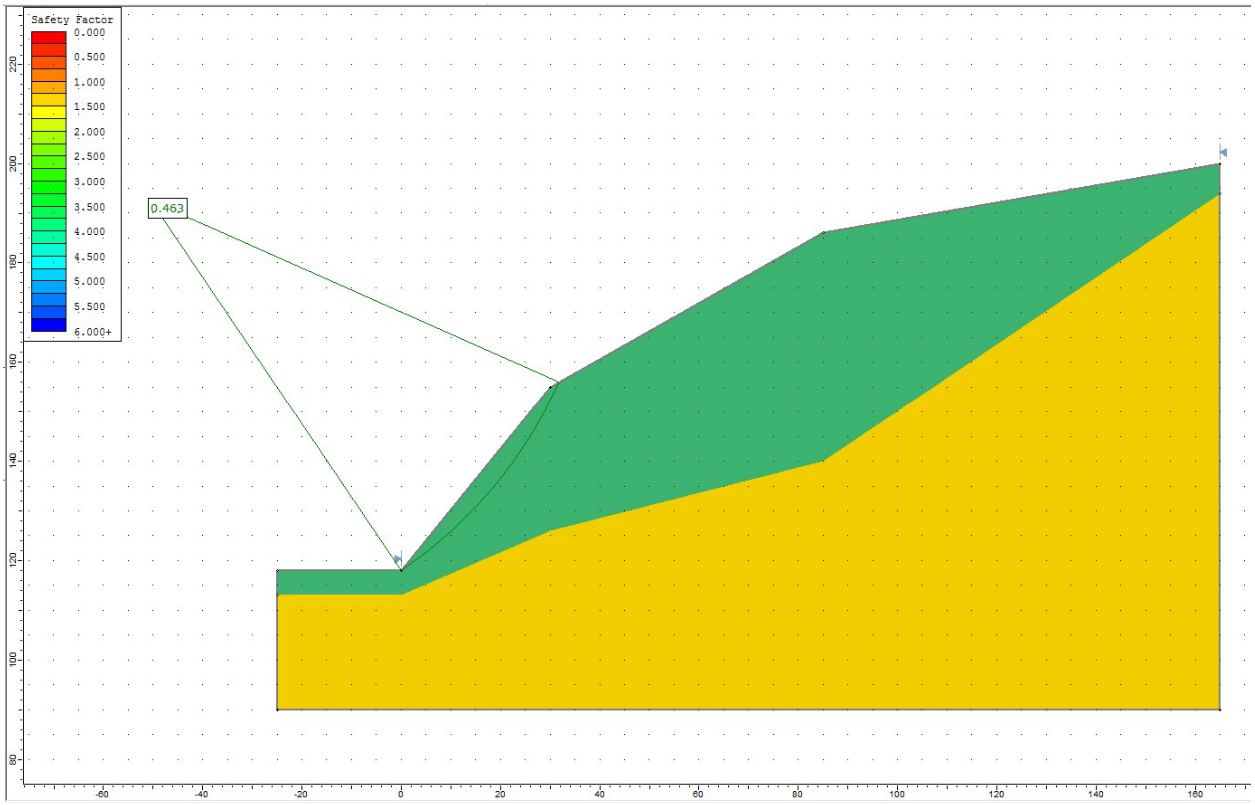

Figure 6.11 – *Slide2* Solution Using the Spencer Method

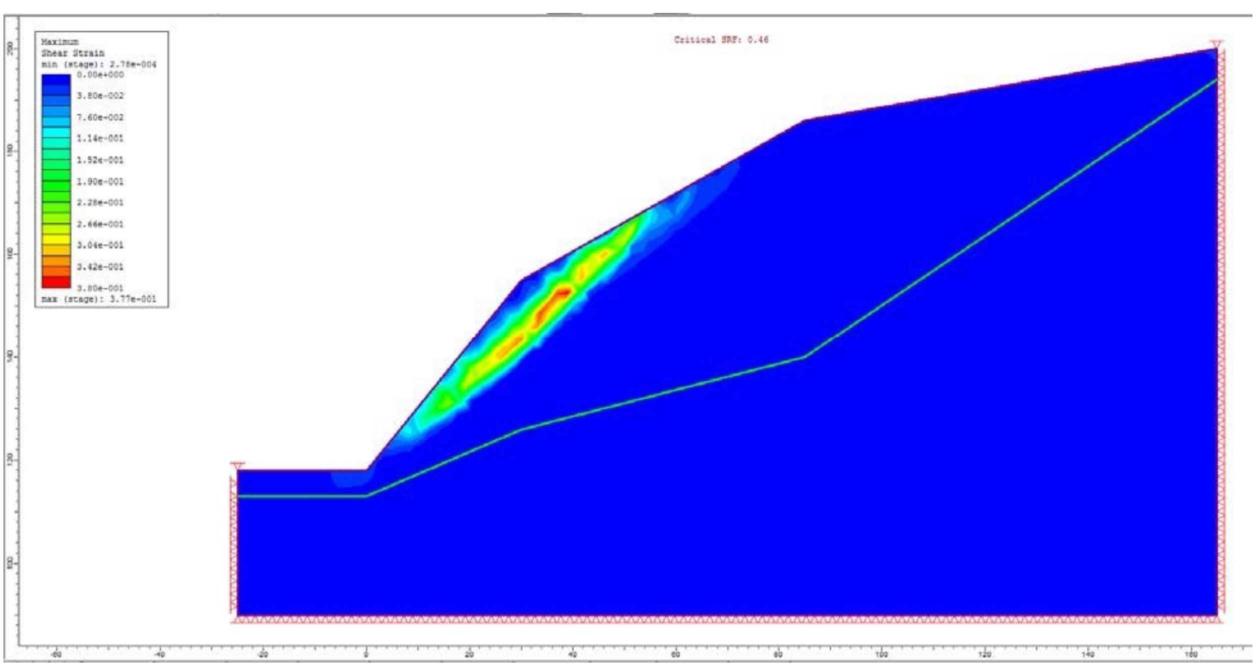

Figure 6.12 – *RS2* Maximum Shear Strain

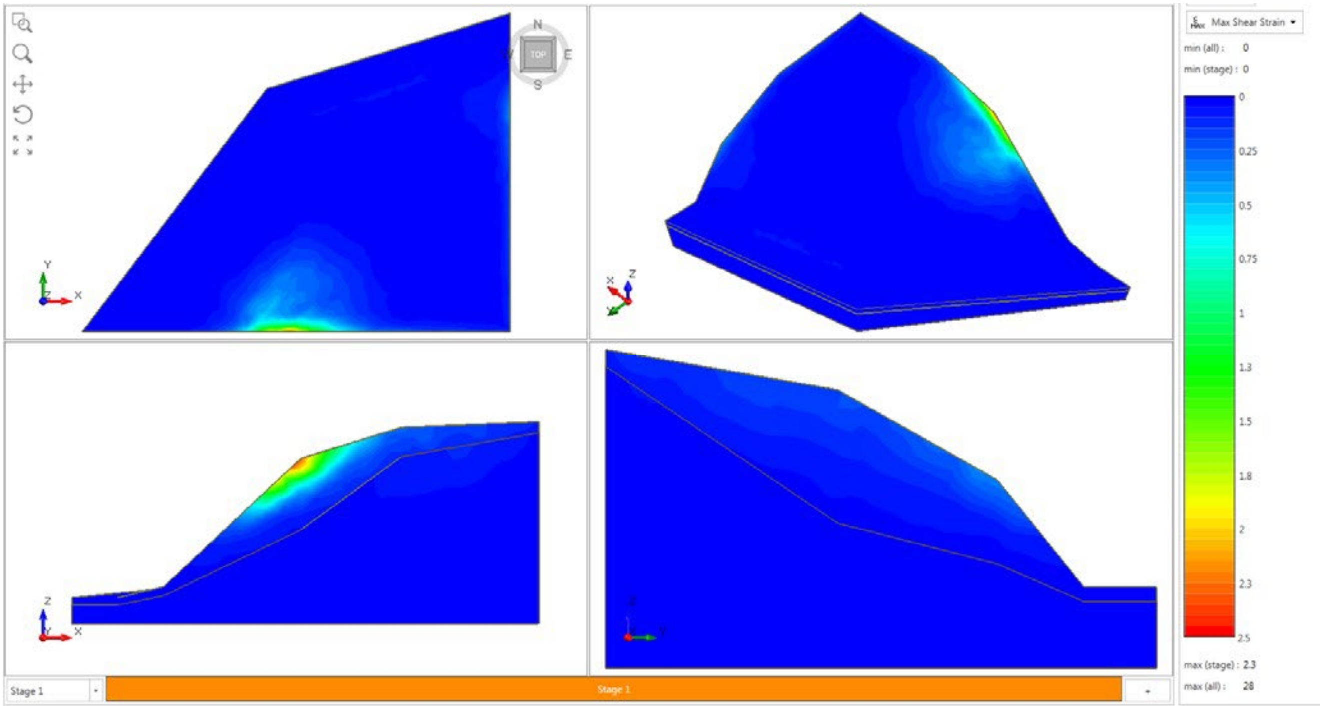

Figure 6.13 – *RS3* Maximum Shear Strain

7. 3D Verification #7

7.1. 3D lofted, (3) materials, water table with ponded water, ellipsoidal with SA

7.1.1. Introduction

This model is taken from Kondalamahanthy's analysis on the Forest City land*Slide2* in South Dakota (2013). A back analysis was done of the slope, with the safety factor as 1.00 to determine the friction angle of the weathered shale. This example takes the friction angle found by Kondalamahanthy for a given water level, and calculates the safety factor using *Slide3* and *RS3*, comparing it with the 1.00 assumed. The model done on *Slide3* and *RS3* is a simplified version of the slope, combining thin layers of different materials with similar properties into one layer with the same properties.

7.1.2. Problem Description

The slope geometry for this example was modeled by lofting six 3D cross sections to each other. The profile in the XZ plane where Y = 2480 ft was used for the *Slide2* 7.0 and *RS2* analyses. The water table is consistent across the cross sections with coordinates (-600 1620), (800, 1620), (1100, 1630), (2000, 1650), (3250, 1700), and (4000, 1750) in the XZ plane. The material properties can be found in Table 7.1. All values are imperial for this example.

7.1.3. Properties

Table 7.1: Material Properties

	c´ (psf)	φ´ (deg.)	γ (lbs/ft^3)
Fresh Shale	1000	15	120
Weathered Shale	0	5.7	115
Till	500	19.3	130

7.1.4. Results

Table 7.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>0.951</td><td>0.660</td><td rowspan="4">0.78</td><td rowspan="4">0.71</td></tr>
<tr><td>GLE</td><td>0.944</td><td>0.659</td></tr>
<tr><td>Janbu</td><td>0.919</td><td>0.644</td></tr>
<tr><td>Spencer</td><td>0.946</td><td>0.663</td></tr>
</table>

Referee: FS 1.00 [Kondalamahanthy, 2013]

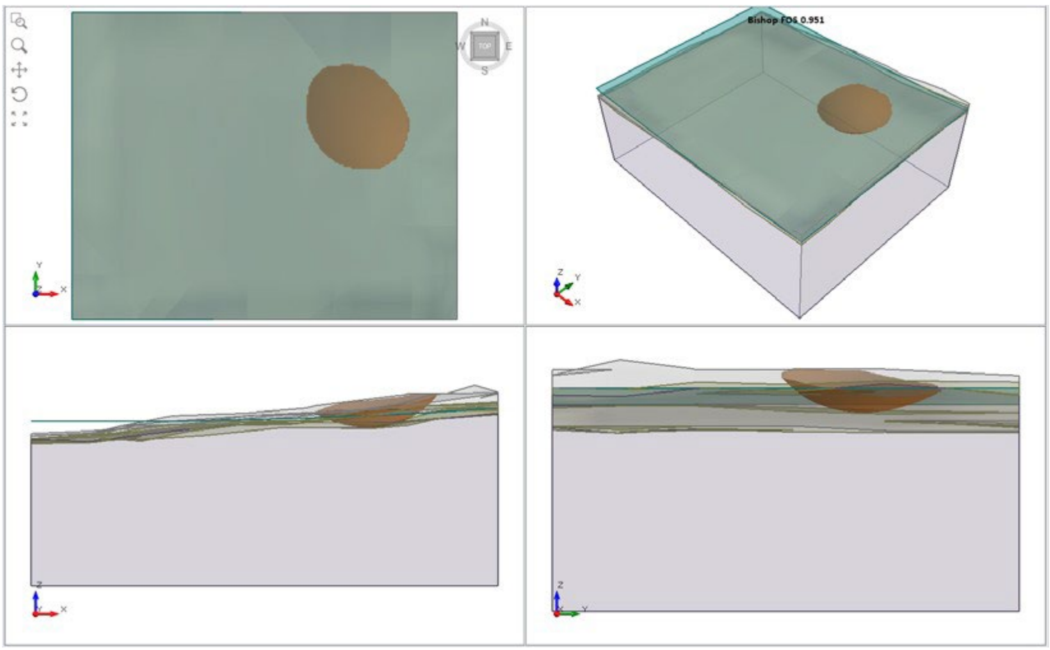

Figure 7.1 – *Slide3* Solution Using the Bishop Method

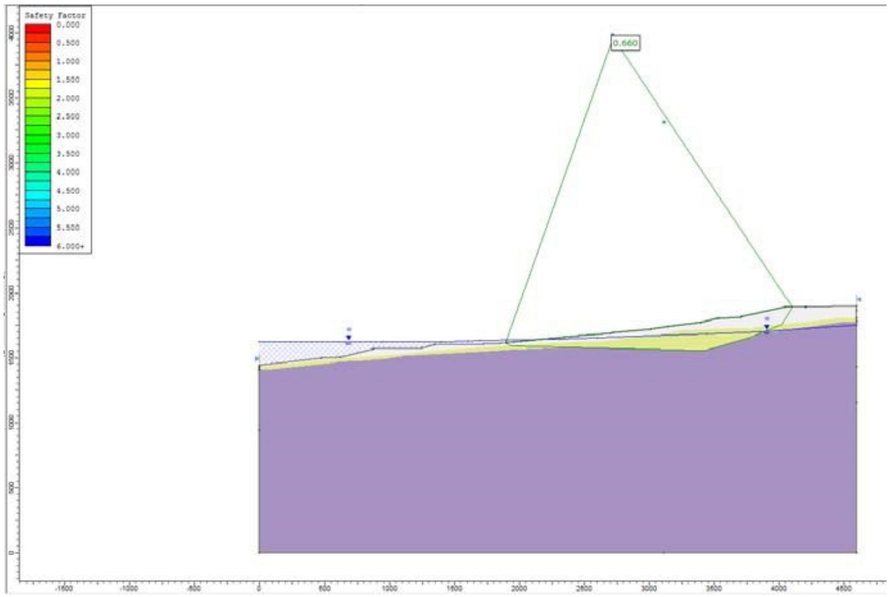

Figure 7.2 – *Slide2* Solution Using the Bishop Method

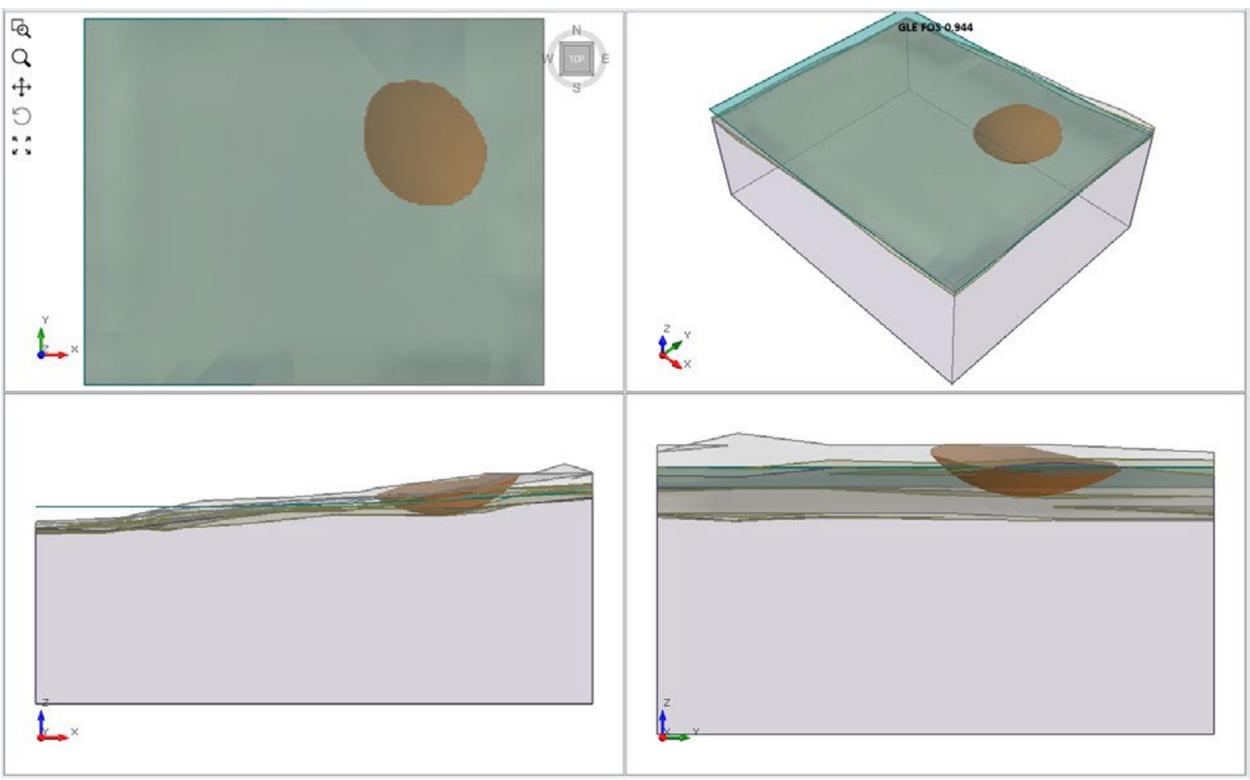

Figure 7.3 – *Slide3* Solution Using the GLE Method

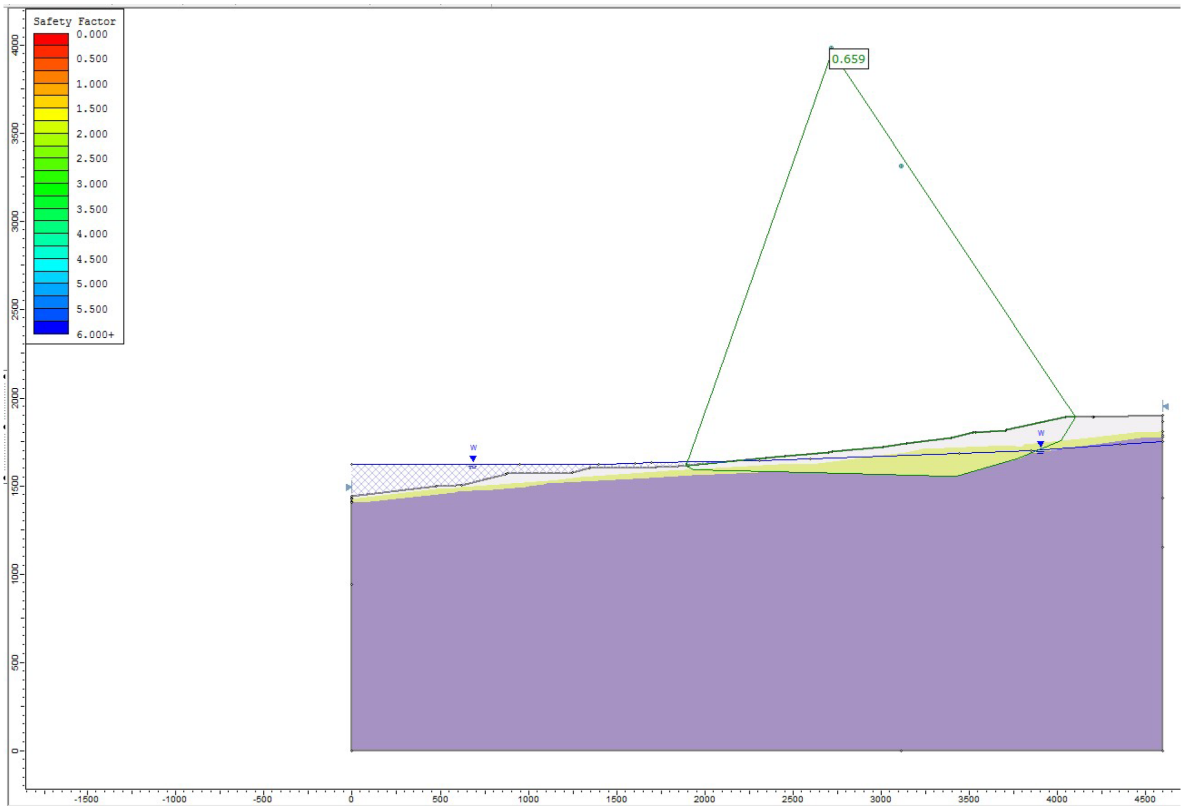

Figure 7.4 – *Slide2* Solution Using the GLE Method

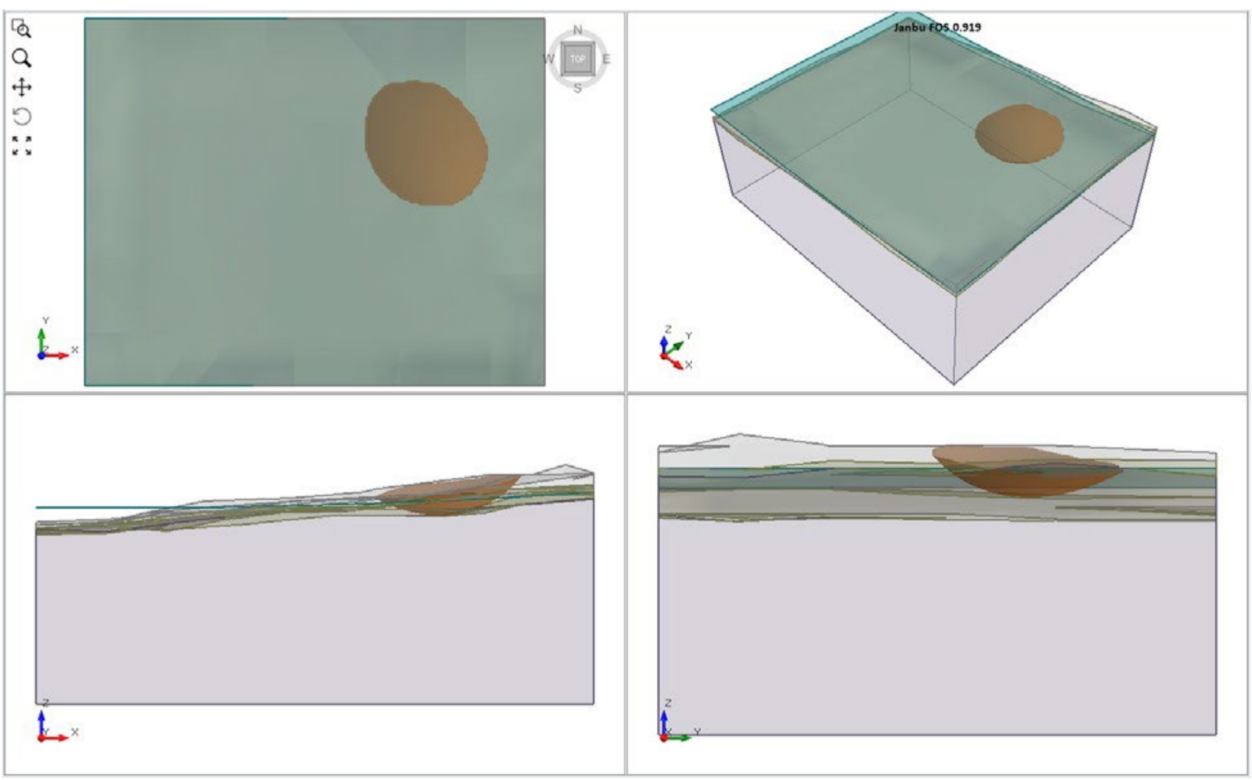

Figure 7.5 – *Slide3* Solution Using the Janbu Method

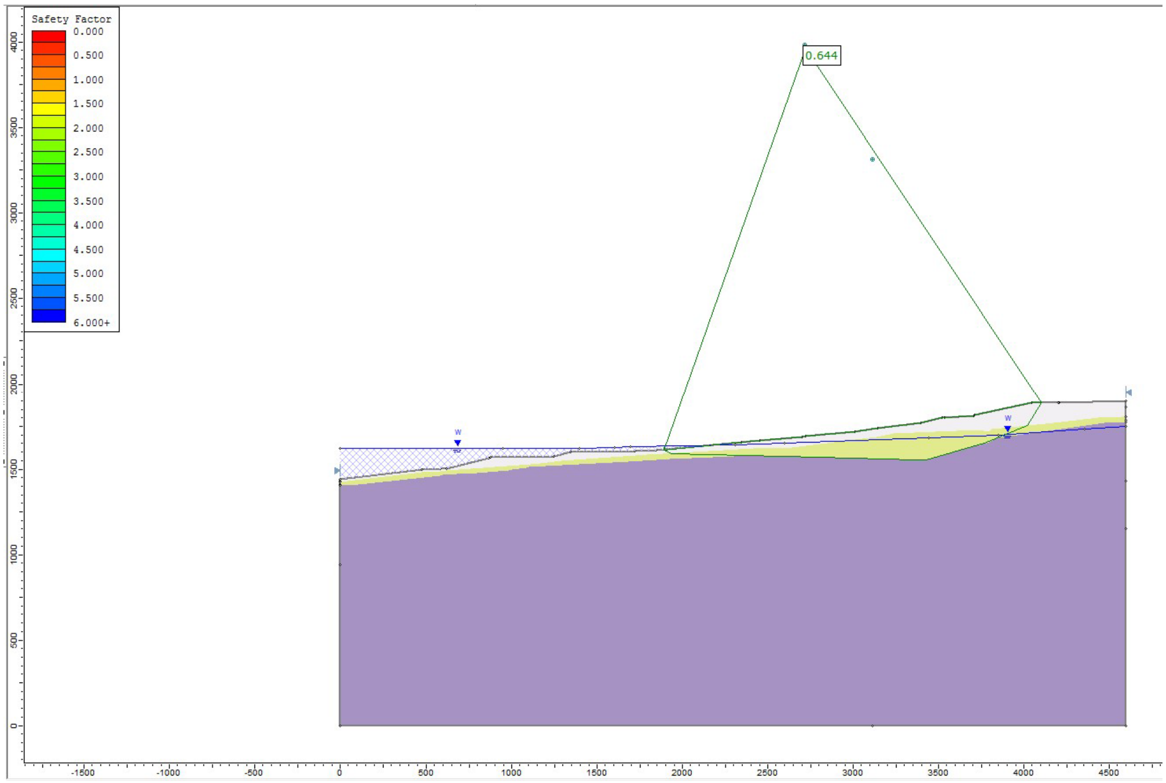

Figure 7.6 – *Slide2* Solution Using the Janbu Method

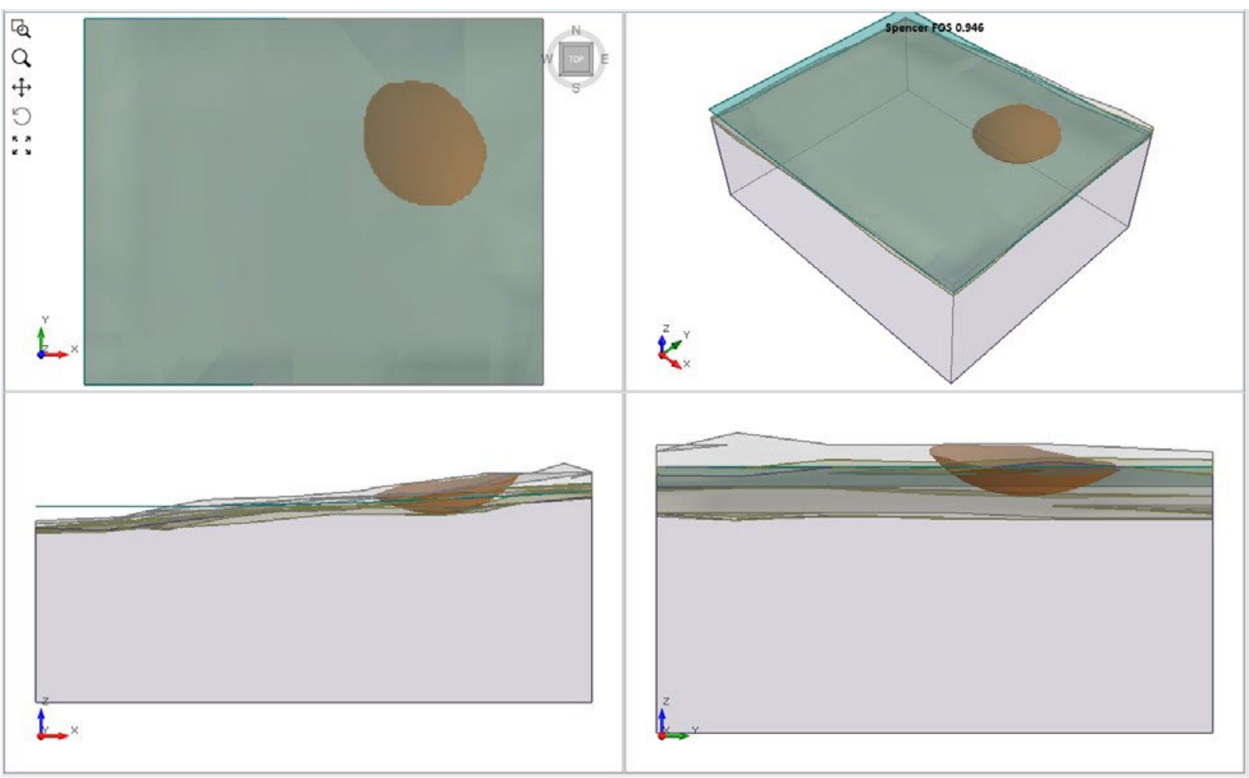

Figure 7.7 – *Slide3* Solution Using the Spencer Method

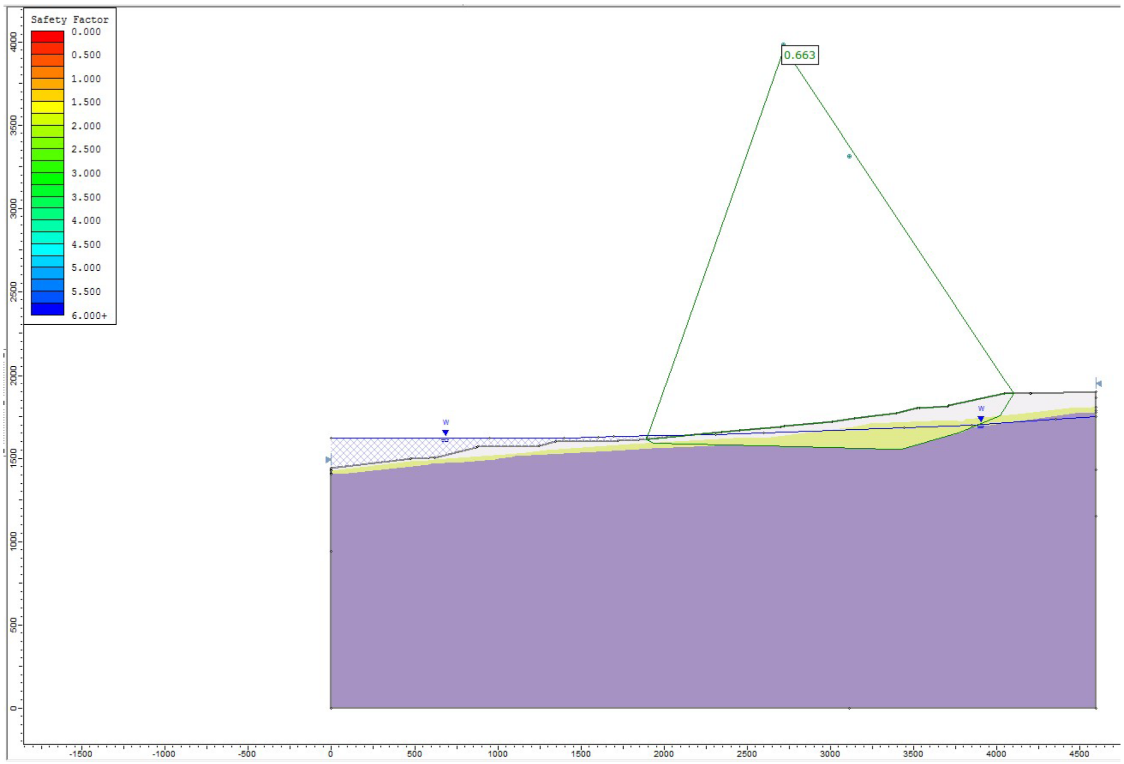

Figure 7.8 – *Slide2* Solution Using the Spencer Method

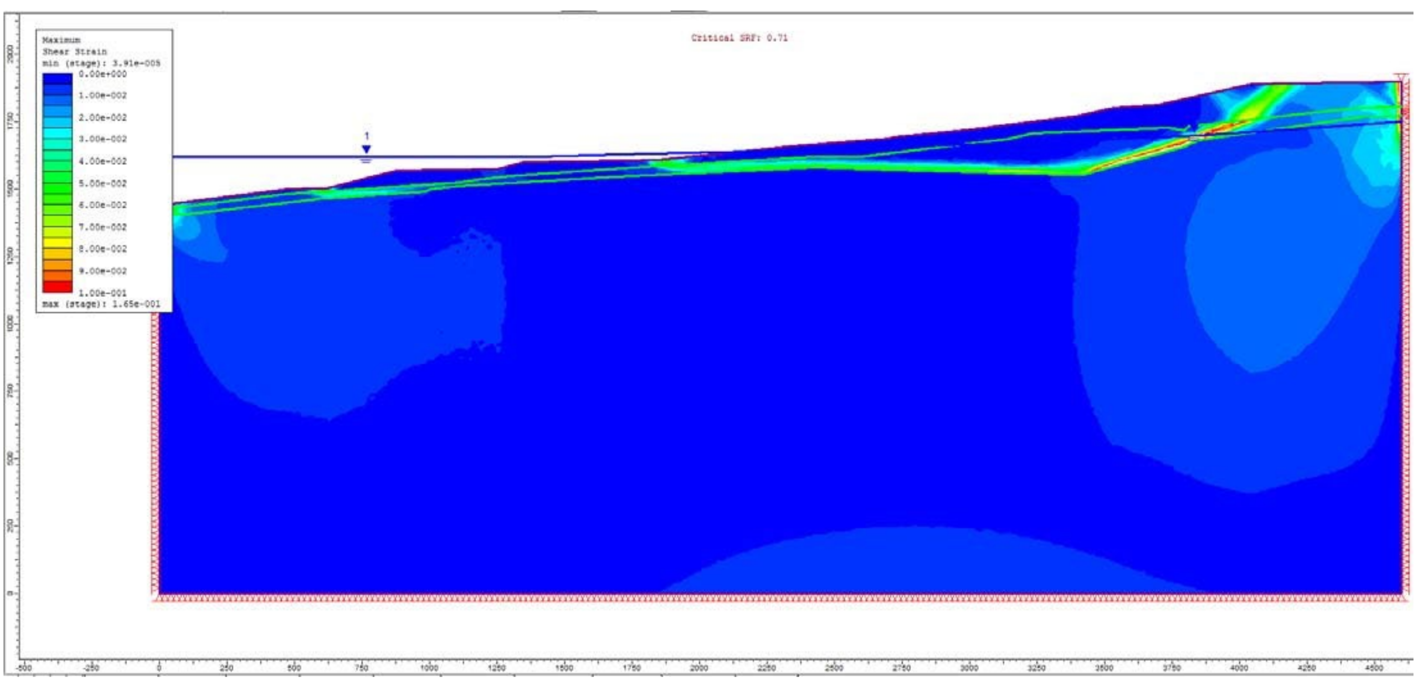

Figure 7.9 – *RS2* Maximum Shear Strain

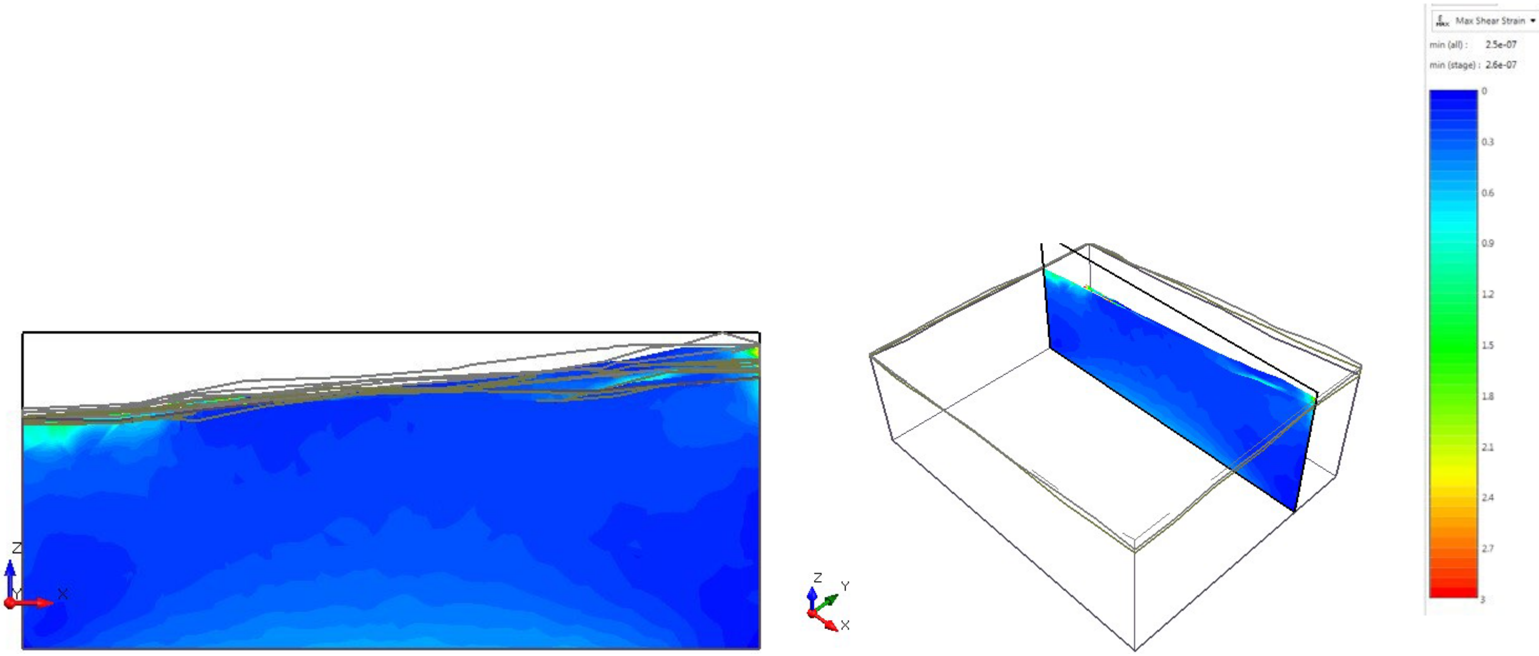

Figure 7.10 – *RS3* Maximum Shear Strain

8. 3D Verification #8

8.1. 3D lofted, homogeneous, ellipsoidal with SA

8.1.1. Introduction

This model is taken from Kalatehjari et al. (2015). It uses Particle Swarm Optimization to find the safety factor of a three-dimensional lofted slope.

8.1.2. Problem Description

This example used three 2D cross sections to create a three-dimensional slope. The first cross section, shown in Figure 8.3.1 is the cross section along the XZ plane. Figure 8.3.2 is the cross along the YZ plane. Figure 8.3.3 is the cross section in between the other two cross sections. The slope is homogeneous, and its soil properties are shown in Table 8.1. This example uses a Particle Swarm search with surface optimization.

8.1.3. Geometry and Properties

8.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Soil	15	20	19

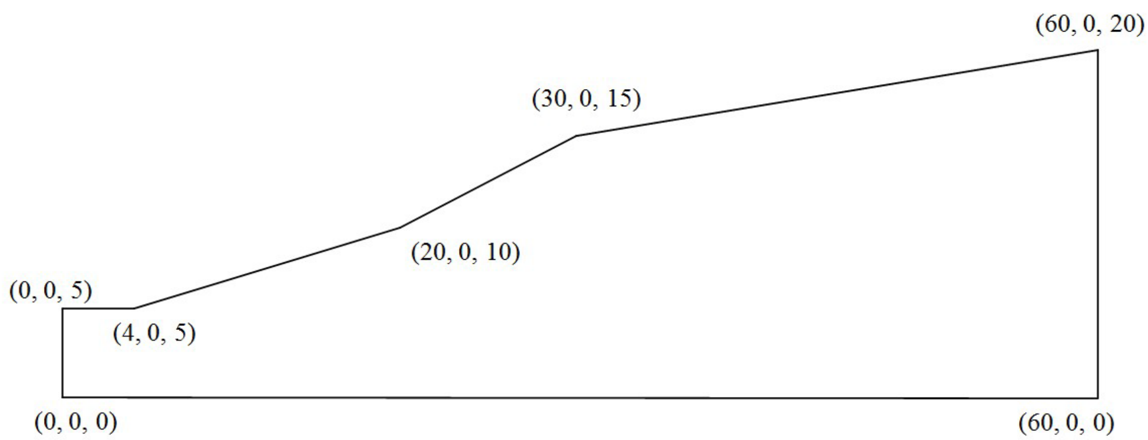

Figure 8.1

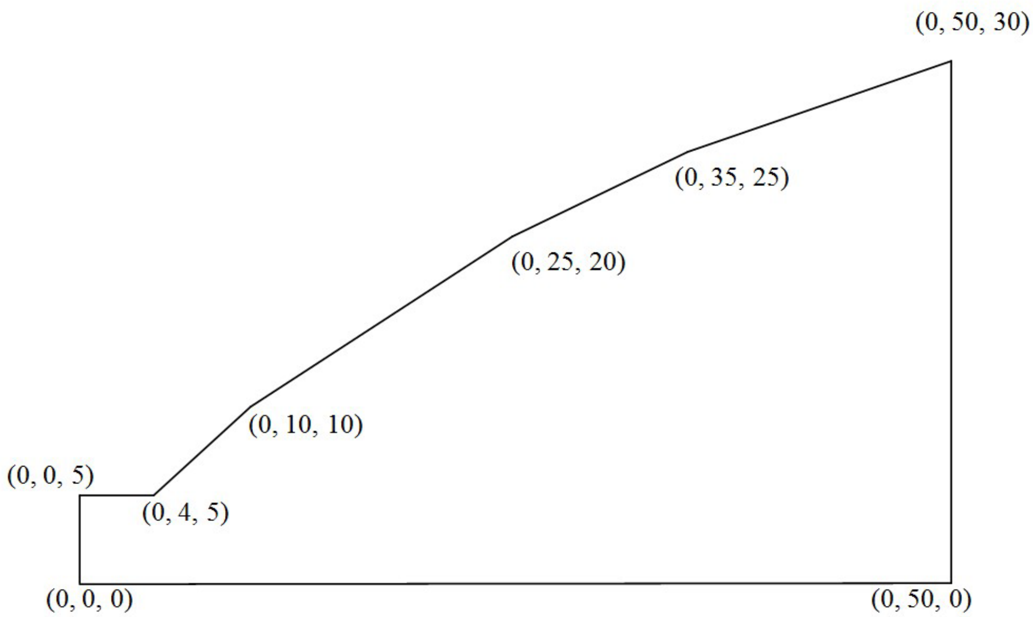

Figure 8.2

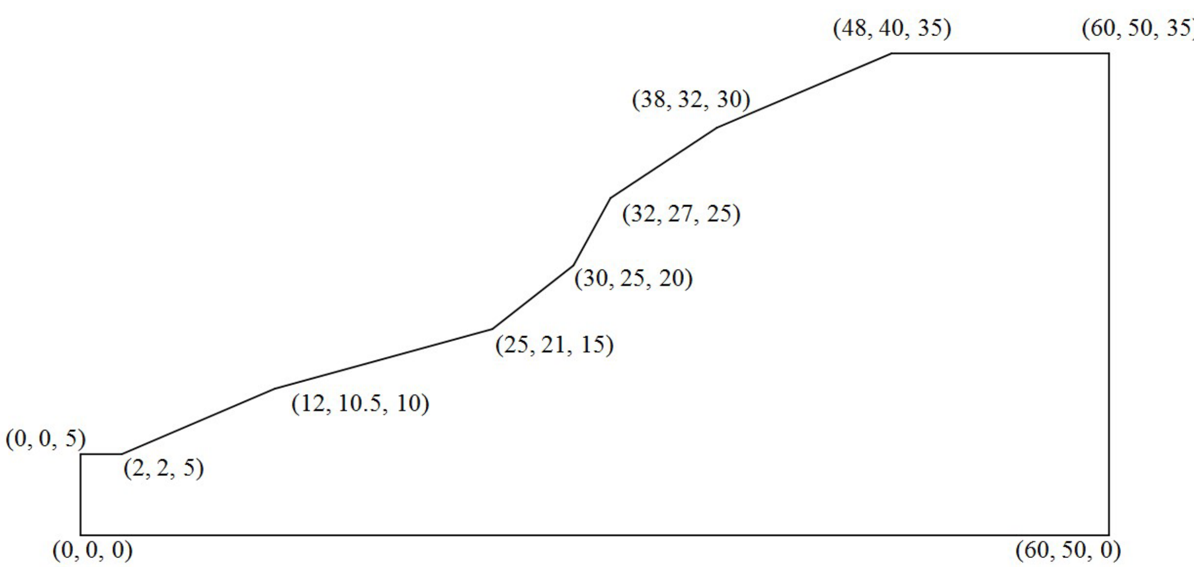

Figure 8.3

8.1.4. Results

Table 8.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.094	0.654	1.16	0.7
GLE	1.124	0.637		
Janbu	1.056	0.612		
Spencer	1.146	0.644		

Referee: FS 1.09 [Kalatehjari et al., 2015]

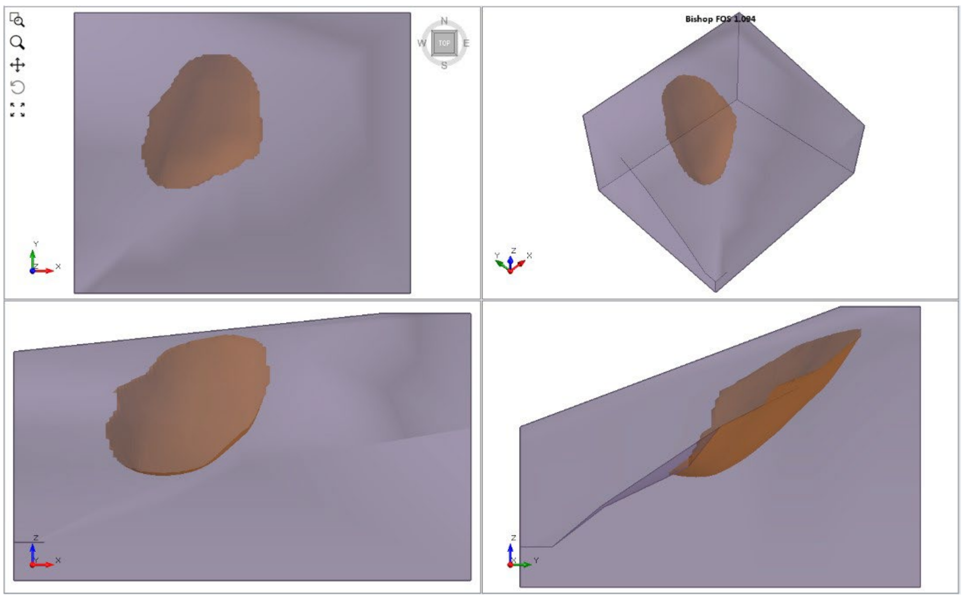

Figure 8.4 – *Slide3* Solution Using the Bishop Method

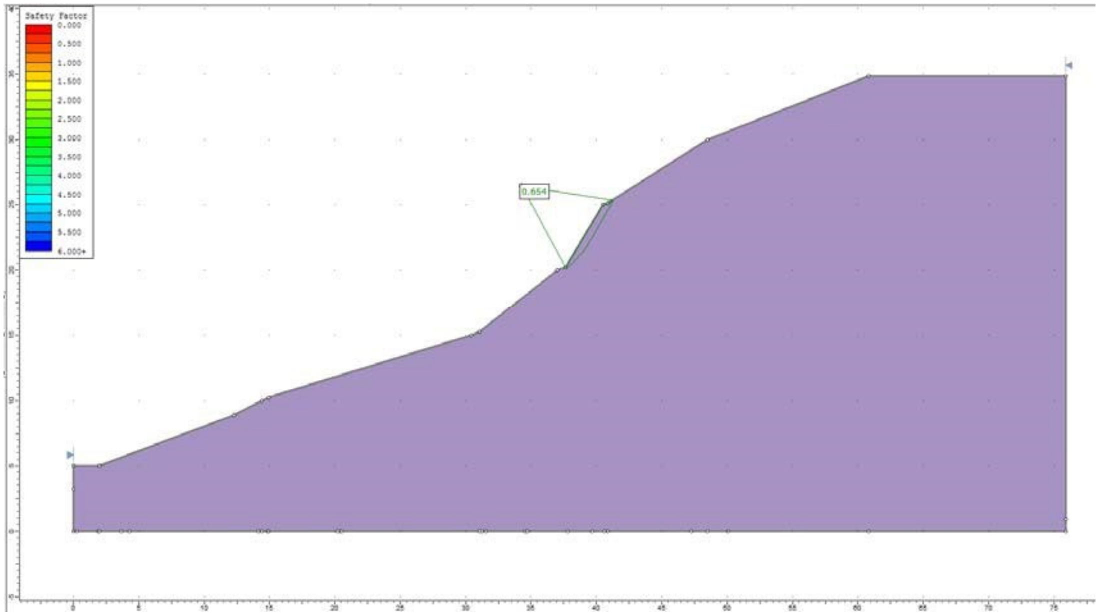

Figure 8.5 – *Slide2* Solution Using the Bishop Method

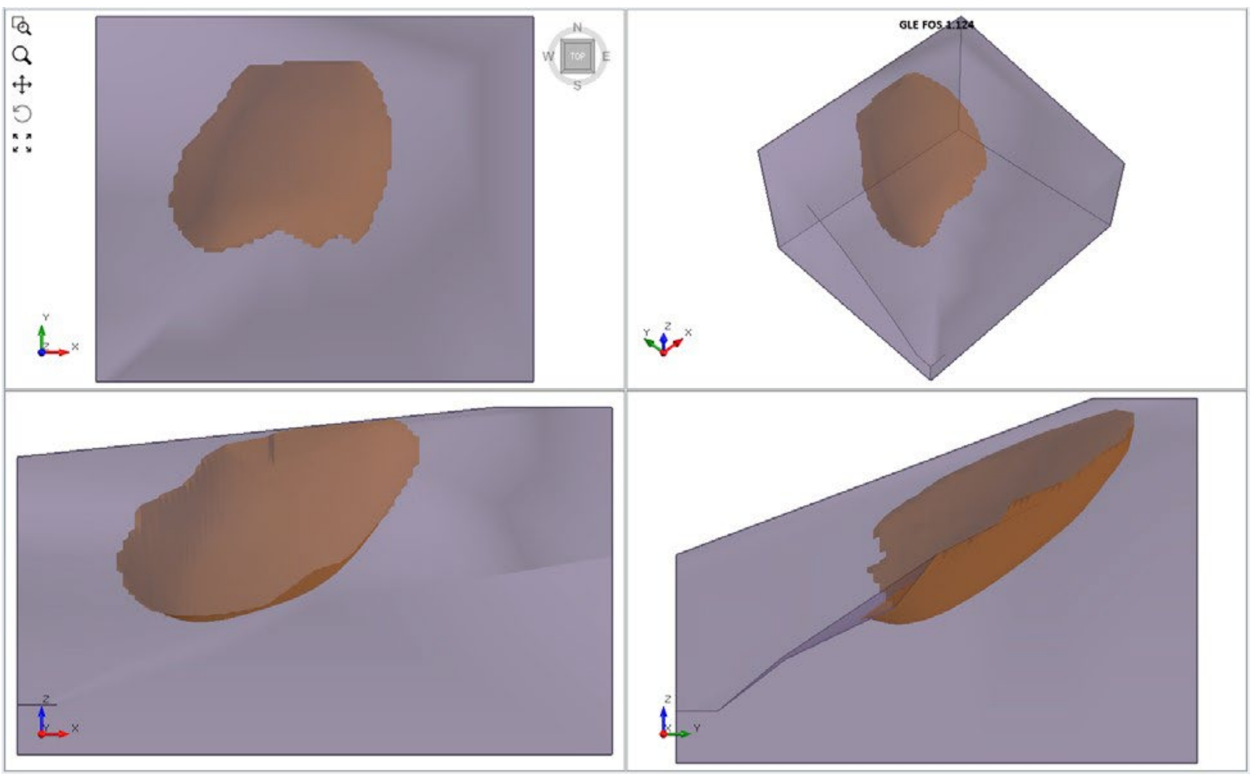

Figure 8.6 – *Slide3* Solution using the GLE Method

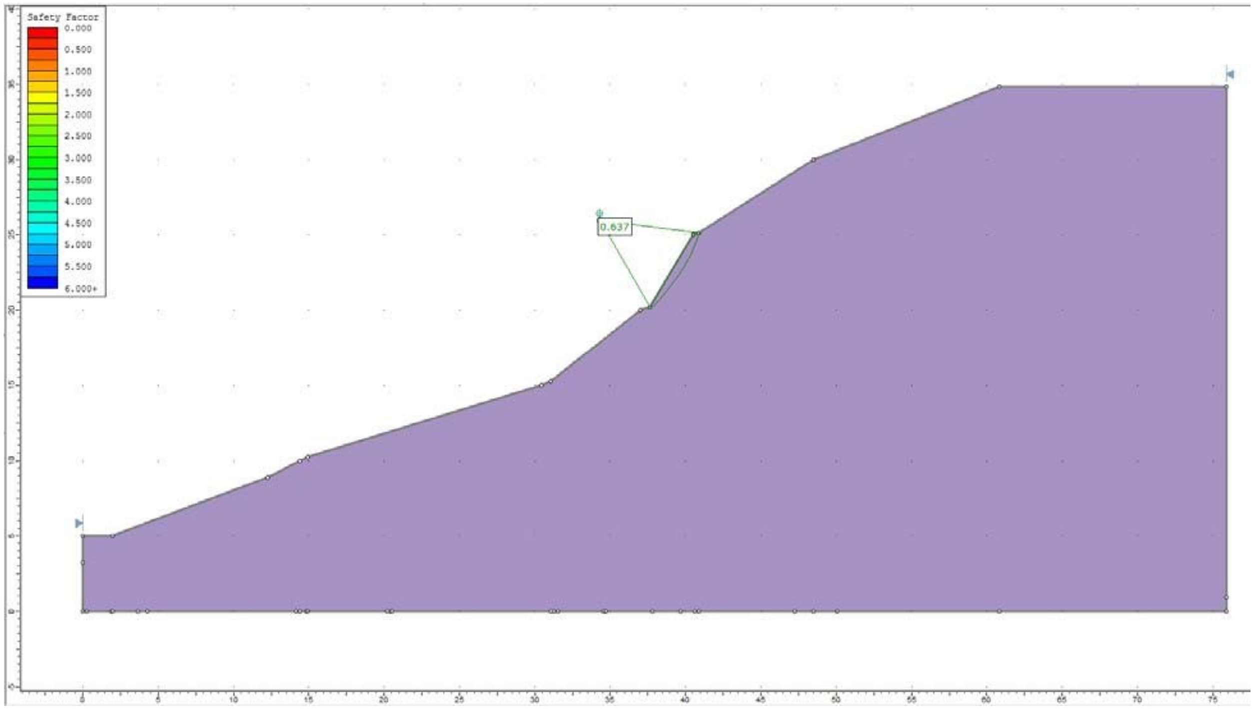

Figure 8.7 – *Slide2* Solution Using the GLE Method

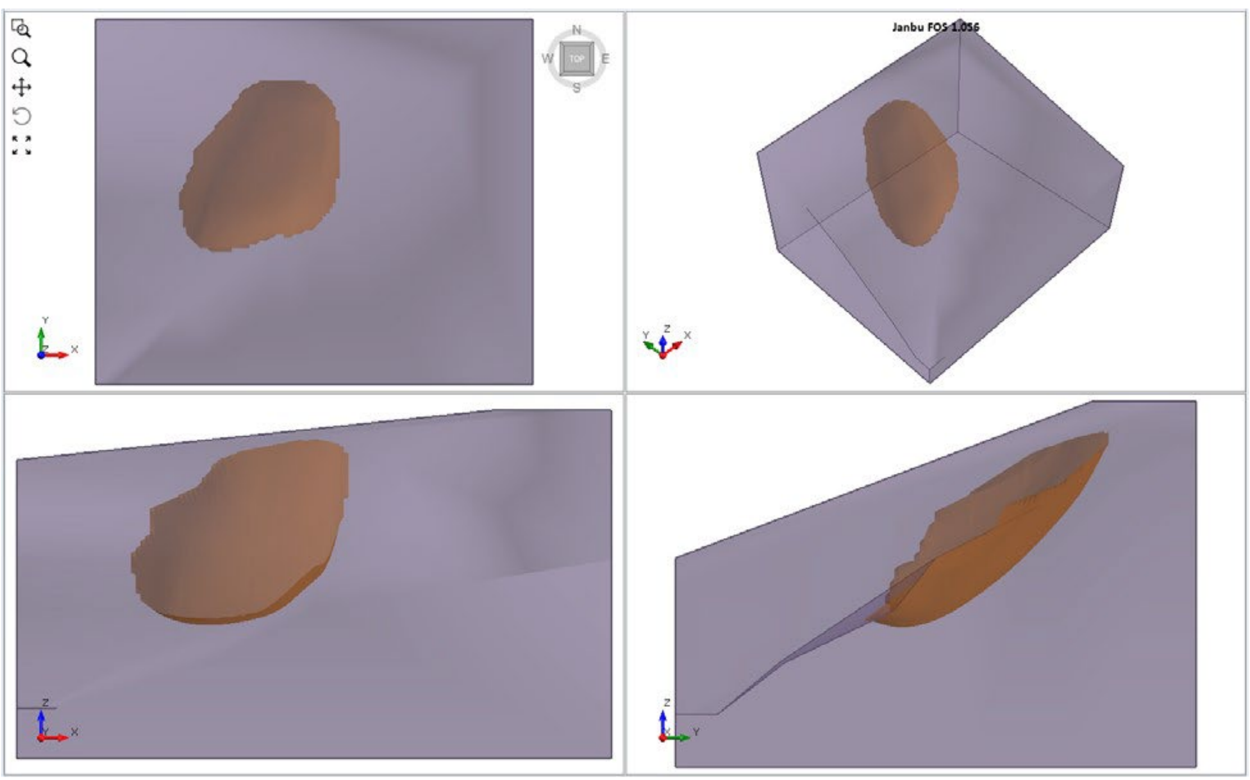

Figure 8.8 – *Slide3* Solution Using the Janbu Method

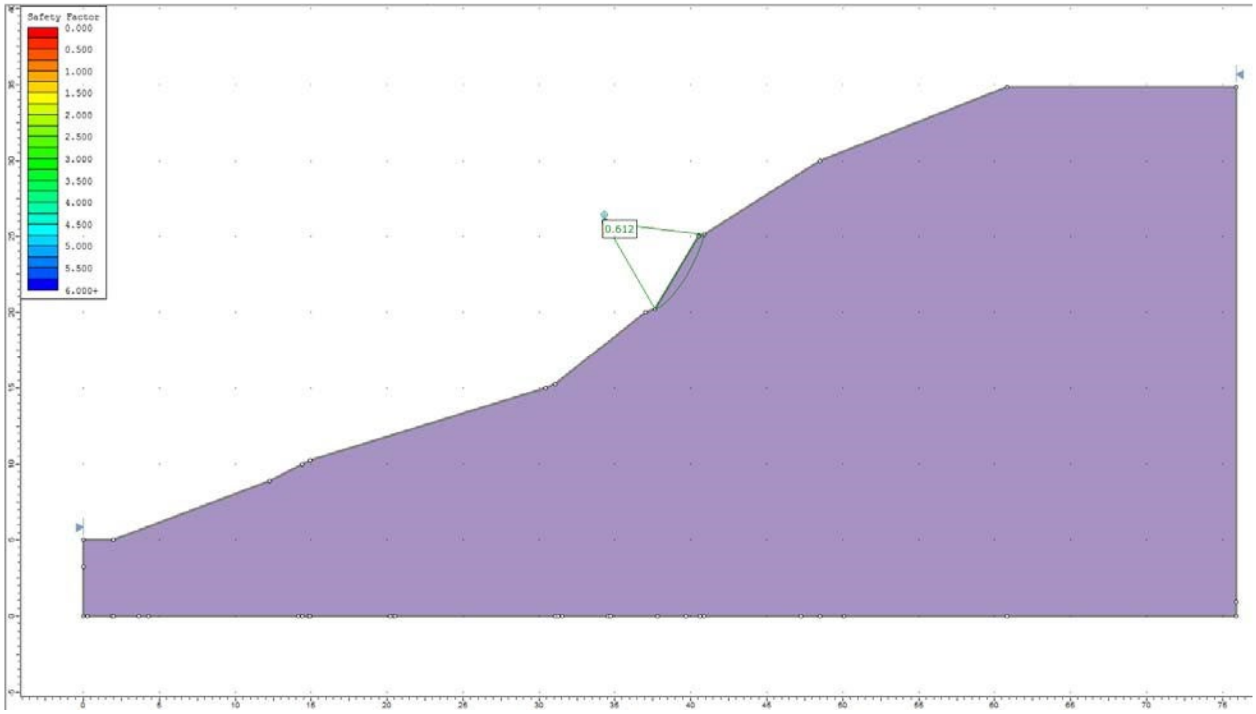

Figure 8.9 – *Slide3* Solution Using the Janbu Method

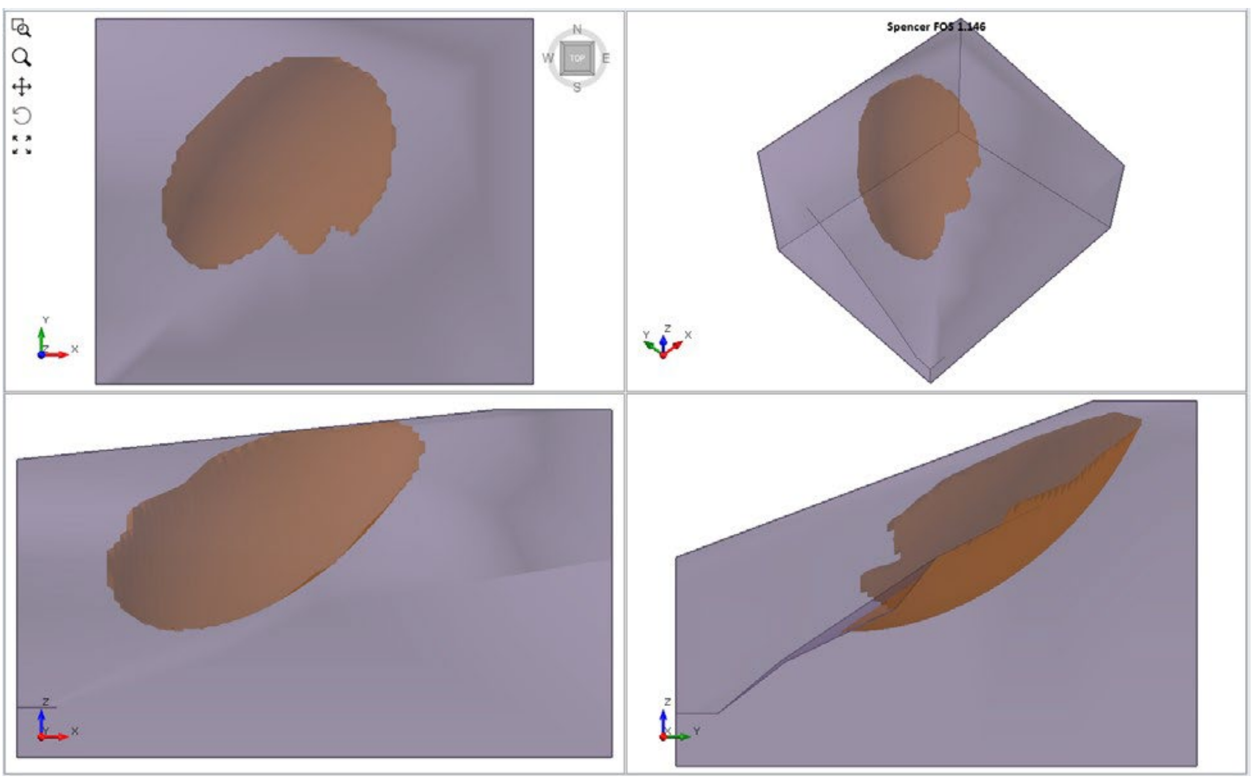

Figure 8.10 – *Slide3* Solution Using the Spencer Method

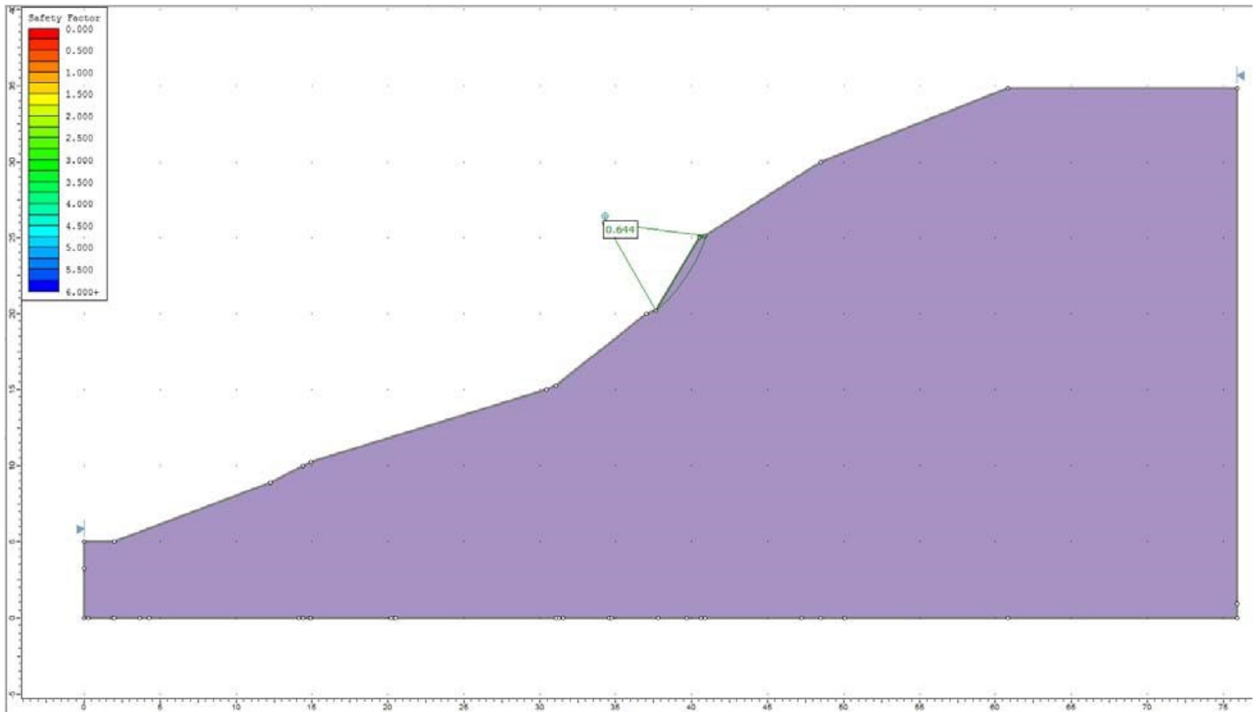

Figure 8.11 – *Slide2* Solution Using the Spencer Method

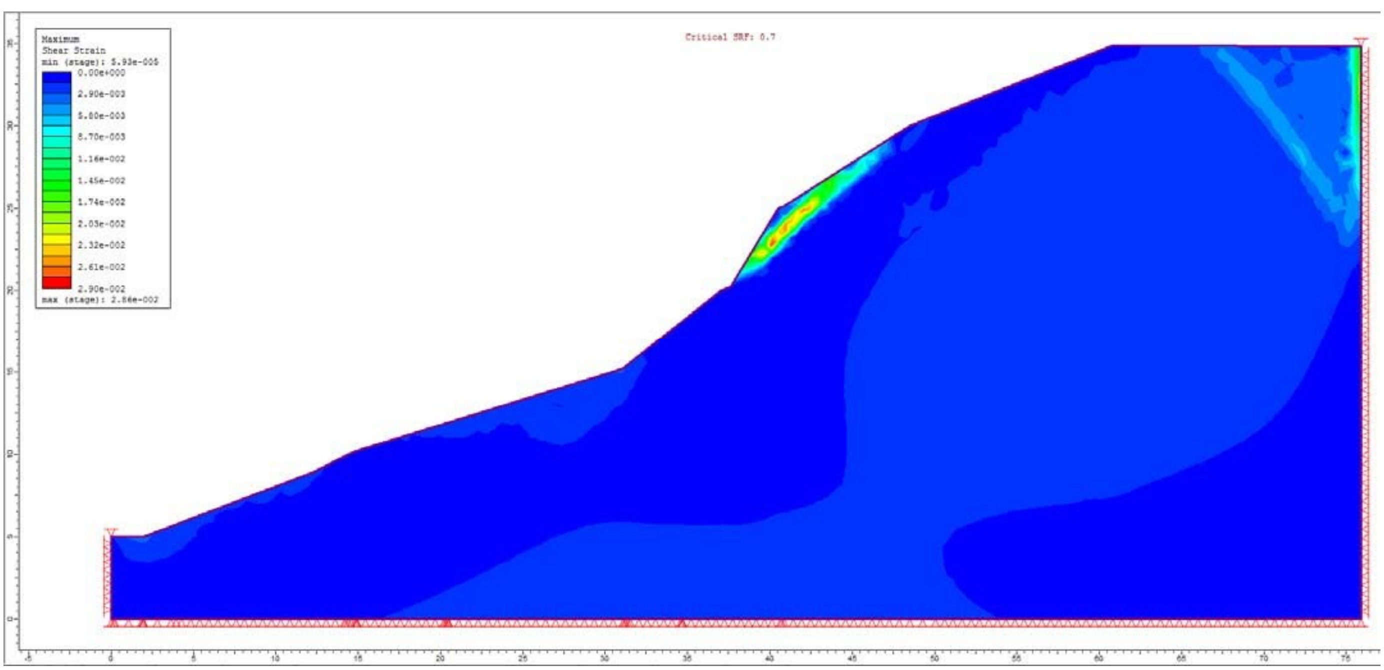

Figure 8.12 – *RS2* Maximum Shear Strain

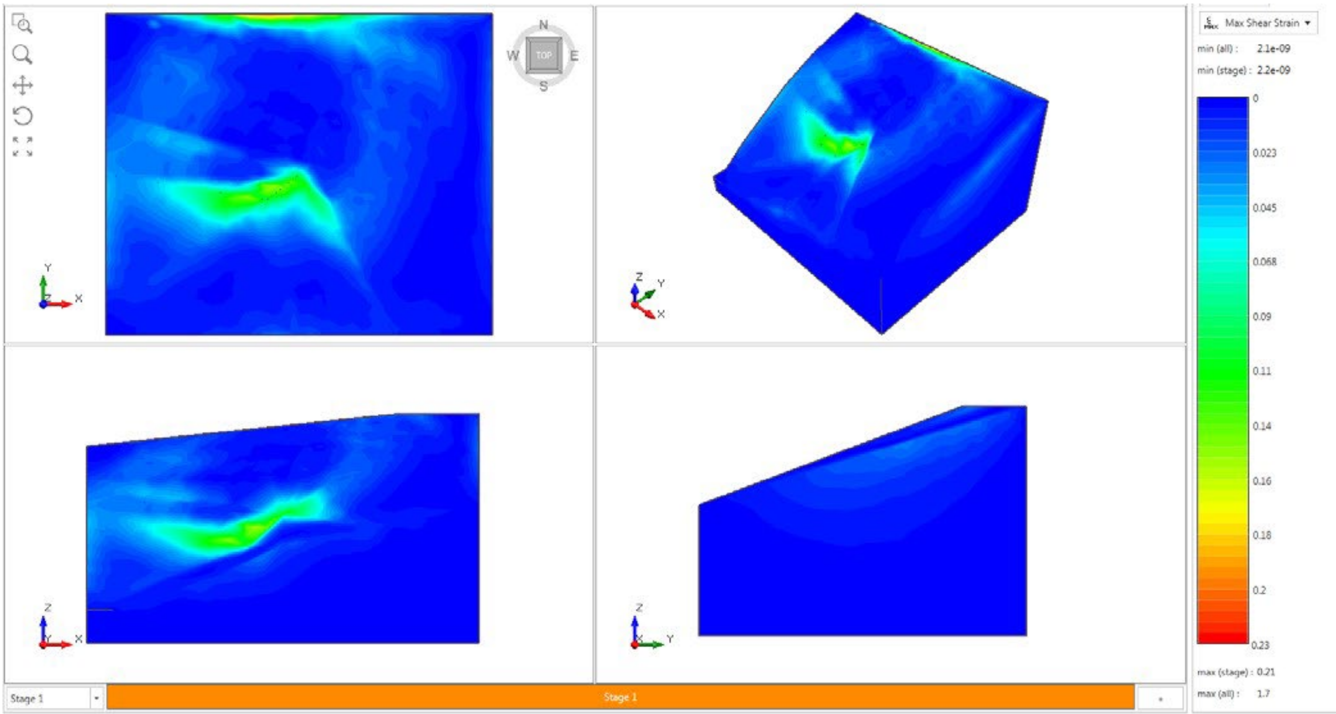

Figure 8.13 – *RS3* Maximum Shear Strain

9. 3D Verification #9

9.1. 3D lofted, (2) materials, water table with ponded water, ellipsoidal with SA

9.1.1. Introduction

This model is taken from Sun et al. (2016). It is a model of the Wujiang land*Slide2* with two different soil characteristics above and below the water table.

9.1.2. Problem Description

This slope was modeled by lofting four 2D cross sections together. The water table is flat across at an elevation of 260 m. The cross section used to calculate the safety factor in *Slide2* 7.0 and *RS2* was taken at Y = 250 m. The slope was modeled with two different soil conditions found above and below the water table, both of which can be found in Table 9.1. A cuckoo search was used to find the ellipsoidal slip surface and corresponding safety factor.

9.1.3. Properties

Figure 9.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Above Water Table	30	30	21.7
Below Water Table	25	24.23	22.1

9.1.4. Results

Table 9.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.195	1.178	1.39	1.3
GLE	1.18	1.169		
Janbu	1.113	1.114		
Spencer	1.179	1.174		

Referee: FS 1.28 [Sun et al., 2016]

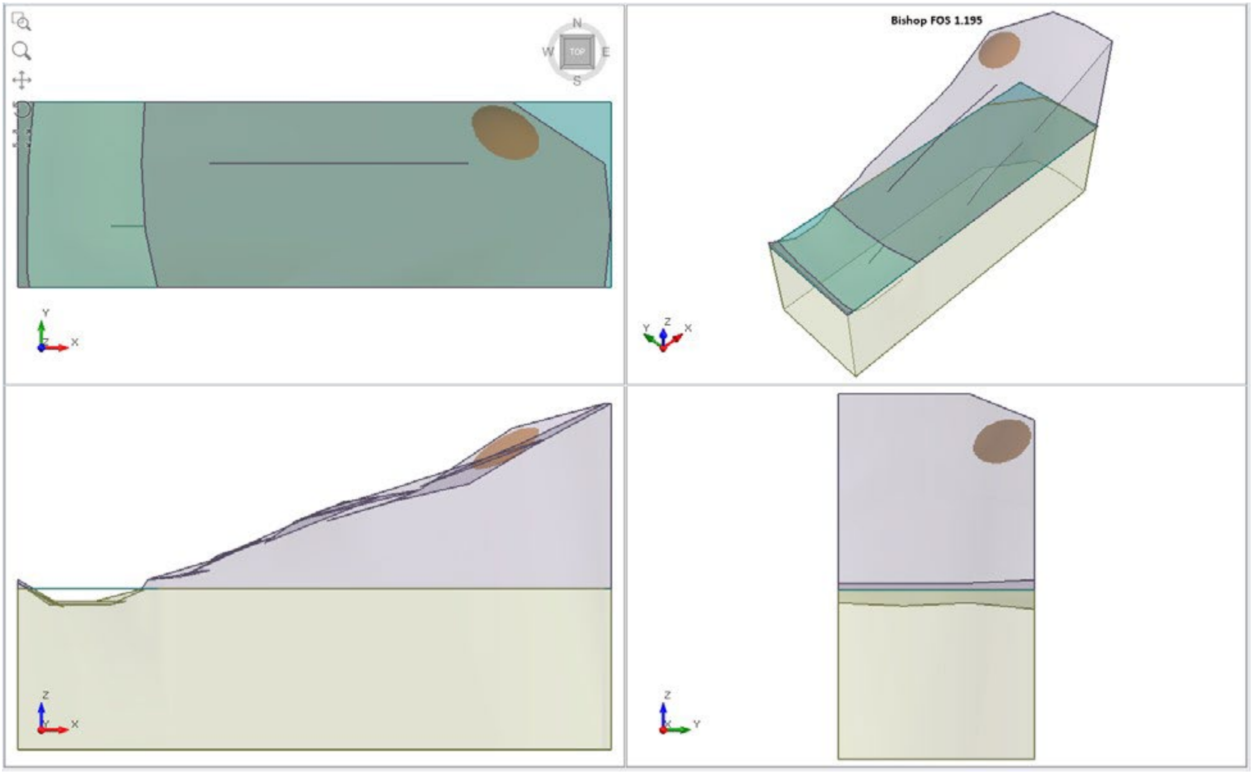

Figure 9.1 – *Slide3* Solution Using the Bishop Method

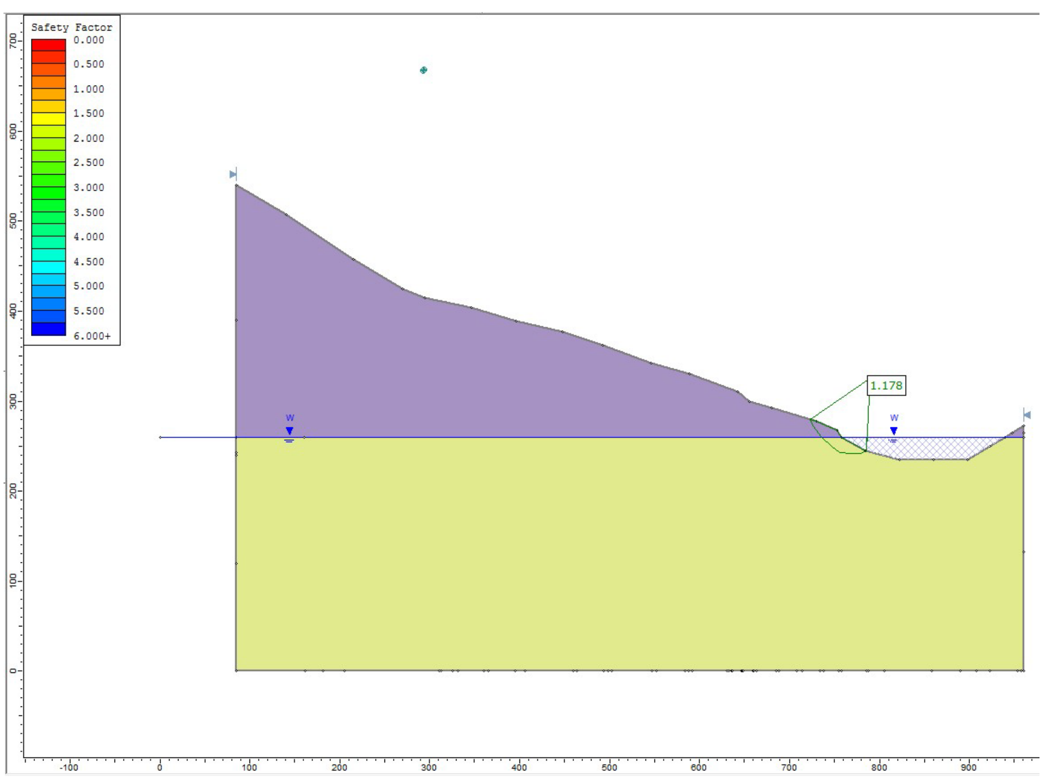

Figure 9.2 – *Slide2* Solution Using the Bishop Method

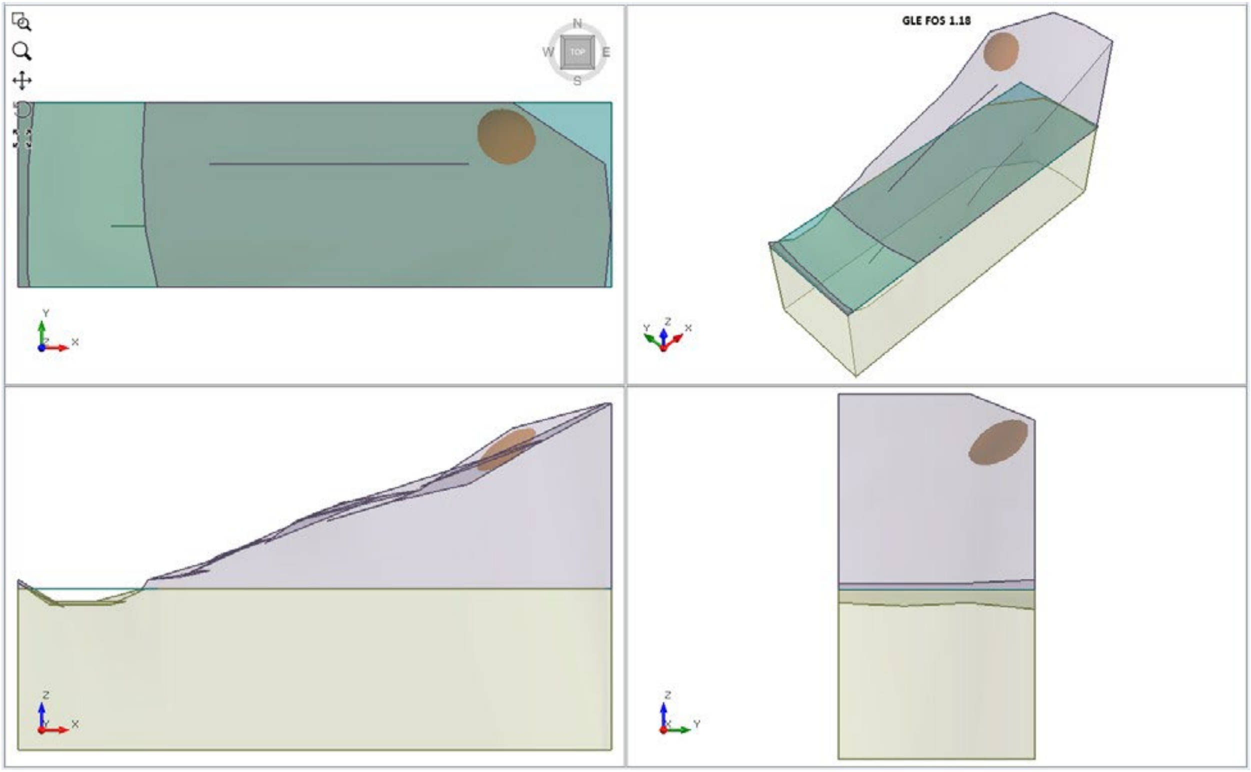

Figure 9.3 – *Slide3* Solution Using the GLE Method

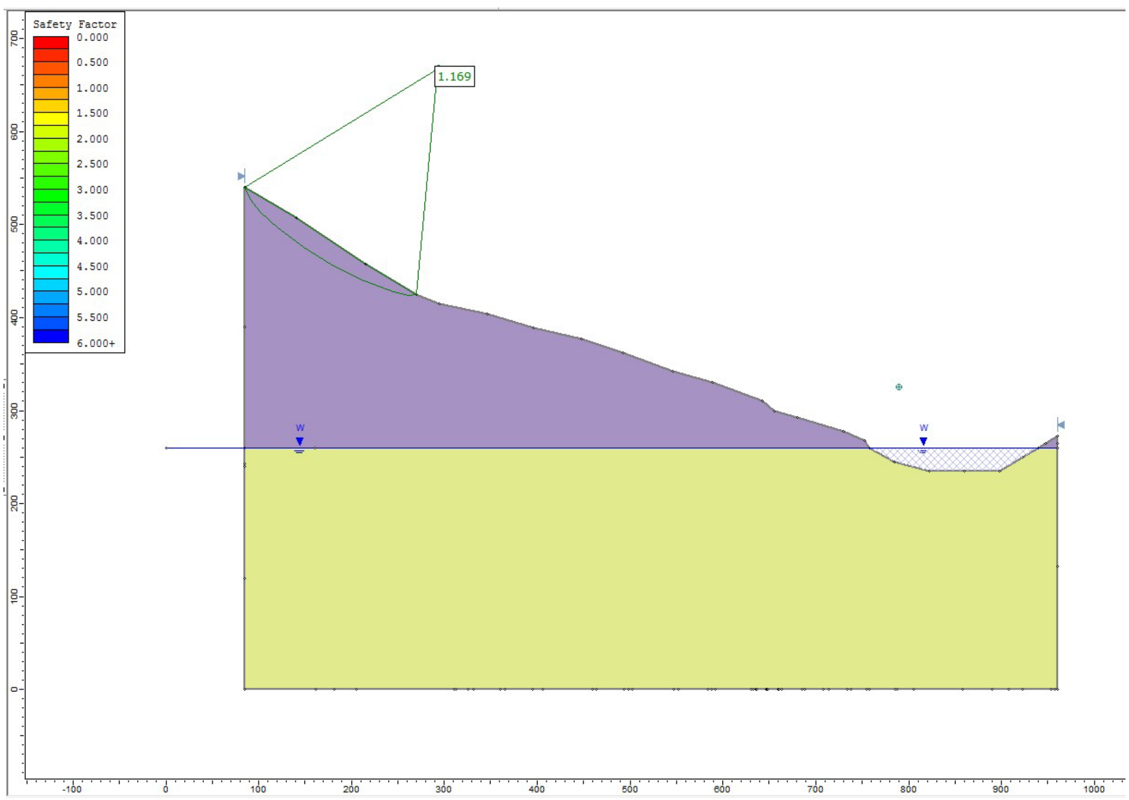

Figure 9.4 – *Slide2* Solution Using the GLE Method

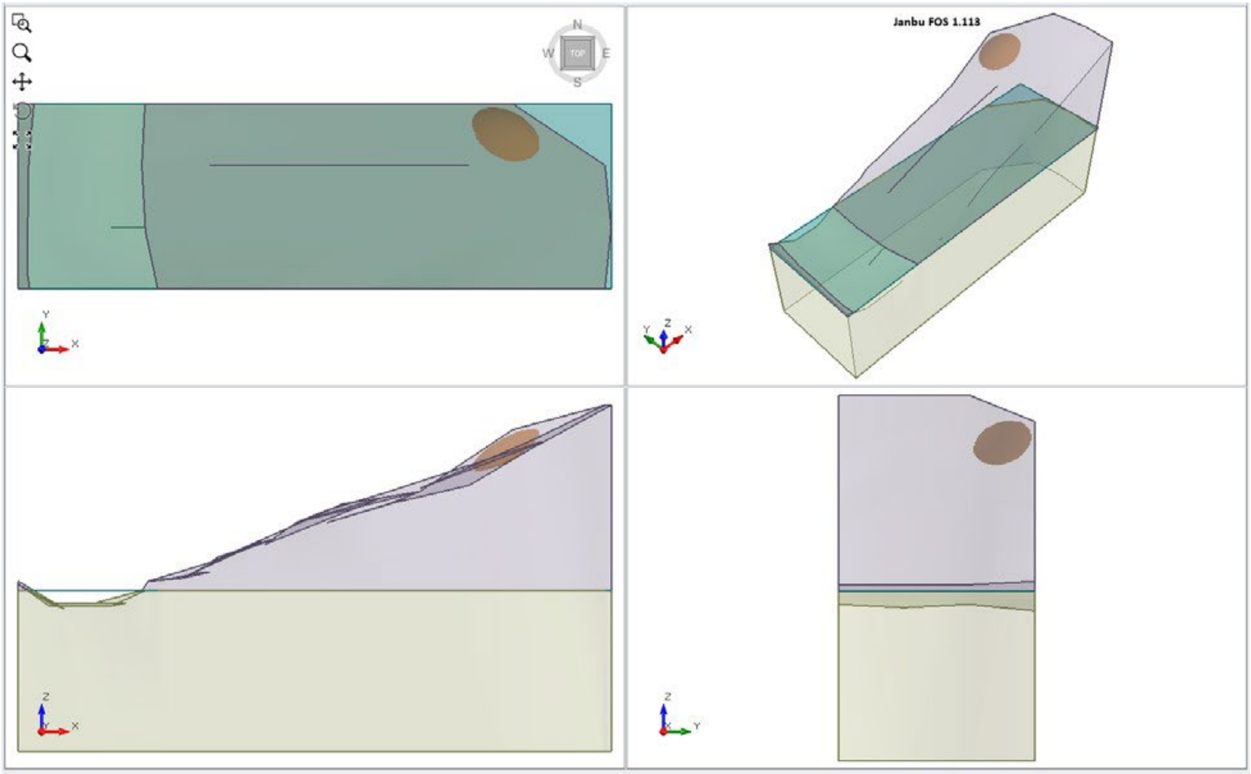

Figure 9.5 – *Slide3* Solution Using the Janbu Method

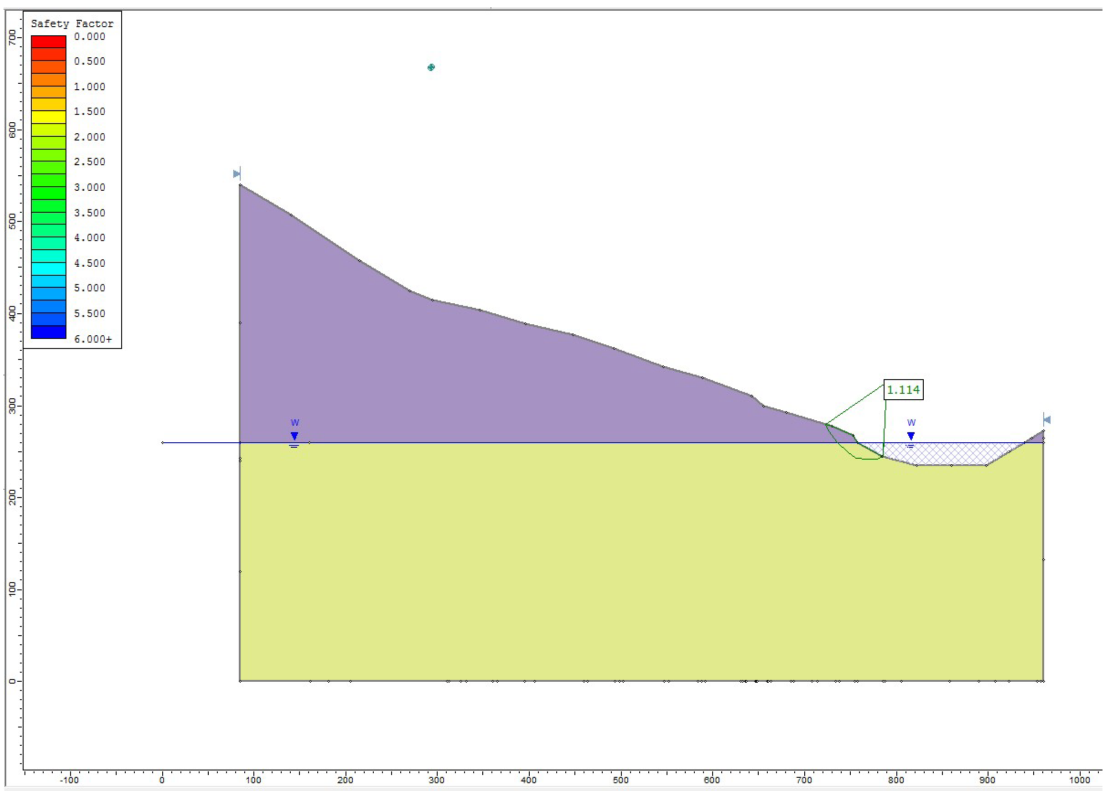

Figure 9.6 – *Slide2* Solution Using the Janbu Method

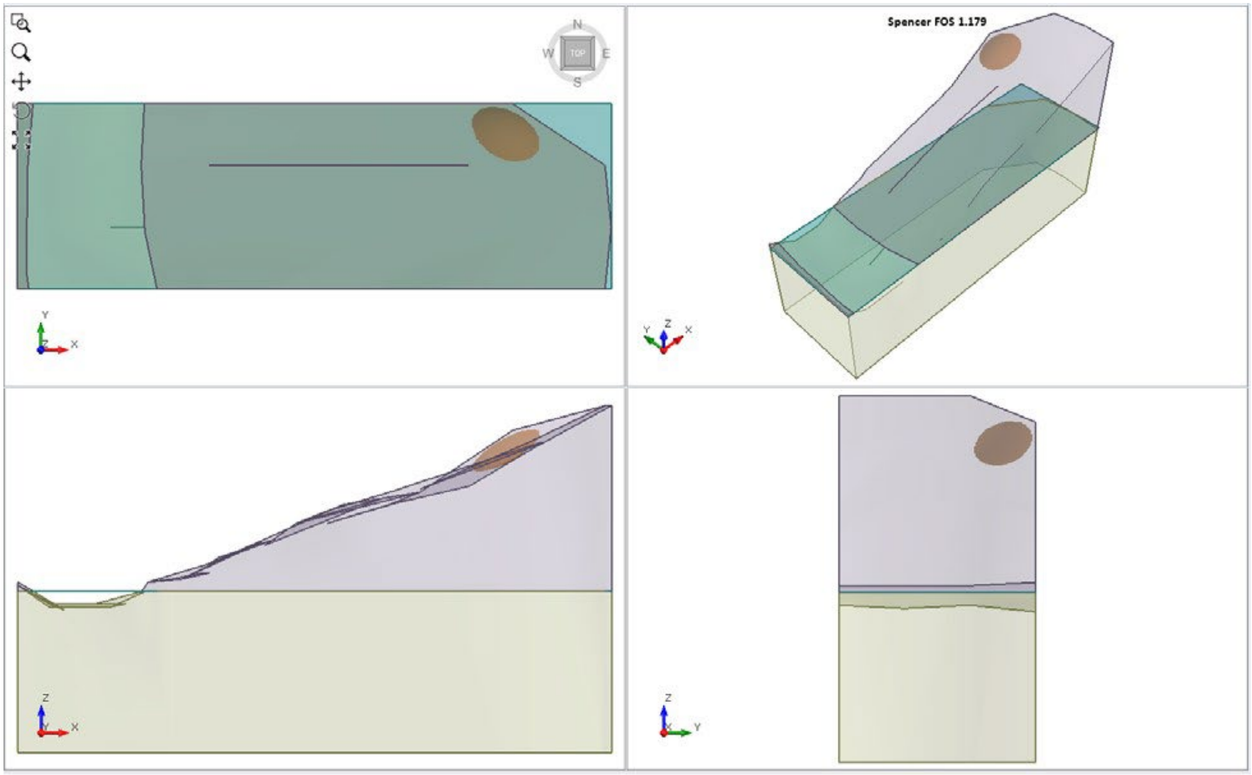

Figure 9.7 – *Slide2* Solution Using the Spencer Method

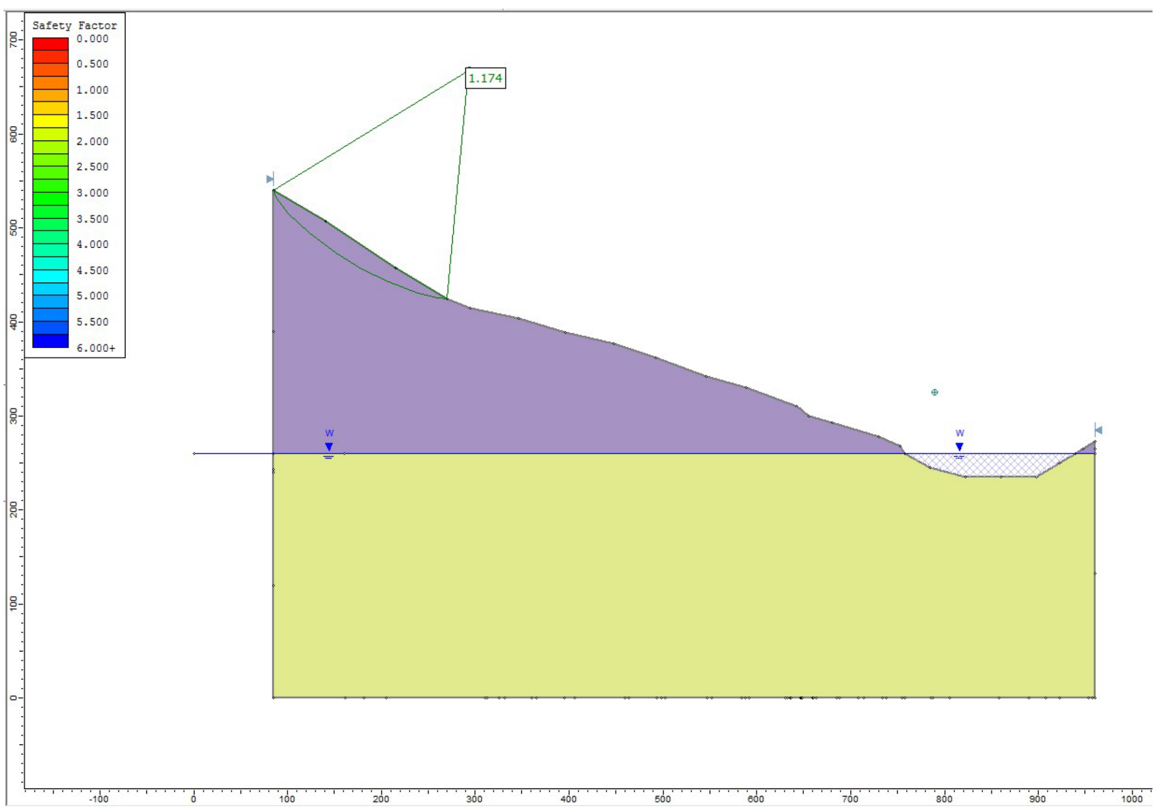

Figure 9.8 – *Slide2* Solution Using the Spencer Method

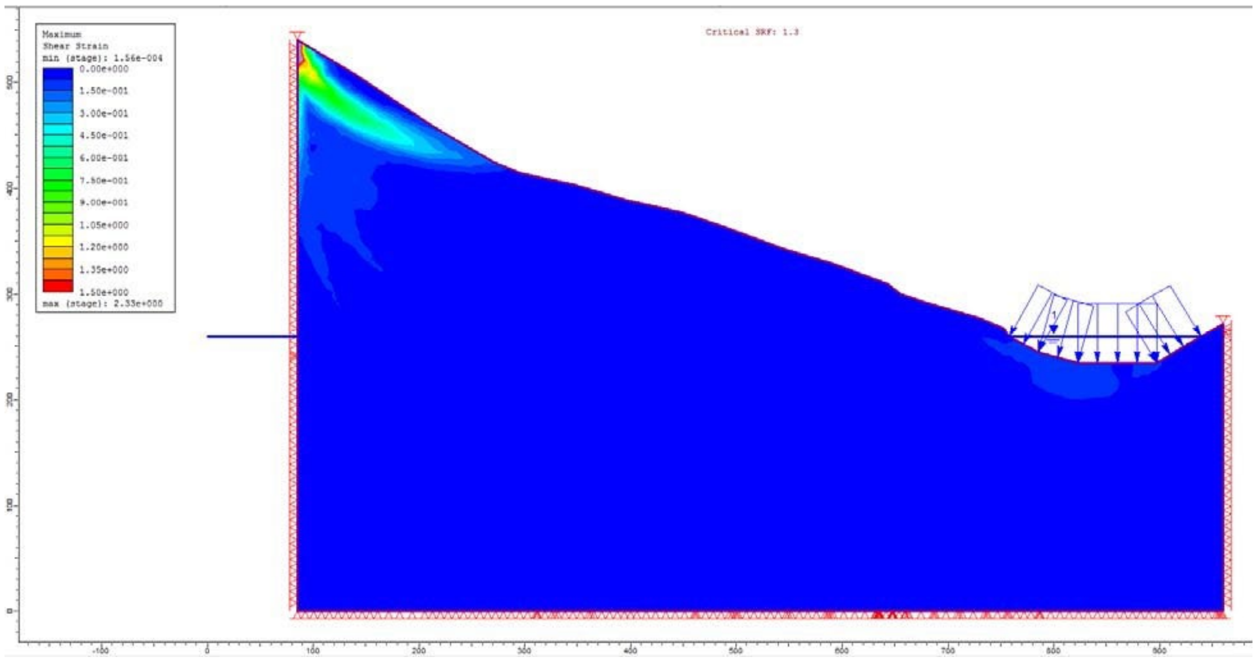

Figure 9.9 – *RS2* Maximum Shear Strain

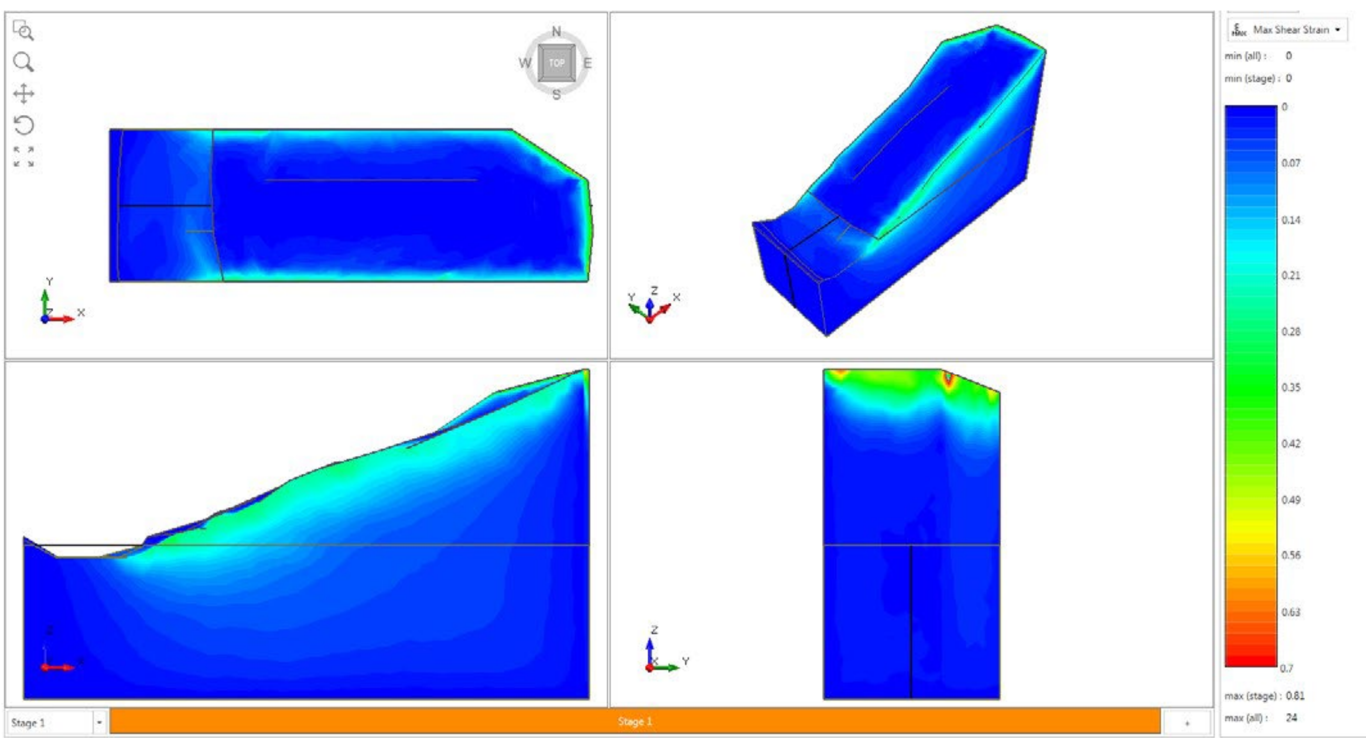

Figure 9.10 – *RS3* Maximum Shear Strain

10. 3D Verification #10

10.1. 3D lofted, (5) materials, slope limits, ellipsoidal

10.1.1. Introduction

This example is taken from Gu et al. (2014). The model is a non-homogeneous 3D slope consisting of lofted cross sections, rather than an extruded 2D section.

10.1.2. Problem Description

Three 2D cross sections were used to construct the 3D slope. The material properties for each layer in the non-homogeneous slope are shown in Table 10.1. There is no groundwater in this example. A cuckoo search was used to find the ellipsoidal slip surface and corresponding factor of safety. A slope limit is defined by volume and has the following coordinates: (-19.95, 1518.01, 834.92), (-19.95, 760.4, 834.92), (-19.95, 1518.01, -2.82), (-19.95, 760.4, -2.82), (510.54, 1518.01, -2.82), (510.54, 1518.01, 834.92), (510.54, 760.4, 834.92), (510.54, 760.4, -2.82). The 2D cross section used to calculate the safety factor in *Slide2* 7.0 and *RS2* was taken at Y = 950 m.

10.1.3. Properties

10.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Malan Loess	24.0	23.7	16.1
Lishi Loess	38.0	22.5	17.3
Wucheng Loess	63.0	22.0	17.5
Sand Gravel	10.0	36.0	18.2
Silty Clay	115.0	26.5	19.0

10.1.4. Results

Table 10.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.045	0.968	1.09	0.98
GLE	1.047	0.965		
Janbu	1.004	0.919		
Spencer	1.049	0.972		

Referee: FS 0.98 – 2D Safety Factor [Gu et al., 2014]

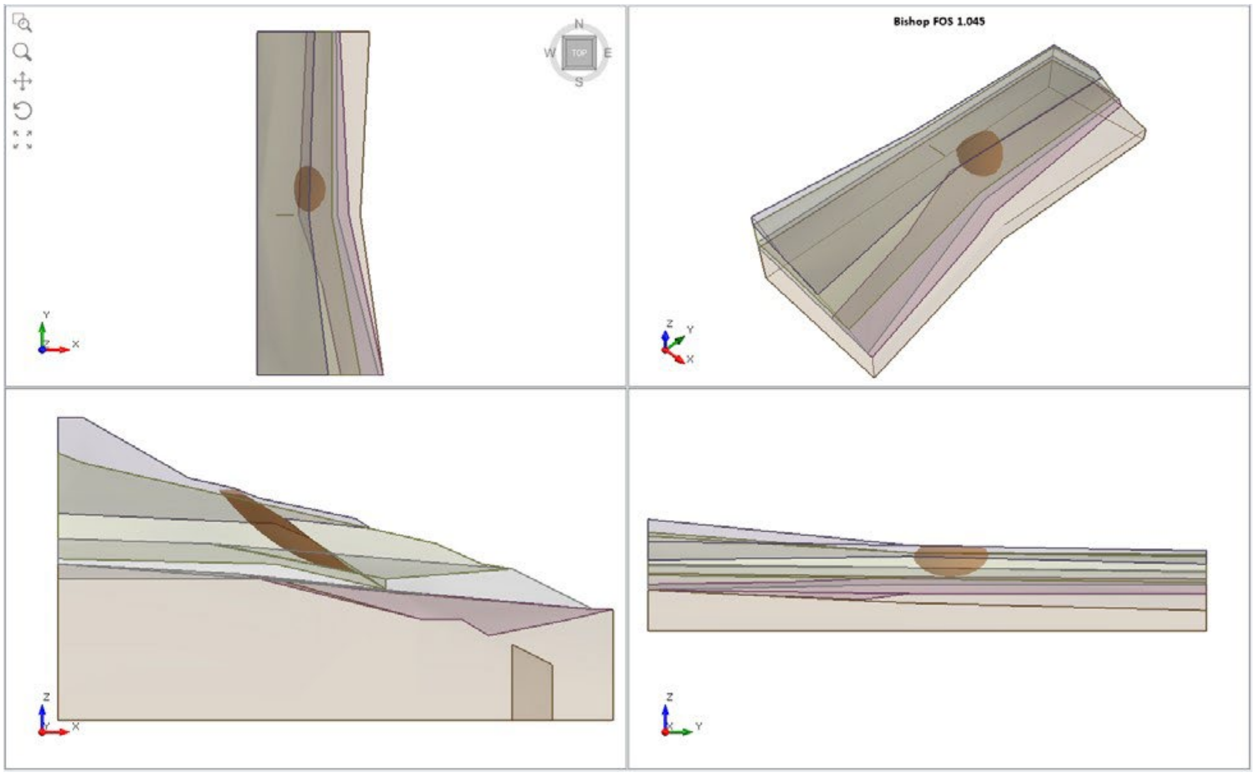

Figure 10.1 – *Slide3* Solution Using the Bishop Method

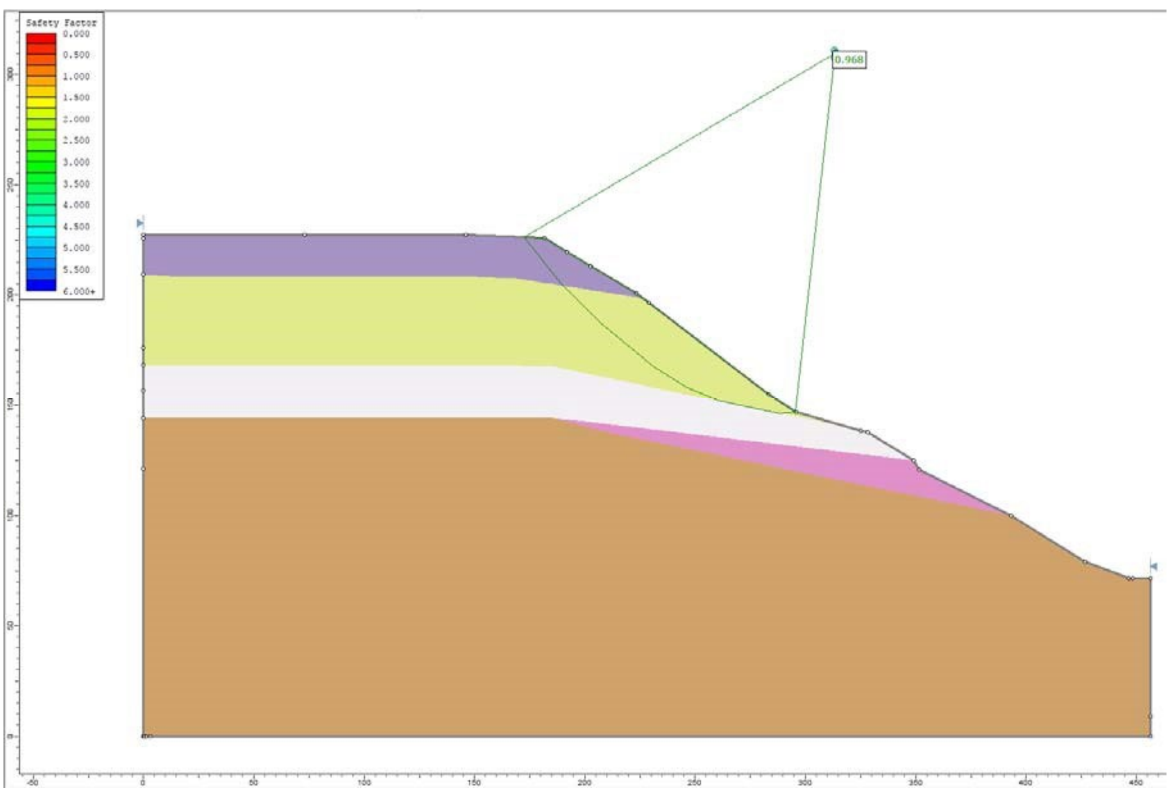

Figure 10.2 – *Slide2* Solution Using the Bishop Solution

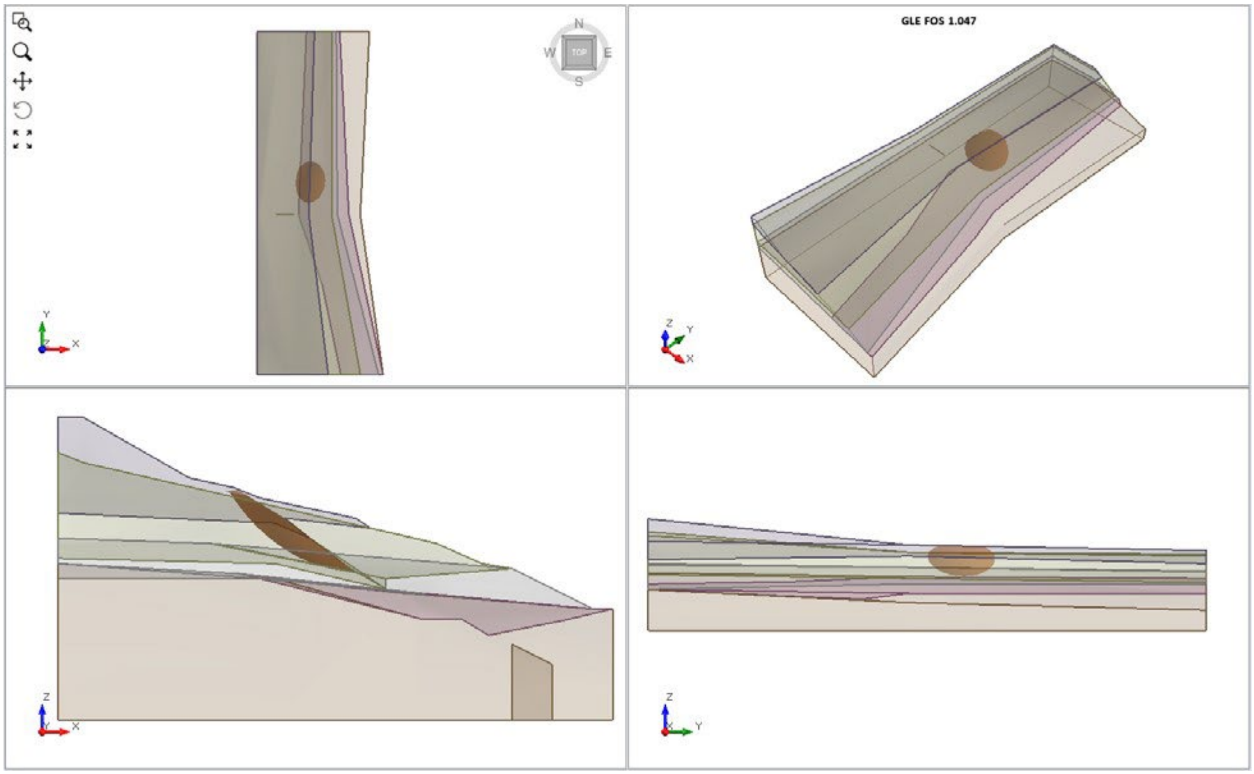

Figure 10.3 – *Slide3* Solution Using the GLE Method

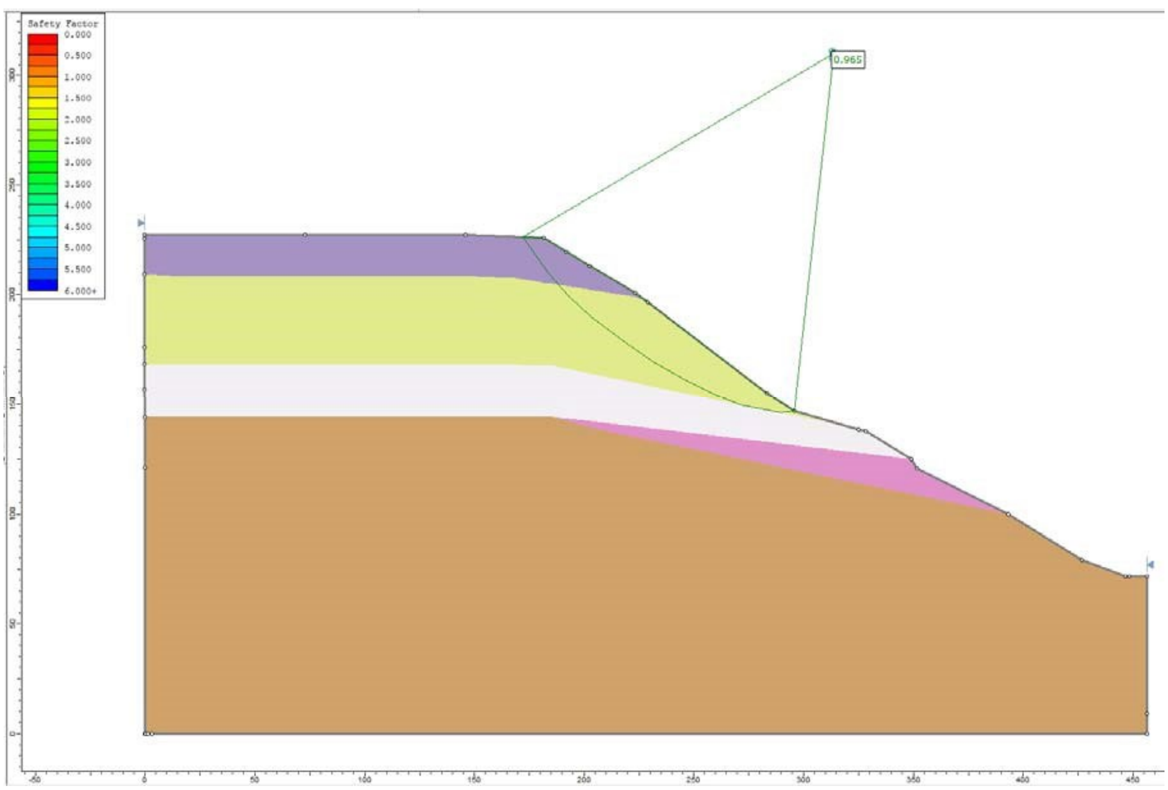

Figure 10.4 – *Slide2* Solution Using the GLE Method

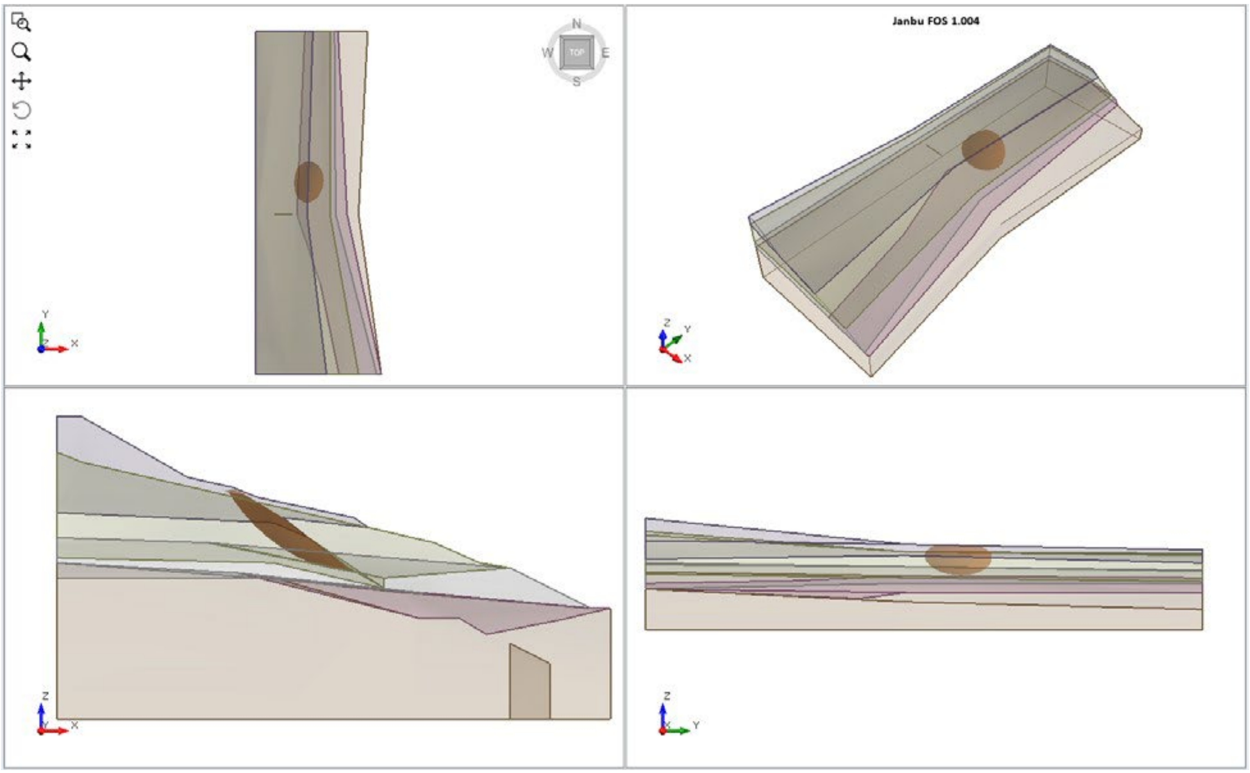

Figure 10.5 – *Slide3* Solution Using the Janbu method

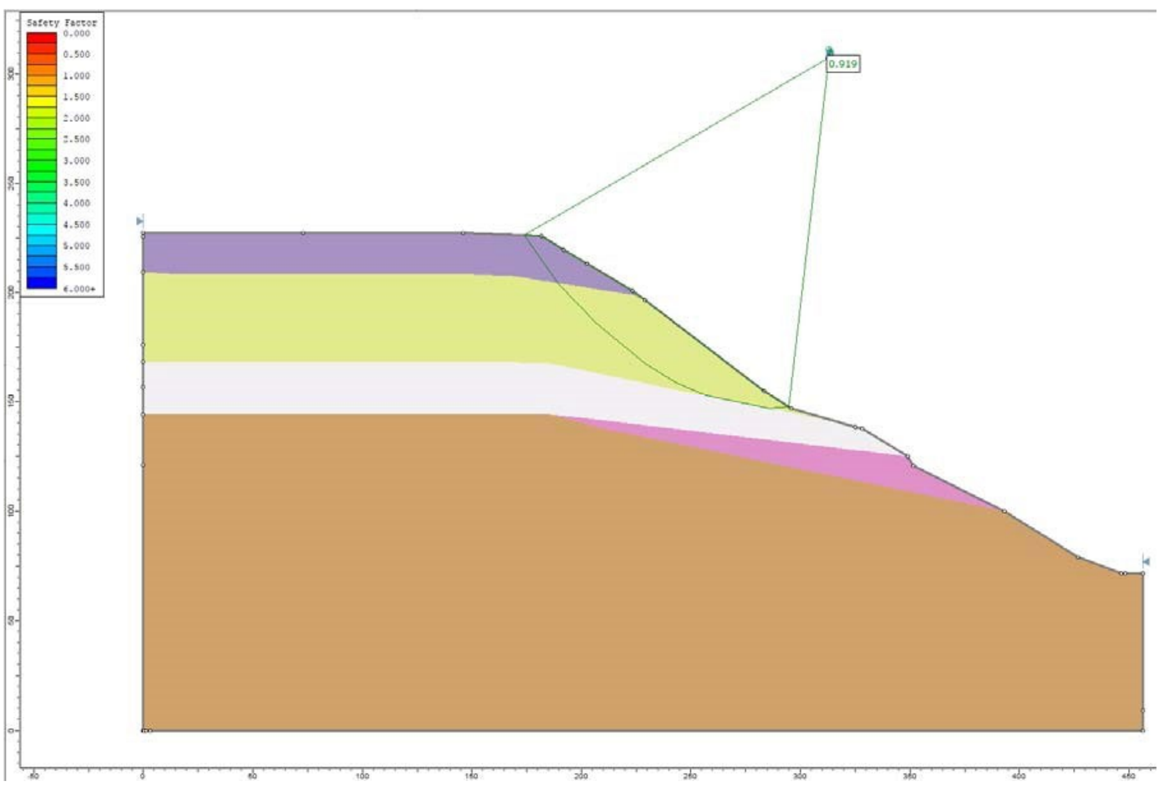

Figure 10.6 – *Slide2* Solution Using the Janbu Method

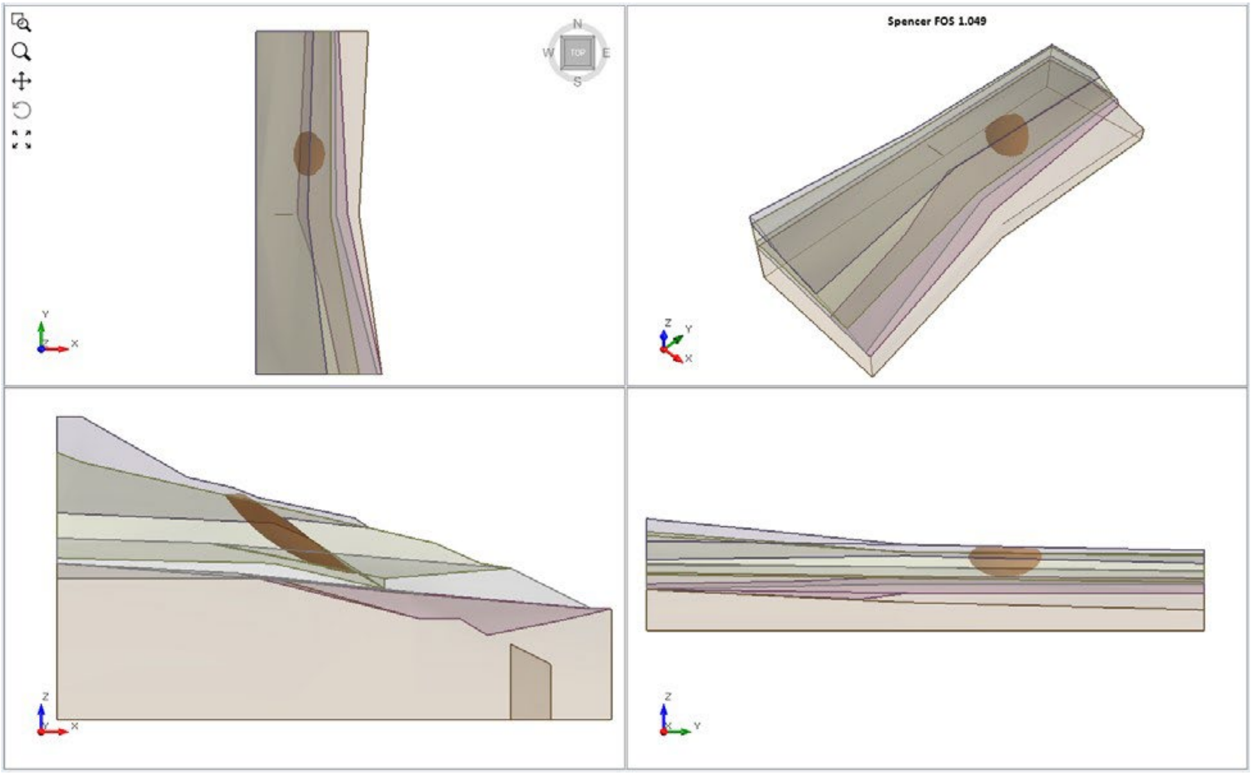

Figure 10.7 – *Slide3* Solution Using the Spencer Method

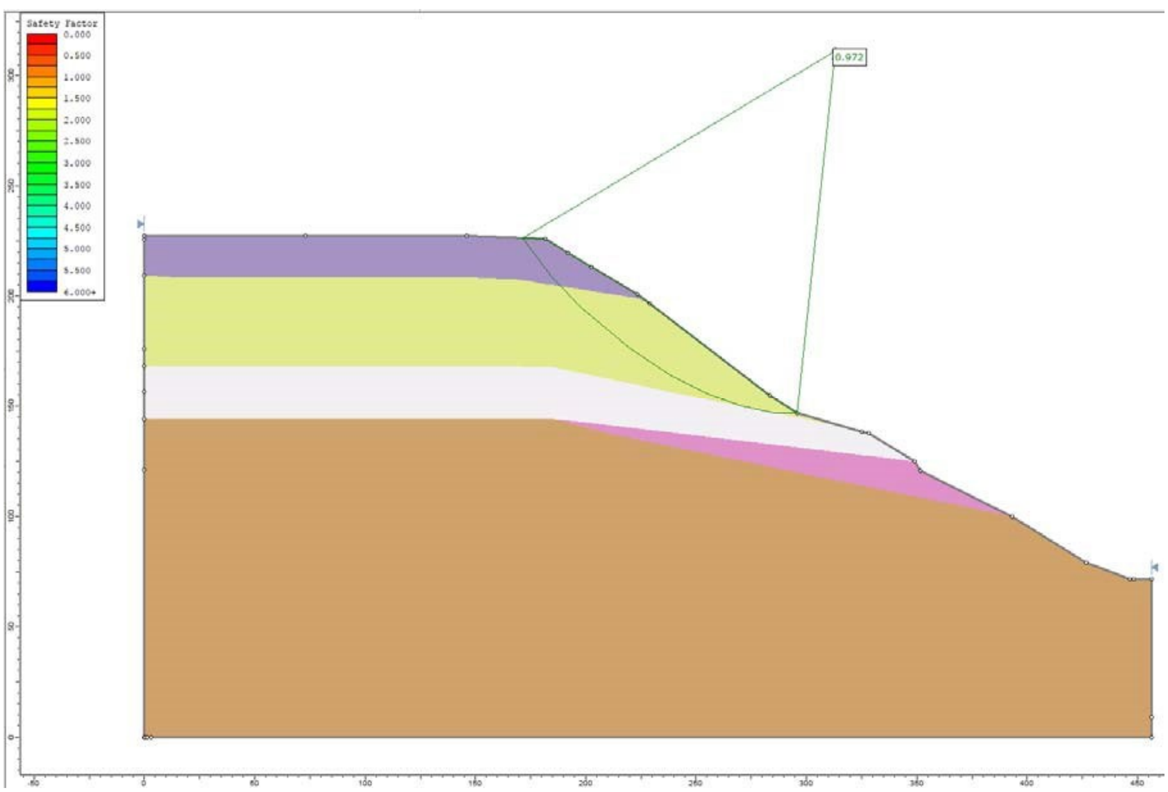

Figure 10.8 – *Slide2* Solution Using the Spencer Method

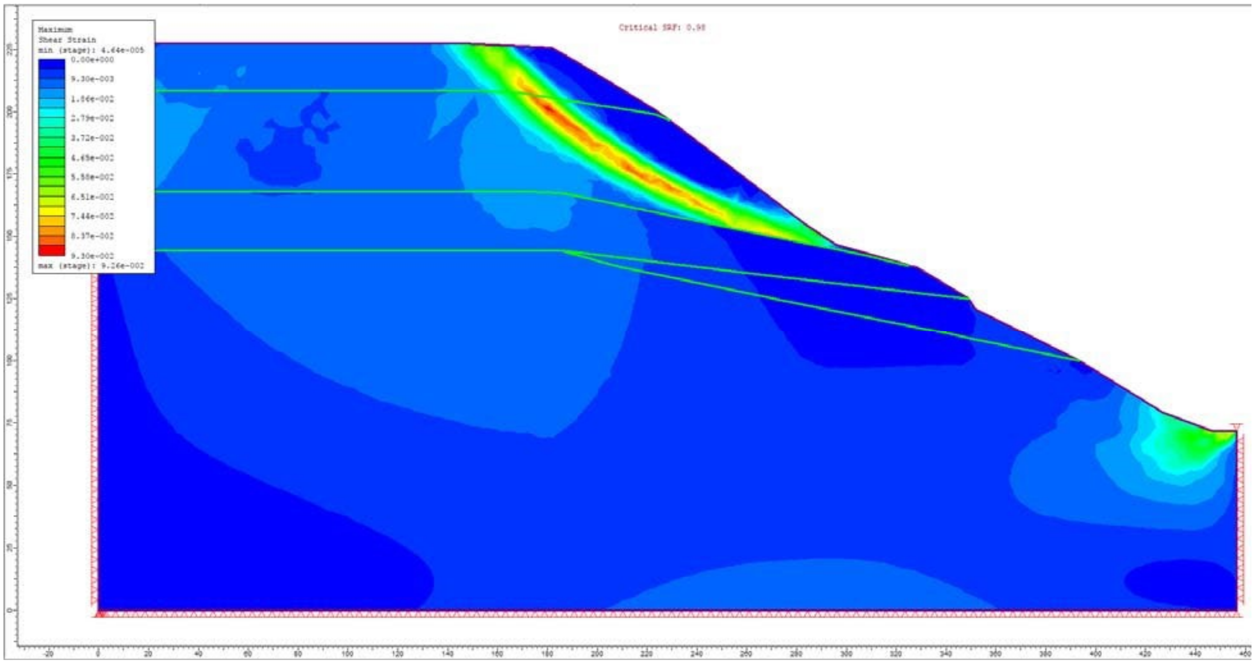

Figure 10.9 – *RS2* Maximum Shear Strain

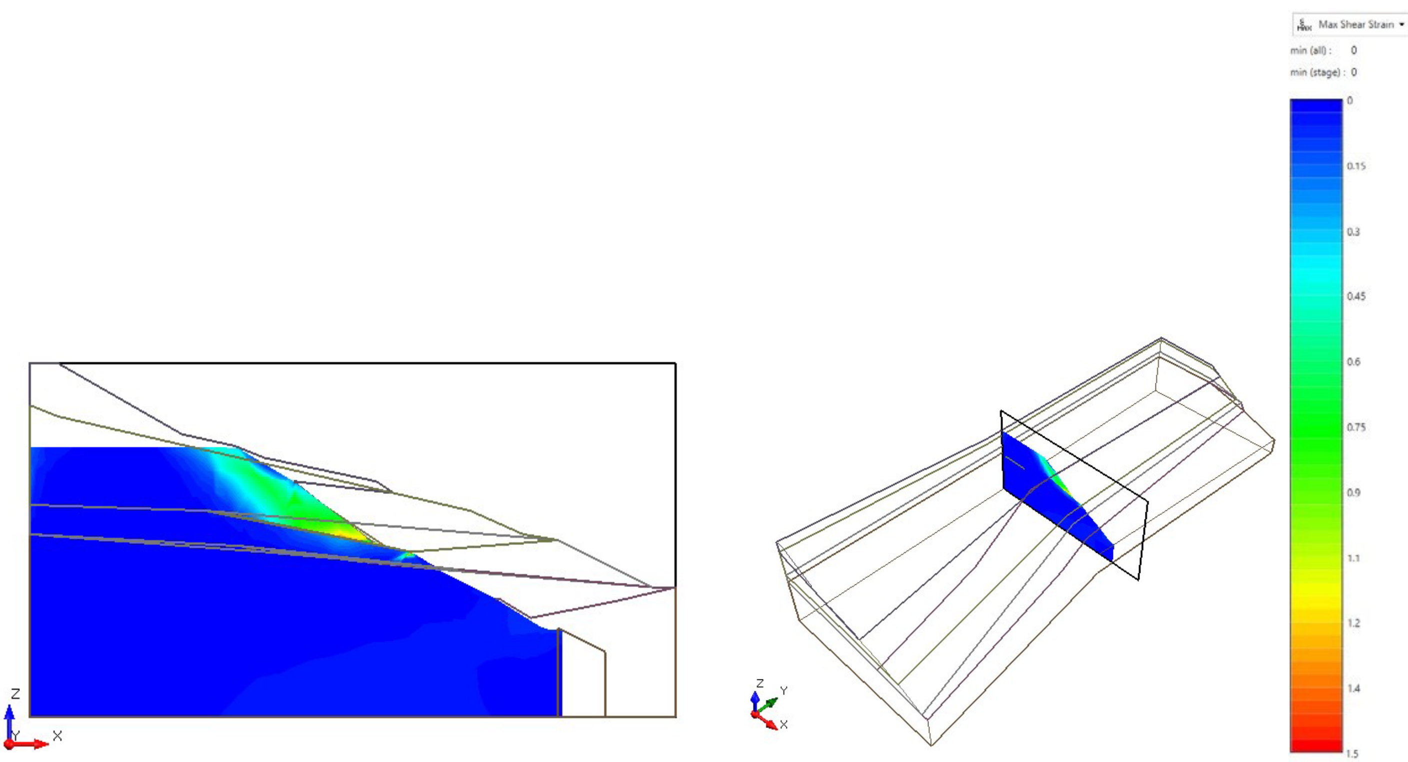

Figure 10.10 – *RS3* Maximum Shear Strain

11. 3D Verification #11

11.1. 3D embankment, vertical cut, homogeneous, ellipsoidal with SA

11.1.1. Introduction

This model is taken from Stauffer (2015.) It is a homogeneous embankment on a stadium that is extruded beyond the embankment. Stauffer did this problem first with no reinforcement and then with soil nails. This is the embankment with no reinforcement.

11.1.2. Problem Description

The 2D cross section of this problem is shown as Figure 11.1. The stadium starts in the XY plane and is extruded 20m; the embankment is extruded 15m with a 5m offset, this can be seen in the top view, Figure 11.2. The material properties are shown in Table 11.1. There is no groundwater or pore pressure. A cuckoo search with optimization is used.

11.1.3. Geometry and Properties

Table 11.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Soil	10	18	15

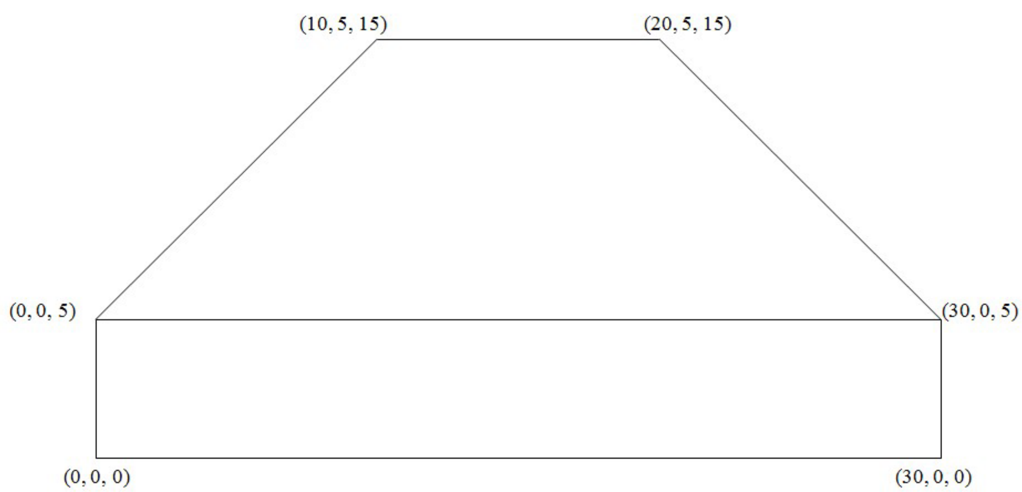

Figure 11.1(a)

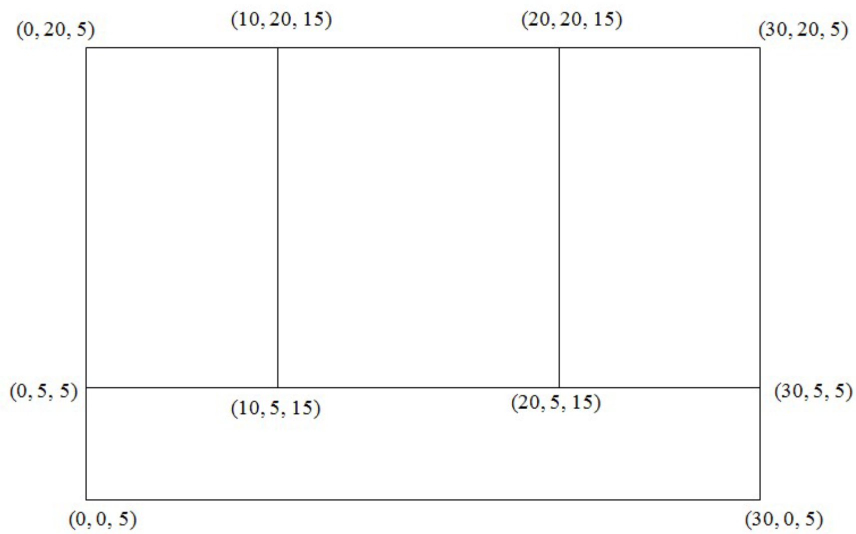

Figure 11.2

11.1.4. Results

Table 11.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	0.541	0.486	0.47	0.46
Janbu	0.533	0.495		

Referee: FS 0.56 [Stauffer, 2015]

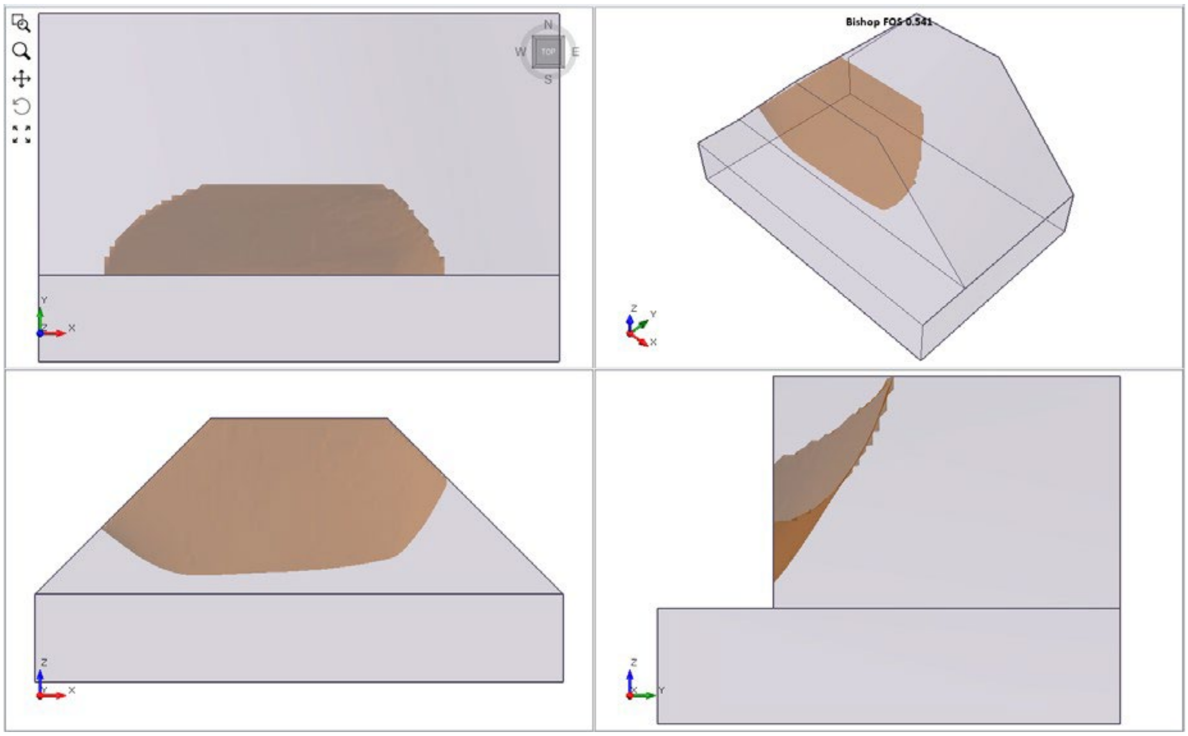

Figure 11.3 – *Slide3* Solution Using the Bishop Method

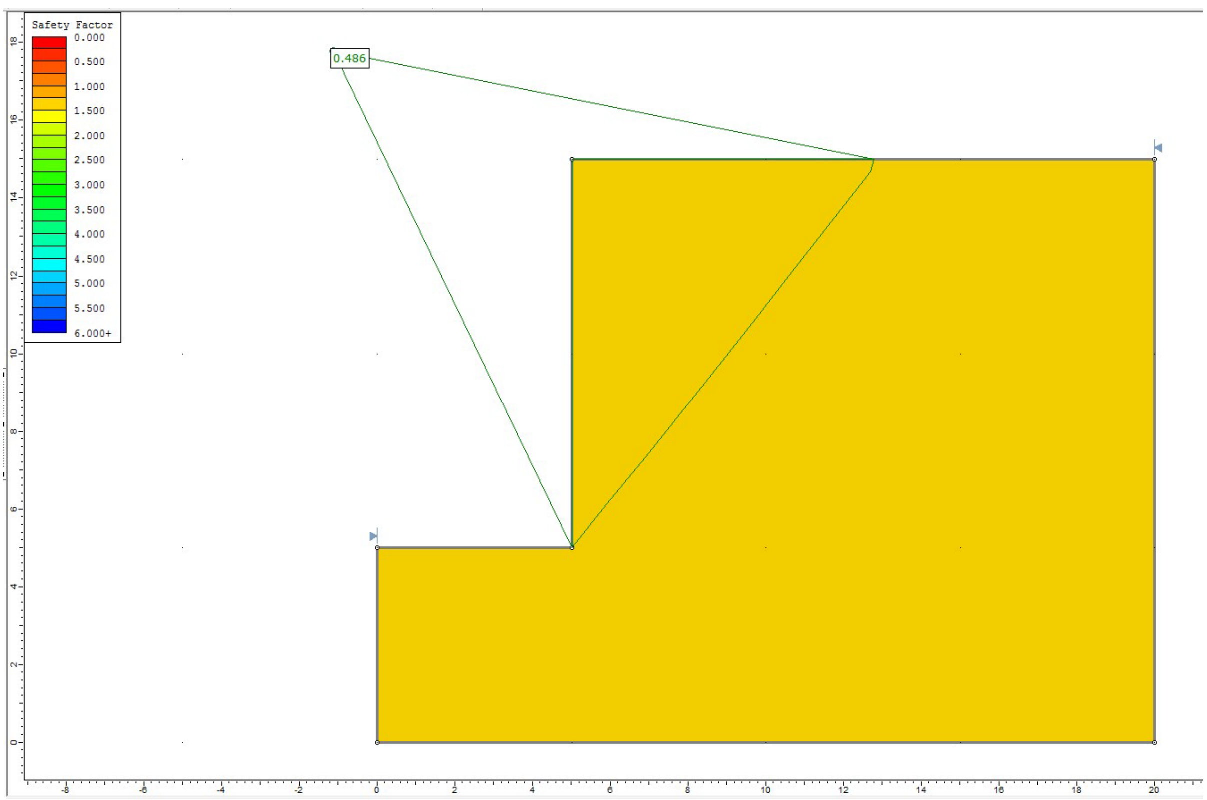

Figure 11.4 – *Slide2* Solution Using the Bishop Method

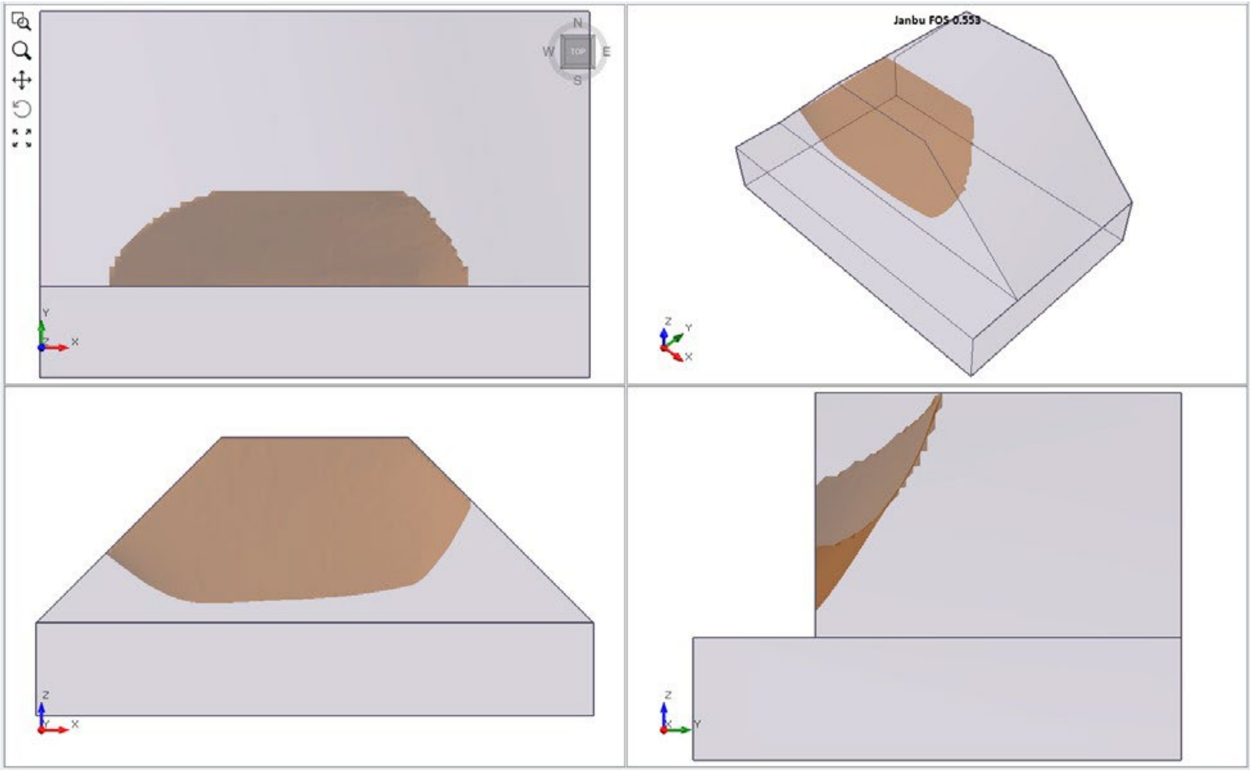

Figure 11.5 – *Slide3* Solution Using the Janbu Method

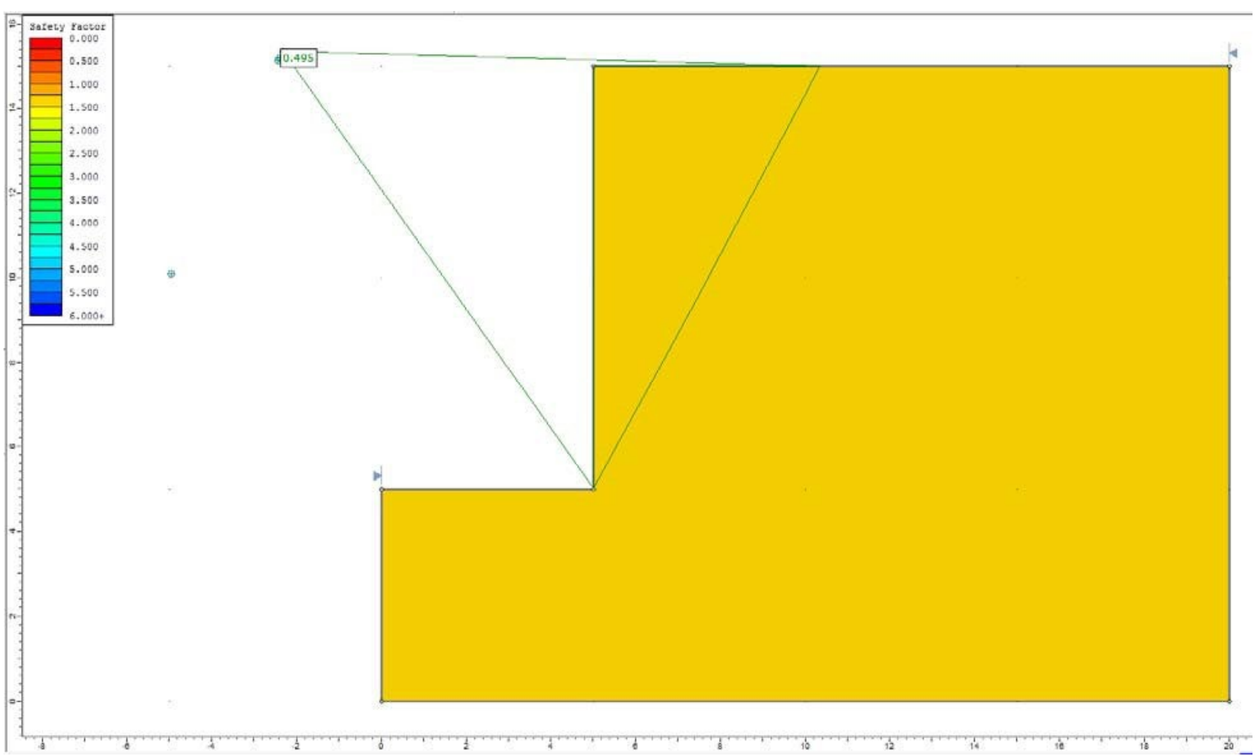

Figure 11.6 – *Slide2* Solution Using the Janbu Method

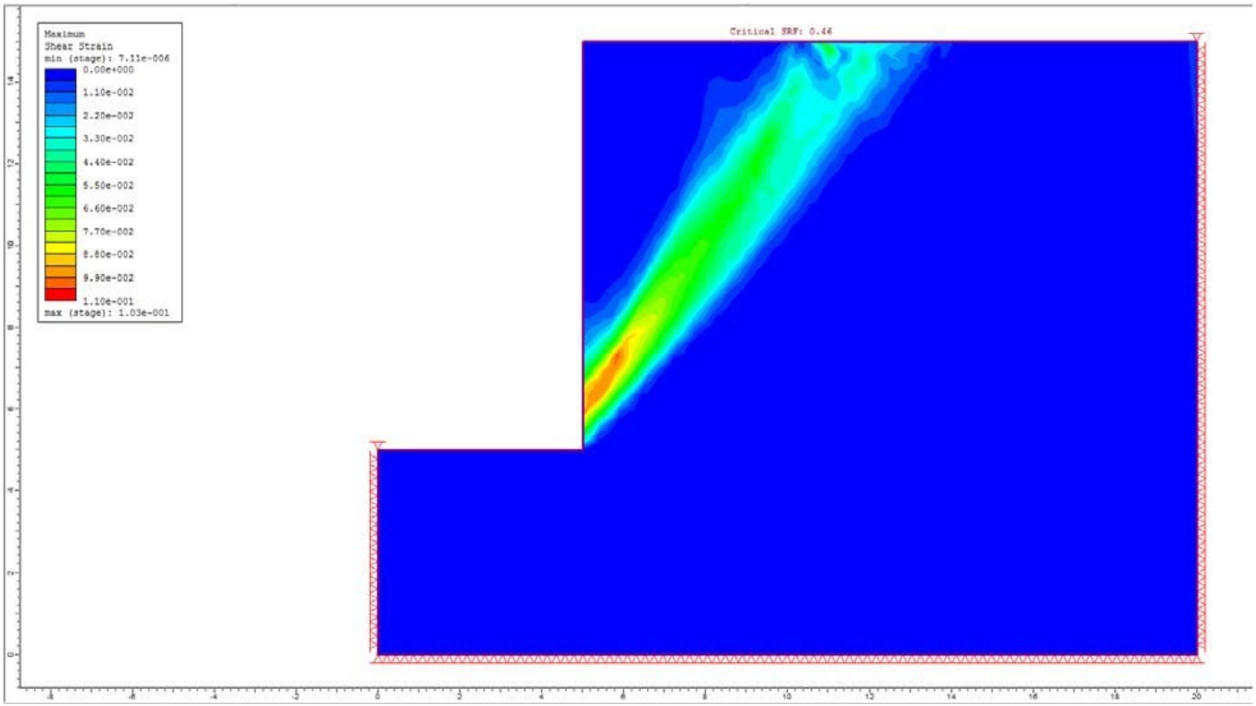

Figure 11.7 – *RS2* Maximum Shear Strain

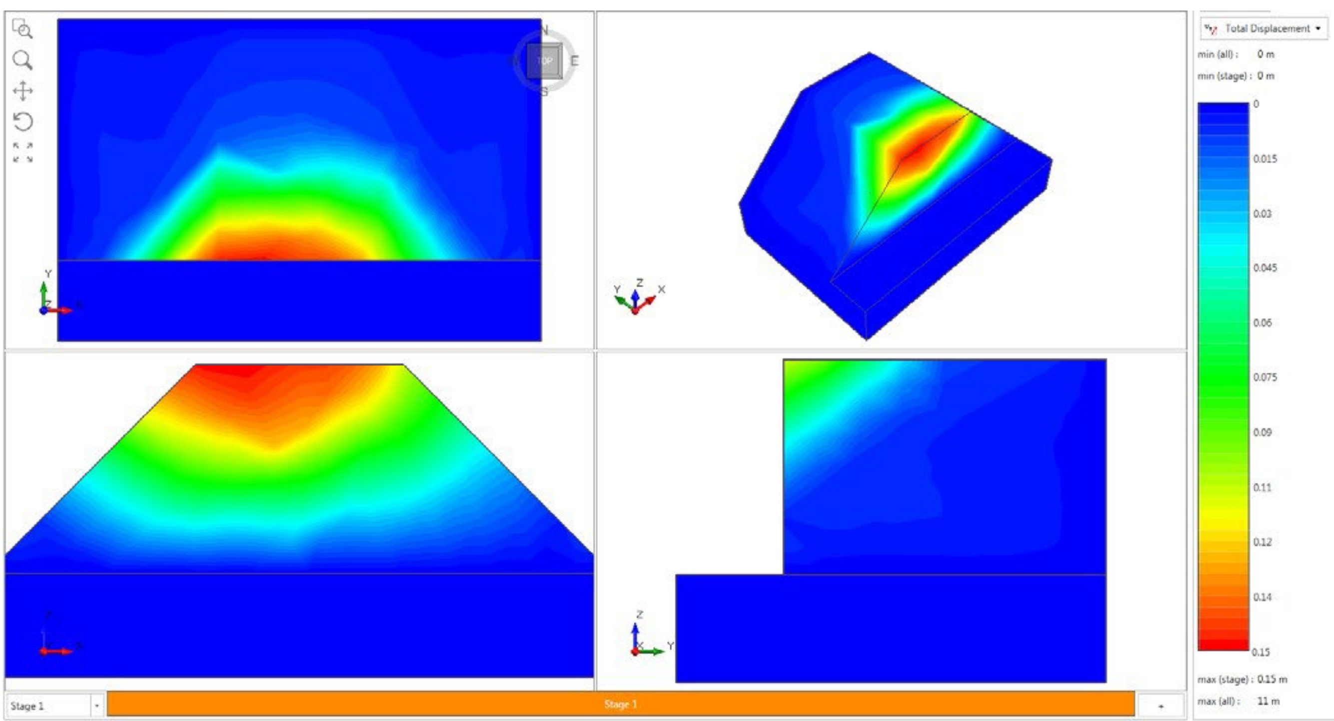

Figure 11.8 – *RS3* Total Displacement

12. 3D Verification #12

12.1. 3D open pit mine, homogeneous, ellipsoidal with SA

12.1.1. Introduction

This example is a fully 3D model of a homogeneous open pit.

12.1.2. Problem Description

The material properties for the open pit can be found in Table 12.1. There is no groundwater in this problem. The ellipsoidal slip surface and corresponding safety factor is required.

12.1.3. Properties

Table 12.1: Material Properties

c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
200	45	20

12.1.4. Results

Table 12.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.57	1.394	1.75	1.41
GLE	1.7	1.368		
Janbu	1.499	1.311		
Spencer	1.611	1.374		

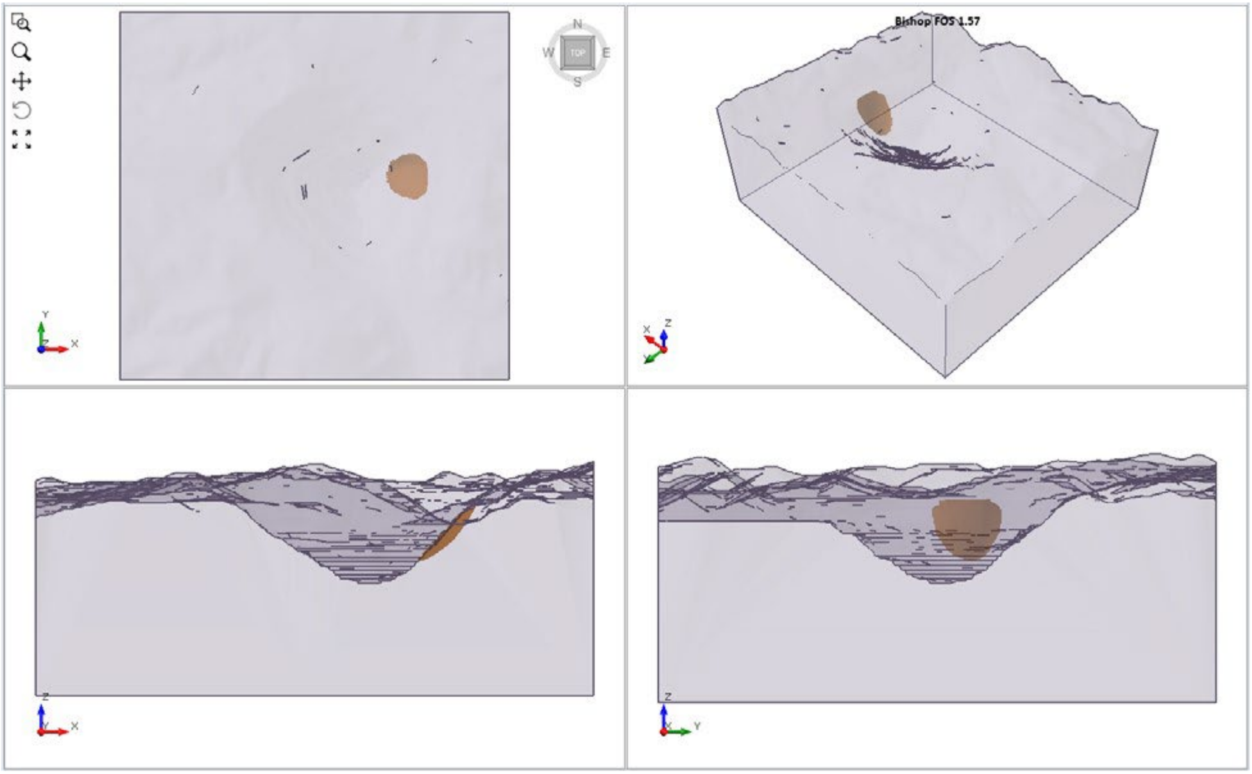

Figure 12.1 – *Slide3* Solution Using the Bishop Method

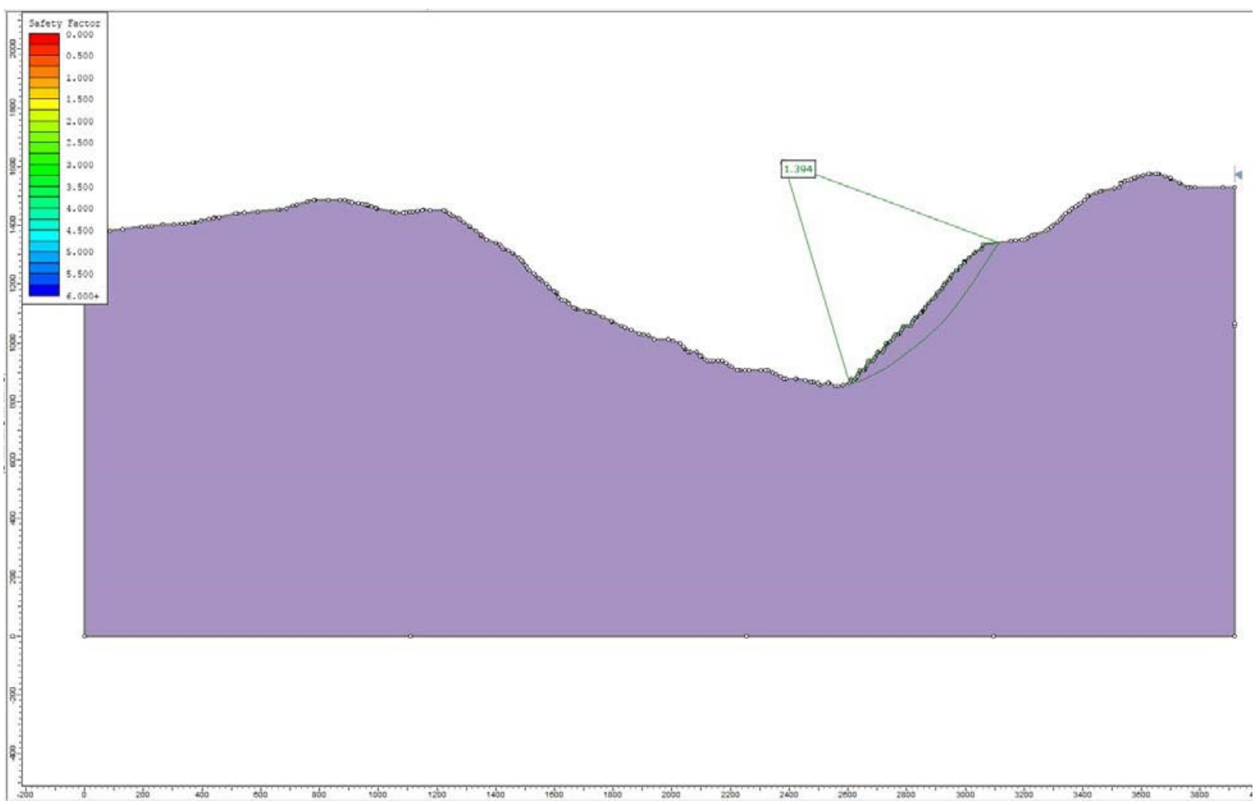

Figure 12.2 – *Slide2* Solution Using the Bishop Method

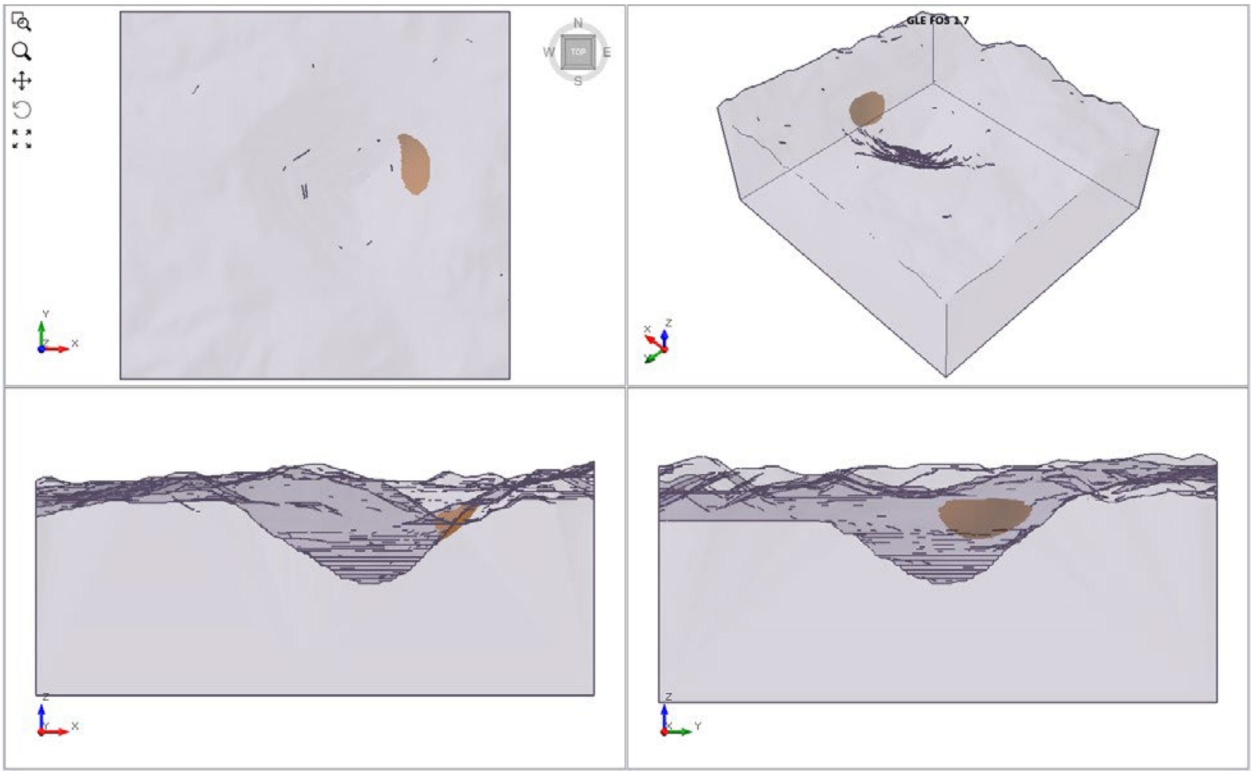

Figure 12.3 – *Slide3* Solution Using the GLE Method

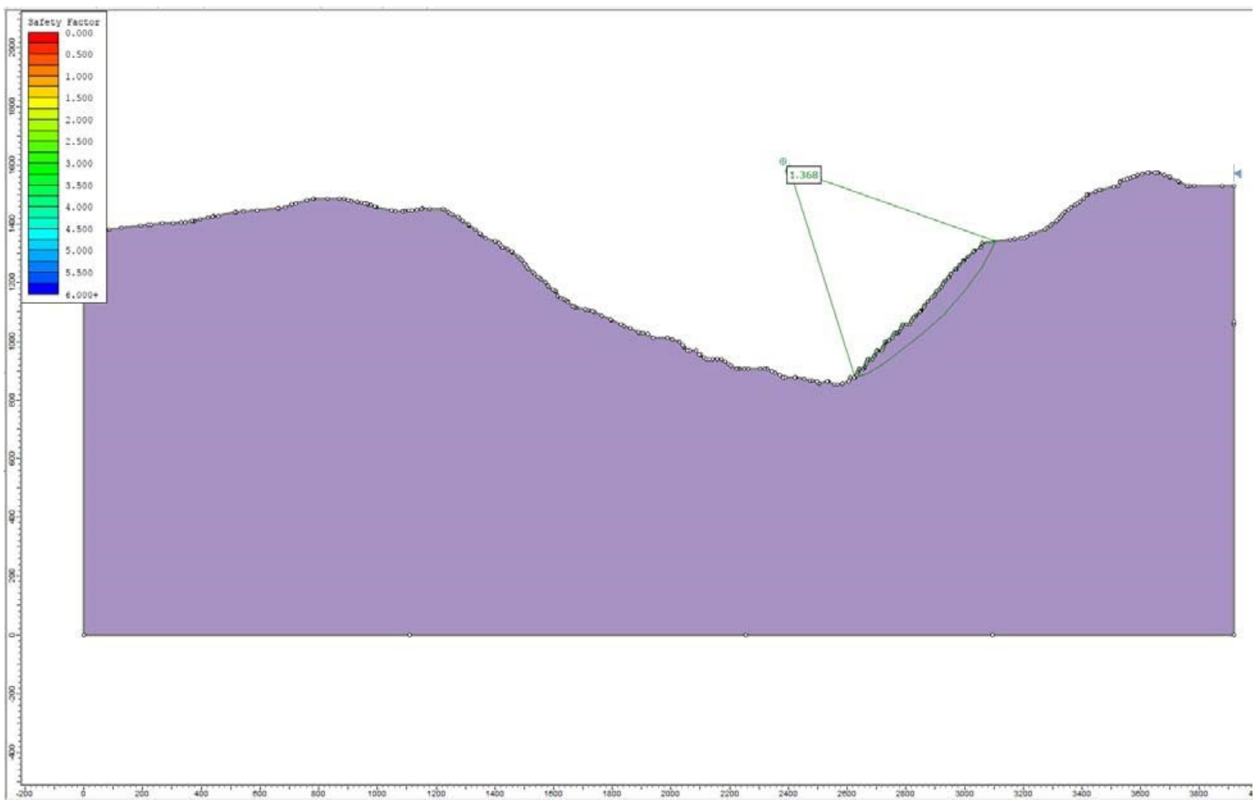

Figure 12.4 – *Slide2* Solution Using the GLE Method

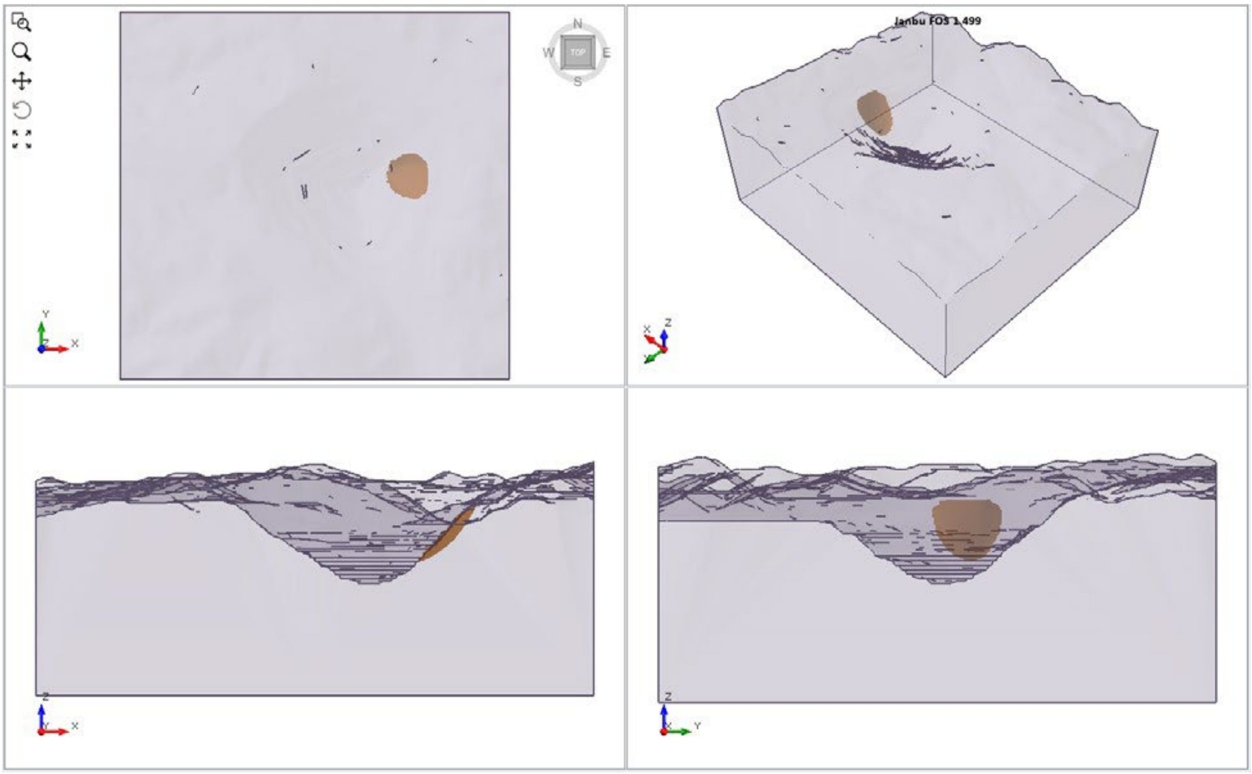

Figure 12.5 – *Slide3* Solution Using the Janbu Method

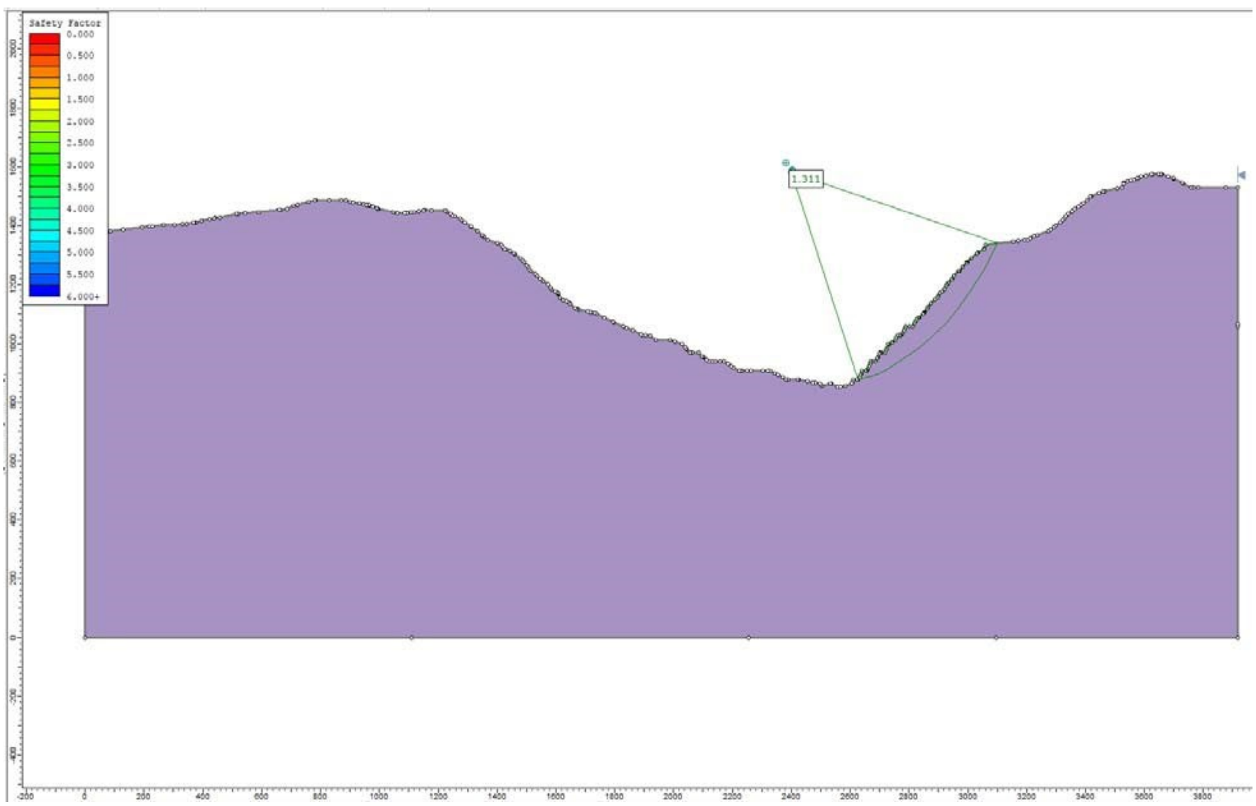

Figure 12.6 – *Slide2* Solution Using the Janbu Method

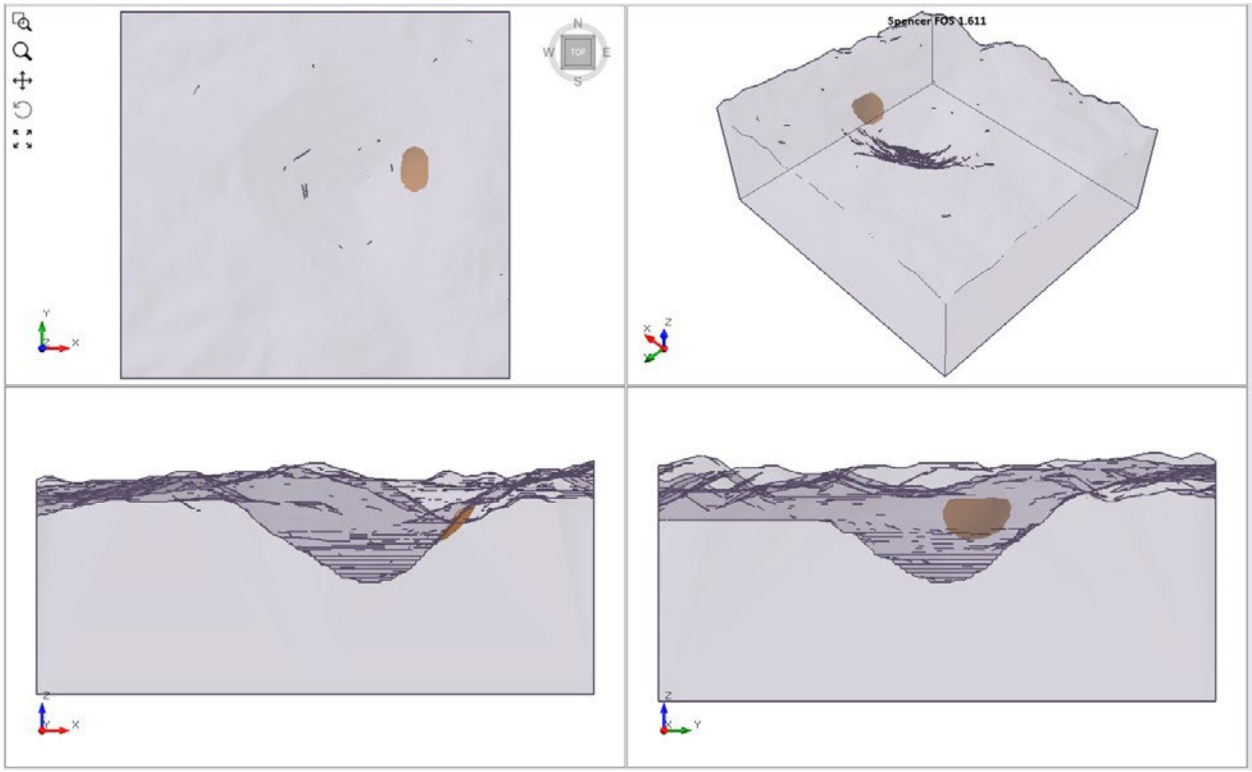

Figure 12.7 – *Slide3* Solution Using the Spencer Method

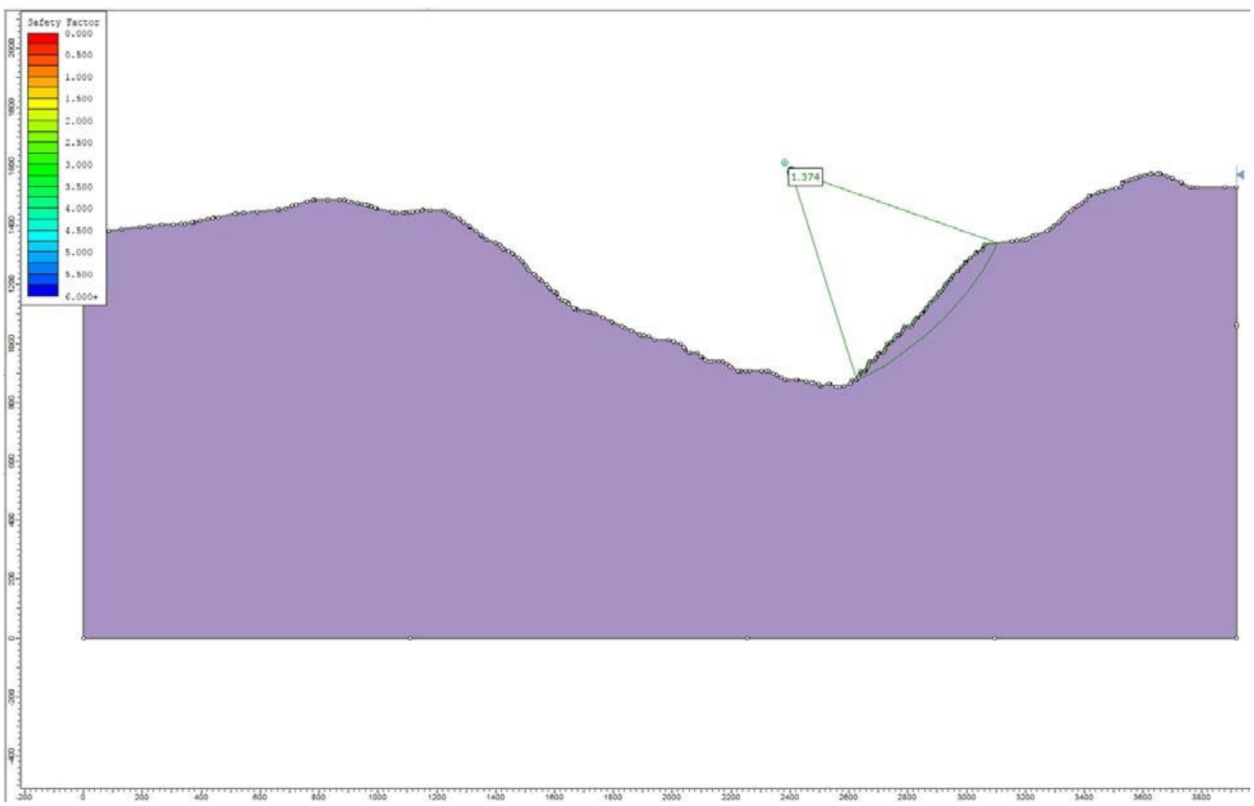

Figure 12.8 – *Slide2* Solution Using the Spencer Method

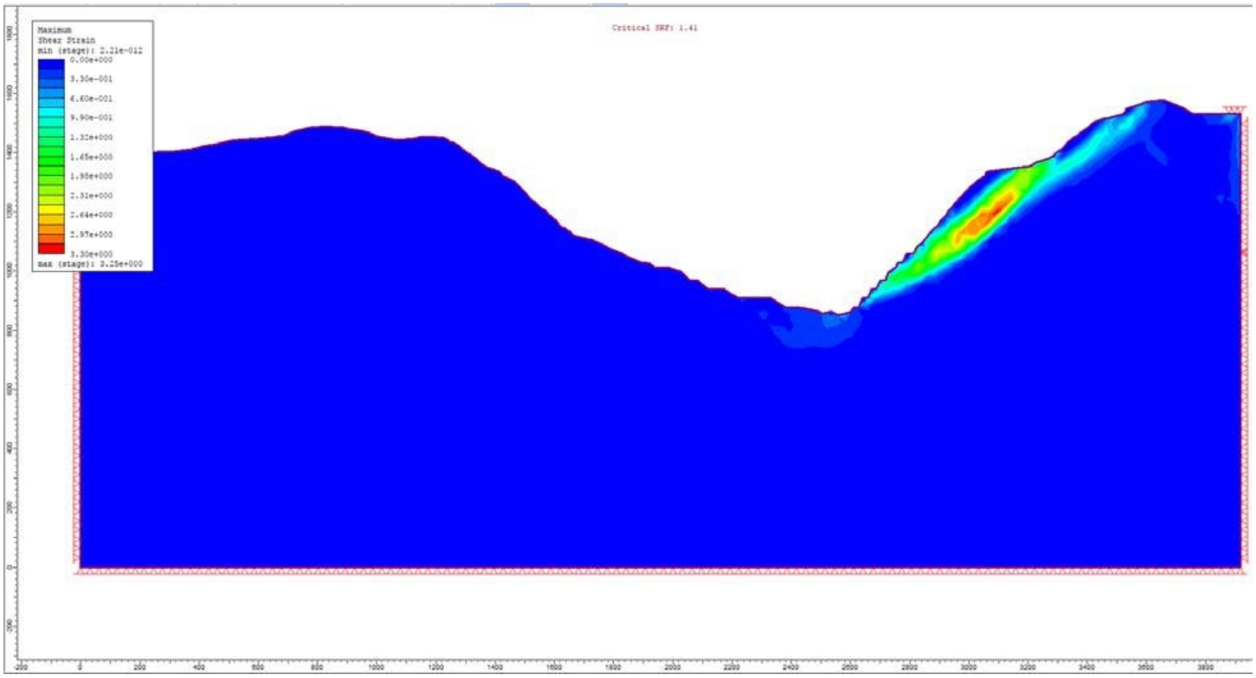

Figure 12.9 – *RS2* Maximum Shear Strain

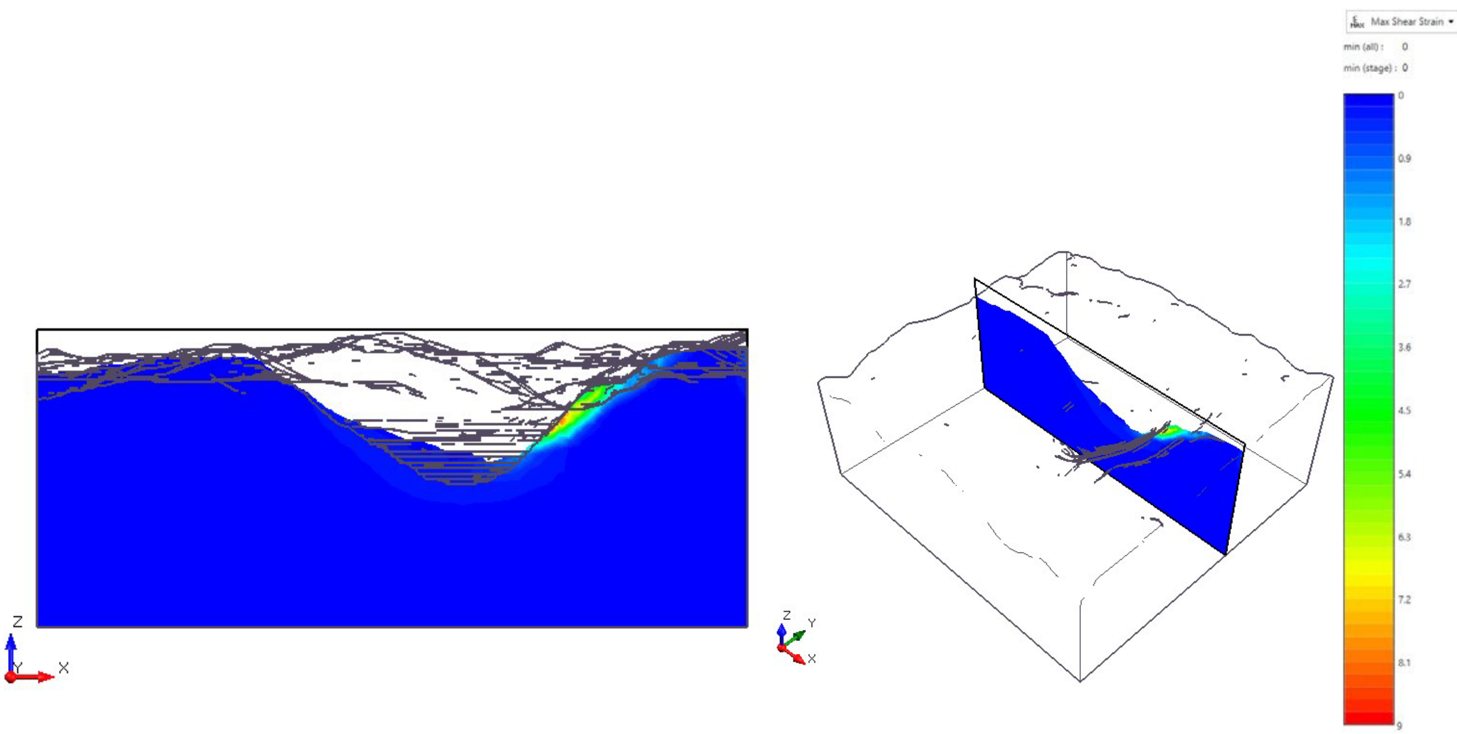

Figure 12.10 – *RS3* Maximum Shear Strain

13. 3D Verification #13

13.1. 3D catchment, homogeneous, water table, ellipsoidal with SA

13.1.1. Introduction

This example is a case study of a land*Slide2* that occurred in the Oregon catchment done by Camargo et al. (2016).

13.1.2. Problem Description

Seven 2D cross sections were lofted together to create the slope for this problem. The points used to create these cross sections are shown in Table 13.1, each cross sections is in the XZ plane at a given Y value and lofted to the cross sections immediate next to them. The entire slope has been cut off at a height of Z = 245 m. The points used to form the water table are shown in Table 13.2. The material properties for the homogeneous slope can be found in Table 13.3. The ellipsoidal slip surface is required.

13.1.3. Geometry and Properties

Table 13.1: Slope Geometry

X	Y	Z	X	Y	Z	X	Y	Z
101	0	256	100.5	3	256	101	8	256
101	0	245	100.5	3	245	101	8	245
151	0	245	150	3	245	151.5	8	245
151	0	294	150	3	294	151.5	8	294
148	0	292	147	3	292	148	8	292
145	0	290	144.5	3	290	146	8	290
142	0	288	141.5	3	288	143	8	288
140	0	286	139	3	286	140.4	8	286
137	0	284	136.5	3	284	137.5	8	284
134.5	0	282	133.5	3	282	135	8	282
132	0	280	131	3	280	132	8	280
129	0	278	128	3	278	130	8	278
126	0	276	125	3	276	128	8	276
123	0	274	122.5	3	274	124.5	8	274
120.5	0	272	120	3	272	122	8	272
118	0	270	117	3	270	120	8	270
115.5	0	268	114.5	3	268	117	8	268

X	Y	Z	X	Y	Z	X	Y	Z
113.5	0	266	112.5	3	266	113.5	8	266
111.5	0	264	110.5	3	264	111.5	8	264
109	0	262	108.5	3	262	109	8	262
107	0	260	106	3	260	106	8	260
104	0	258	103	3	258	103.5	8	258
102.5	13	254	101.5	18	252	101	23	254
102.5	13	245	101.5	18	245	101	23	245
153	13	245	151	18	245	151	23	245
153	13	294	151	18	292	151	23	292
150	13	292	148.5	18	290	148	23	290
147.5	13	290	146	18	288	145.5	23	288
145	13	288	144.5	18	286	142.5	23	286
142.5	13	286	141	18	284	140	23	284
140	13	284	138.5	18	282	137.5	23	282
137.5	13	282	136	18	280	135	23	280
134.5	13	280	134	18	278	133	23	278
131.5	13	278	131.5	18	276	131	23	276
129.5	13	276	129	18	274	129	23	274
127	13	274	126.5	18	272	127	23	272
125	13	272	124	18	270	124.5	23	270
122.5	13	270	122	18	268	122.5	23	268
120	13	268	120	18	266	120	23	266
117	13	266	118	18	264	118	23	264
114.5	13	264	116.5	18	262	116	23	262
112	13	262	113.5	18	260	113.5	23	260
110	13	260	111	18	258	110.5	23	258
107	13	258	108	18	256	105	23	256
104.5	13	256	105	18	254			
100	28	256	141	28	284	125	28	270
100	28	245	138	28	282	122.5	28	268
151.5	28	245	135.5	28	280	120	28	266
151.5	28	294	133.5	28	278	117	28	264
150	28	292	131.5	28	276	113	28	262
147.5	28	290	129	28	274	107.5	28	260
145.5	28	288	127	28	272	104	28	258
143	28	286						

Table 13.2 Water Table

X	Y	Z	X	Y	Z	X	Y	Z
101	0	256	101	3	256	101	8	256
104	0	258	103	3	258	103.5	8	258
107	0	260	106	3	260	106.5	8	260
109	0	262	109	3	262	109.5	8	262
111.5	0	264	111	3	264	111.5	8	264
114	0	266	113	3	266	114	8	266
116	0	268	115	3	268	117.5	8	268
118	0	270	117.5	3	270	120	8	270
120.5	0	272	120	3	272	122.5	8	272
123	0	274	123	3	274	125	8	274
126	0	276	126	3	276	127.5	8	276
129	0	278	128.5	3	278	130.5	8	278
132.5	0	280	131.5	3	280	132.5	8	280
136	0	282	135	3	282	136	8	282
102	13	254	103	18	252	102	23	254
105	13	256	105.5	18	254	107	23	256
107.5	13	258	109	18	256	111.5	23	258
110.5	13	260	111.5	18	258	114	23	260
113	13	262	114	18	260	116	23	262
116	13	264	116.5	18	262	118	23	264
118	13	266	118.5	18	264	120	23	266
121	13	268	120.5	18	266	123	23	268
123.5	13	270	123	18	268	125	23	270
125.5	13	272	125	18	270	127.5	23	272
127.5	13	274	127.5	18	272	129.5	23	274
130	13	276	130	18	274	132	23	276
132	13	278	132	18	276	134	23	278
135	13	280	135	18	278	136	23	280
139	13	282	137.5	18	280	139	23	282
			140.5	18	282			
101.5	28	256	121	28	266	132	28	276
104.5	28	258	123	28	268	134.5	28	278
108.5	28	260	125.5	28	270	136.5	28	280
114	28	262	127.5	28	272	139.5	28	282
117	28	264	130	28	274			

Table 13.3: Material Properties

	c′ (kN/m^2)	φ′ (deg.)	γ (kN/m^3)
Soil	22	40	13.73

13.1.4. Results

Table 13.4: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.048</td><td>0.491</td><td rowspan="4">0.97</td><td rowspan="4">0.56</td></tr>
<tr><td>GLE</td><td>1.075</td><td>0.660</td></tr>
<tr><td>Janbu</td><td>0.985</td><td>0.371</td></tr>
<tr><td>Spencer</td><td>0.961</td><td>0.538</td></tr>
</table>

Referee: FS 1.00[Camargo et al., 2016]

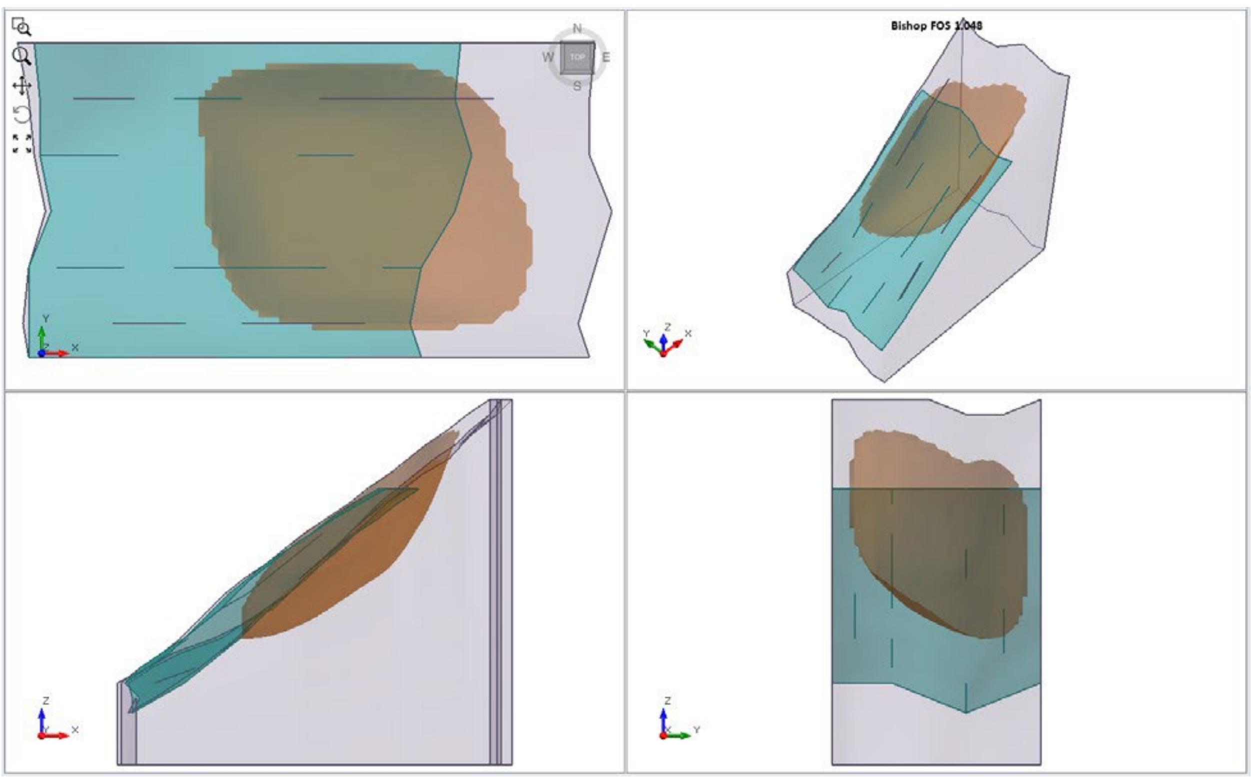

Figure 13.1 – *Slide3* Solution Using the Bishop Method

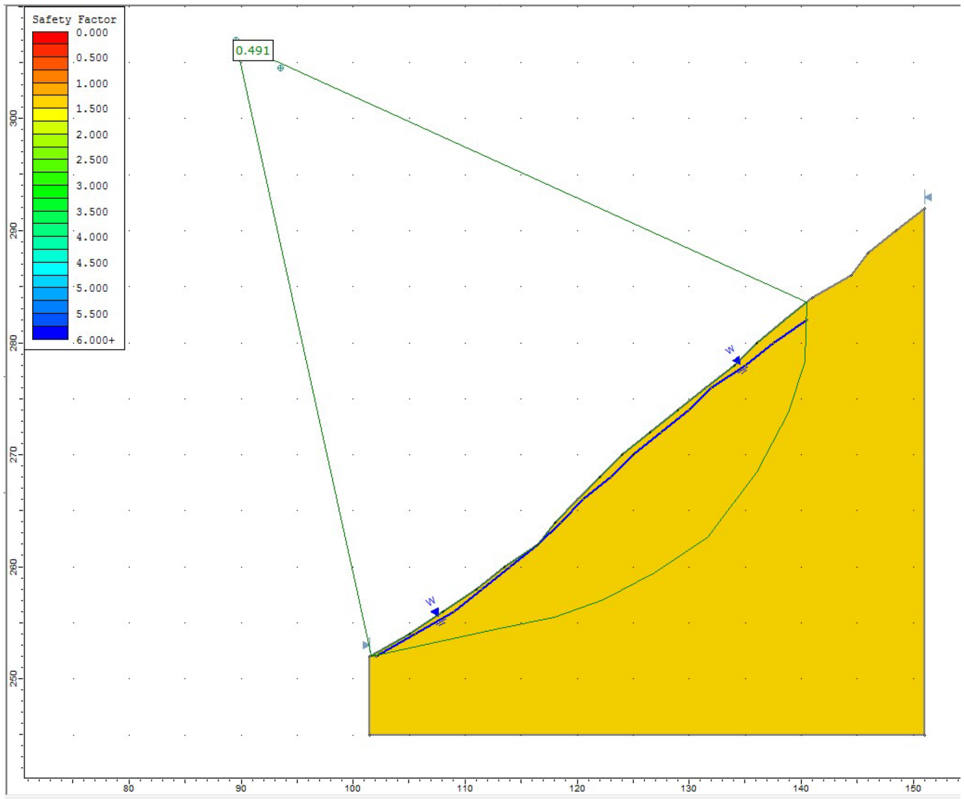

Figure 13.2 – *Slide2* Solution Using the Bishop Method

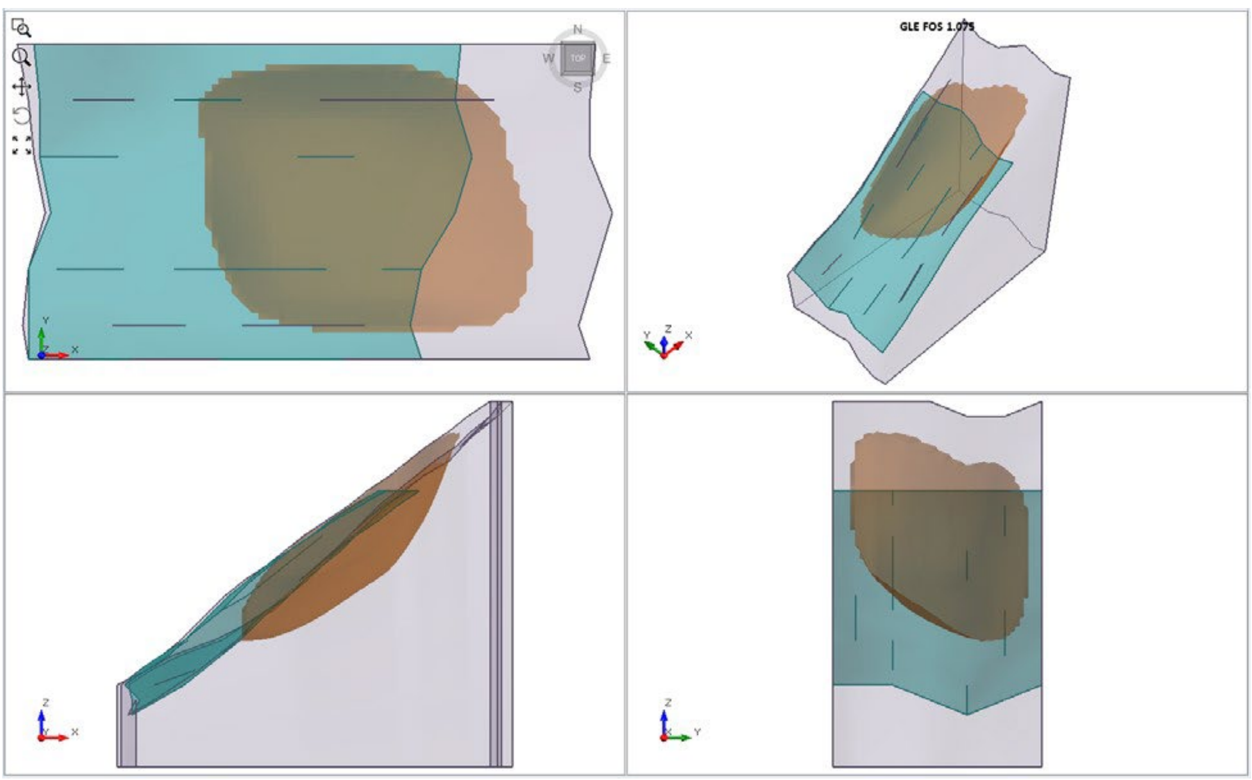

Figure 13.3 – *Slide3* Solution Using the GLE Method

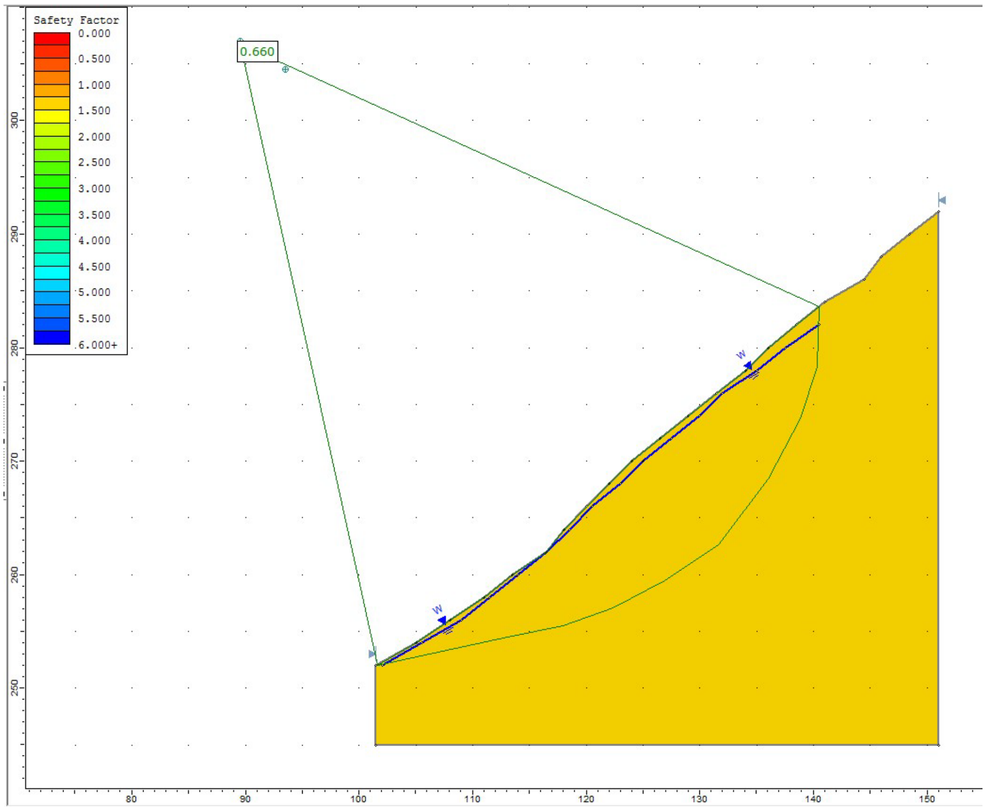

Figure 13.4 – *Slide2* Solution Using the GLE Method

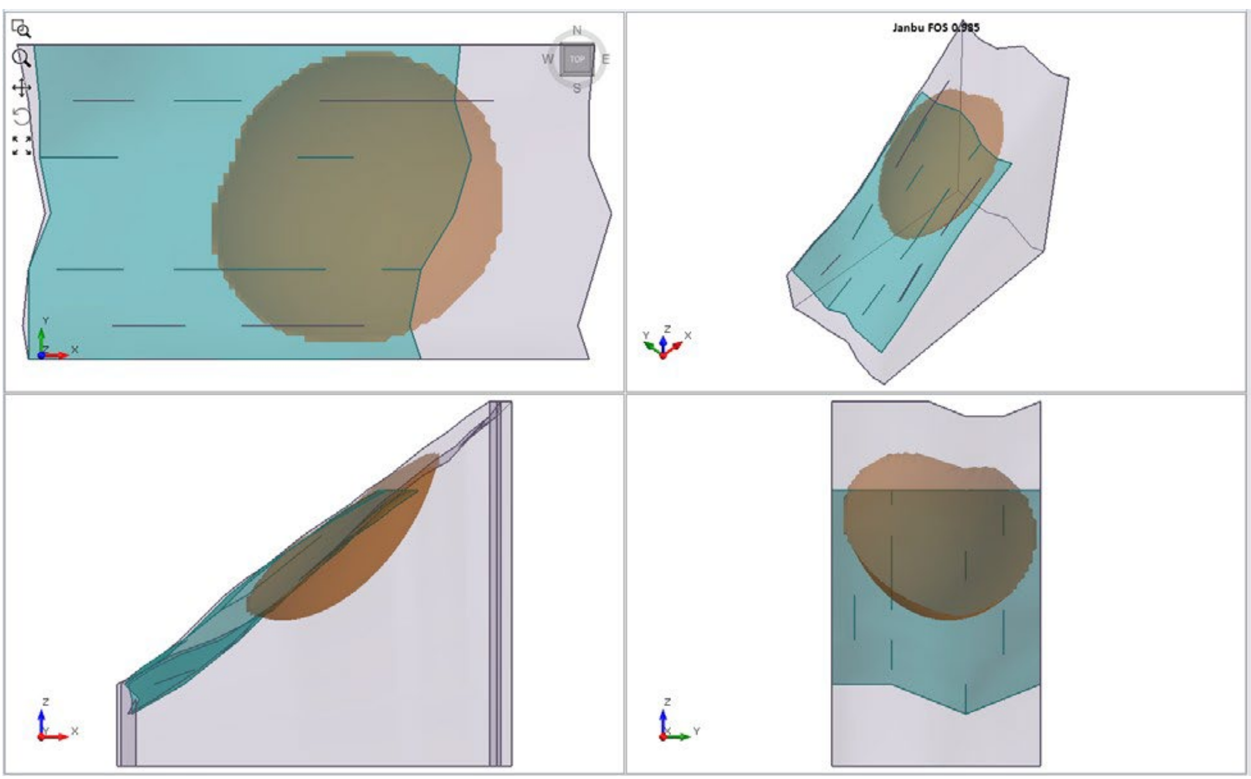

Figure 13.5 – *Slide3* Solution Using the Janbu Method

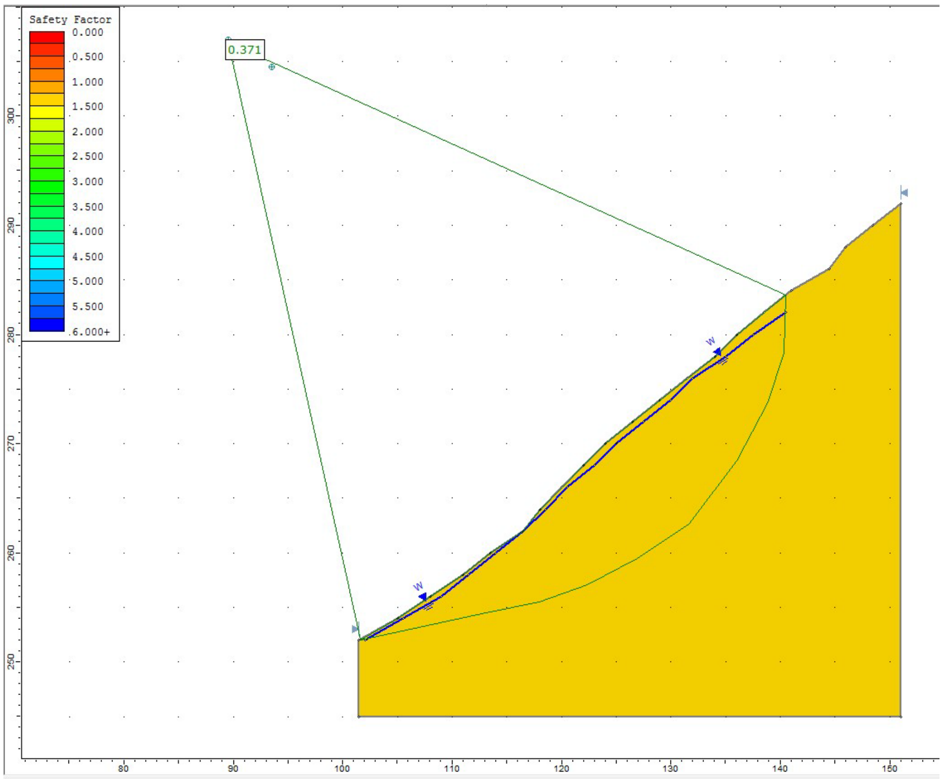

Figure 13.6 – *Slide2* Solution Using the Janbu Method

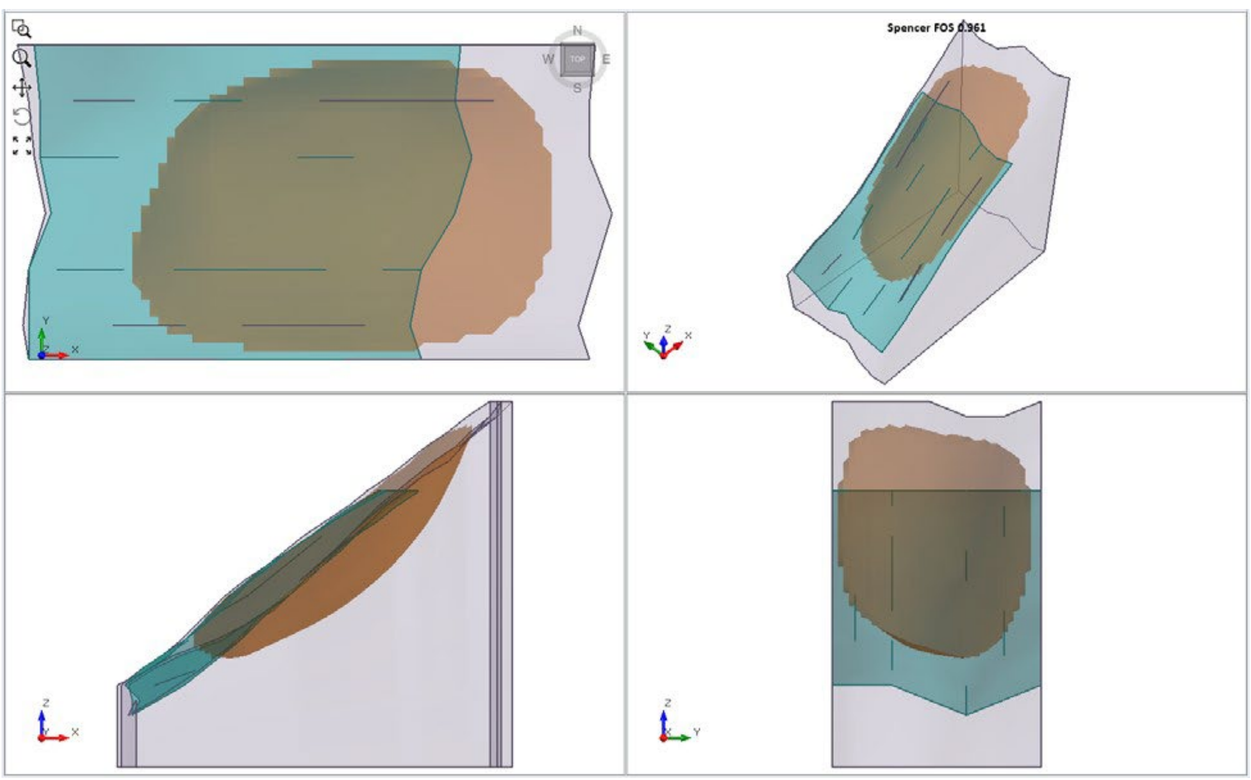

Figure 13.7 – *Slide3* Solution Using the Spencer Method

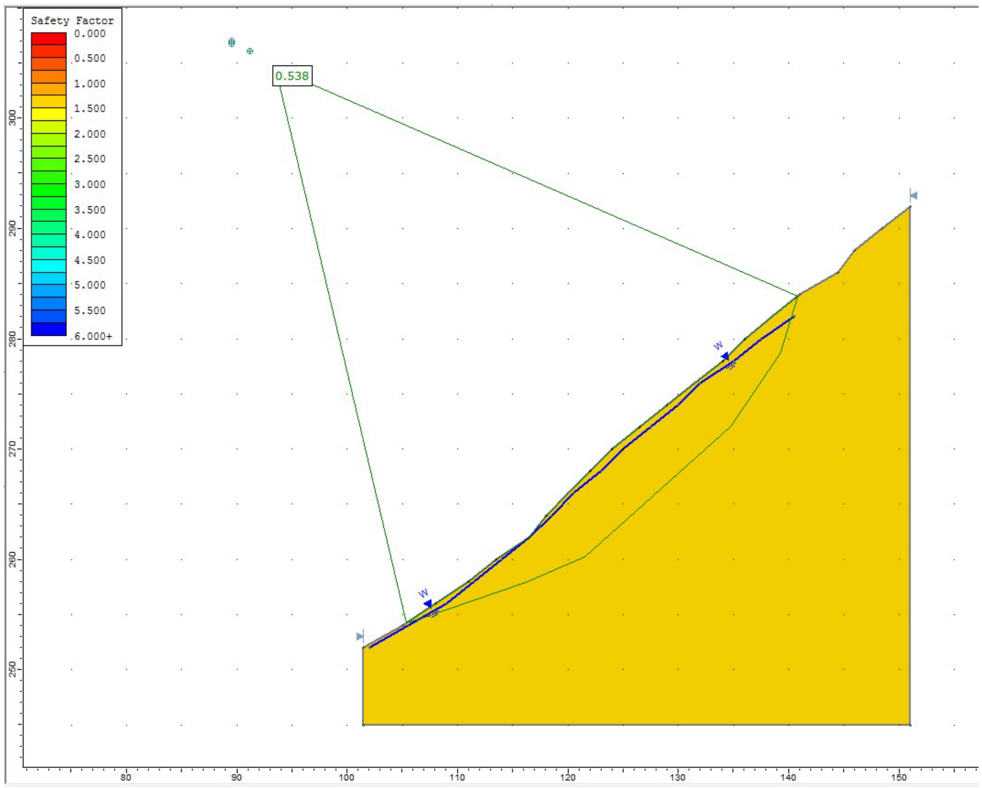

Figure 13.8 – *Slide2* Solution Using the Spencer Method

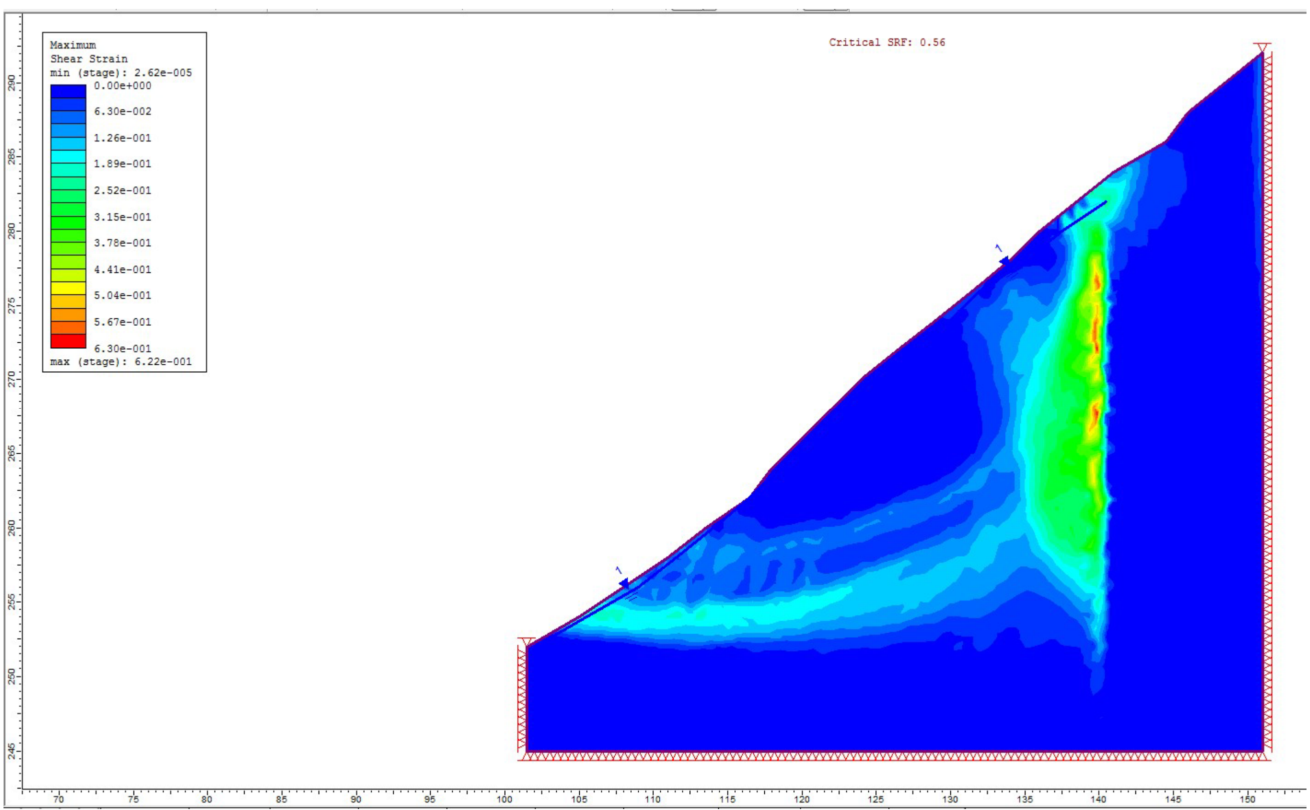

Figure 13.9 – *RS2* Maximum Shear Strain

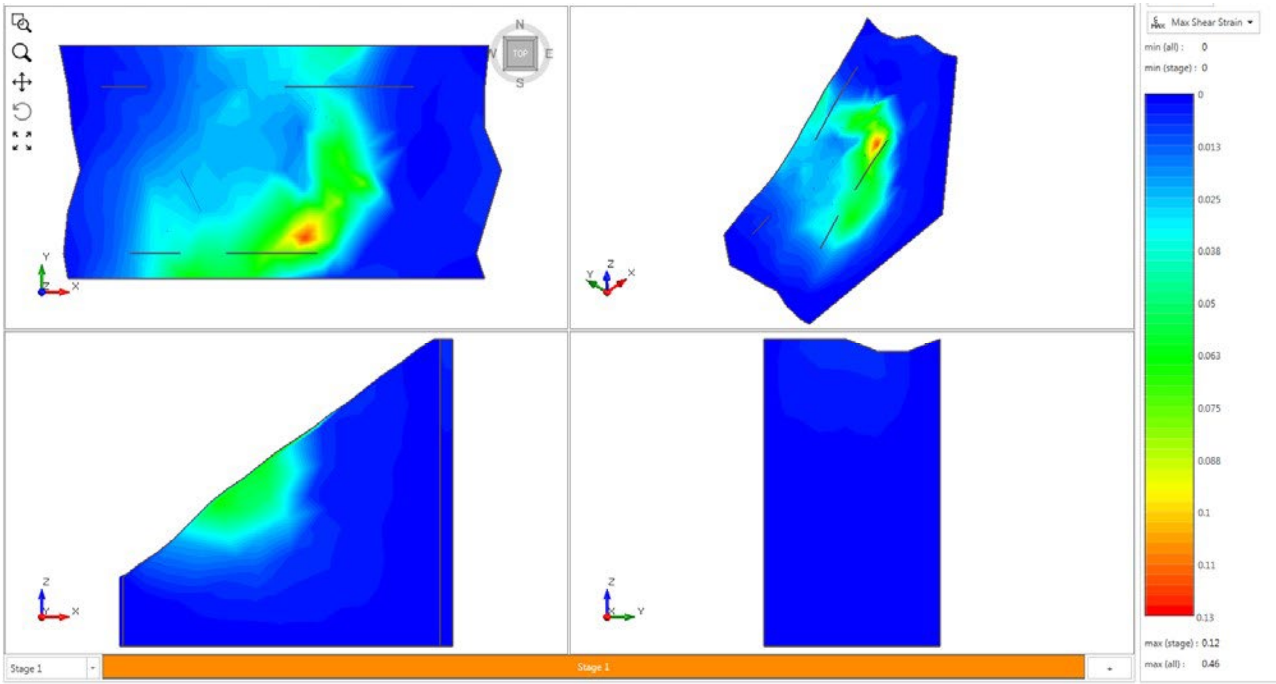

Figure 13.10 – *RS3* Maximum Shear Strain

14. 3D Verification #14

14.1. 3D volcano, homogeneous, spherical

14.1.1. Introduction

This example is taken from Reid et al. (2000). A model of Mount St. Helens has been analyzed under several conditions. This is the first condition: dry with no seismic loading.

14.1.2. Problem Description

This example is a 3D homogeneous model with no pore pressures, supports, or loading. The material properties can be found in Table 14.1. The spherical slip surface is required. The 2D cross section used to find the safety factor in *Slide2* and *RS2* was in the YZ plane and taken at X = 4300 m.

14.1.3. Properties

Table 14.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Rock	1000	40	24

14.1.4. Results

Table 14.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>2.225</td><td>2.091</td><td rowspan="4">2.23</td><td rowspan="4">2.1</td></tr>
<tr><td>GLE</td><td>2.219</td><td>2.088</td></tr>
<tr><td>Janbu</td><td>2.11</td><td>1.978</td></tr>
<tr><td>Spencer</td><td>2.219</td><td>2.088</td></tr>
</table>

Referee: FS 2.23 using the Bishop Method [Reid et al., 2000]

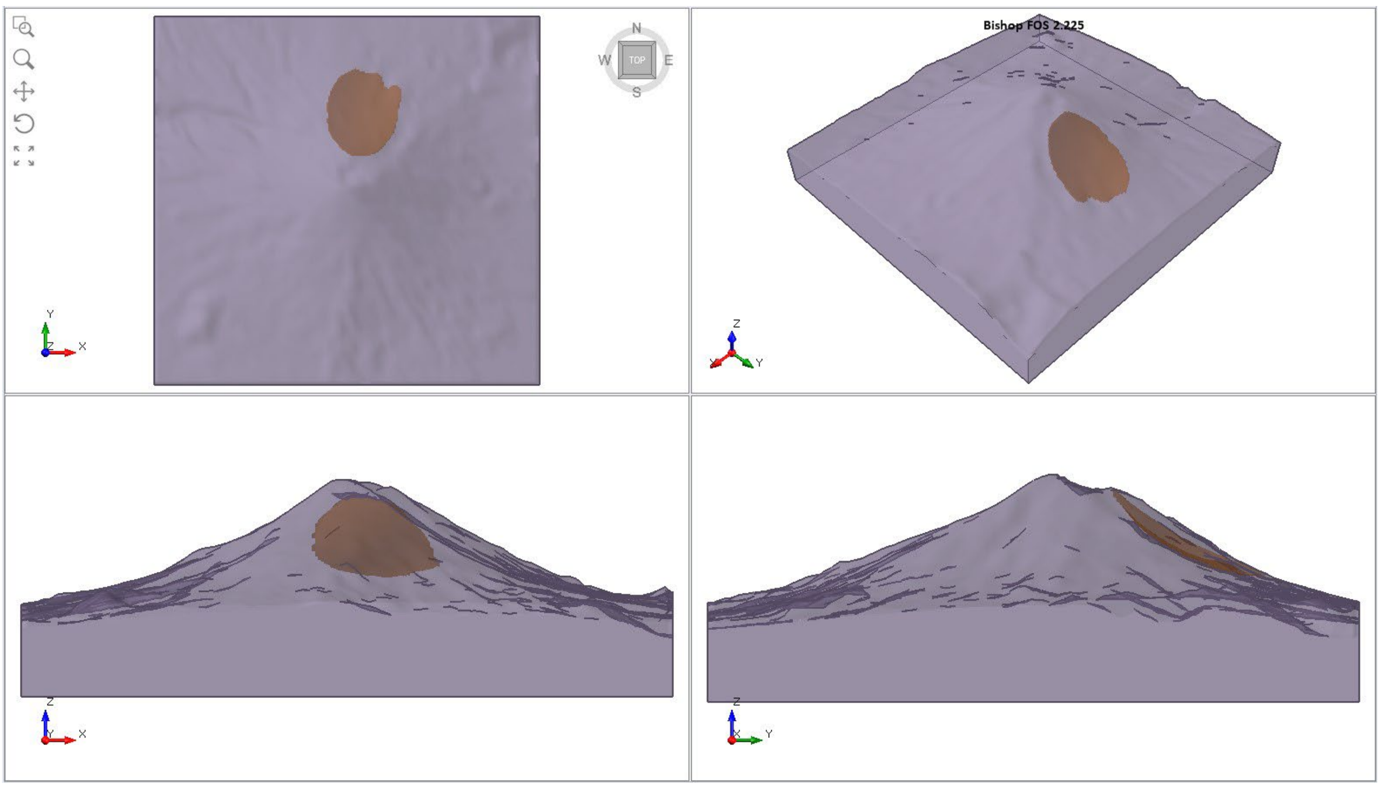

Figure 14.1 – *Slide3* Solution Using the Bishop Method

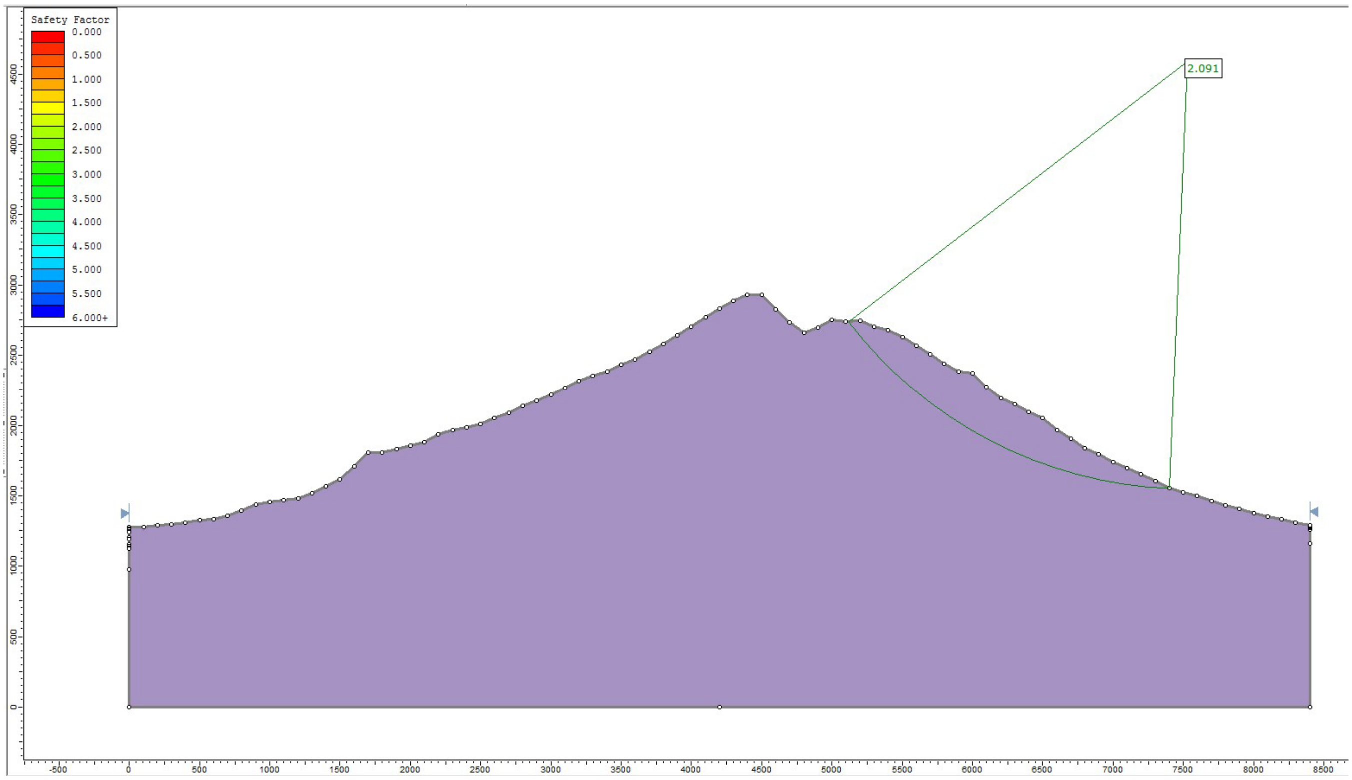

Figure 14.2 – *Slide2* Solution Using the Bishop Method

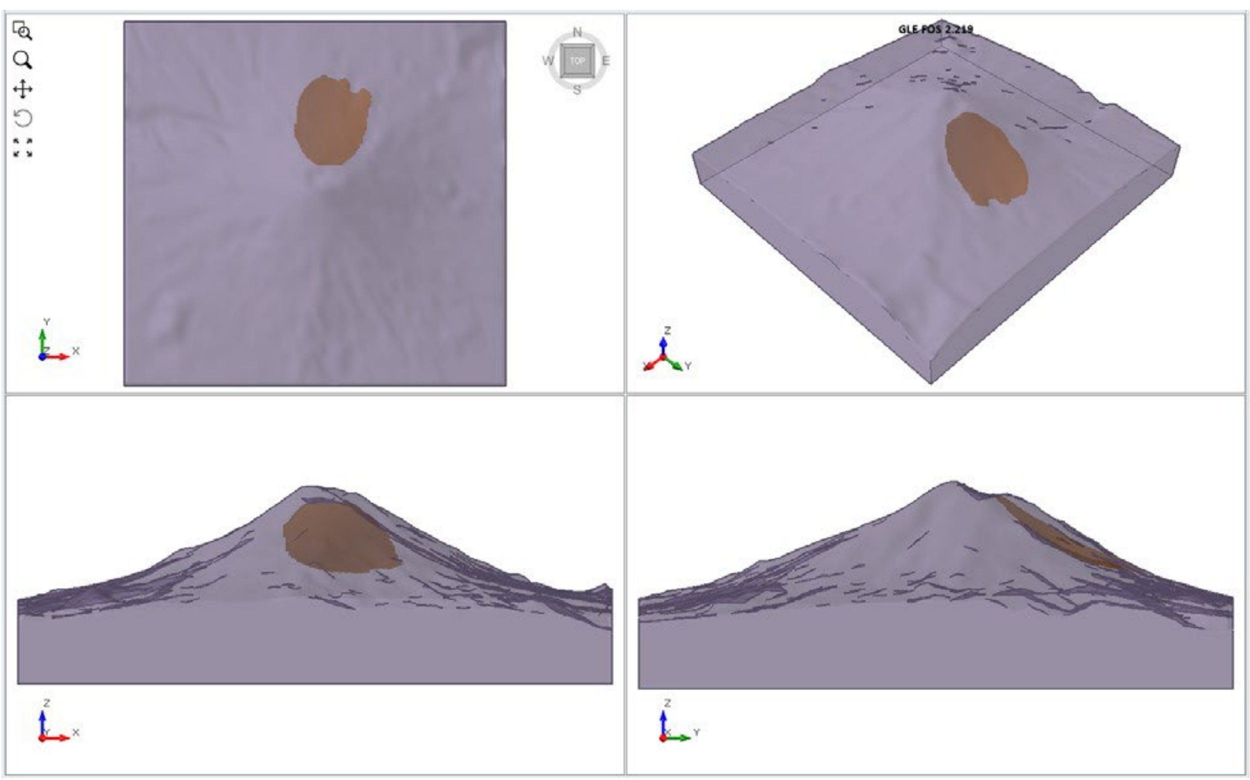

Figure 14.3 – *Slide3* Solution Using the GLE Method

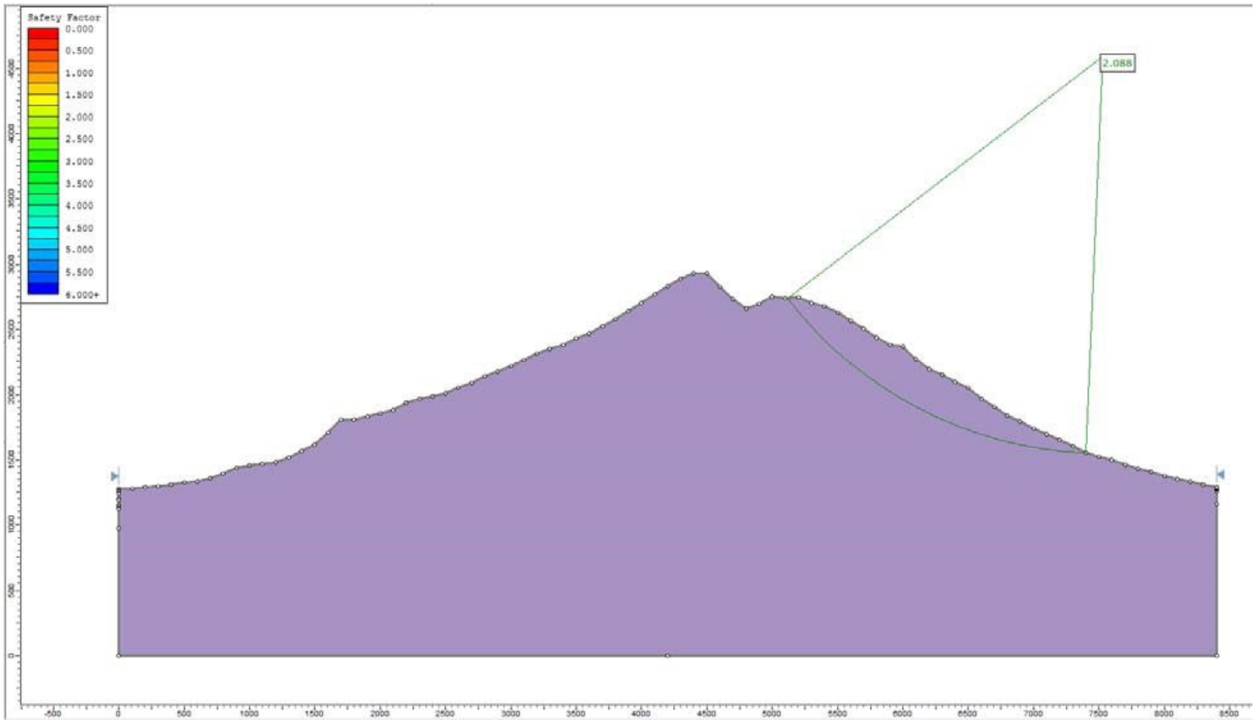

Figure 14.4 – *Slide2* Solution Using the GLE Method

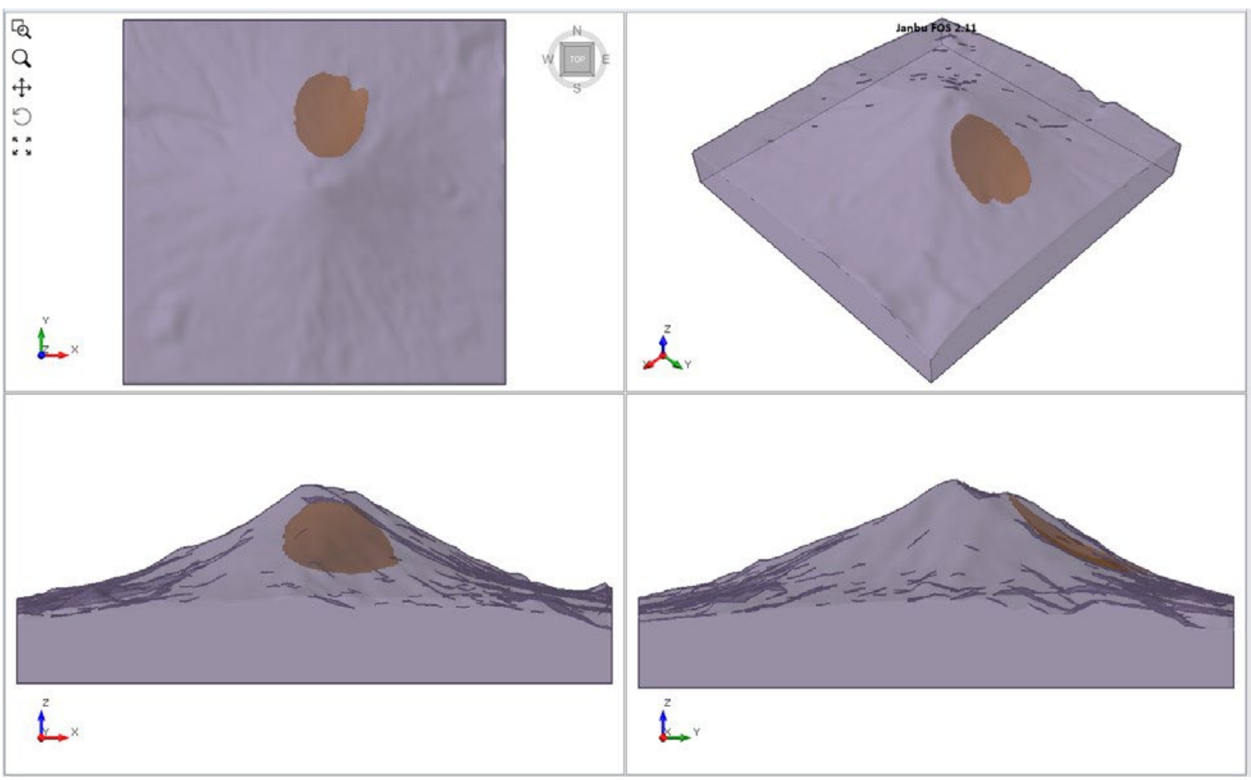

Figure 14.5 – *Slide3* Solution Using the Janbu Method

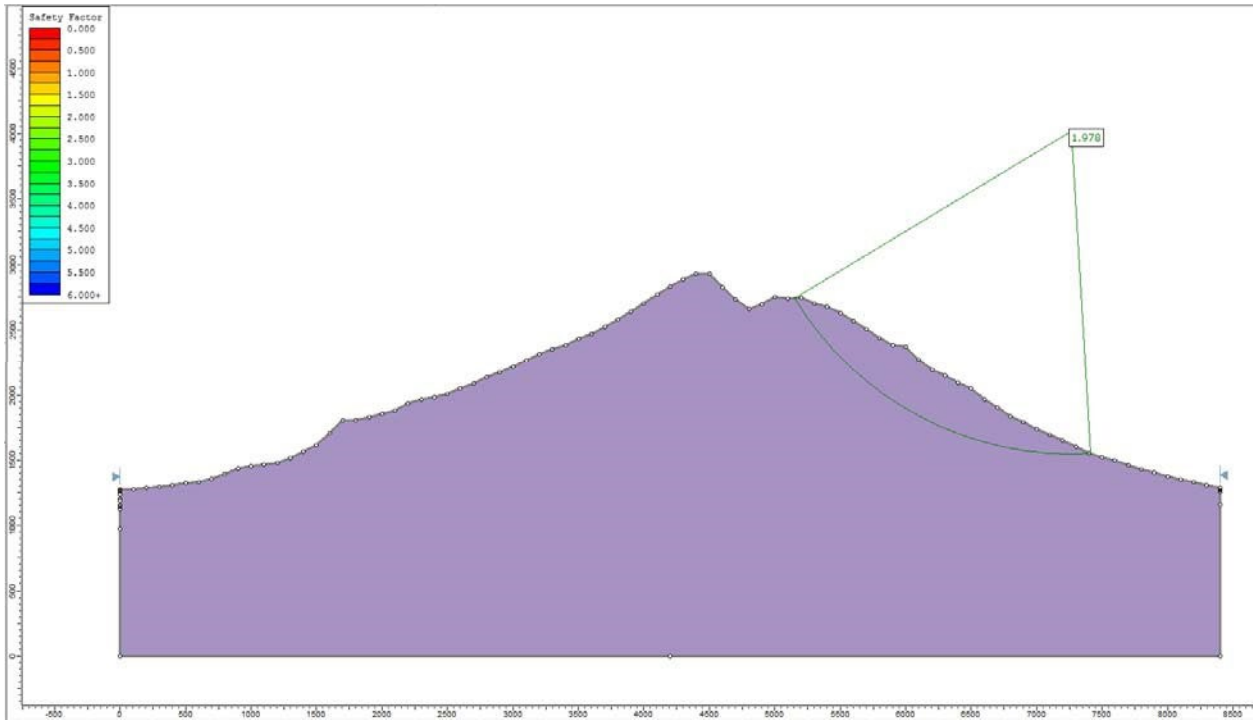

Figure 14.6 – *Slide2* Solution Using the Janbu Method

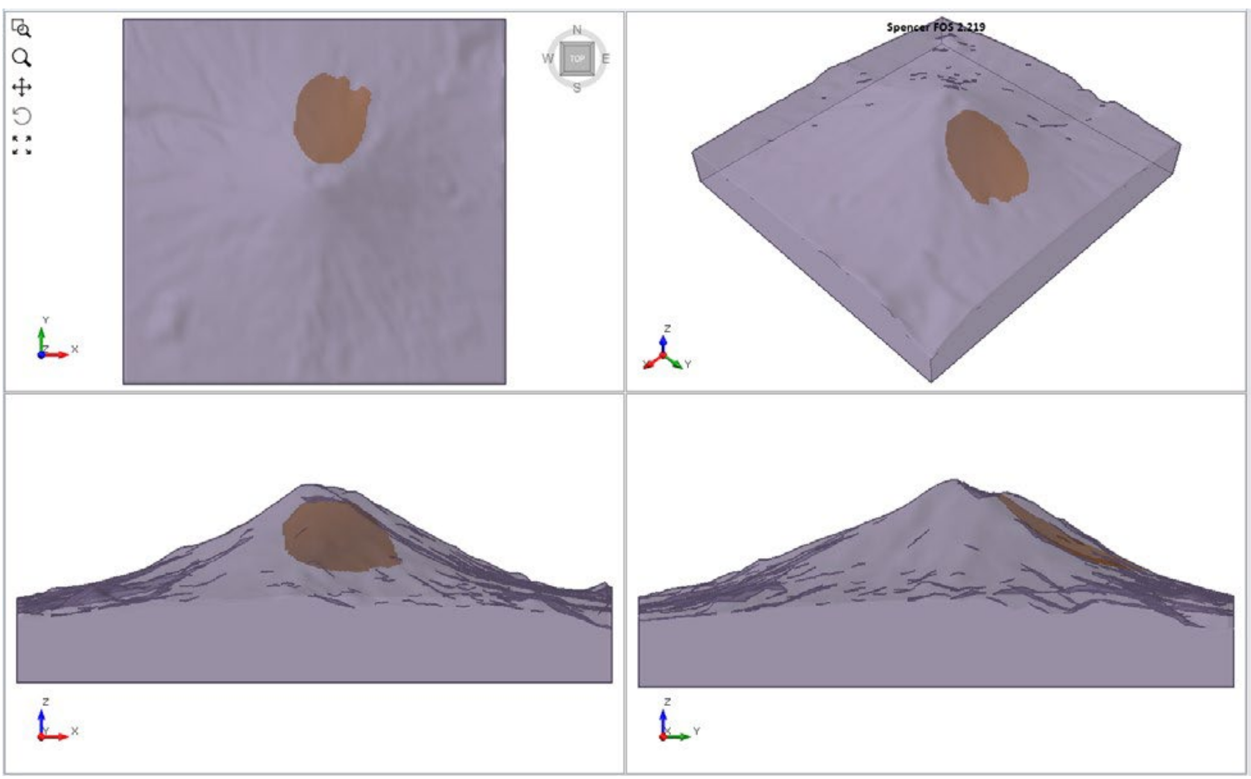

Figure 14.7 – *Slide3* Solution Using the Spencer Method

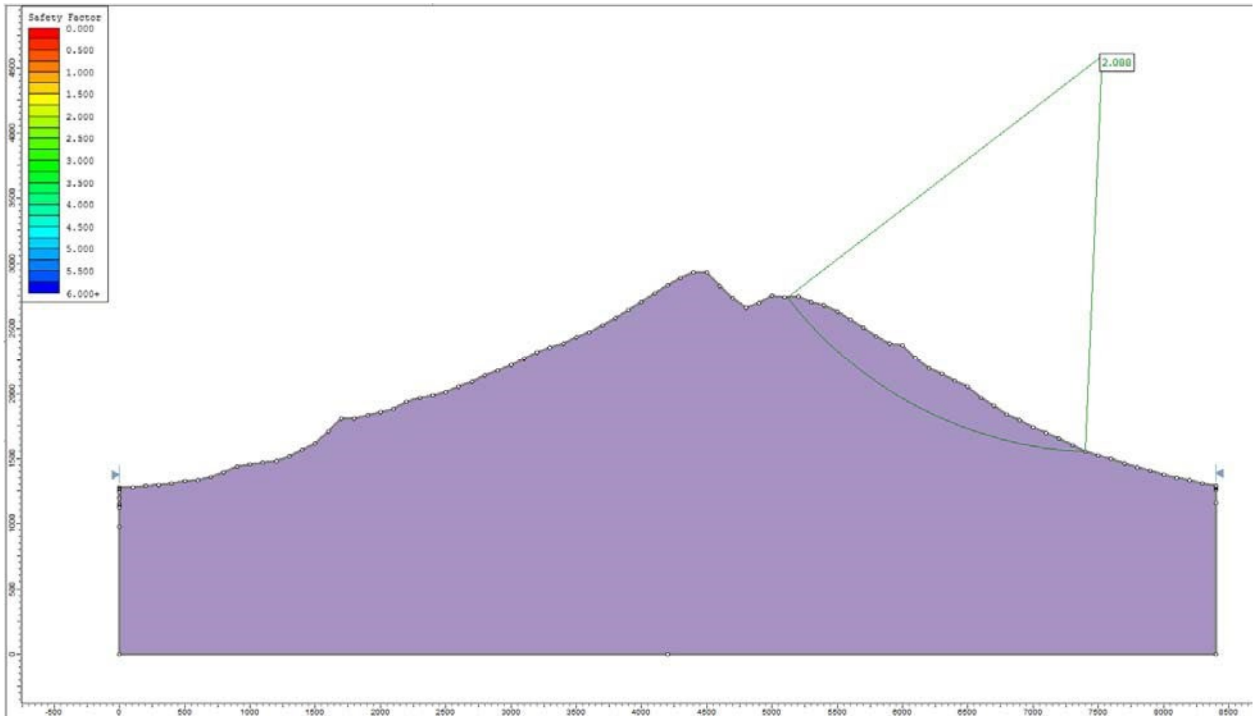

Figure 14.8 – *Slide2* Solution Using the Spencer Method

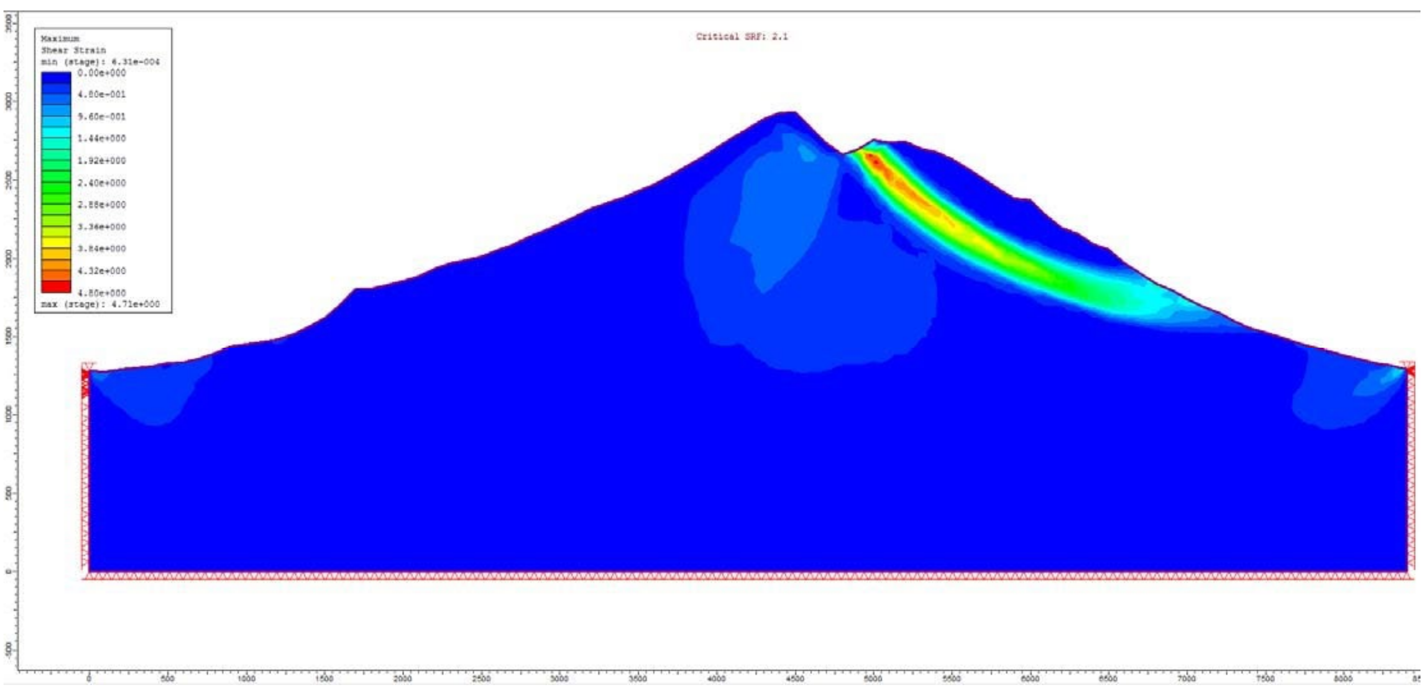

Figure 14.9 – *RS2* Maximum Shear Strain

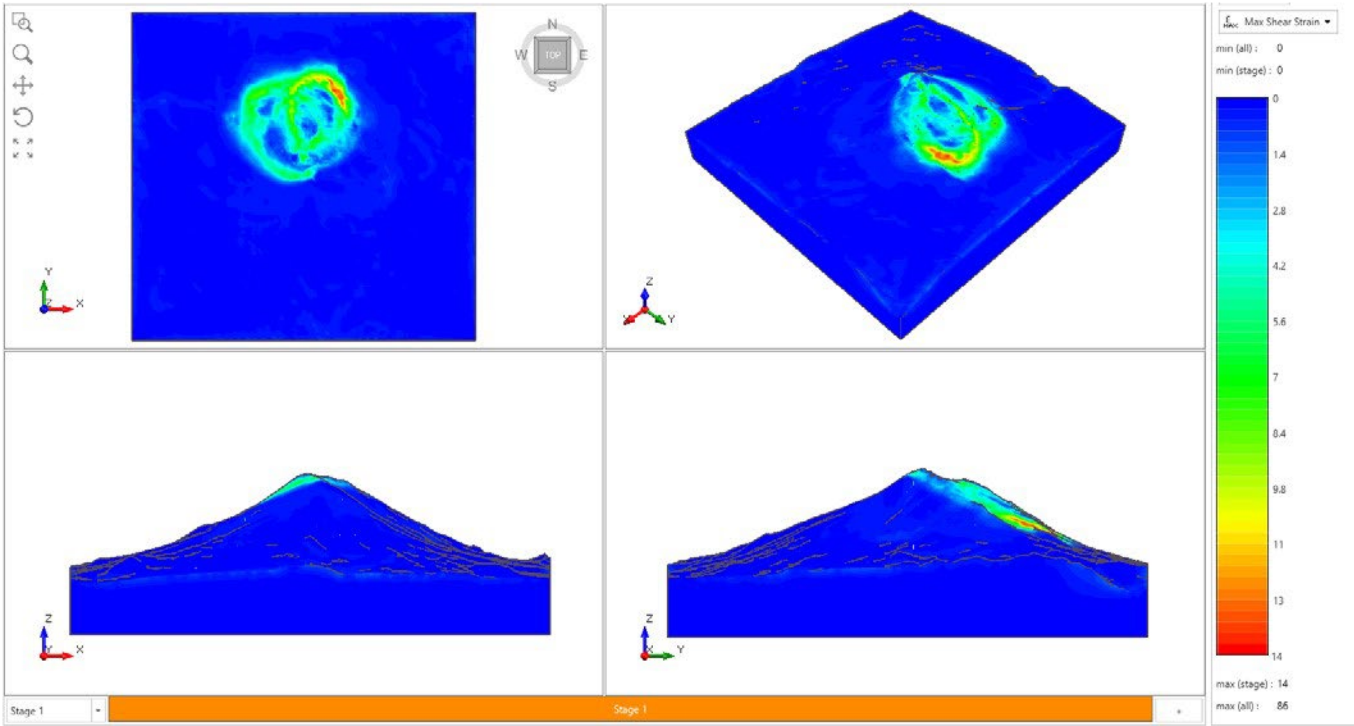

Figure 14.10 – *RS3* Maximum Shear Strain

15. 3D Verification #15

15.1. 3D volcano, homogeneous, Ru coefficient, spherical

15.1.1. Introduction

This example is taken from Reid et al. (2000). A model of Mount St. Helens has been analyzed under several conditions. This is the second condition: pore pressure modeled with Ru.

15.1.2. Problem Description

This example is a 3D homogeneous model with no supports or loading. Pore pressure is uniform and expressed as Ru = 0.3. The material properties can be found in Table 15.1. The spherical slip surface is required. The 2D cross section used to find the safety factor in *Slide2* and *RS2* was in the YZ plane and taken at X = 4300 m.

15.1.3. Properties

Table 15.1: Material Properties

	c′ (kN/m^2)	φ′ (deg.)	γ (kN/m^3)
Rock	1000	40	24

15.1.4. Results

Table 15.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.513	1.461	1.56	1.45
GLE	1.529	1.463		
Janbu	1.429	1.346		
Spencer	1.543	1.465		

Referee: FS 1.59 using the Bishop Method [Reid et al., 2000]

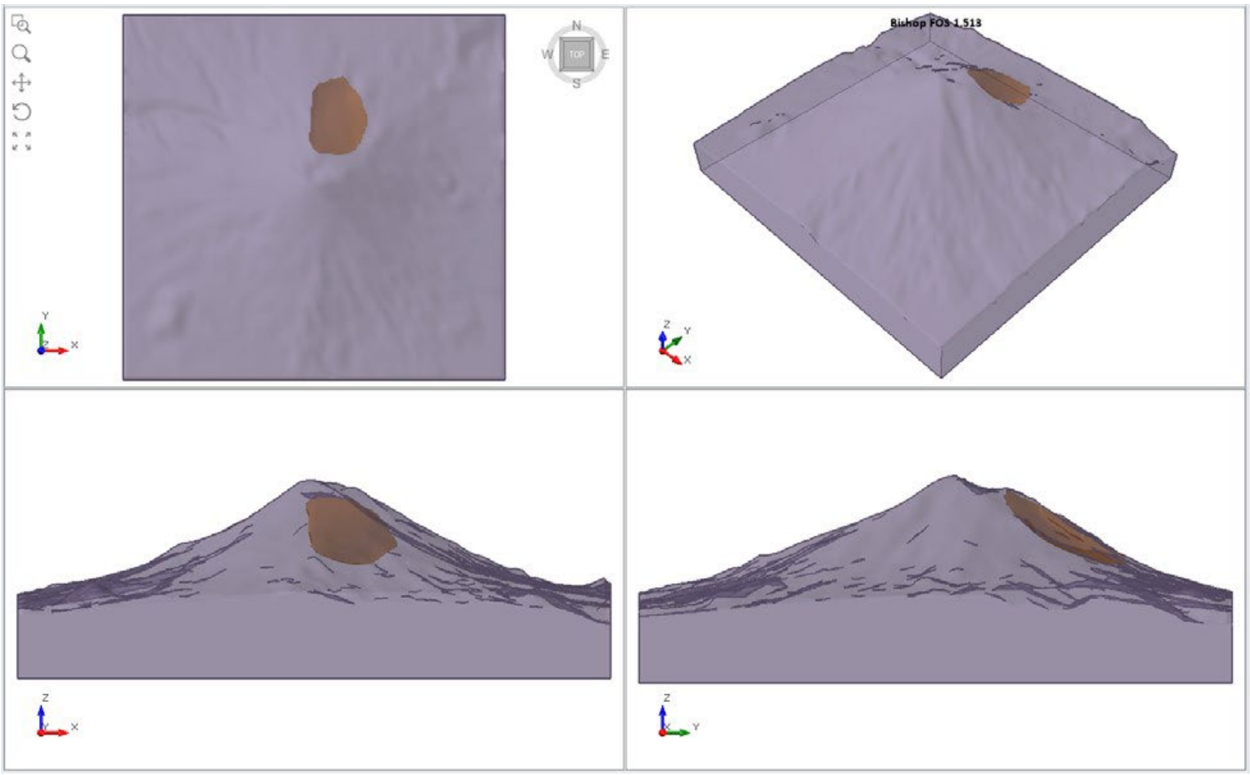

Figure 15.1 – *Slide3* Solution Using the Bishop Method

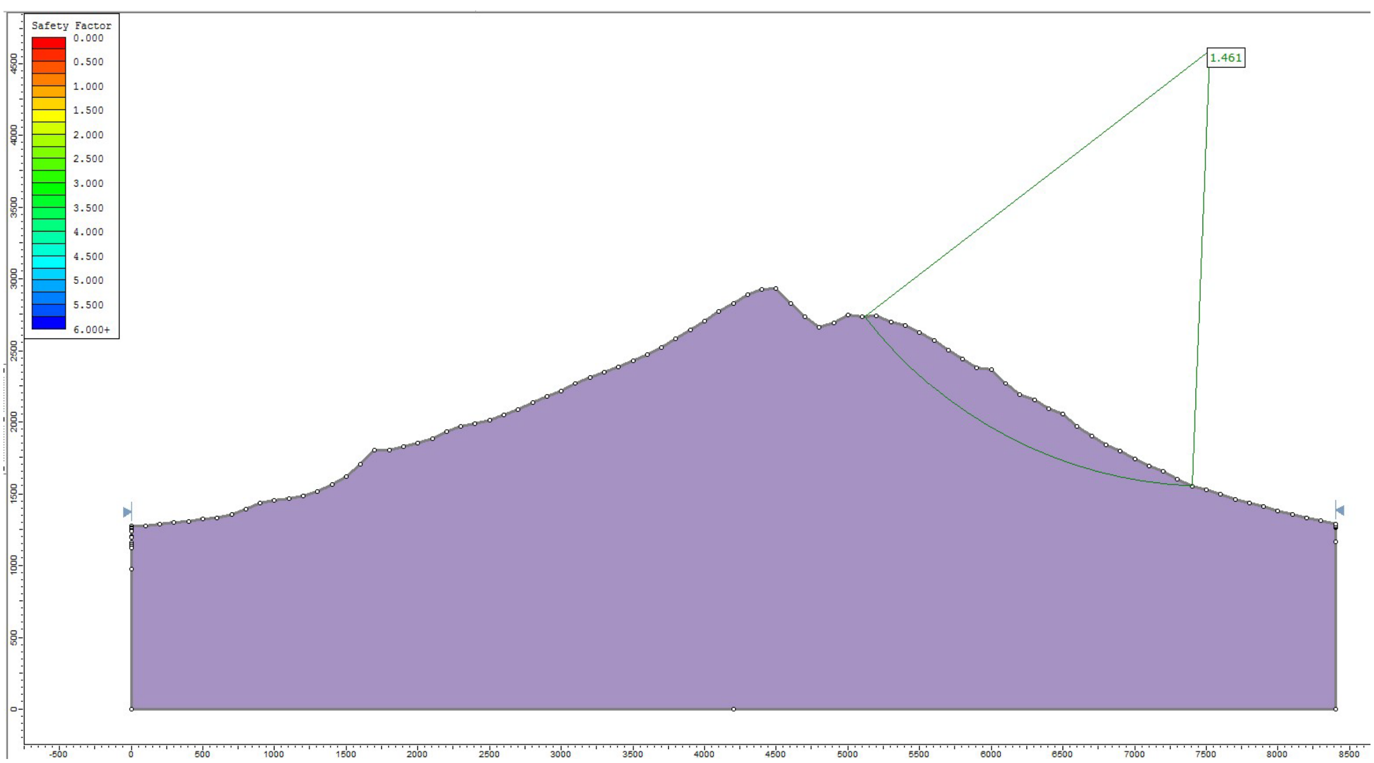

Figure 15.2 – *Slide2* Solution Using the Bishop Method

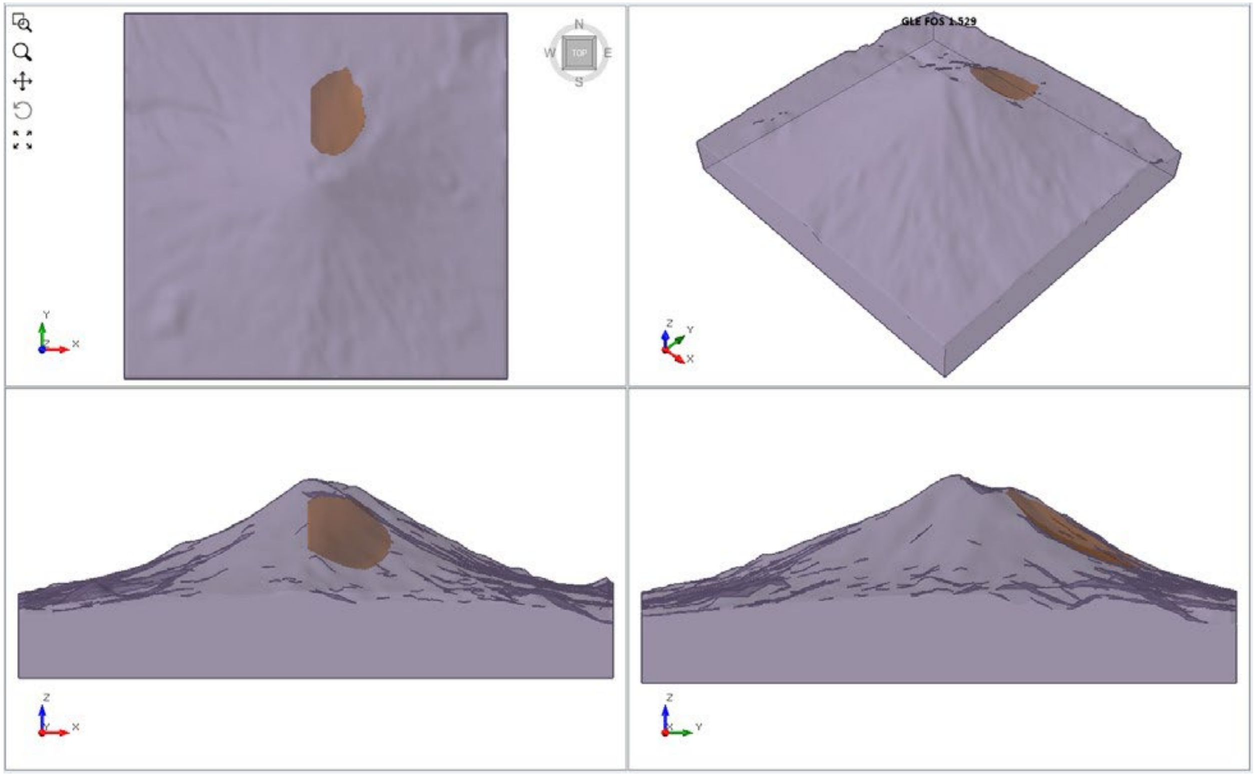

Figure 15.3 – *Slide3* Solution Using the GLE Method

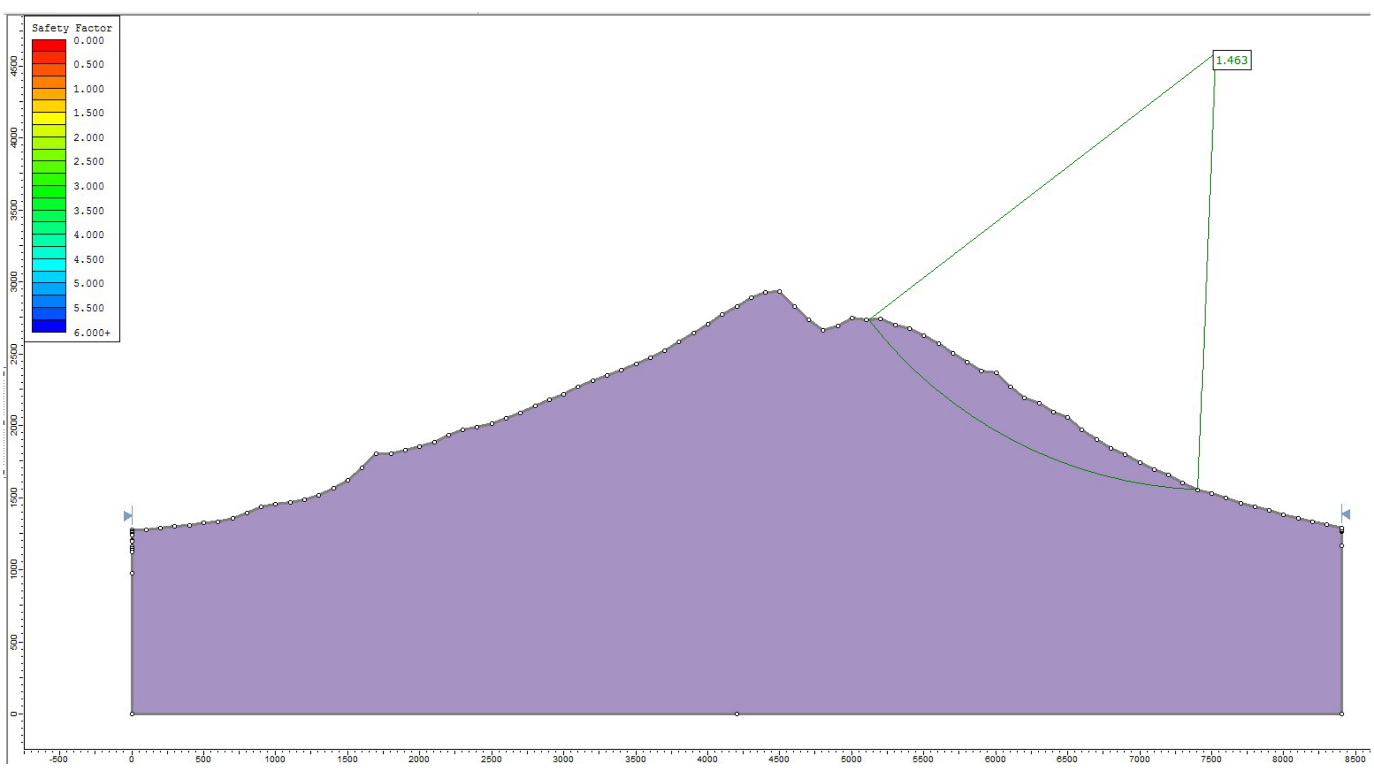

Figure 15.4 – *Slide2* Solution Using the GLE Method

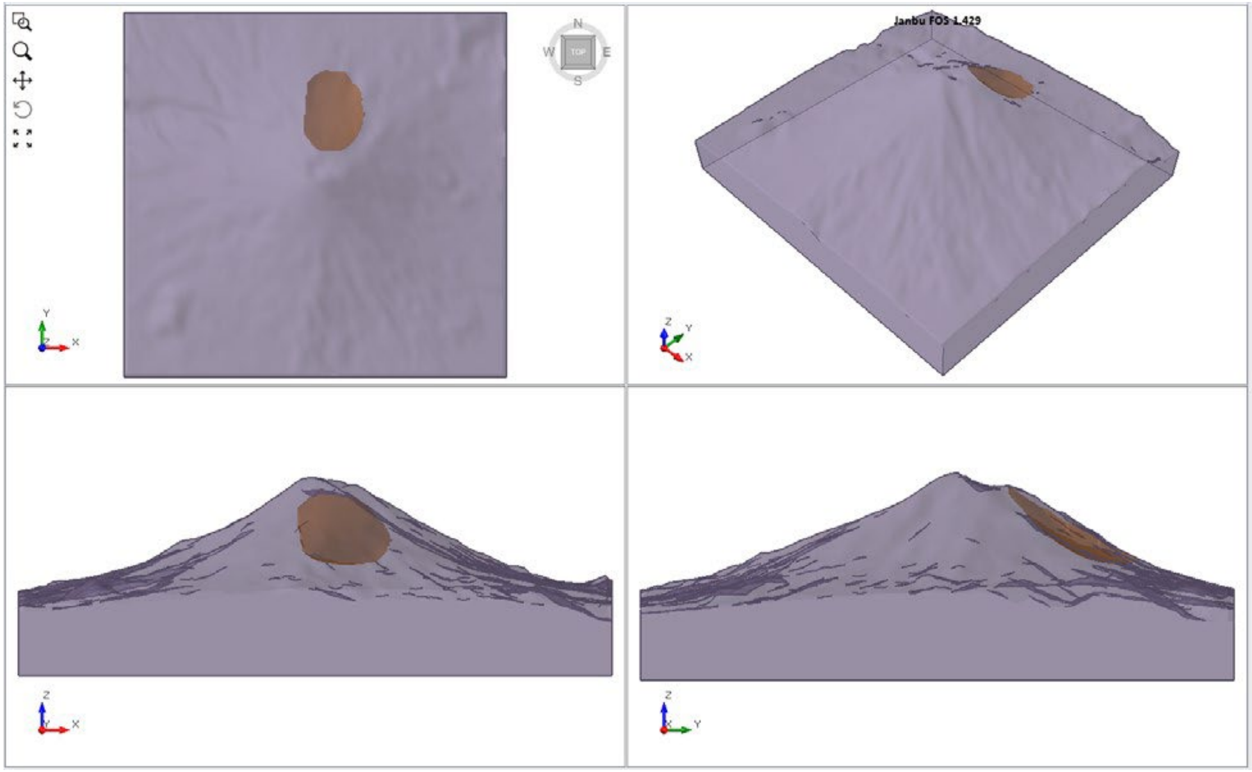

Figure 15.5 – *Slide3* Solution Using the Janbu Method

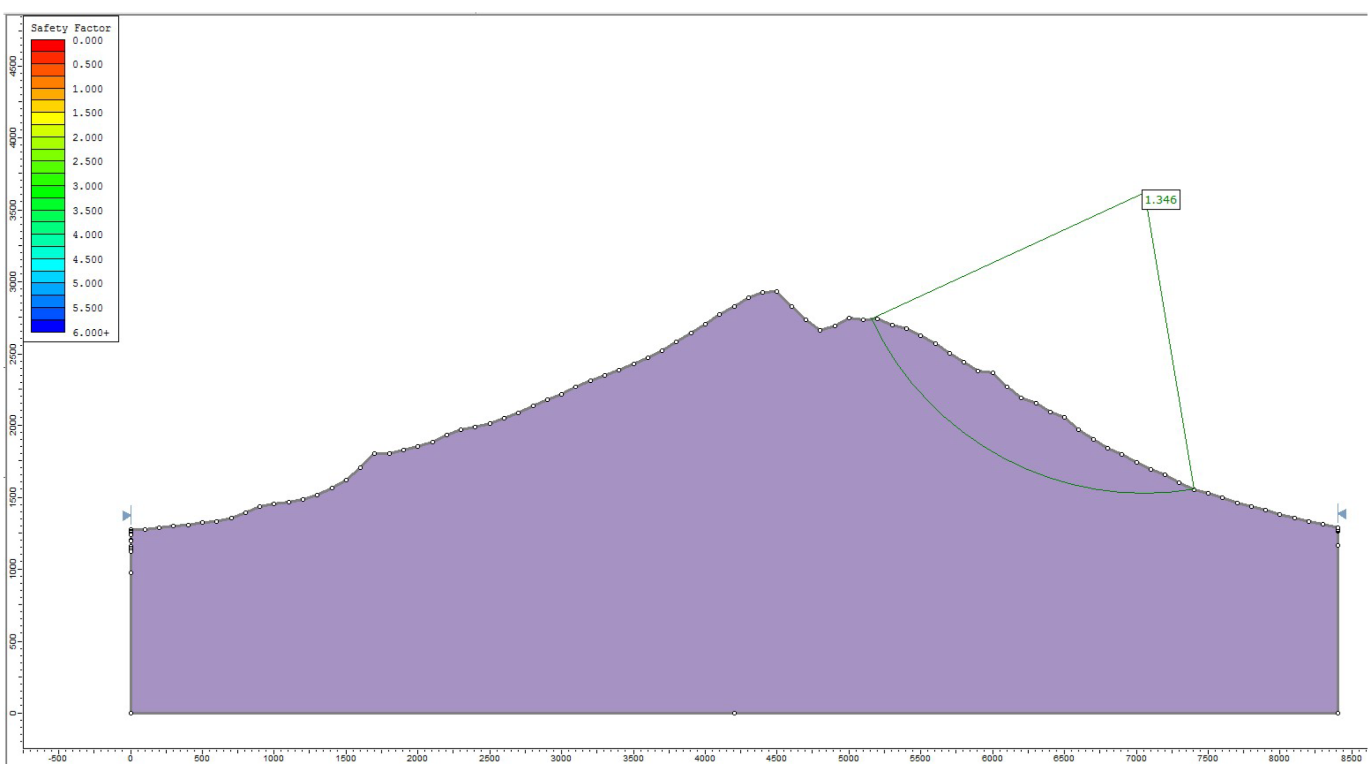

Figure 15.6 – *Slide2* Solution Using the Janbu Method

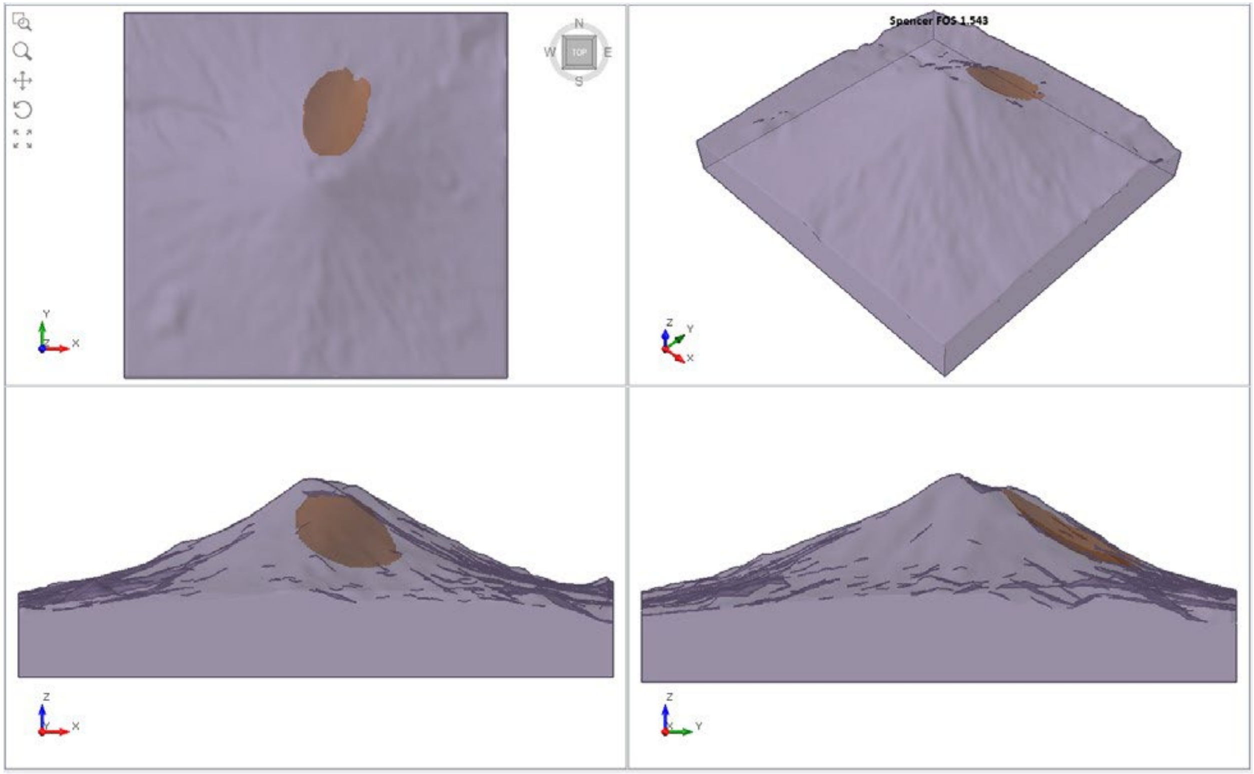

Figure 15.7 – *Slide3* Solution Using the Spencer Method

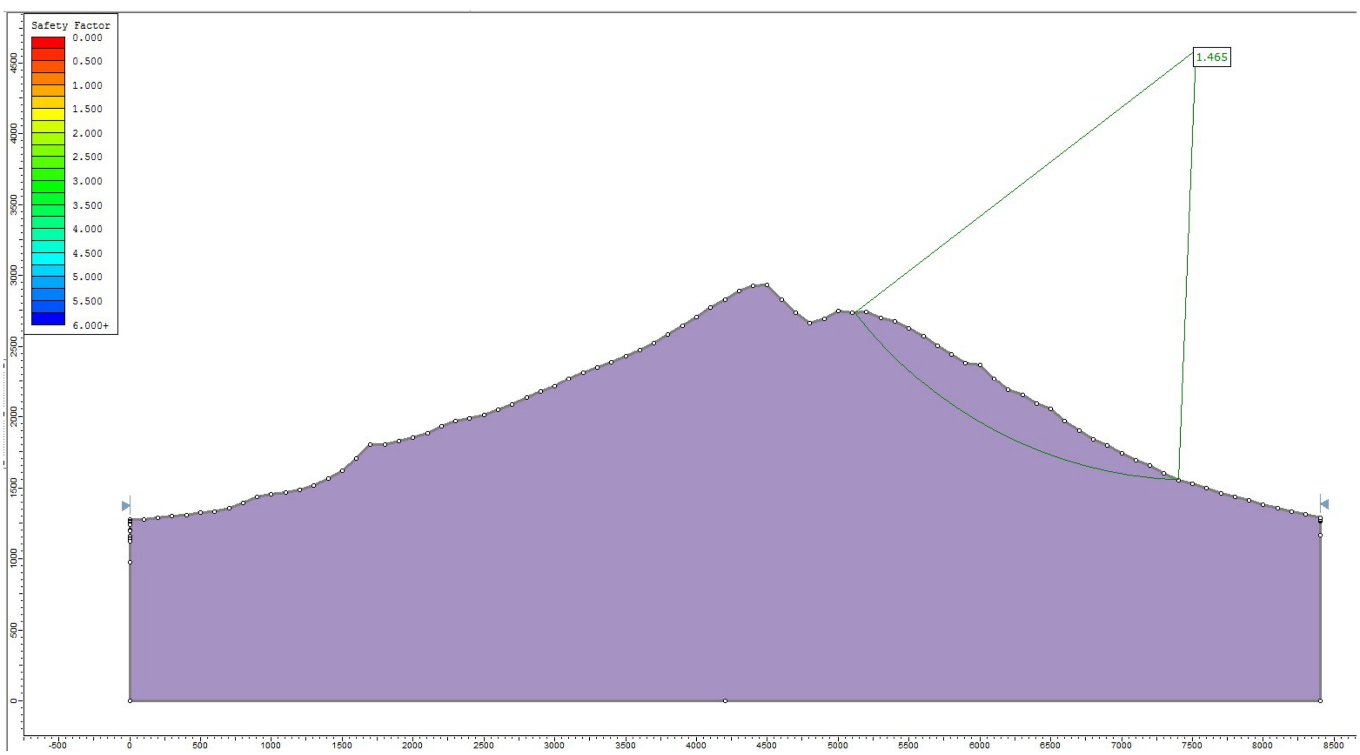

Figure 15.8 – *Slide2* Solution Using the Spencer Method

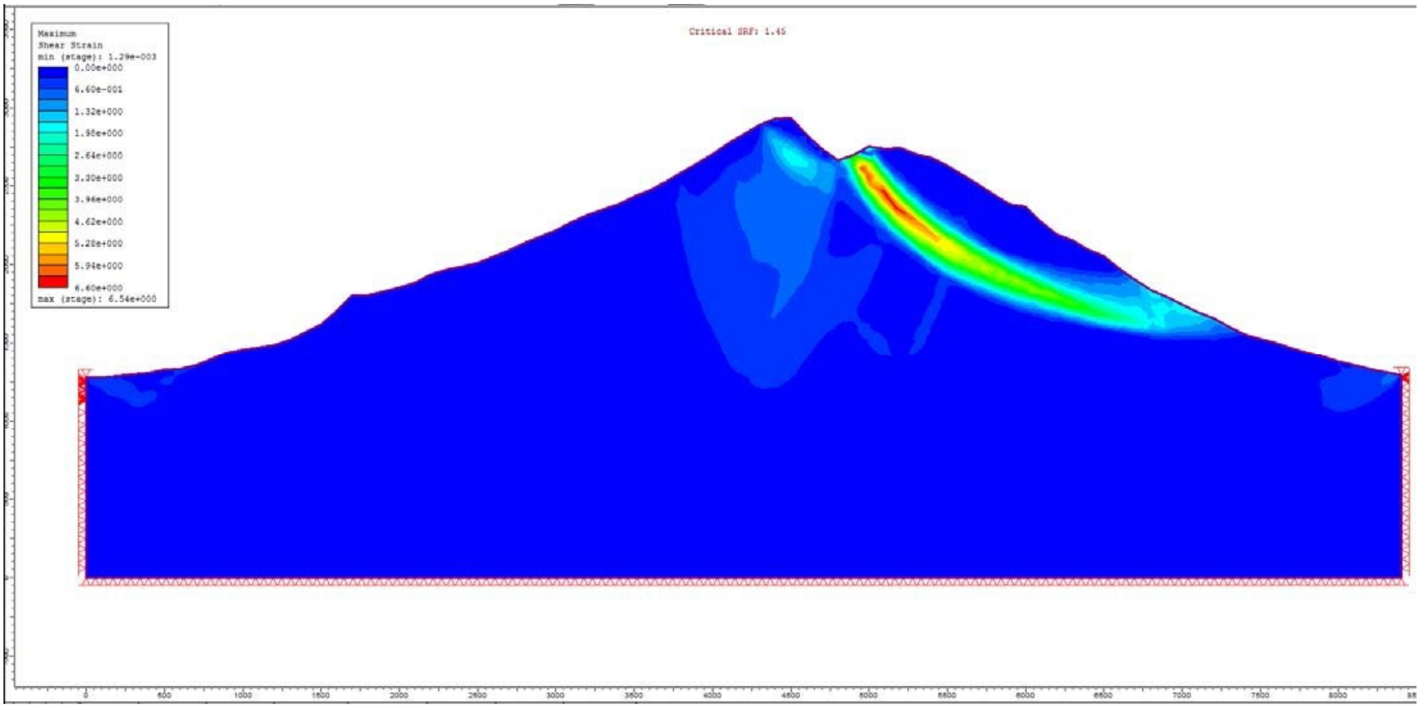

Figure 15.9 – *RS2* Maximum Shear Strain

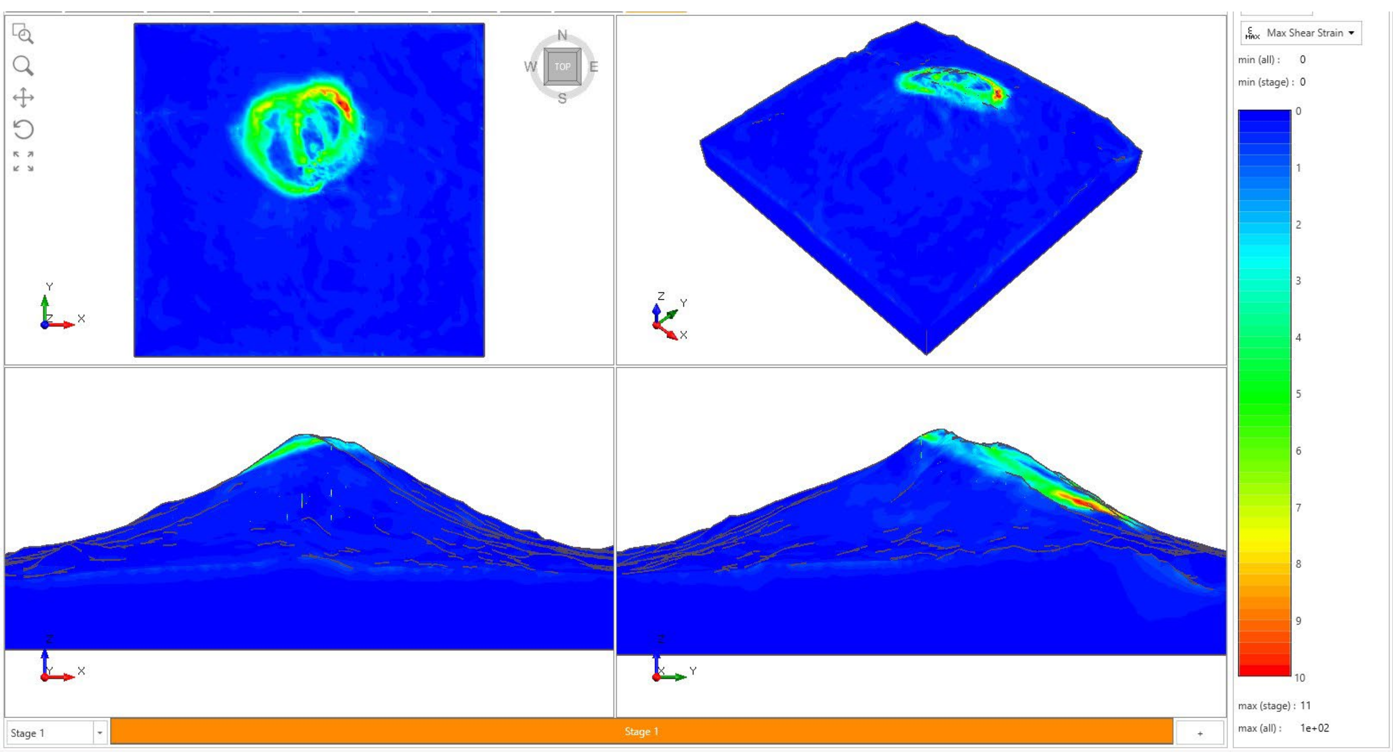

Figure 15.10 – *RS3* Maximum Shear Strain

16. 3D Verification #16

16.1. 3D volcano, homogeneous, seismic loading, spherical

16.1.1. Introduction

This example is taken from Reid et al. (2000). A model of Mount St. Helens has been analyzed under several conditions. This is the third condition: dry with seismic loading.

16.1.2. Problem Description

This example is a 3D homogeneous model with no pore pressures or supports. There is horizontal seismic loading with k = 0.2g. The material properties can be found in Table 16.1. The spherical slip surface is required. The 2D cross section used to find the safety factor in *Slide2* and *RS2* was in the YZ plane and taken at X = 4300 m.

16.1.3. Properties

Table 16.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Rock	1000	40	24

16.1.4. Results

Table 16.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.473</td><td>1.426</td><td rowspan="4">1.54</td><td rowspan="4">1.41</td></tr>
<tr><td>GLE</td><td>1.494</td><td>1.431</td></tr>
<tr><td>Janbu</td><td>1.42</td><td>1.335</td></tr>
<tr><td>Spencer</td><td>1.499</td><td>1.432</td></tr>
</table>

Referee: FS 1.52 using the Bishop Method [Reid et al., 2000]

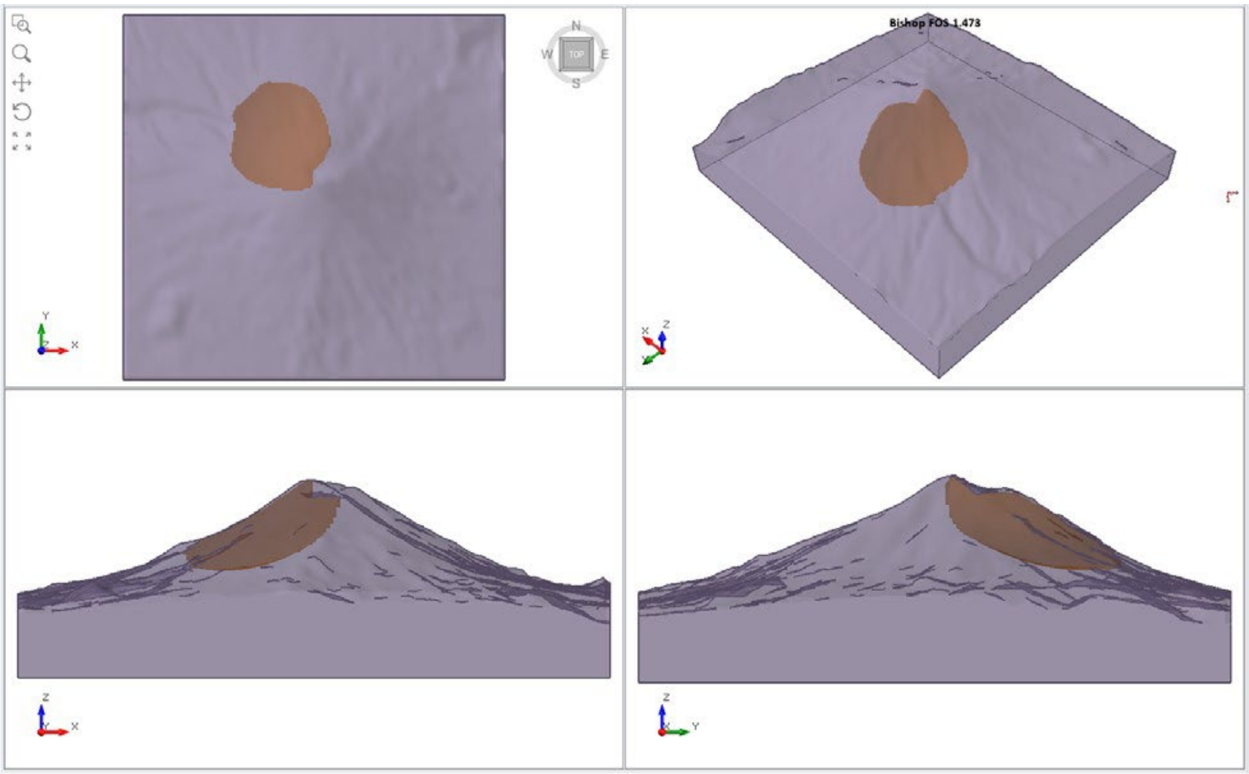

Figure 16.1 – *Slide3* Solution Using the Bishop Method

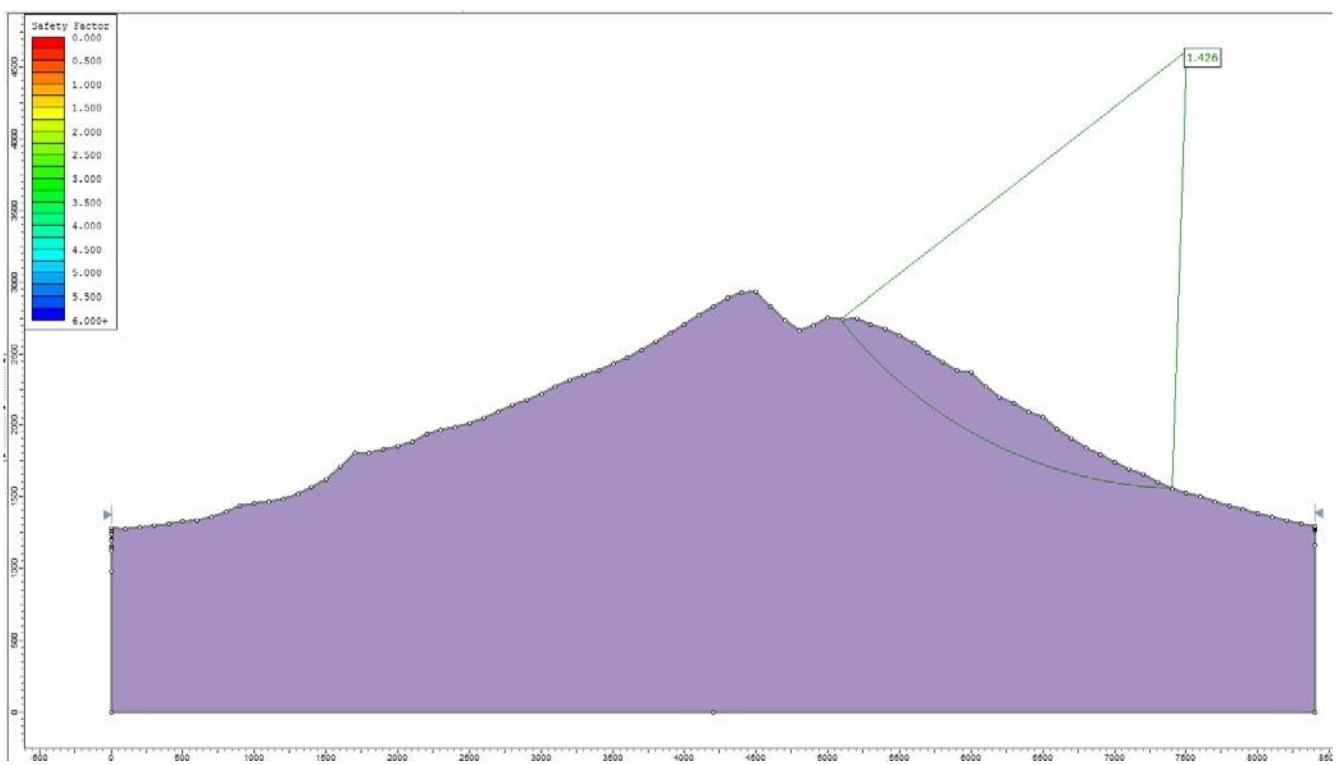

Figure 16.2 – *Slide2* Solution Using the Bishop Method

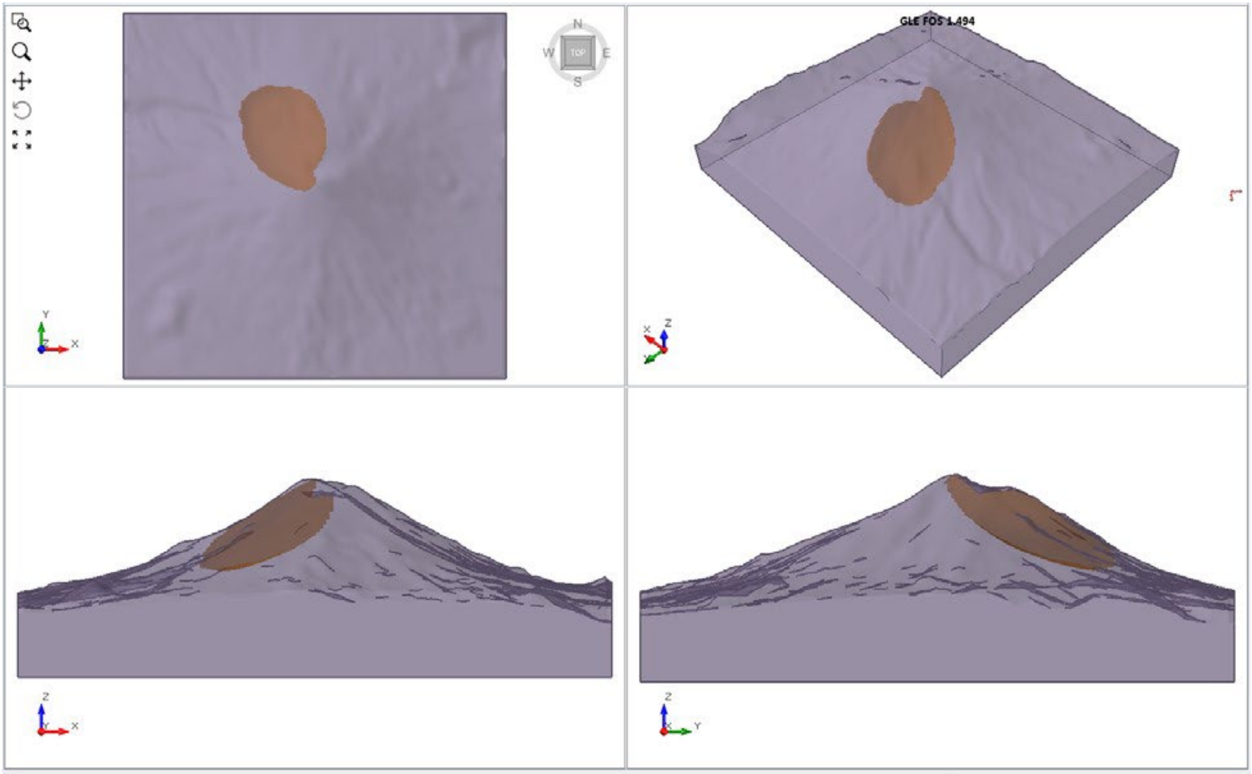

Figure 16.3 – *Slide3* Solution Using the GLE Method

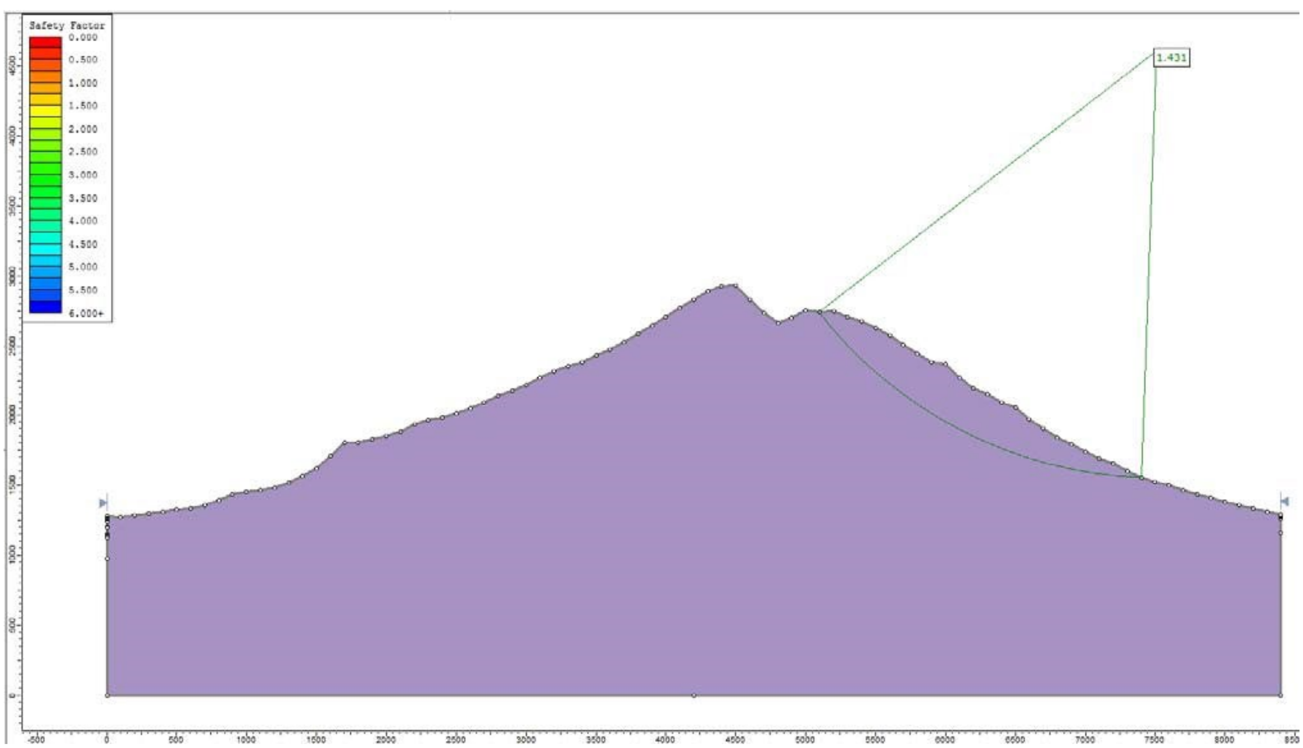

Figure 16.4 – *Slide2* Solution Using the GLE Method

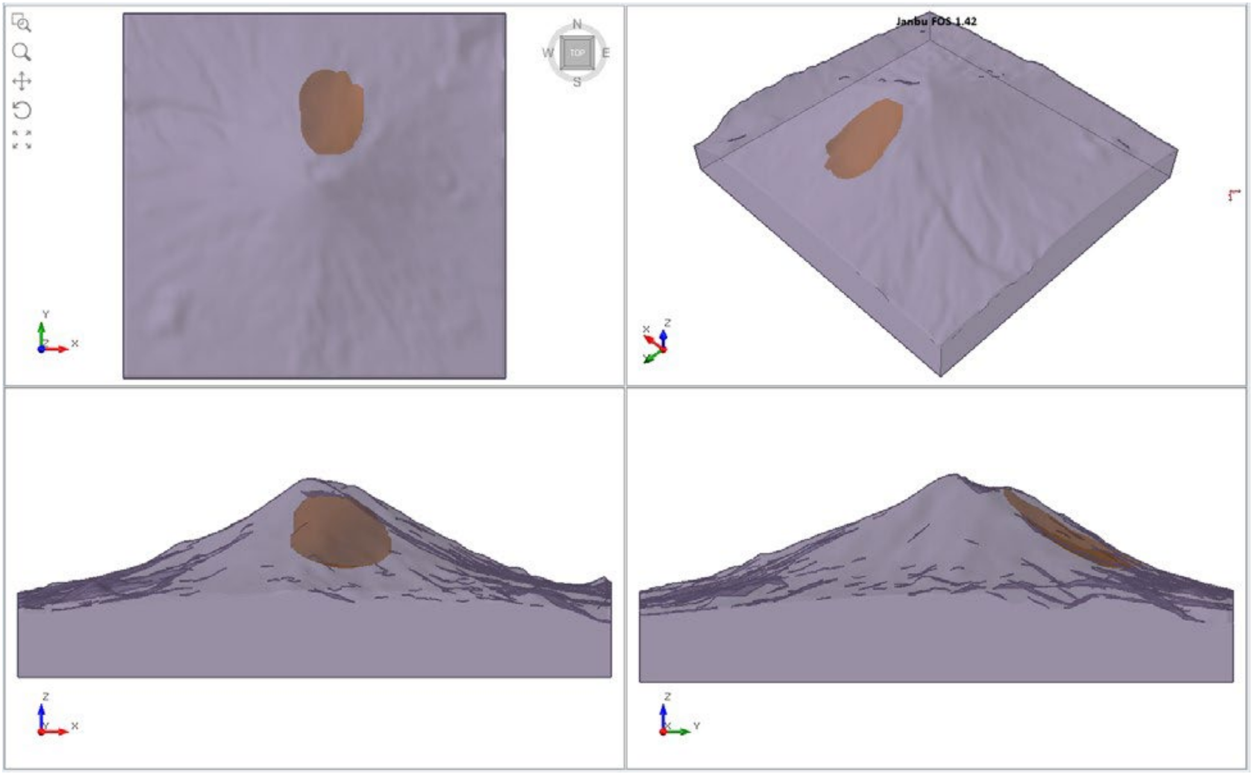

Figure 16.5 – *Slide3* Solution Using the Janbu Method

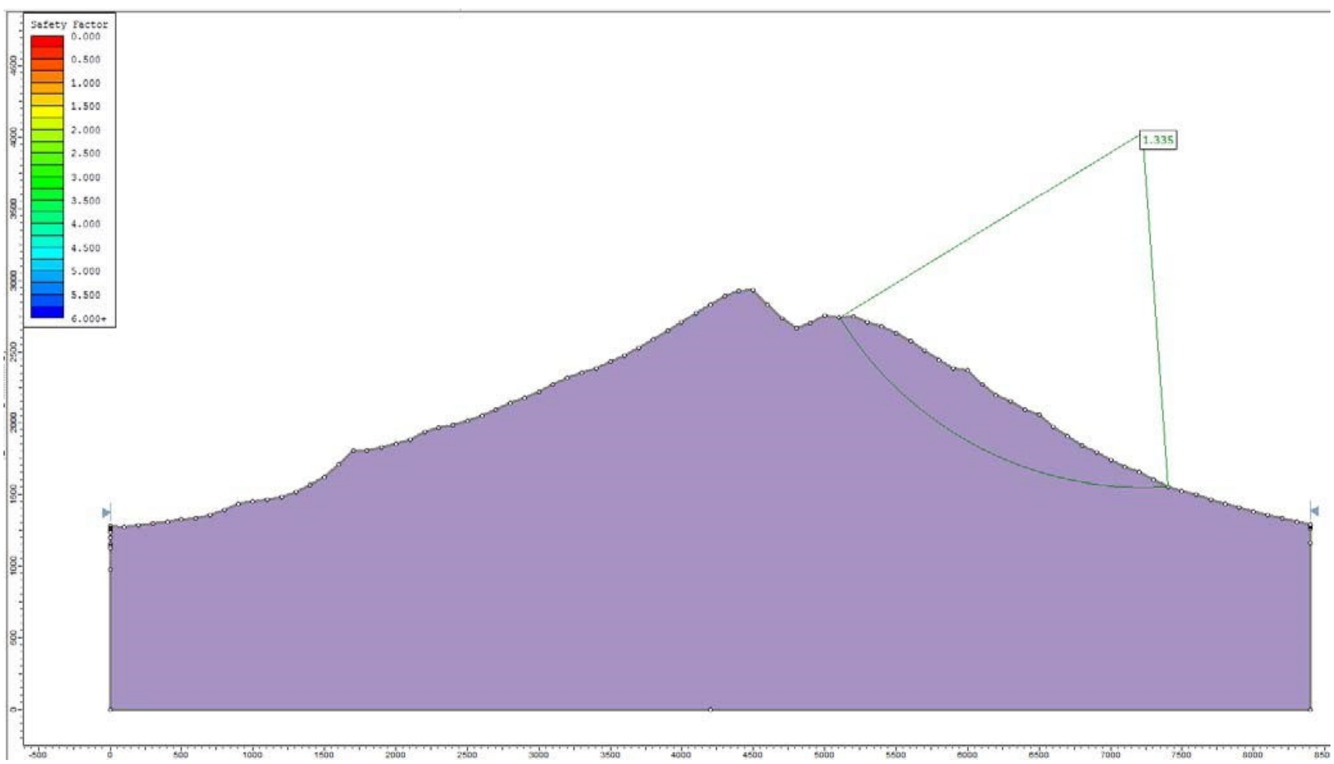

Figure 16.6 – *Slide2* Solution Using the Janbu Method

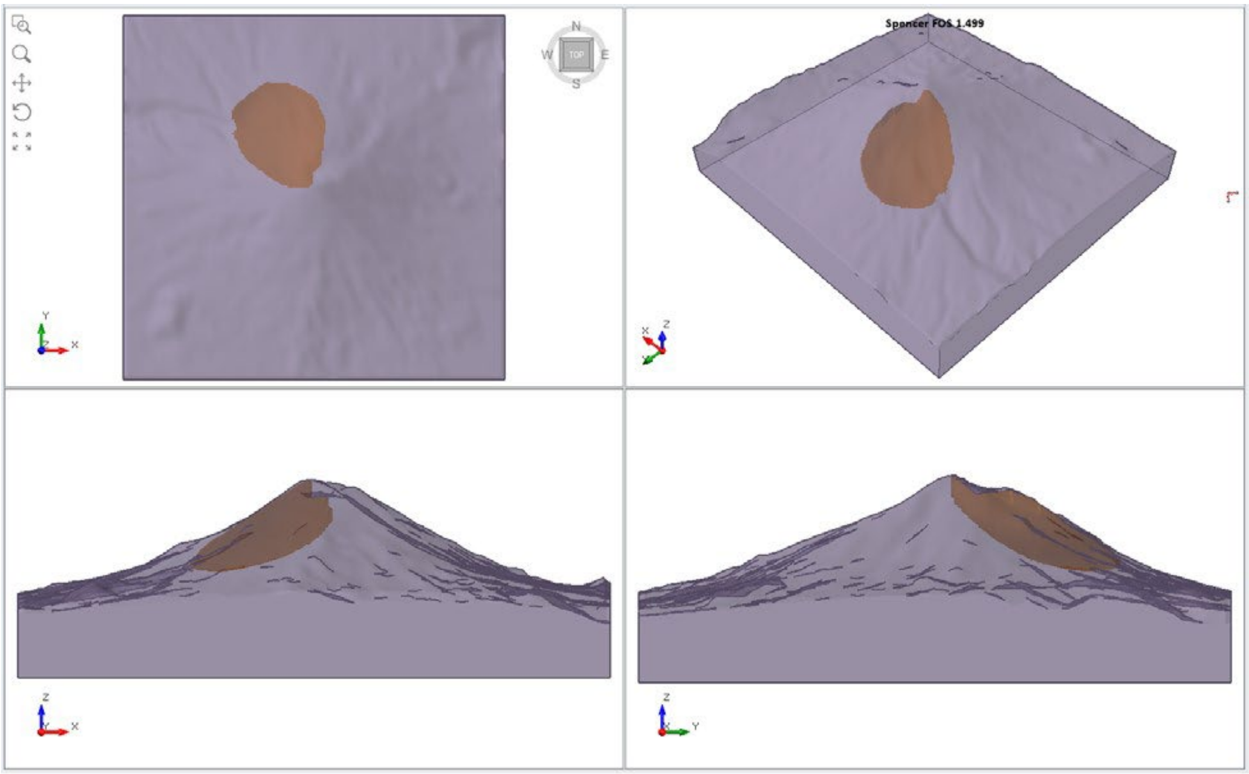

Figure 16.7 – *Slide3* Solution Using the Spencer Method

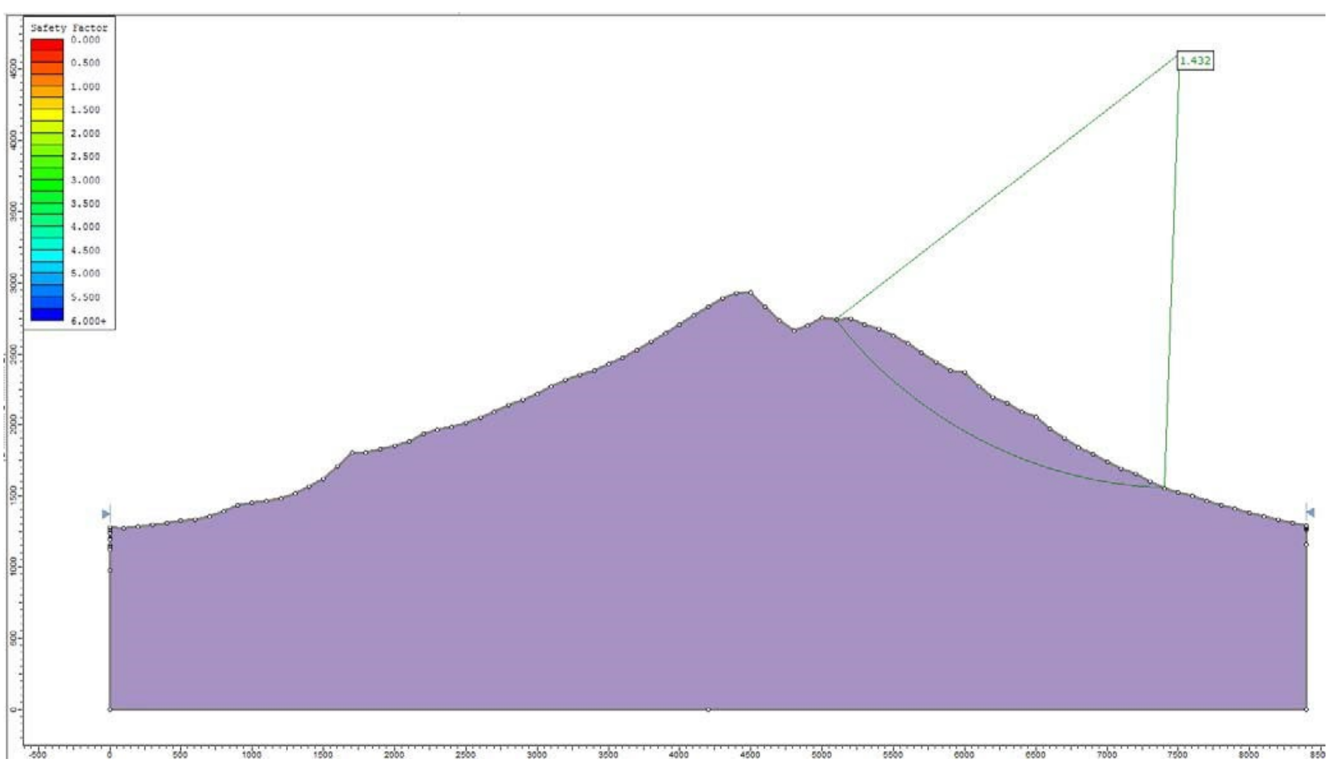

Figure 16.8 – *Slide2* Solution Using the Spencer Method

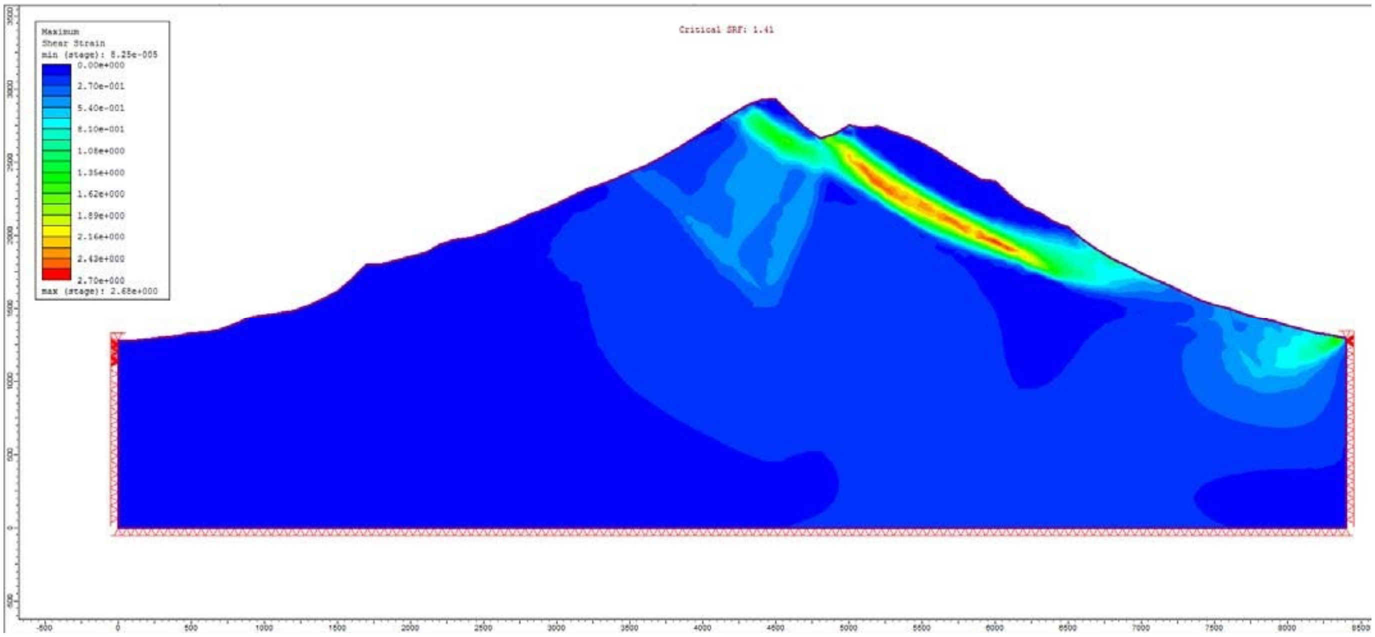

Figure 16.9 – *RS2* Maximum Shear Strain

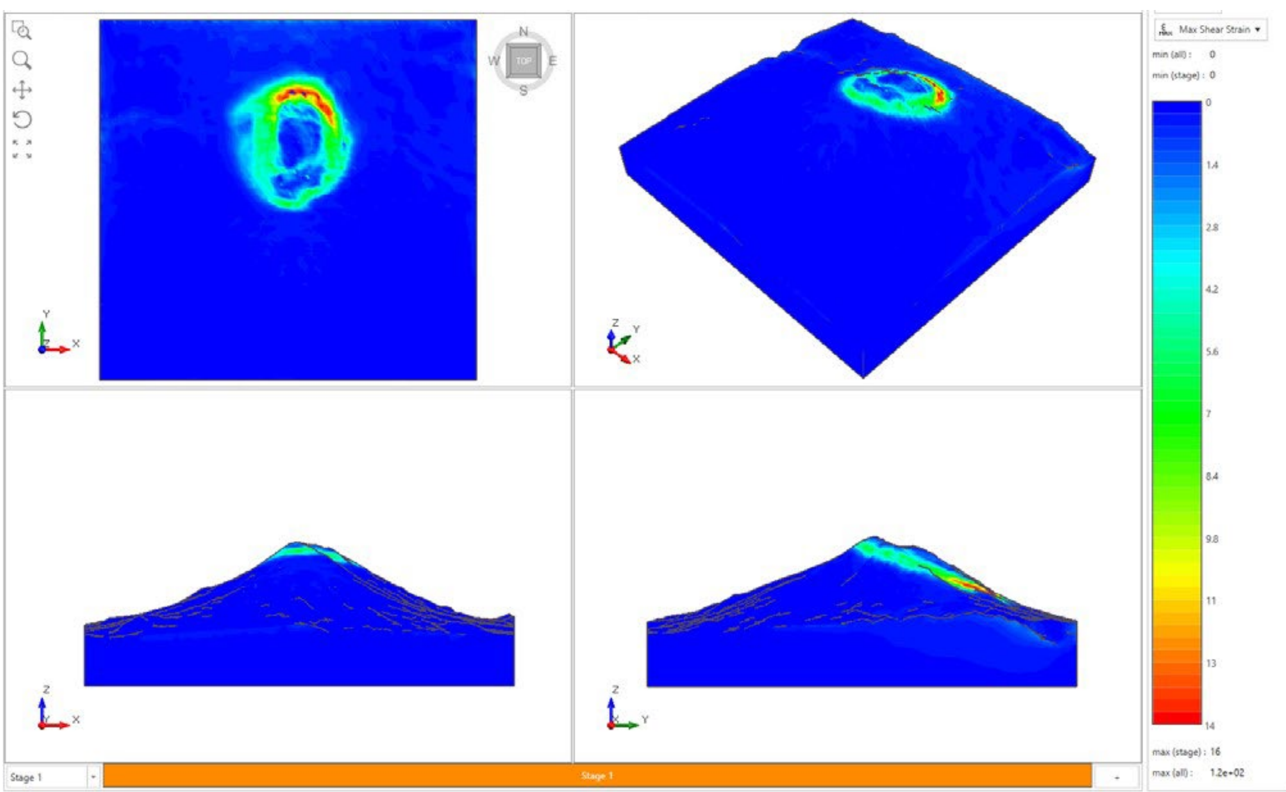

Figure 16.10 – *RS3* Maximum Shear Strain

17. 3D Verification #17

17.1. 3D volcano, homogeneous, Ru coefficient, seismic loading, spherical

17.1.1. Introduction

This example is taken from Reid et al. (2000). A model of Mount St. Helens has been analyzed under several conditions. This is the last condition: the volcano with and Ru coefficient and seismic loading.

17.1.2. Problem Description

This example is a 3D homogeneous model. There is horizontal seismic loading with k = 0.2g. Pore pressure is modeled as Ru = 0.3. The material properties can be found in Table 80.1. The spherical slip surface is required. The 2D cross section used to find the safety factor in *Slide2* and *RS2* was in the YZ plane and taken at X = 4300 m.

17.1.3. Properties

Table 17.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Rock	1000	40	24

17.1.4. Results

Table 17.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.004</td><td>0.964</td><td rowspan="4">1.05</td><td rowspan="4">0.92</td></tr>
<tr><td>GLE</td><td>1.053</td><td>0.983</td></tr>
<tr><td>Janbu</td><td>0.933</td><td>0.881</td></tr>
<tr><td>Spencer</td><td>1.034</td><td>0.984</td></tr>
</table>

Referee: FS 1.05 using the Bishop Method [Reid et al., 2000]

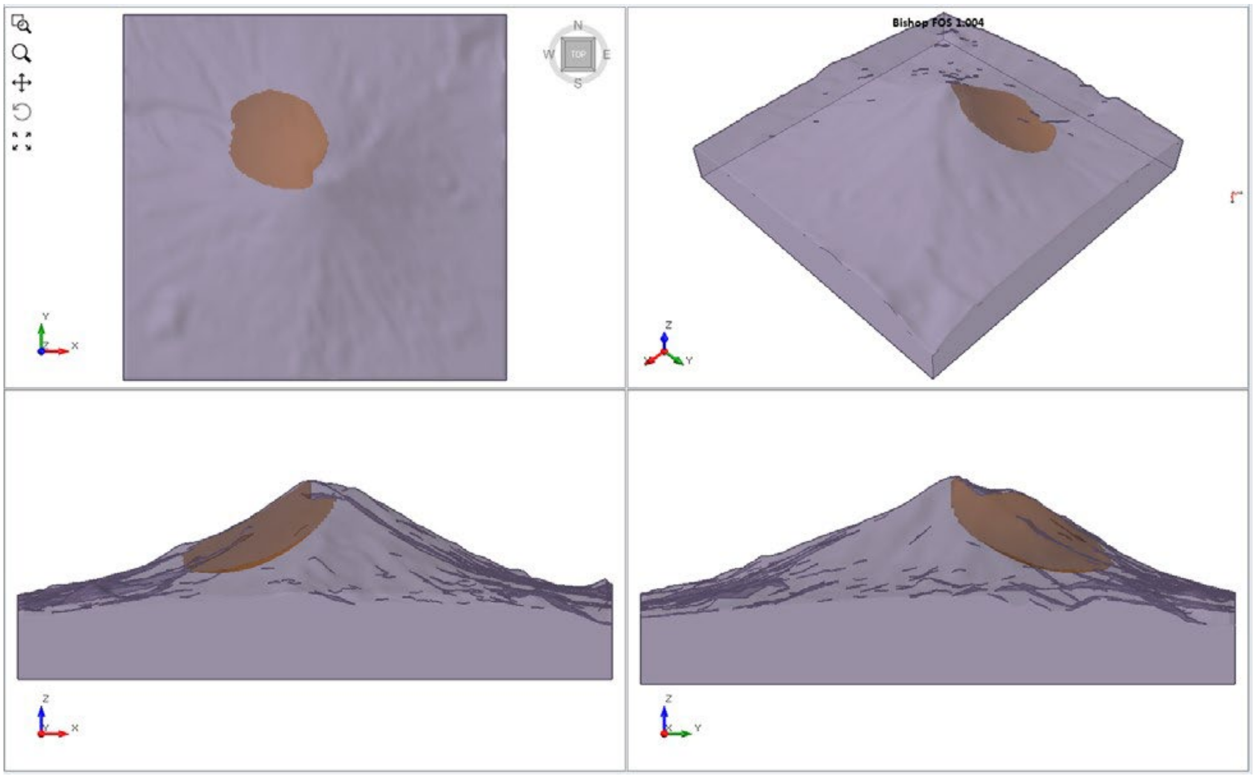

Figure 17.1 – *Slide3* Solution Using the Bishop Method

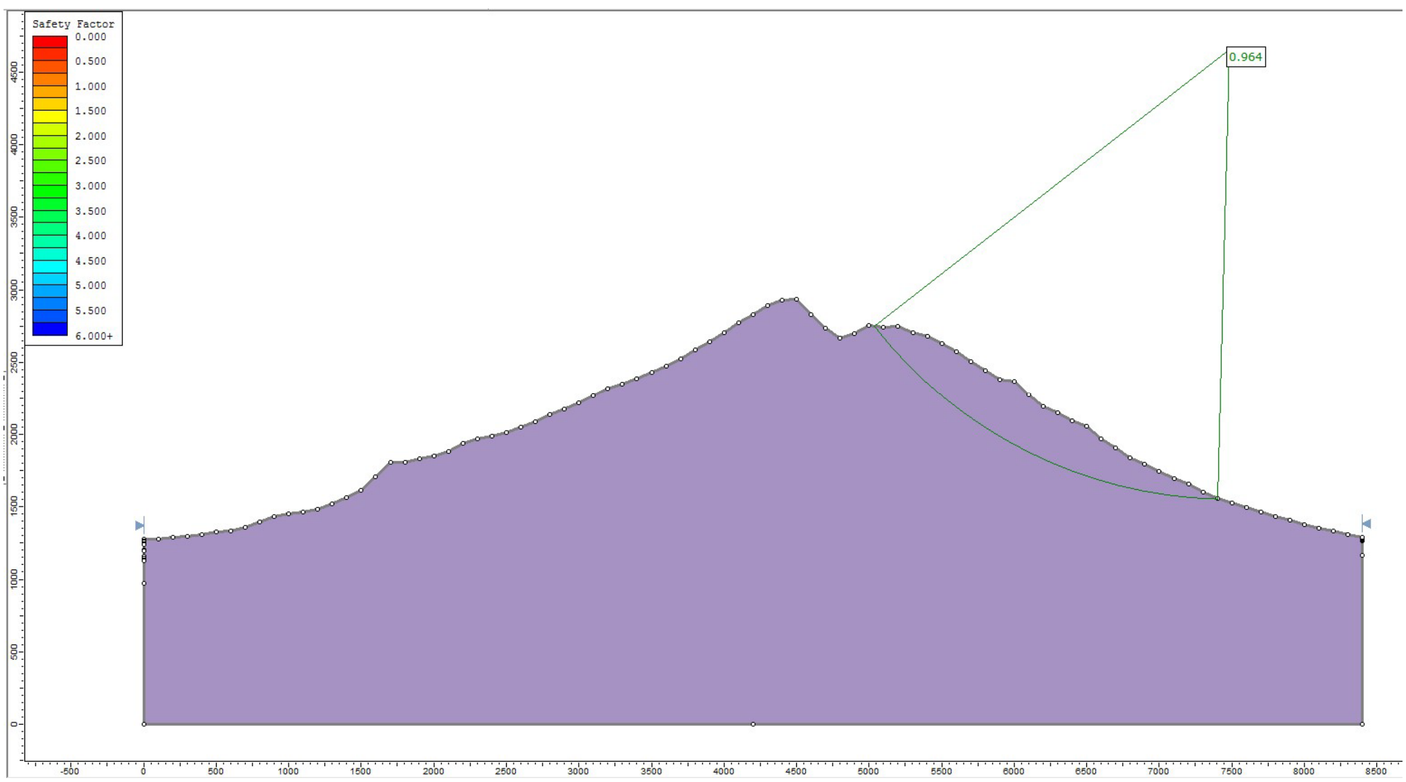

Figure 17.2 – *Slide2* Solution Using the Bishop Method

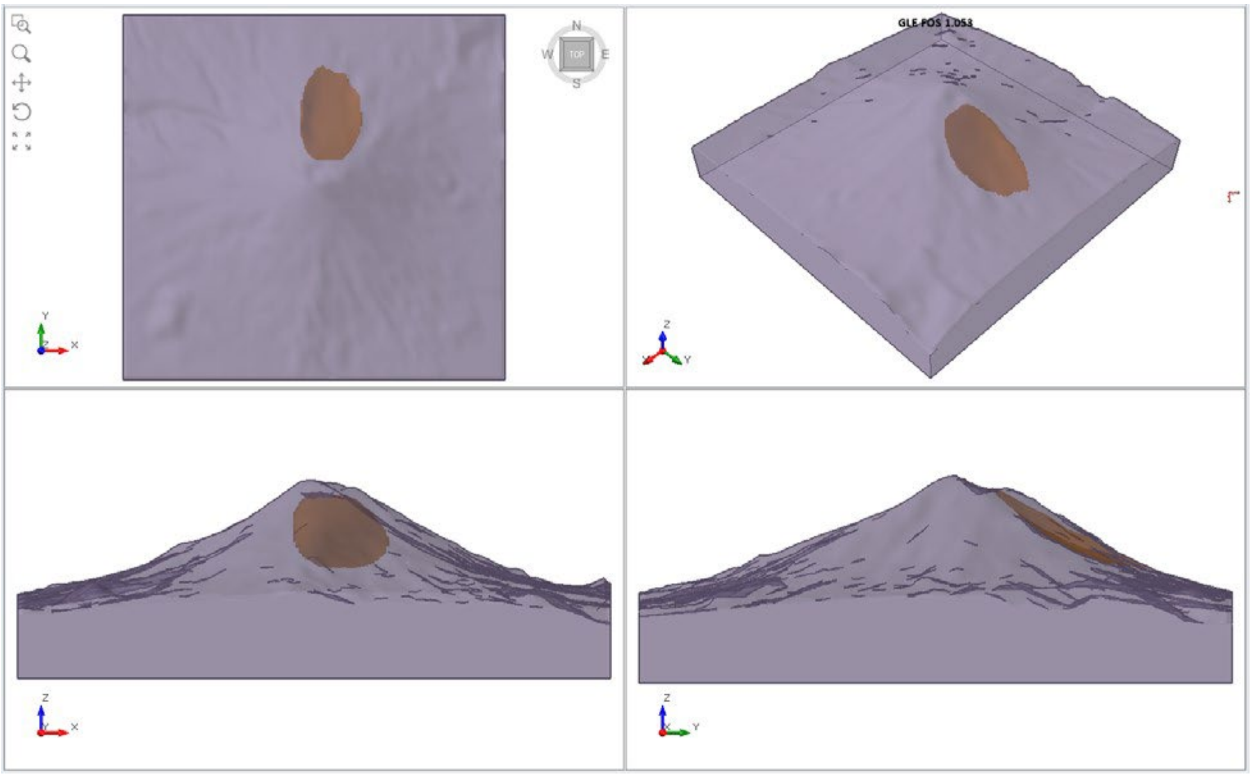

Figure 17.3 – *Slide3* Solution Using the GLE Method

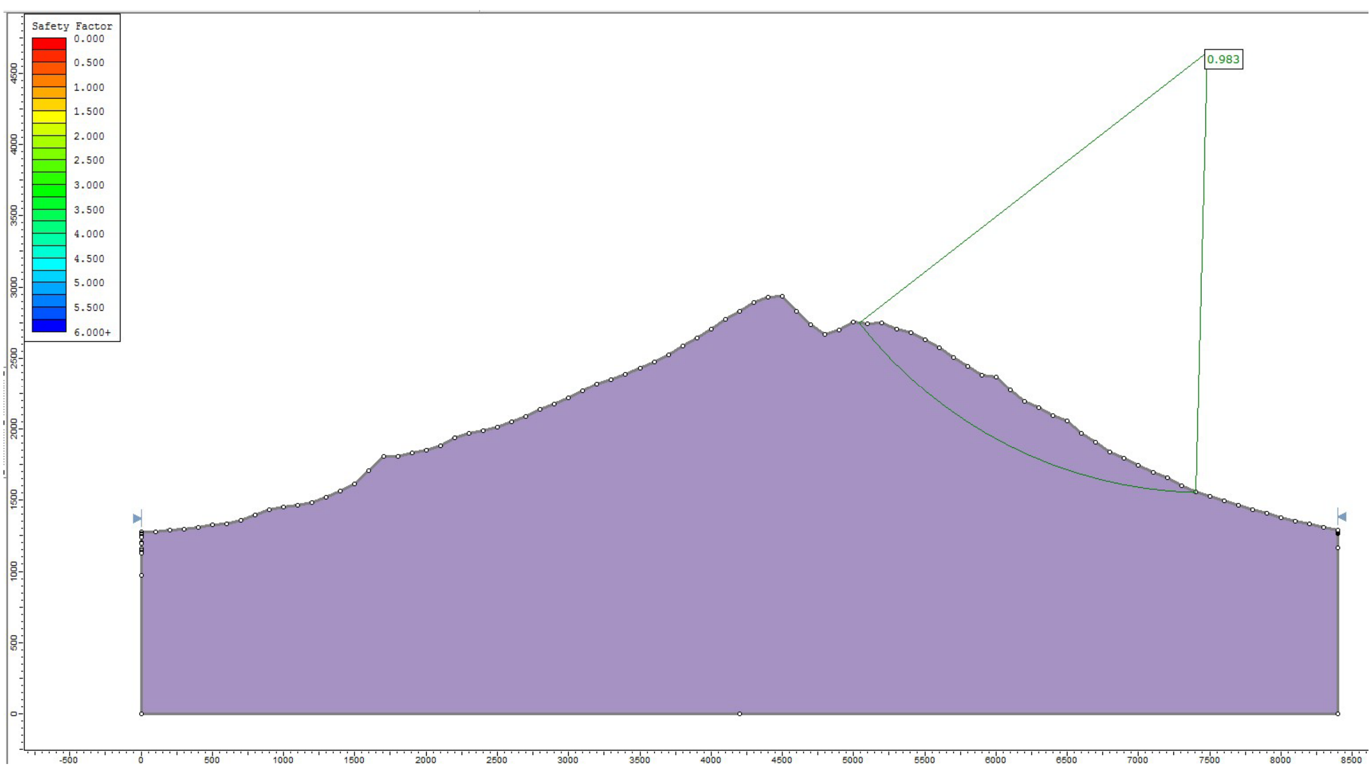

Figure 17.4 – *Slide2* Solution Using the GLE Method

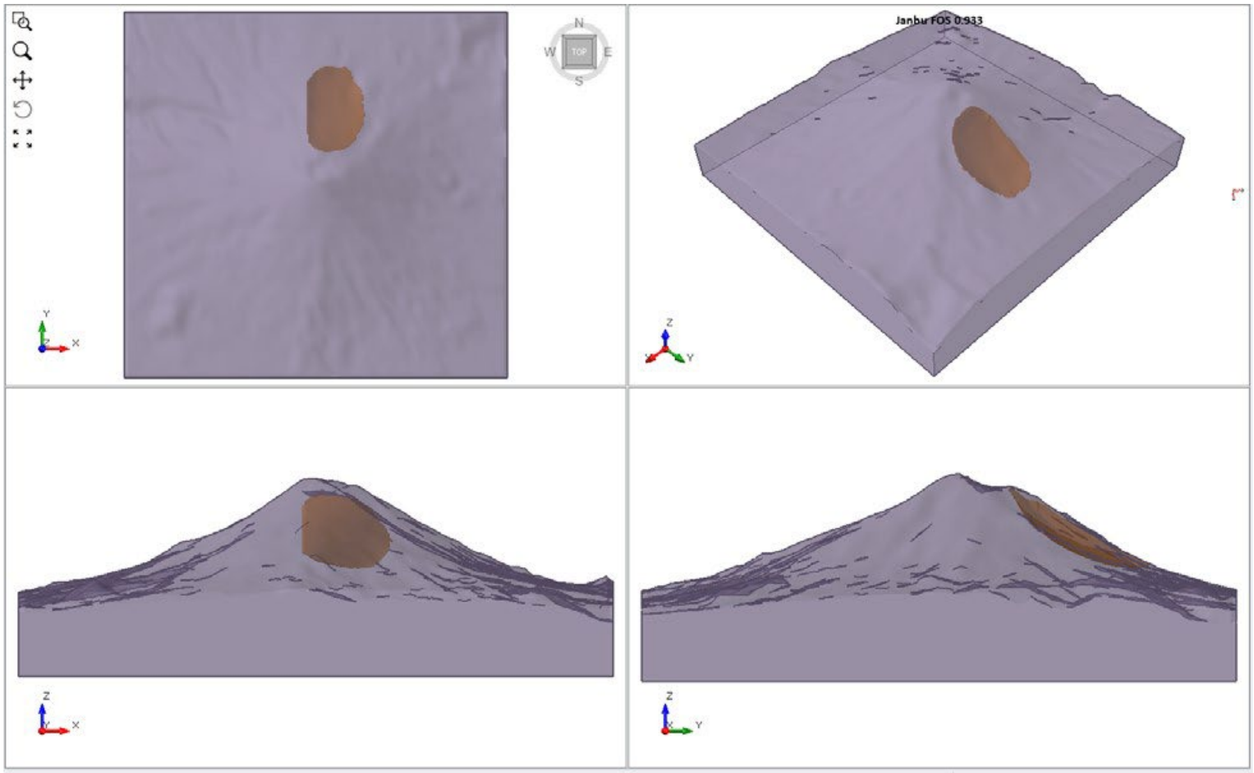

Figure 17.5 – *Slide3* Solution Using the Janbu Method

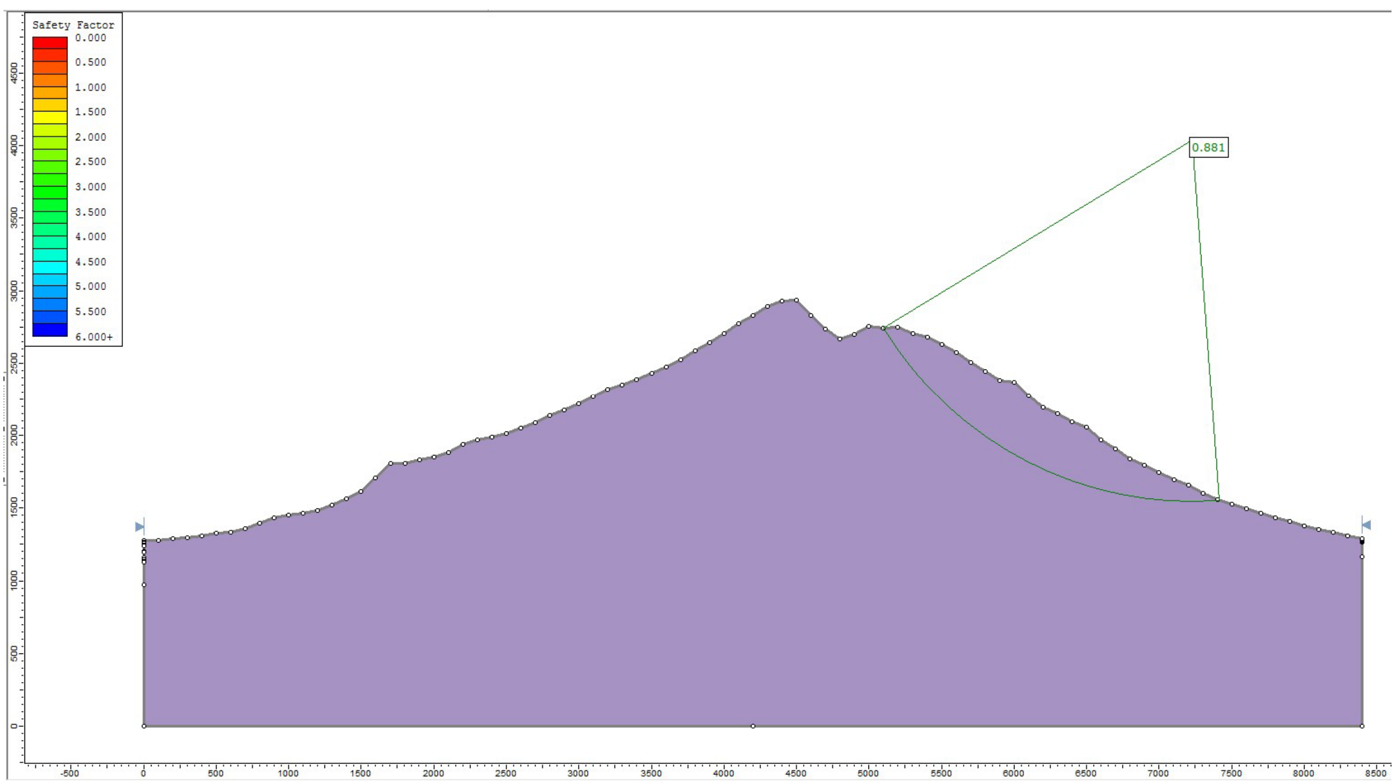

Figure 17.6 – *Slide2* Solution Using the Janbu Method

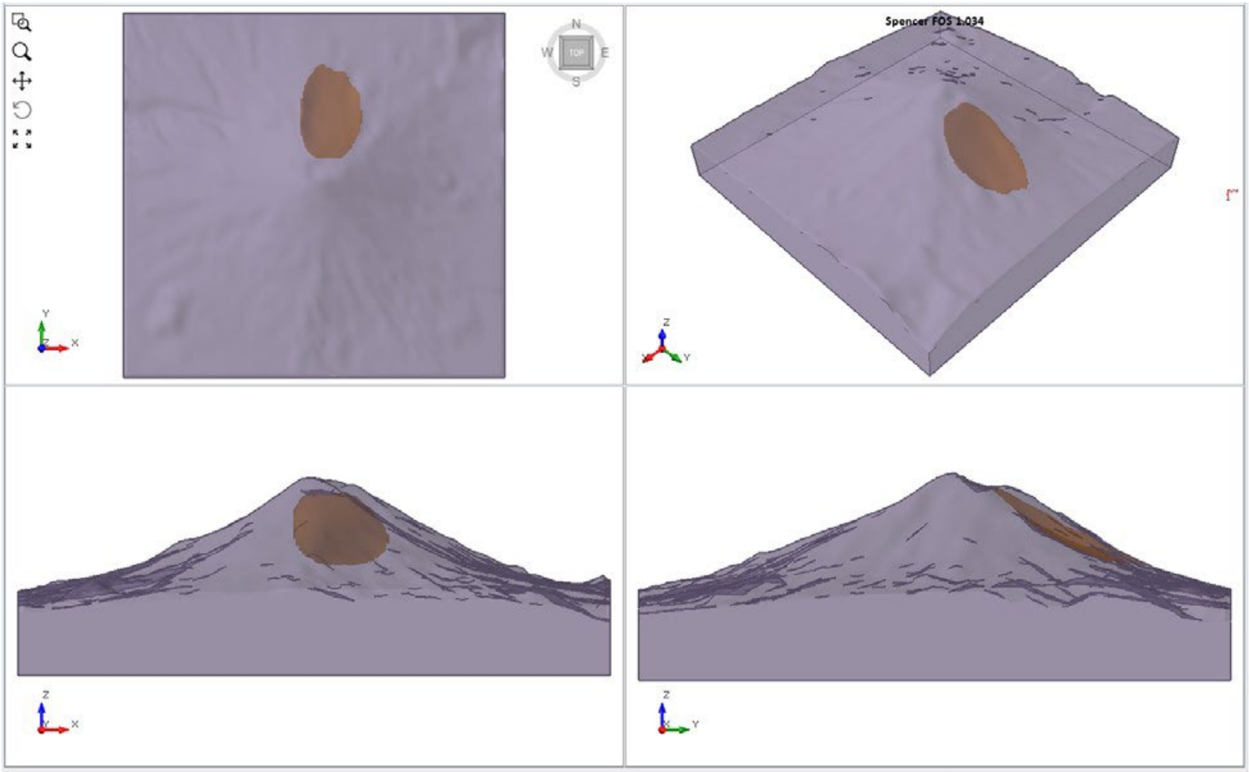

Figure 17.7 – *Slide3* Solution Using the Spencer Method

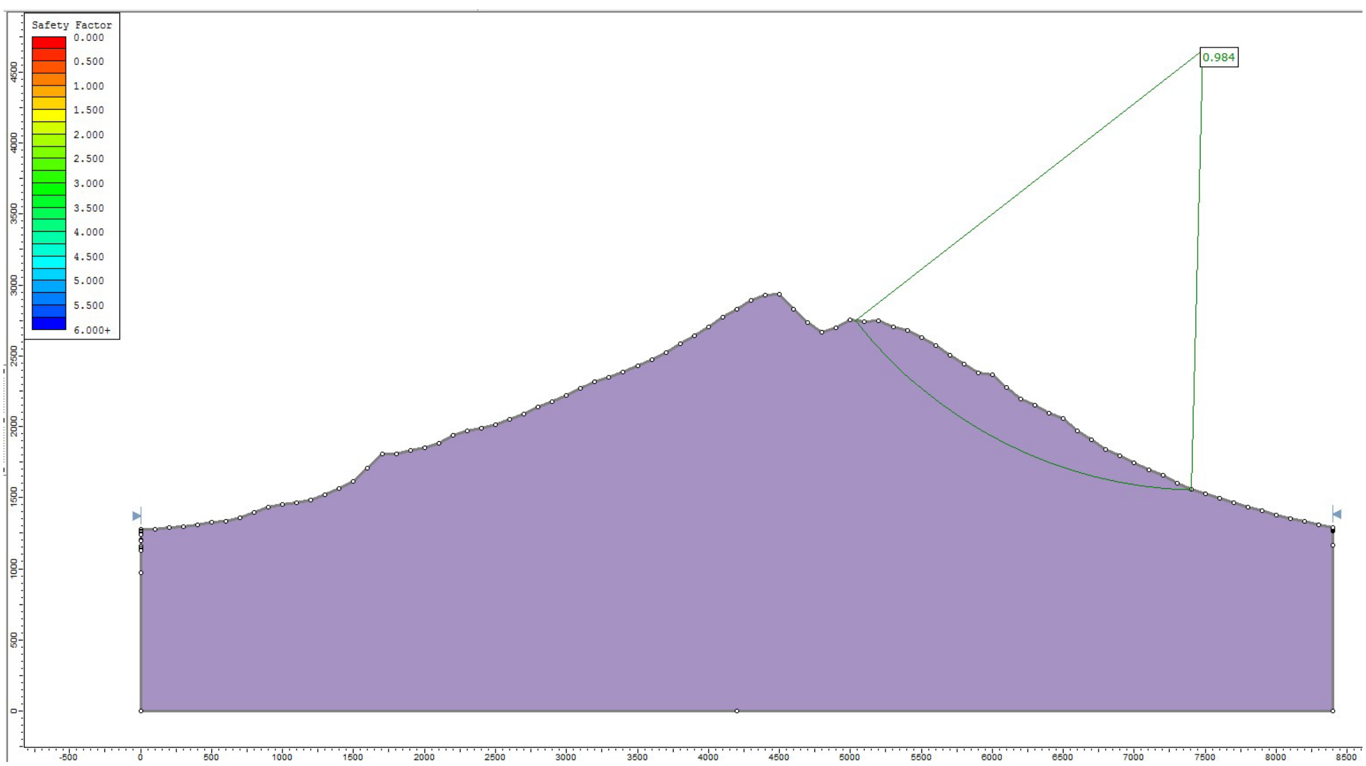

Figure 17.8 – *Slide2* Solution Using the Spencer Method

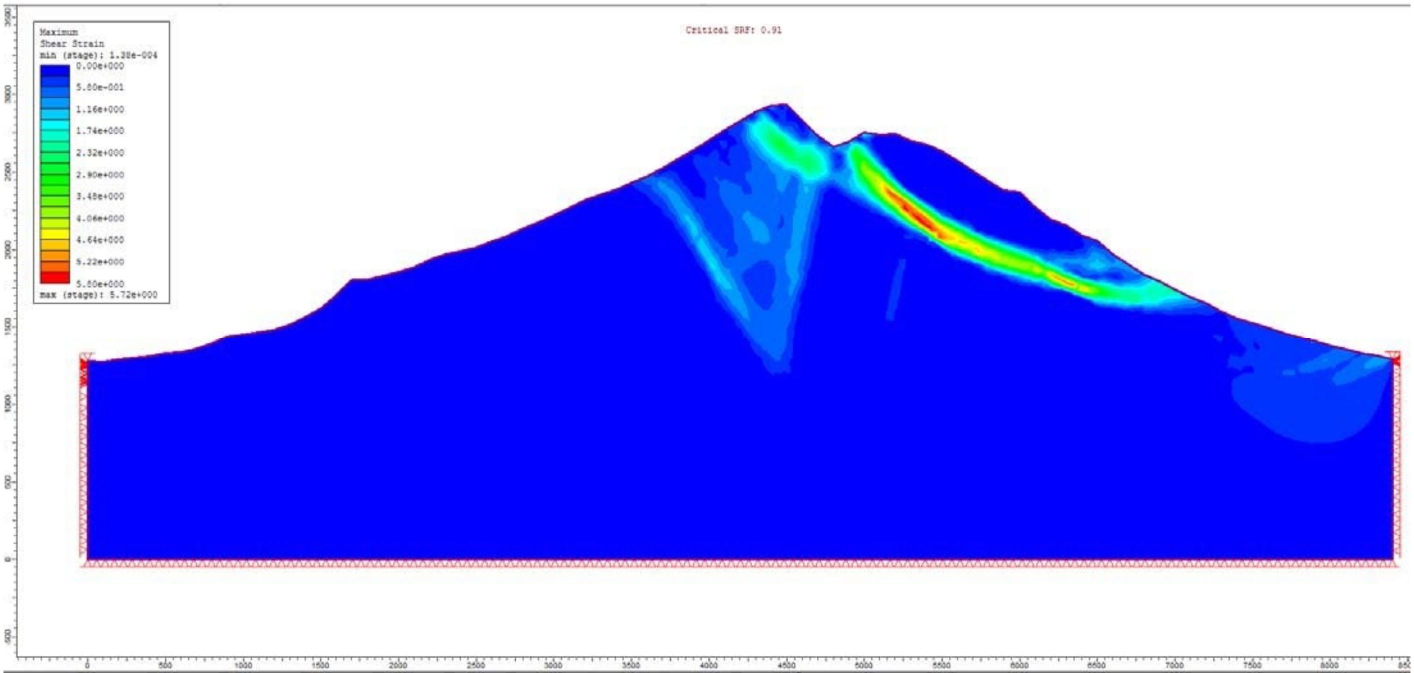

Figure 17.9 – *RS2* Maximum Shear Strain

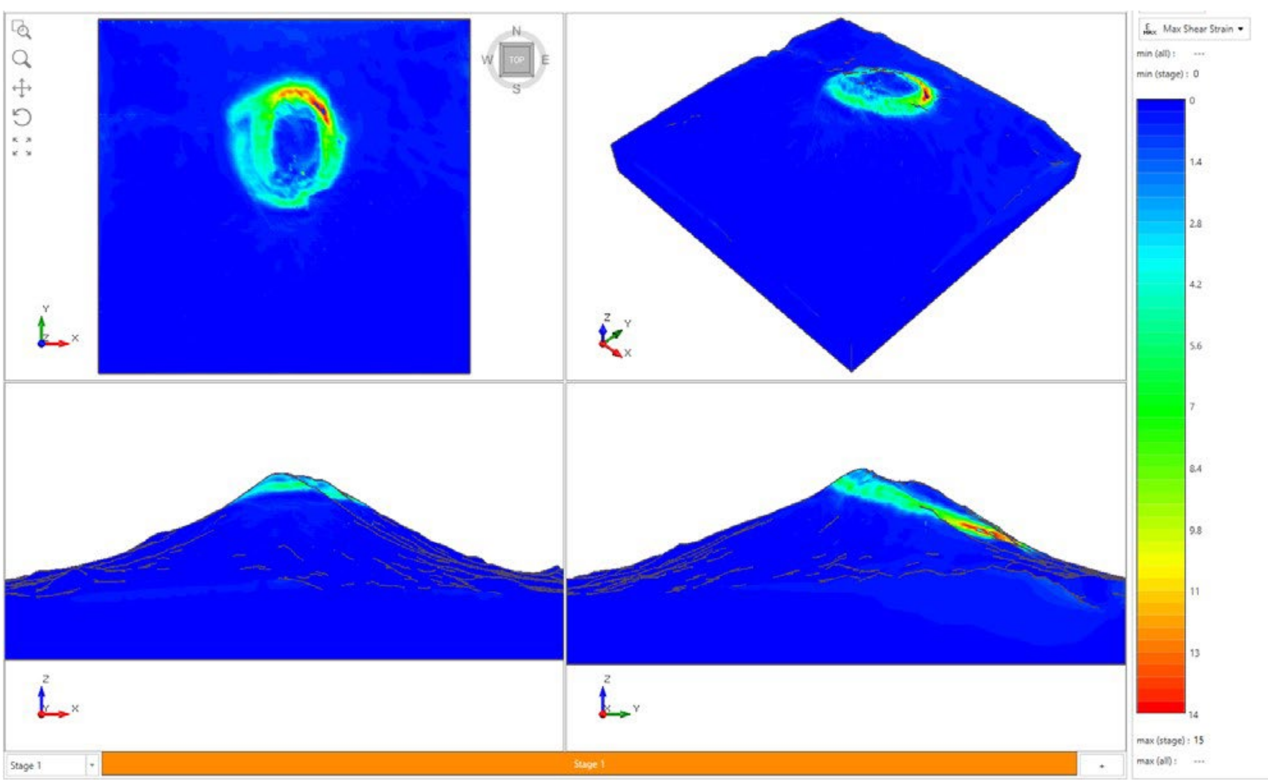

Figure 17.10 – *RS3* Maximum Shear Strain

18. 3D Verification #18

18.1. 3D model, weak layer, ellipsoidal with SA

18.1.1. Introduction

This example is a 3D model with a weak layer.

18.1.2. Problem Description

This model was created by importing the surface geometry, copying it, and separating it, to create the geometry for the surface, as well as the top and bottom of the weak layer. Each surface was extruded down and cut by the surface below it. The bottom surface was extruded down and cut by a box at the base. The material properties for both the soil and the weak layer can be found in Table 18.1. The ellipsoidal slip surface and corresponding safety factor is required.

18.1.3. Properties

Table 18.1: Material Properties

	c′ (kN/m^2)	φ′ (deg.)	γ (kN/m^3)	Tensile Strength (kPa)
Soil	400	30	19	400
Weak Layer	50	25	19	50

18.1.4. Results

Table 18.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.555</td><td>1.322</td><td rowspan="4">1.76</td><td rowspan="4">1.4</td></tr>
<tr><td>GLE</td><td>1.664</td><td>1.400</td></tr>
<tr><td>Janbu</td><td>1.525</td><td>1.278</td></tr>
<tr><td>Spencer</td><td>1.71</td><td>1.423</td></tr>
</table>

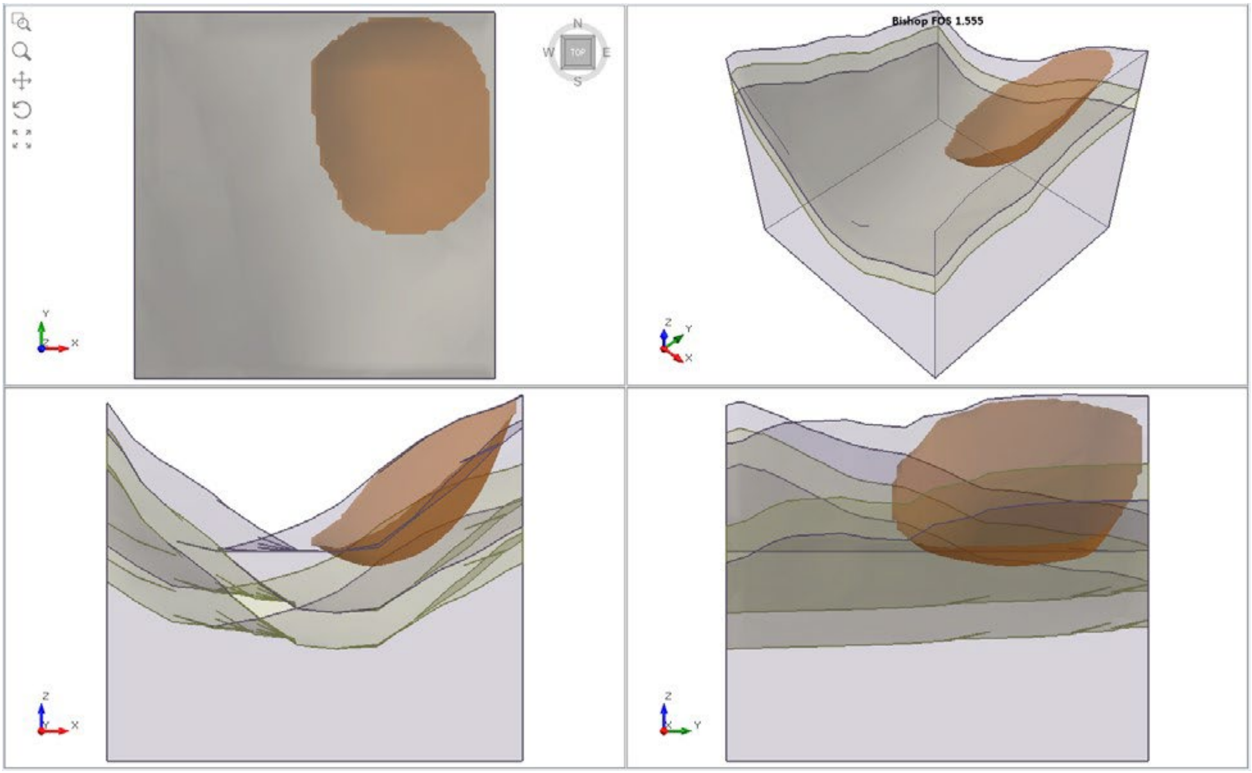

Figure 18.1 – *Slide3* Solution Using the Bishop Method

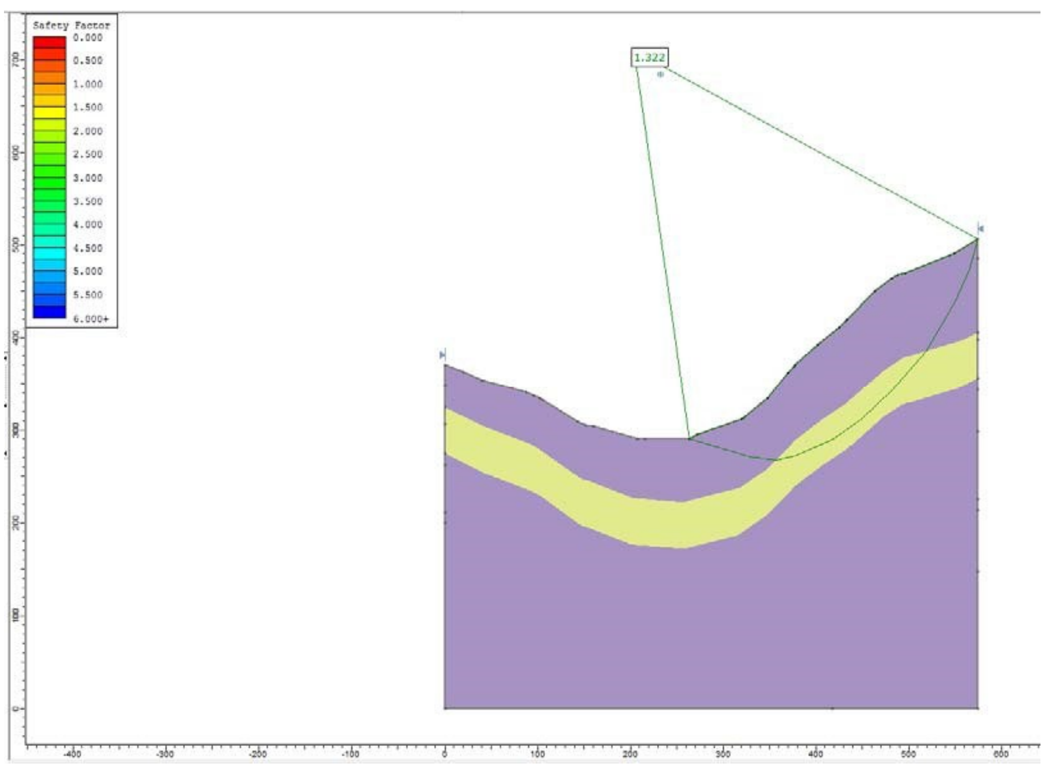

Figure 18.2 – *Slide2* Solution Using the Bishop Method

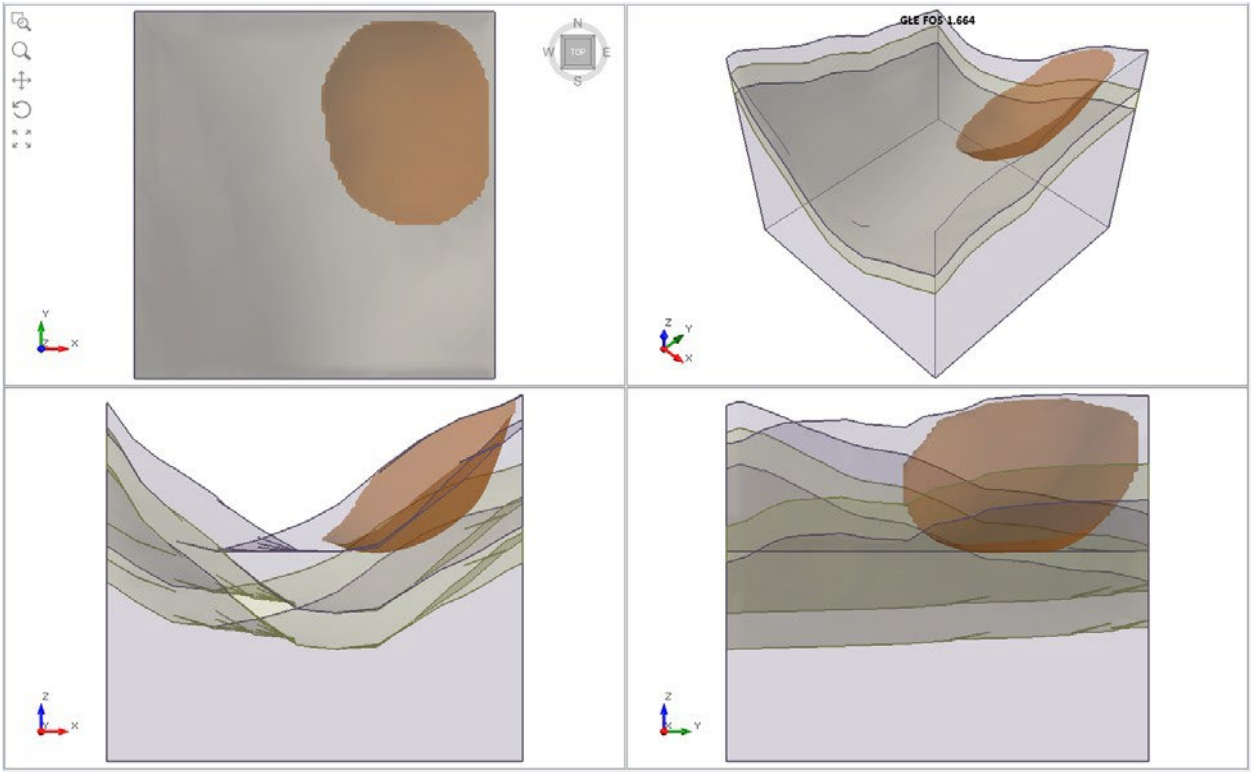

Figure 18.3 – *Slide3* Solution Using the GLE Method

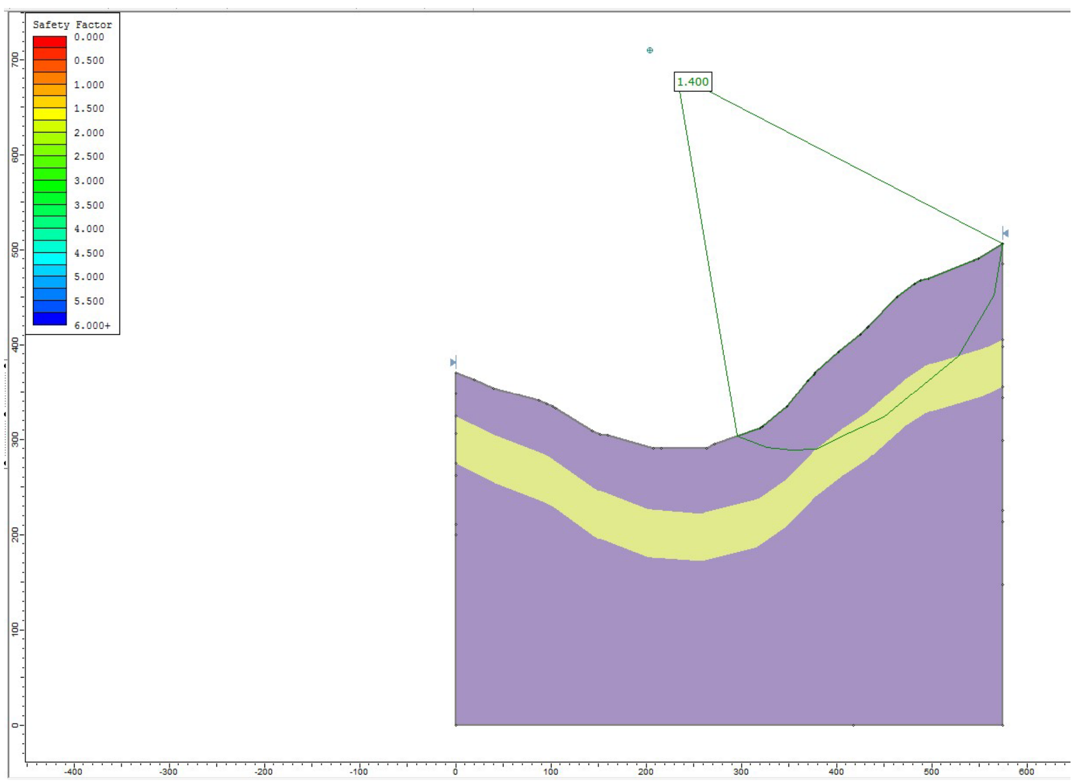

Figure 18.4 – *Slide2* Solution Using the GLE Method

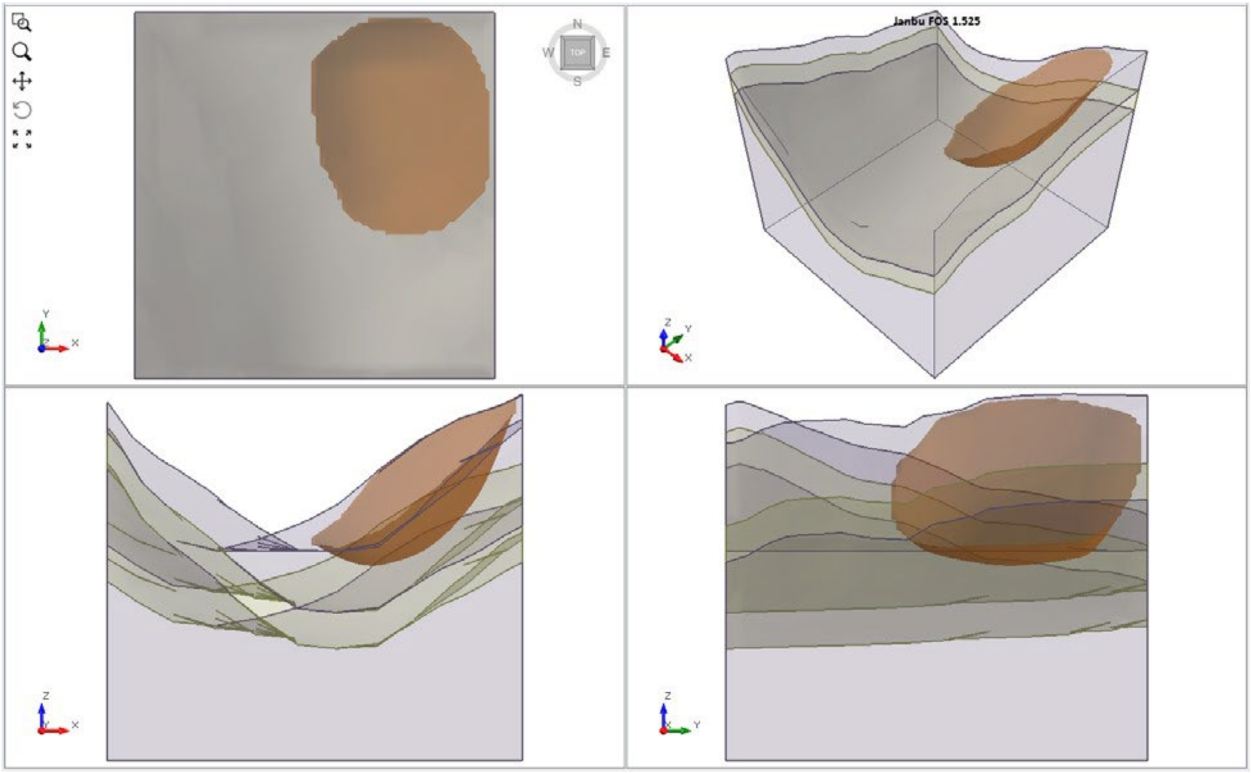

Figure 18.5 – *Slide3* Solution Using the Janbu Method

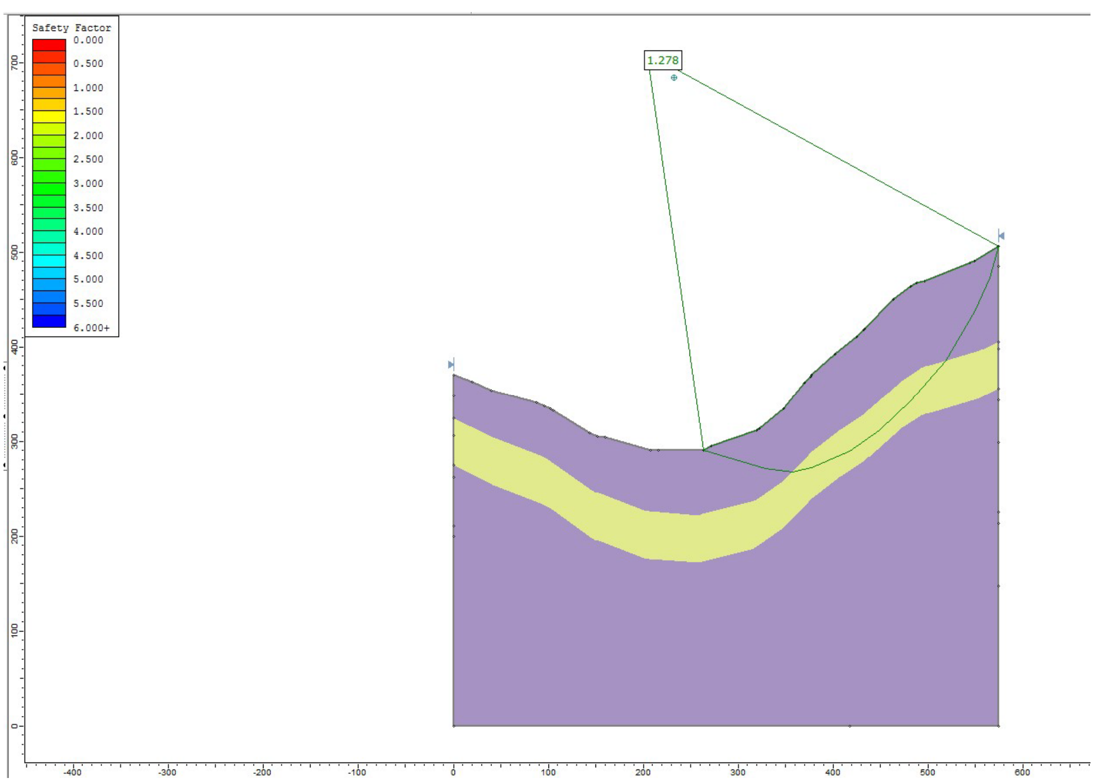

Figure 18.6 – *Slide2* Solution Using the Janbu Method

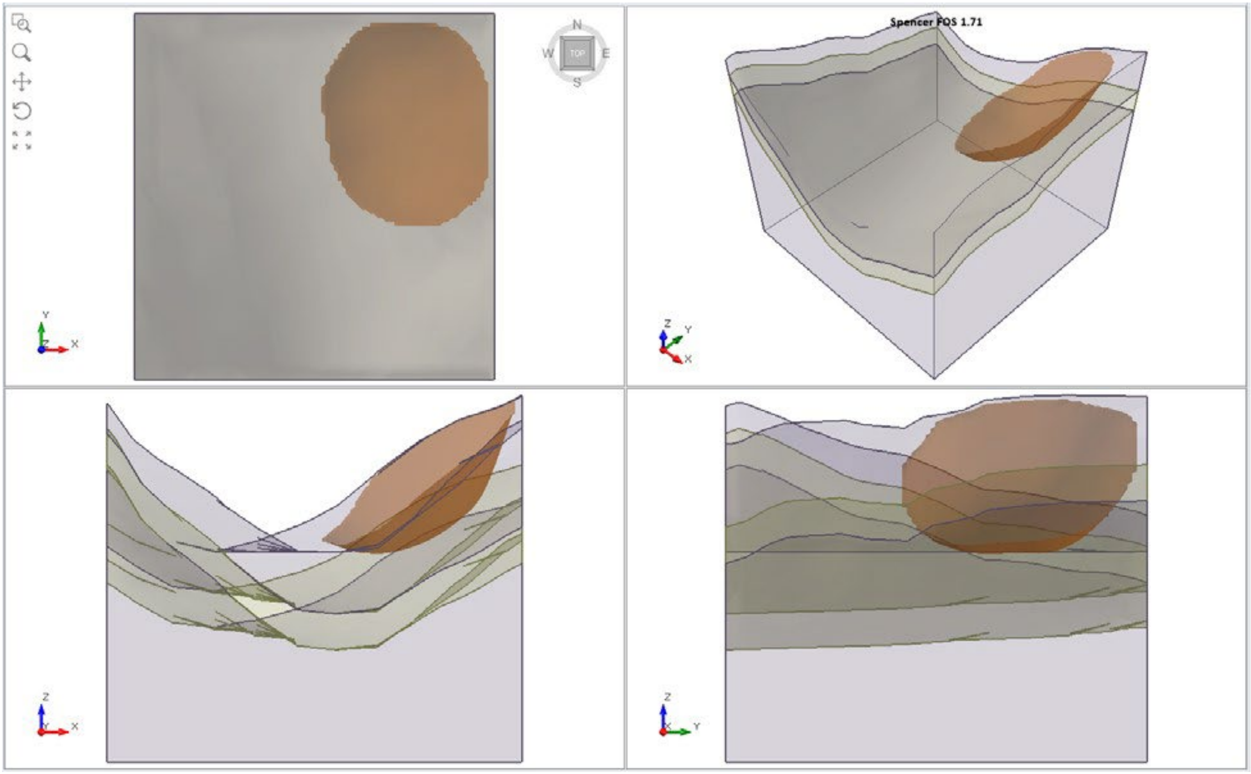

Figure 18.7 – *Slide3* Solution Using the Spencer Method

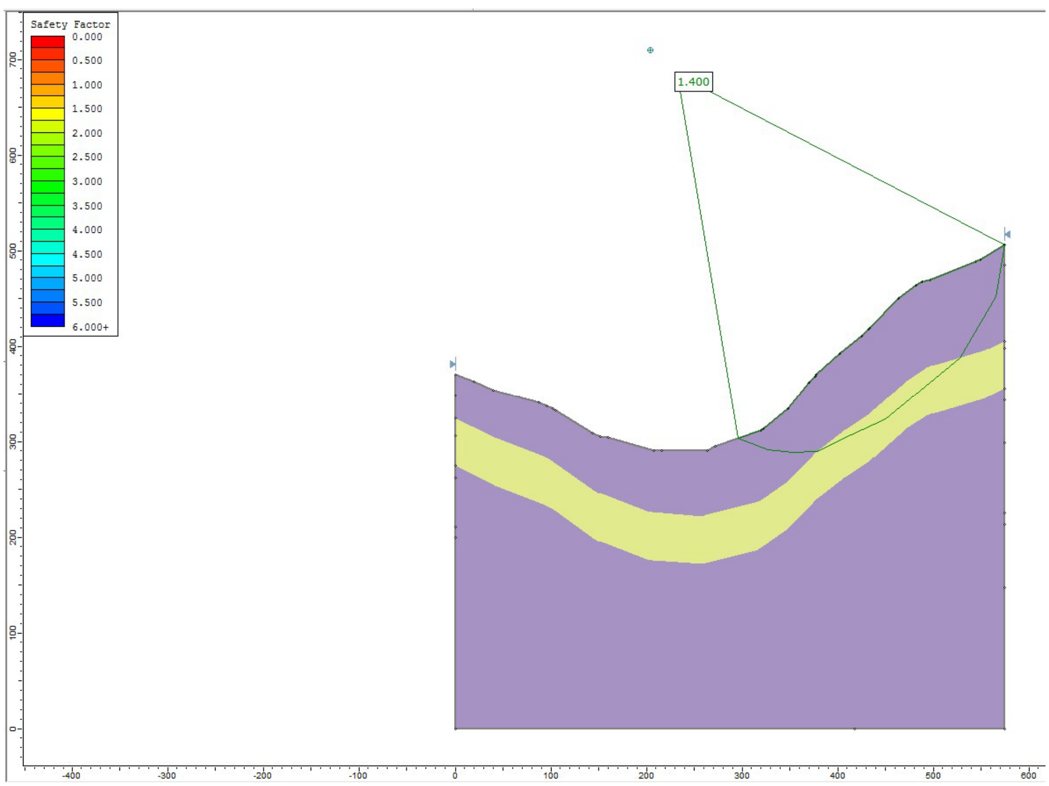

Figure 18.8 – *Slide2* Solution Using the Spencer Method

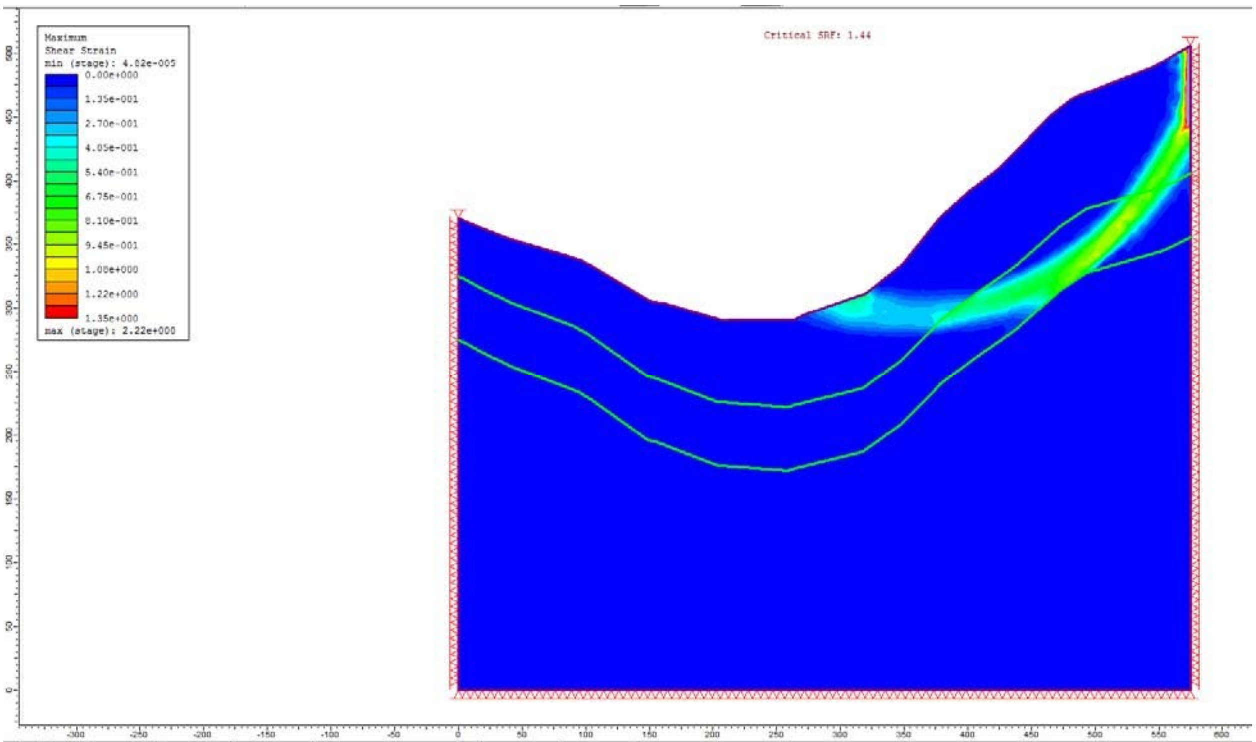

Figure 18.9 – *RS2* Maximum Shear Strain

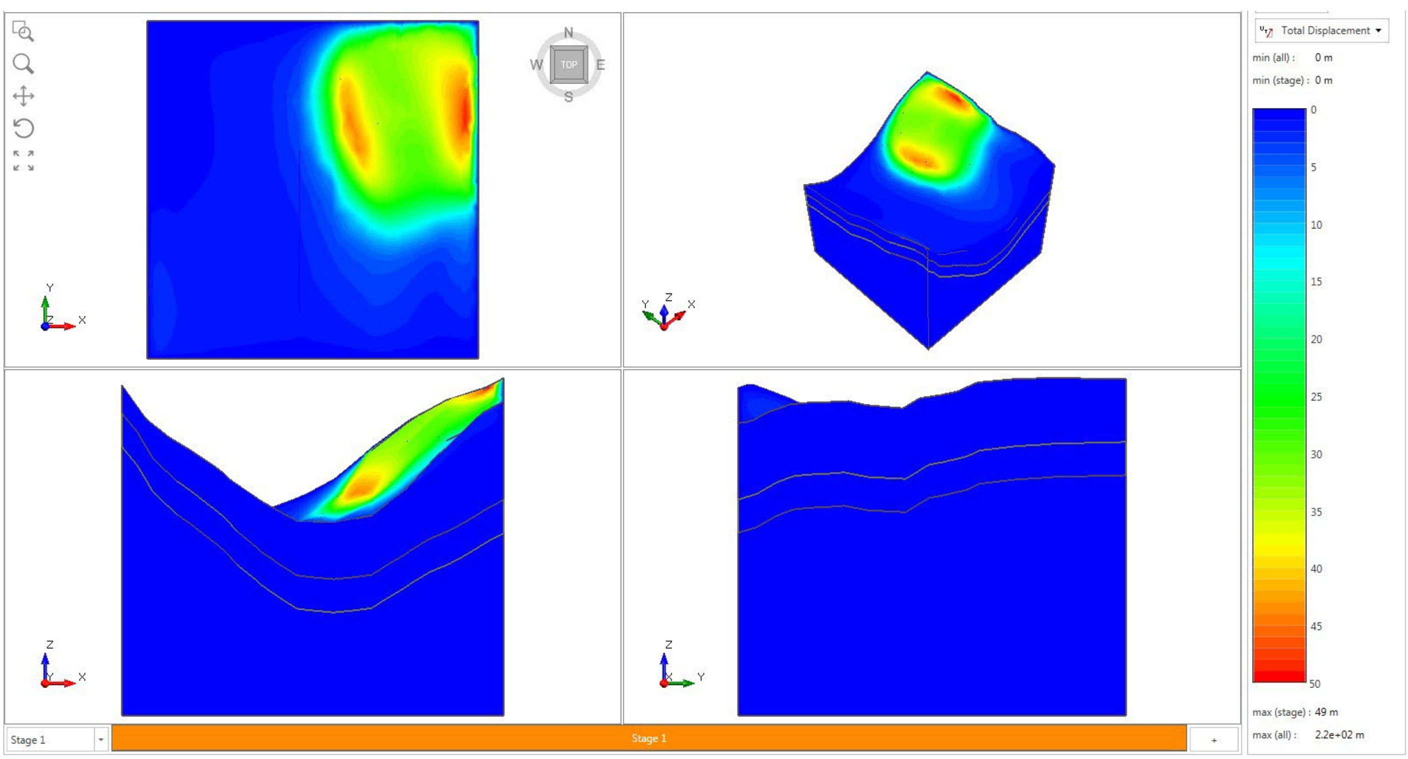

Figure 18.10 – *RS3* Total Displacement

19. 3D Verification #19

19.1. 3D coal mine, (6) materials, ellipsoidal with SA

19.1.1. Introduction

This is a model of a 3D non-homogeneous coal mine.

19.1.2. Problem Description

This example is a 3D coal mine consisting of 6 materials. The properties for all of the materials can be found in Table 19.1. There is no pore pressure modeled in this problem. The ellipsoidal slip surface and corresponding safety factor is required.

19.1.3. Properties

Table 19.1: Material Properties

Material	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Fault Plane	2	15	15
Weathered Tertiary (conservative)	20	25	18
Coal	35	30	15
Weathered Coal	2	15	15
Cat 2 Spoil	30	28	18
Fresh CMR	150	35	24

19.1.4. Results

Table 19.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	0.841	0.421	0.98	0.36
GLE	0.846	0.418		
Janbu	0.819	0.418		
Spencer	0.896	0.423		

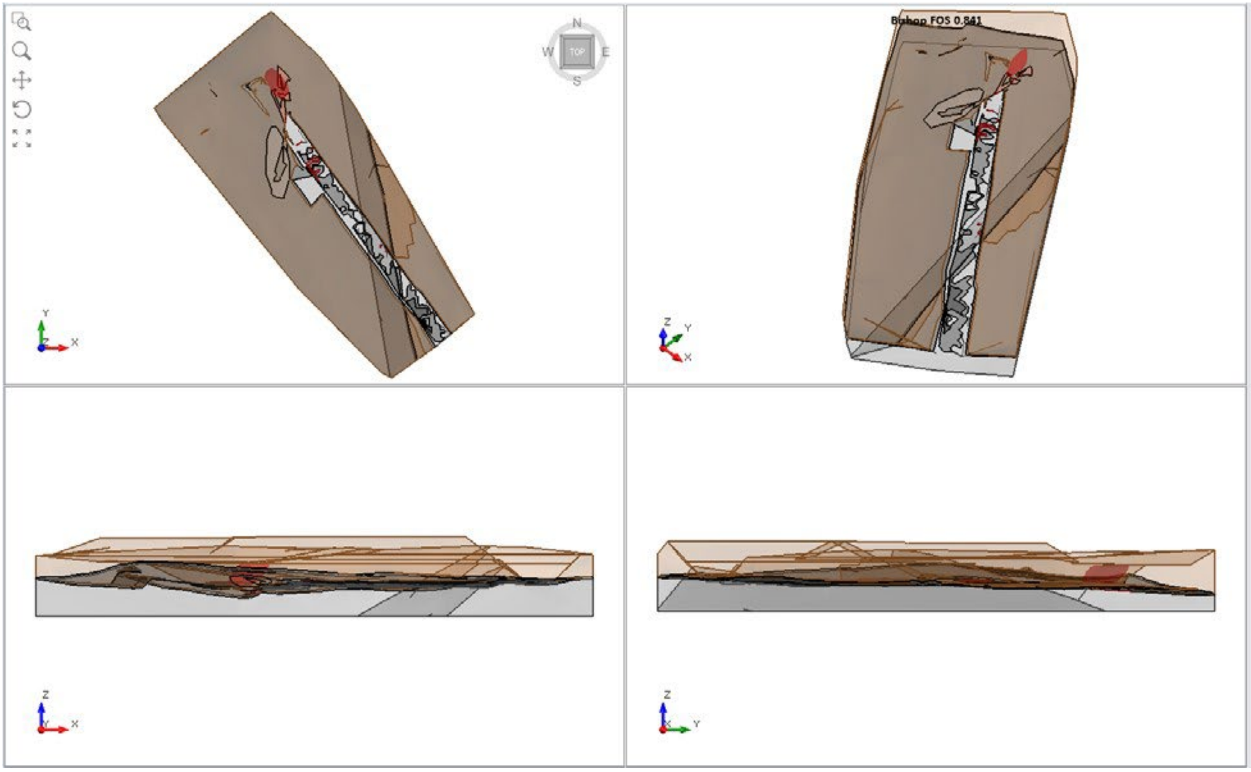

Figure 19.1 – *Slide3* Solution Using the Bishop Method

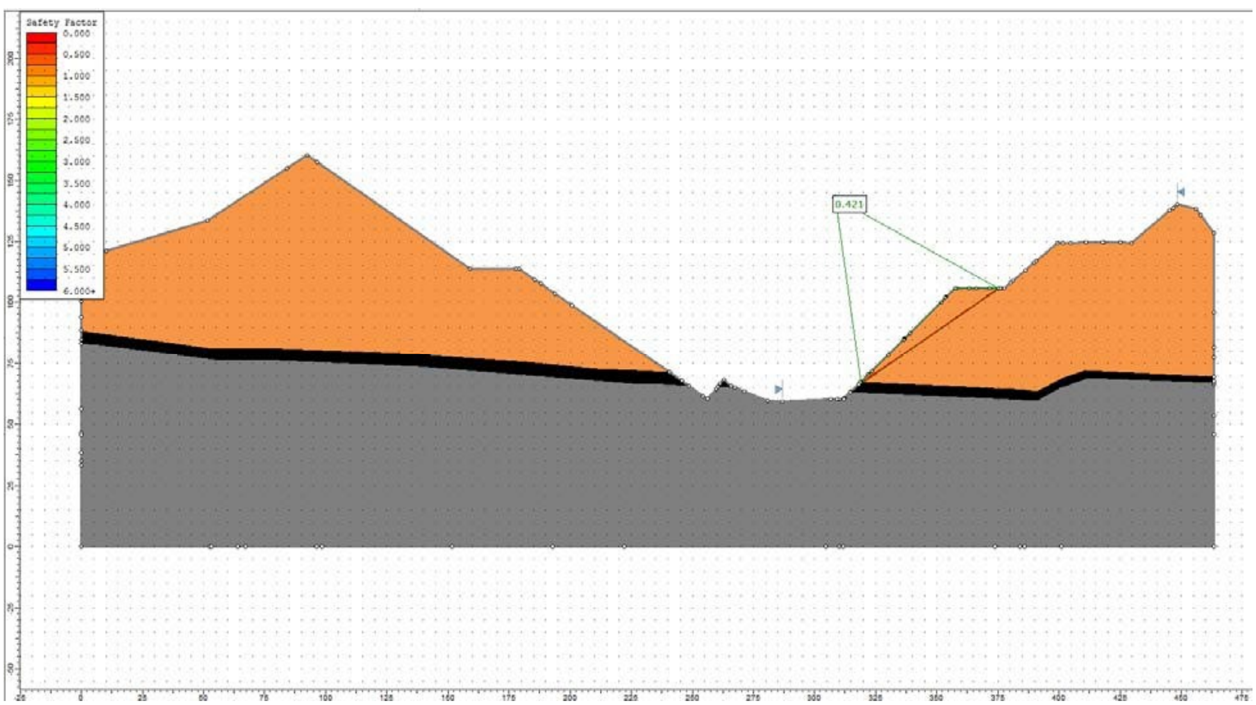

Figure 19.2 – *Slide2* Solution Using the Bishop Method

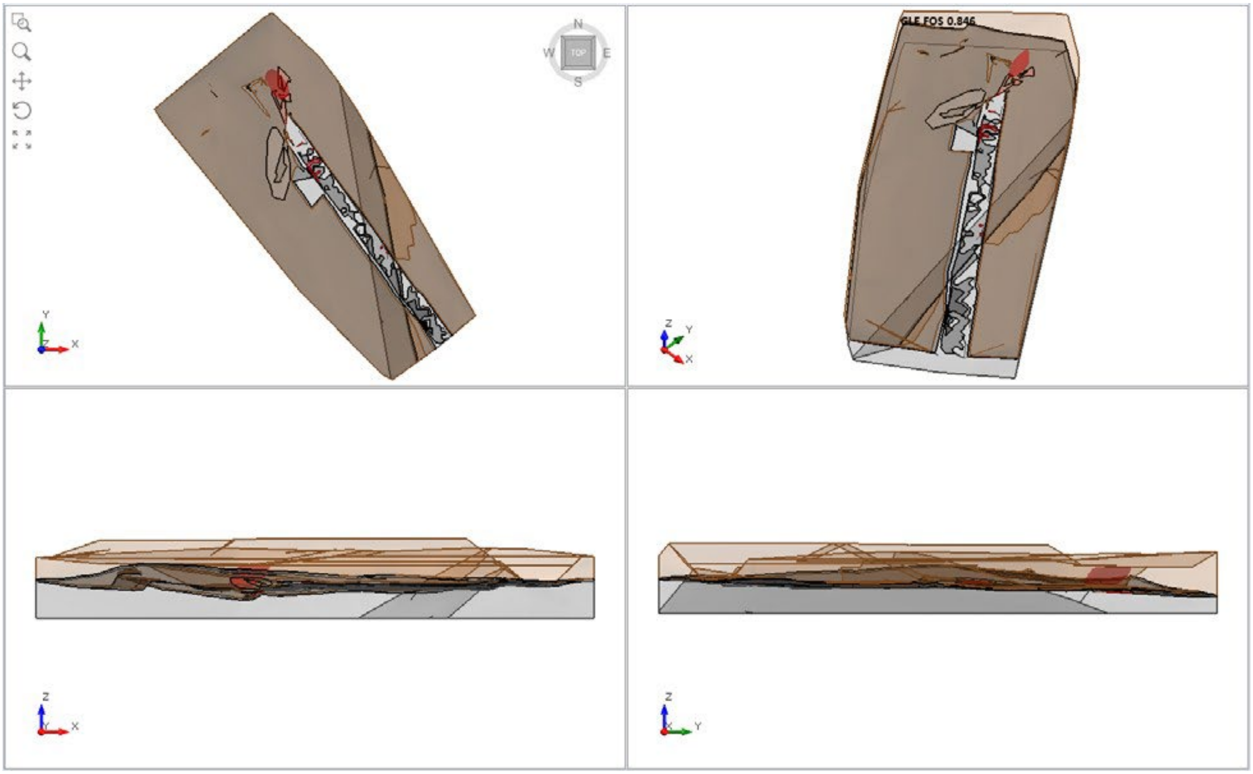

Figure 19.3 – *Slide3* Solution Using the GLE Method

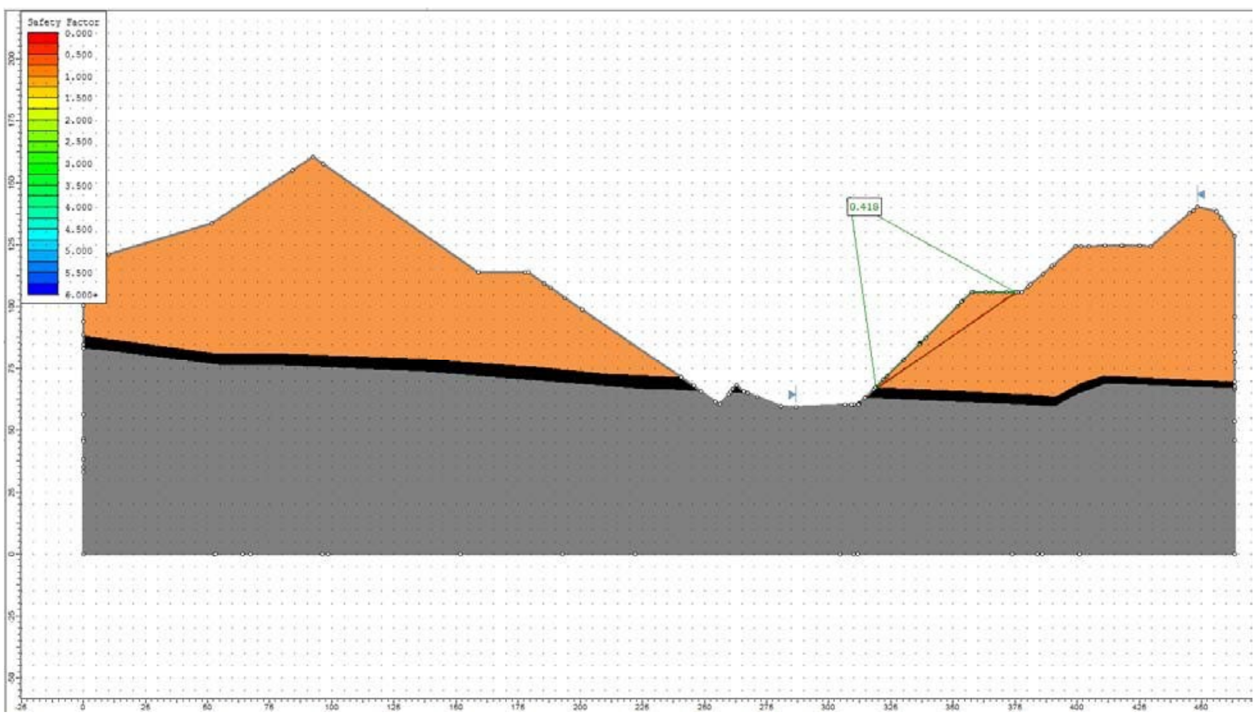

Figure 19.4 – *Slide2* Solution Using the GLE Method

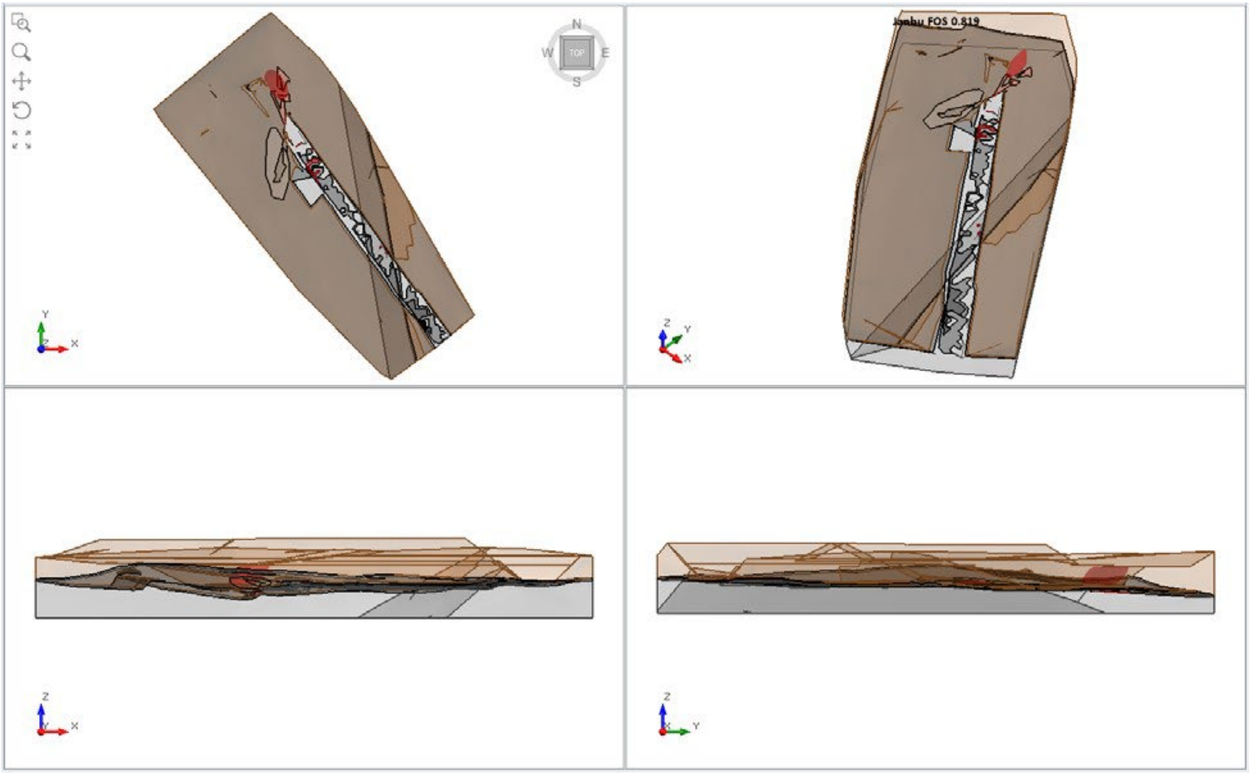

Figure 19.5 – *Slide3* Solution Using the Janbu Method

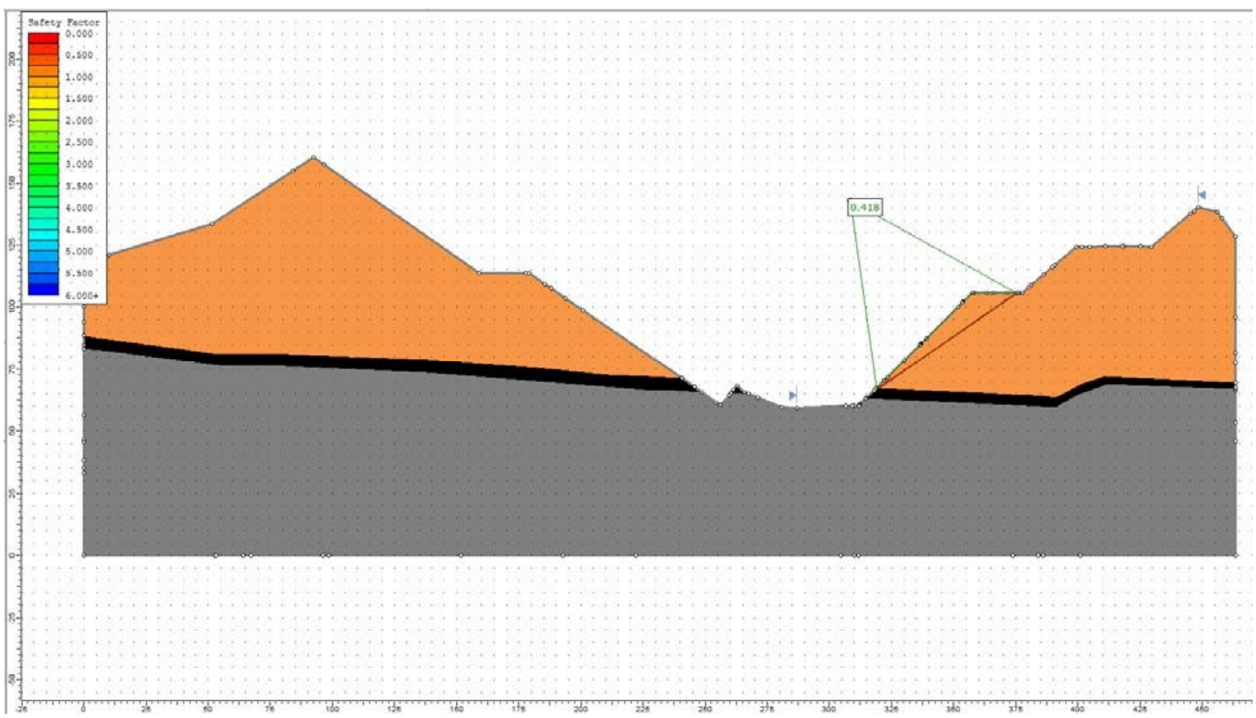

Figure 19.6 – *Slide3* Solution Using the Janbu Method

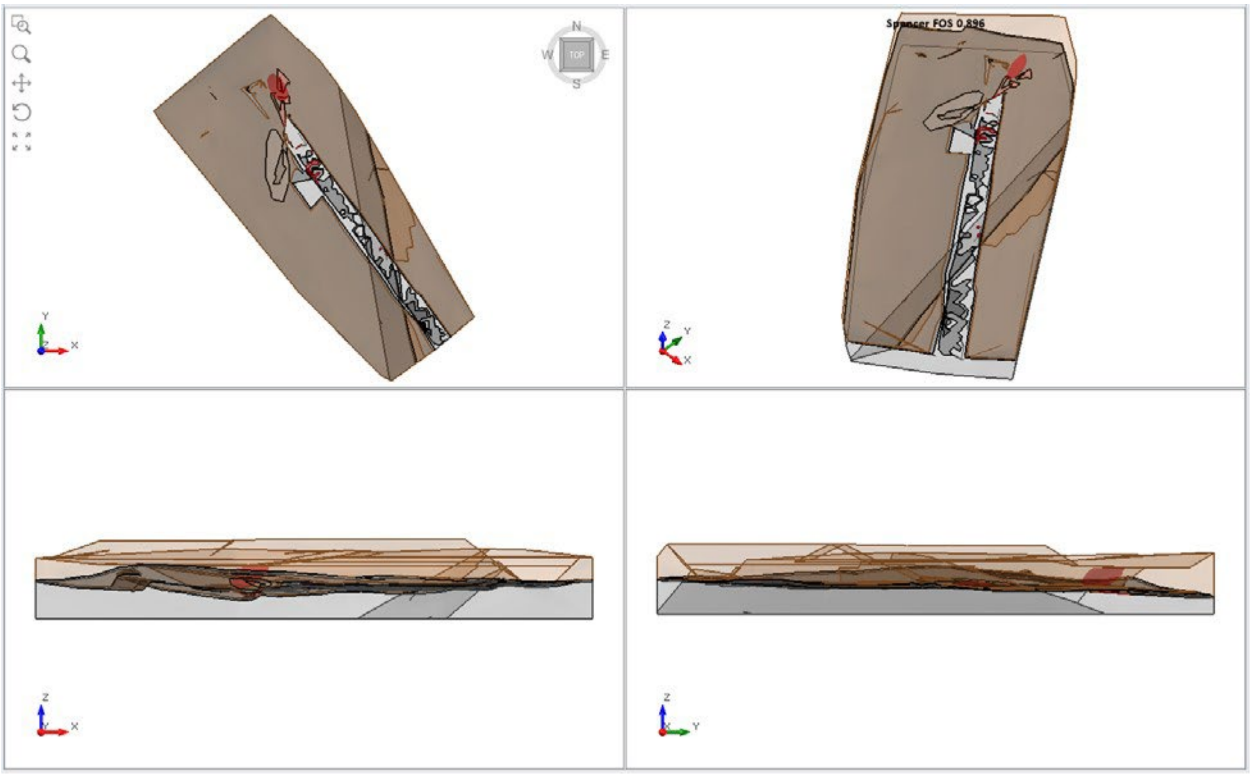

Figure 19.7 – *Slide3* Solution Using the Spencer Method

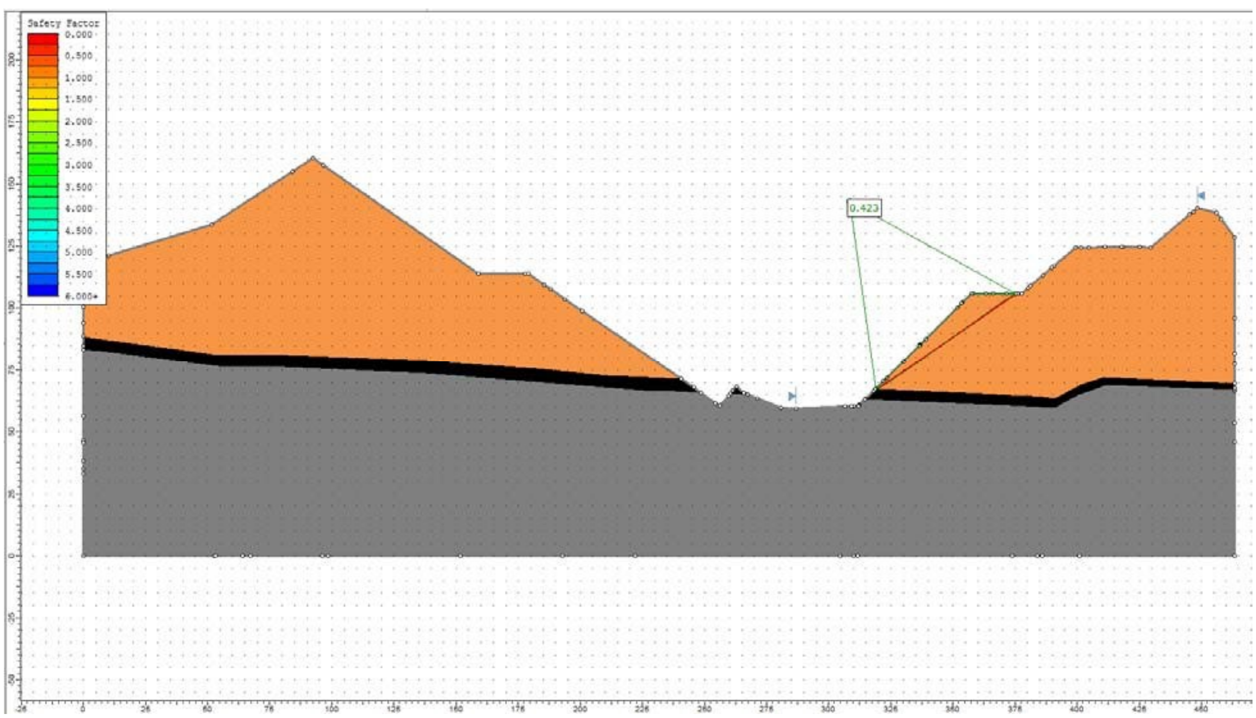

Figure 19.8 – *Slide3* Solution Using the Spencer Method

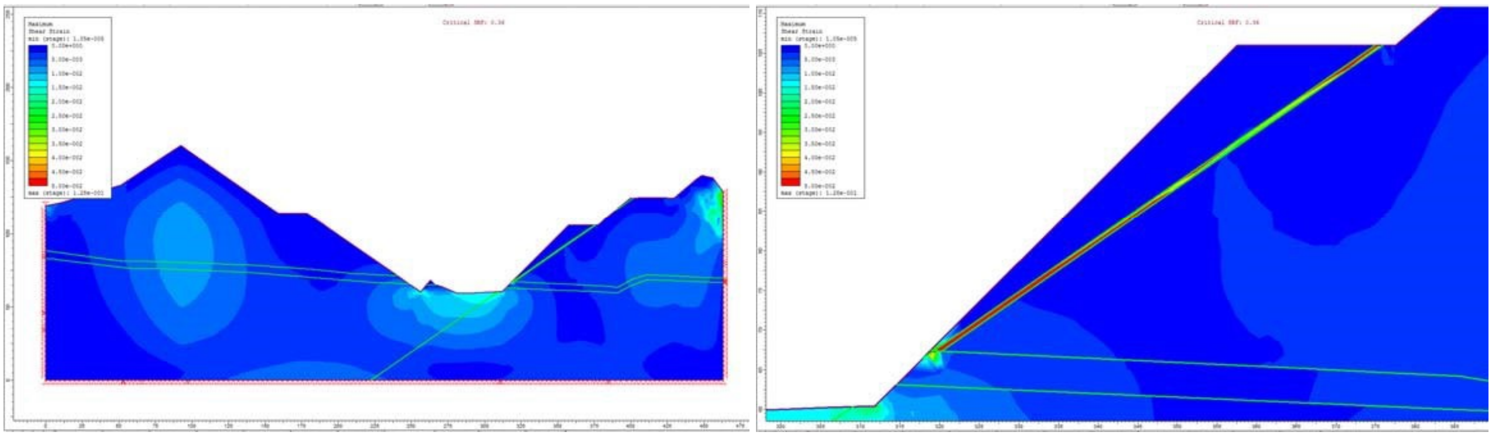

Figure 19.9 – *RS2* Maximum Shear Strain

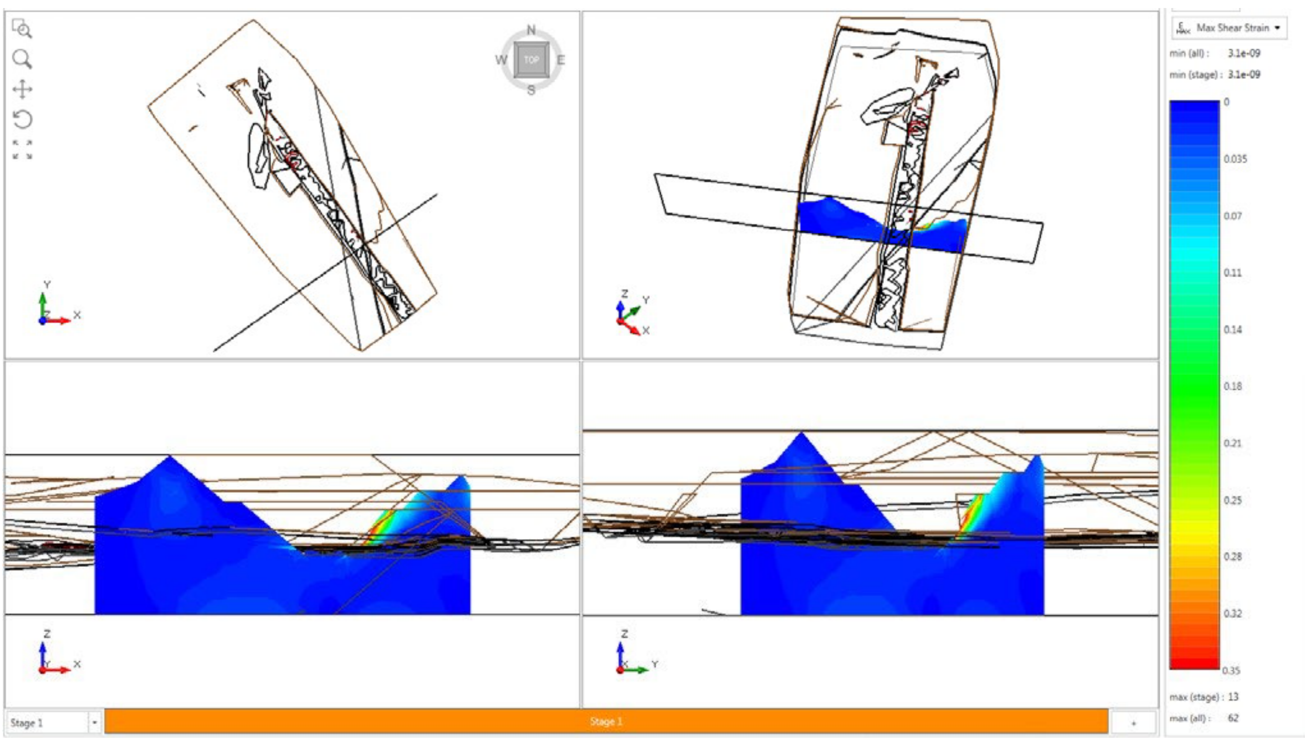

Figure 19.10 – *RS3* Maximum Shear Strain

20. 3D Verification #20

20.1. 3D coal mine, (3) materials + anisotropic material, slope limits, ellipsoidal with SA

20.1.1. Introduction

This example is a 3D coal mine with anisotropic material.

20.1.2. Problem Description

This example consists of 3 materials, whose properties can be found in Table 20.1, and one anisotropic material, whose properties can be found in Table 20.2. The ellipsoidal slip surface and corresponding safety factor is required.

20.1.3. Properties

Table 20.1: Material Properties

Material	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Joint	2	12	15
Coal	35	30	15
Fresh CMR	120	30	24

Table 20.2: Anisotropic Properties

<table>
<tr><th>Material</th><th>γ (kN/m^3)</th><th>Base Material</th><th>Material</th><th>Dip</th><th>Dip Direction</th><th>A</th><th>B</th></tr>
<tr><td rowspan="2">Jointed CMR</td><td rowspan="2">20</td><td rowspan="2">Fresh CMR</td><td>Joint</td><td>81</td><td>132</td><td>5</td><td>10</td></tr>
<tr><td>Joint</td><td>74</td><td>49</td><td>5</td><td>10</td></tr>
</table>

20.1.4. Results

Table 20.3: Safety Factors Safety Factors Using *Slide3* and *Slide2* 7.0

Method	*Slide3*	*Slide2* 7.0
Bishop	1.1	0.615
GLE	1.165	1.107
Janbu	1.085	0.474

Spencer	1.146	1.077

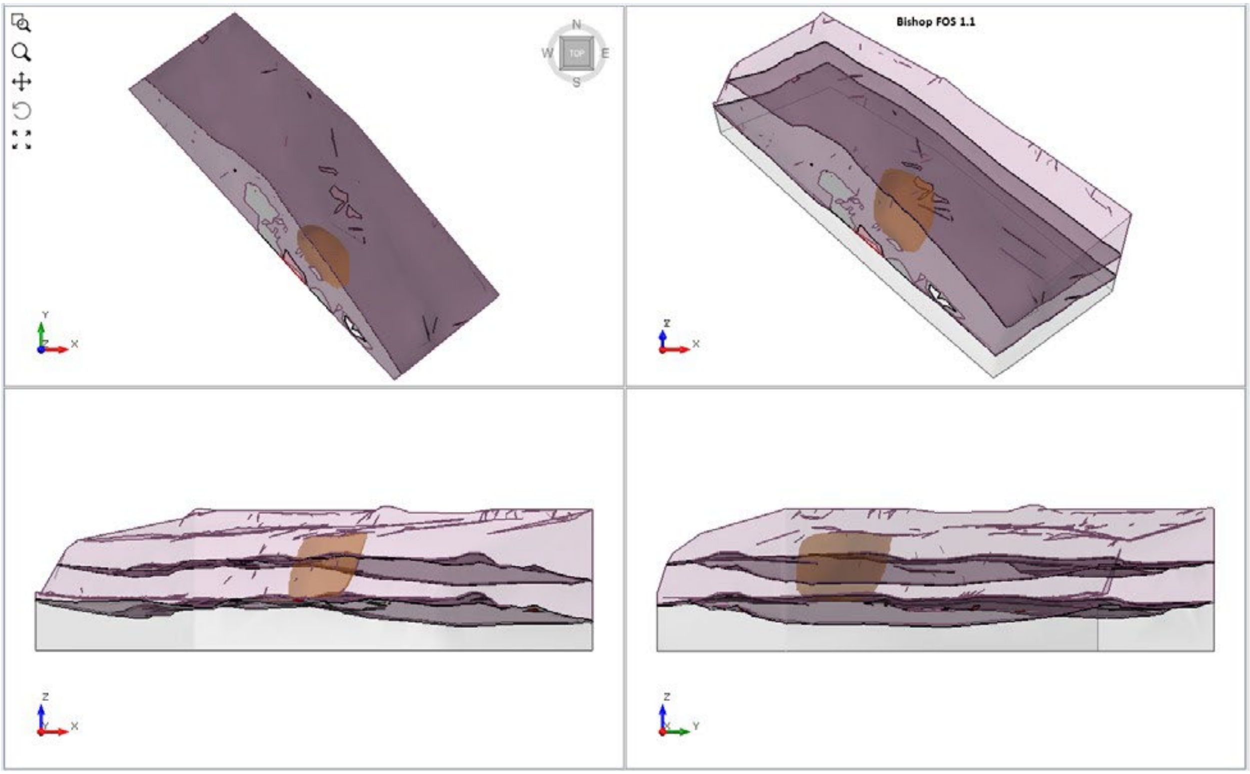

Figure 20.1 – *Slide3* Solution Using the Bishop Method

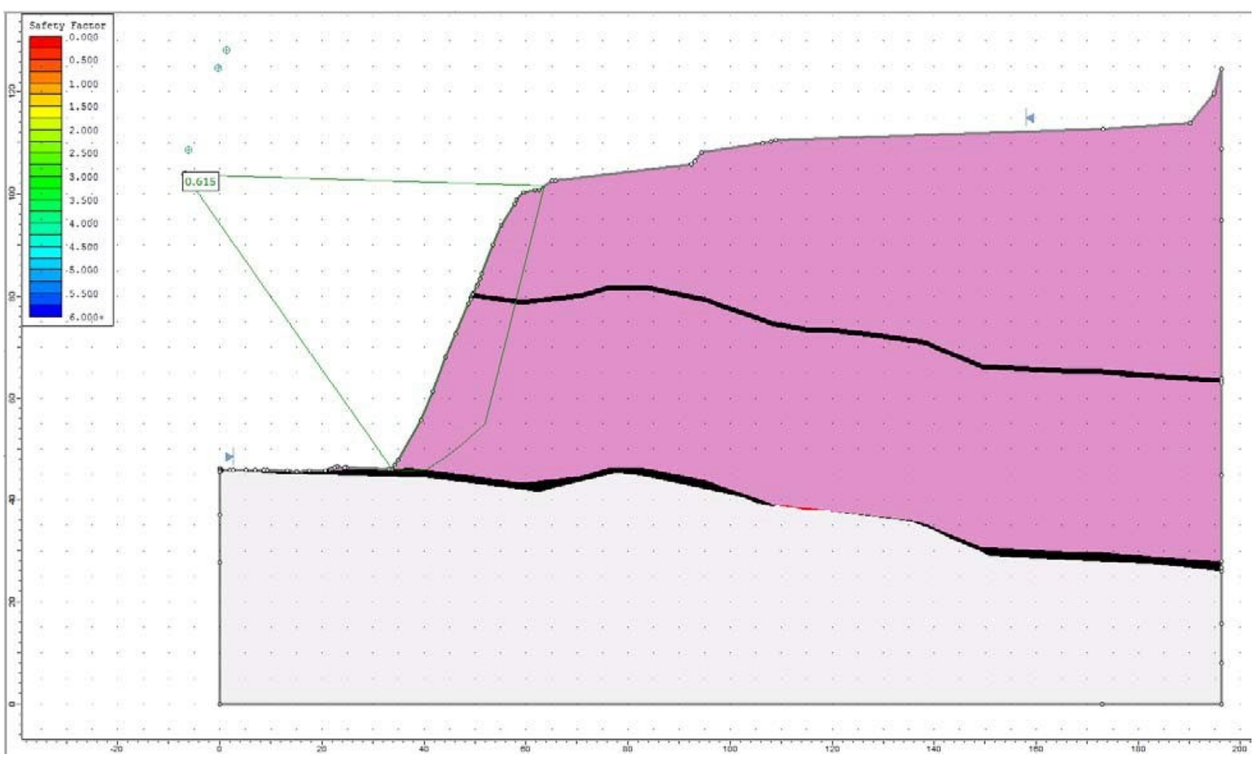

Figure 20.2 – *Slide2* Solution Using the Bishop Method

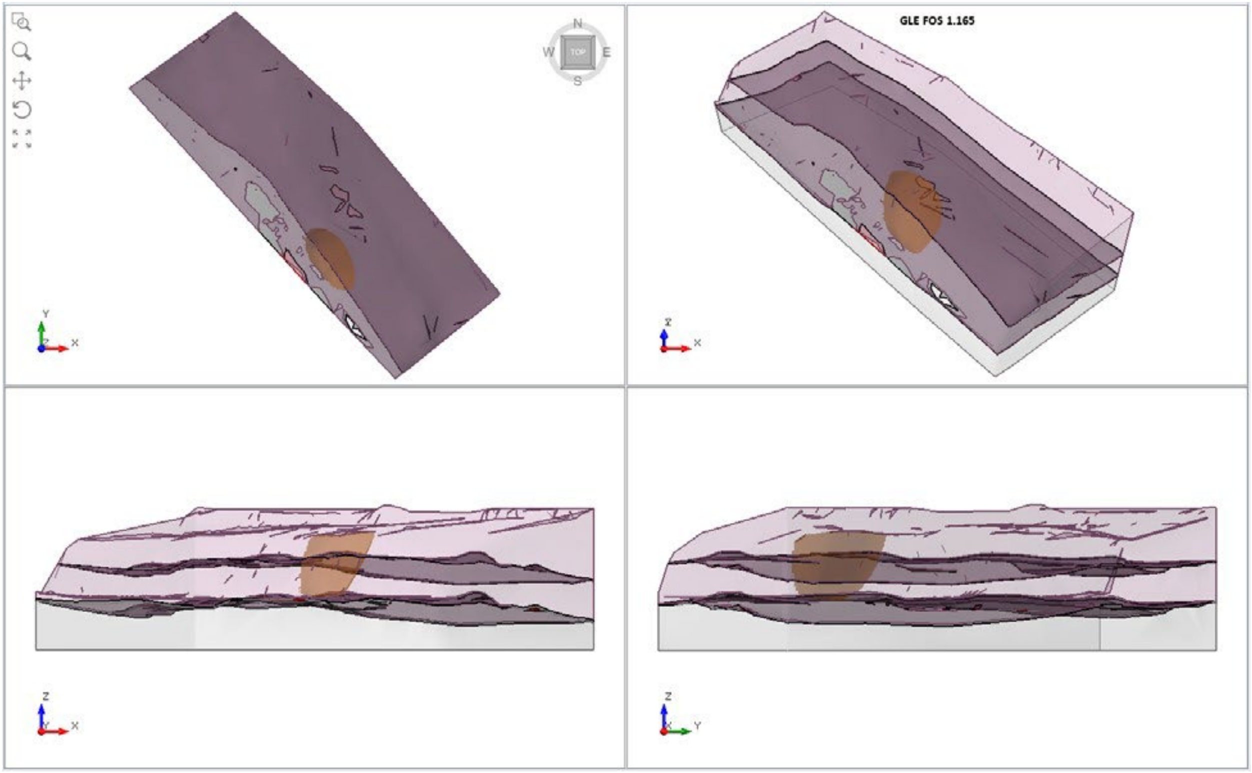

Figure 20.3 – *Slide3* Solution Using the GLE Method

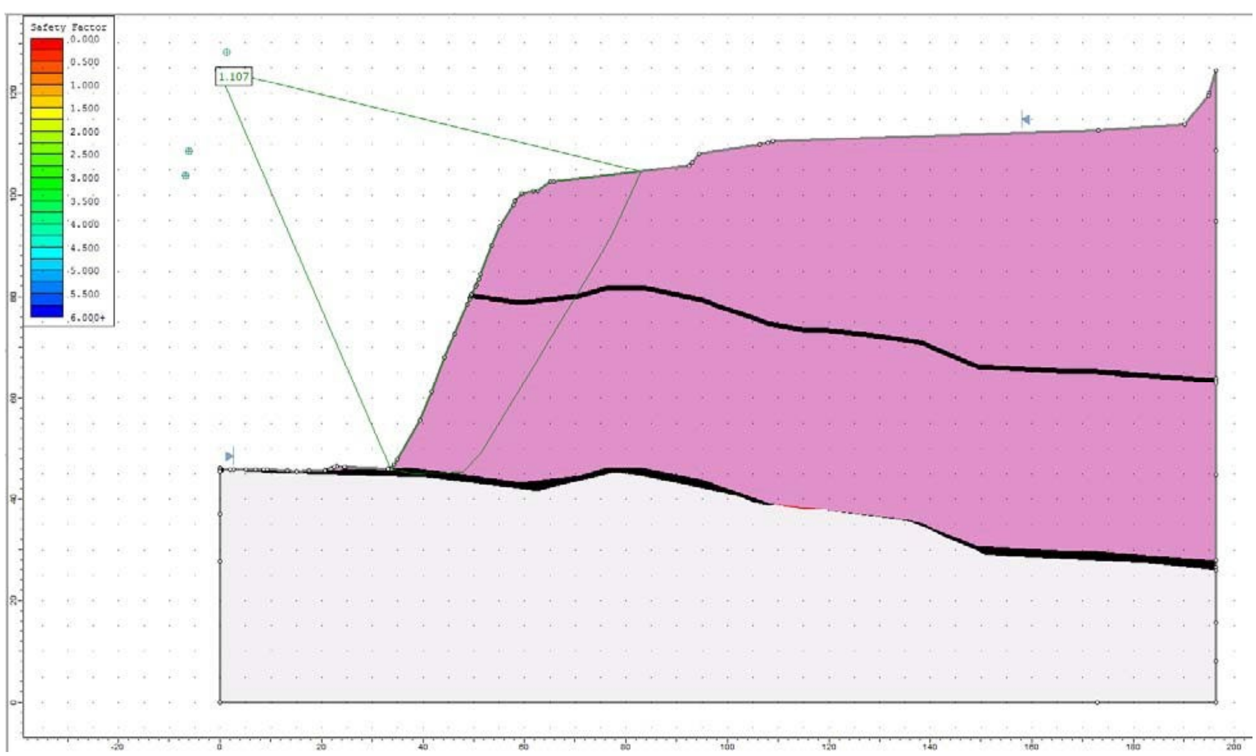

Figure 20.4 – *Slide2* Solution Using the GLE Method

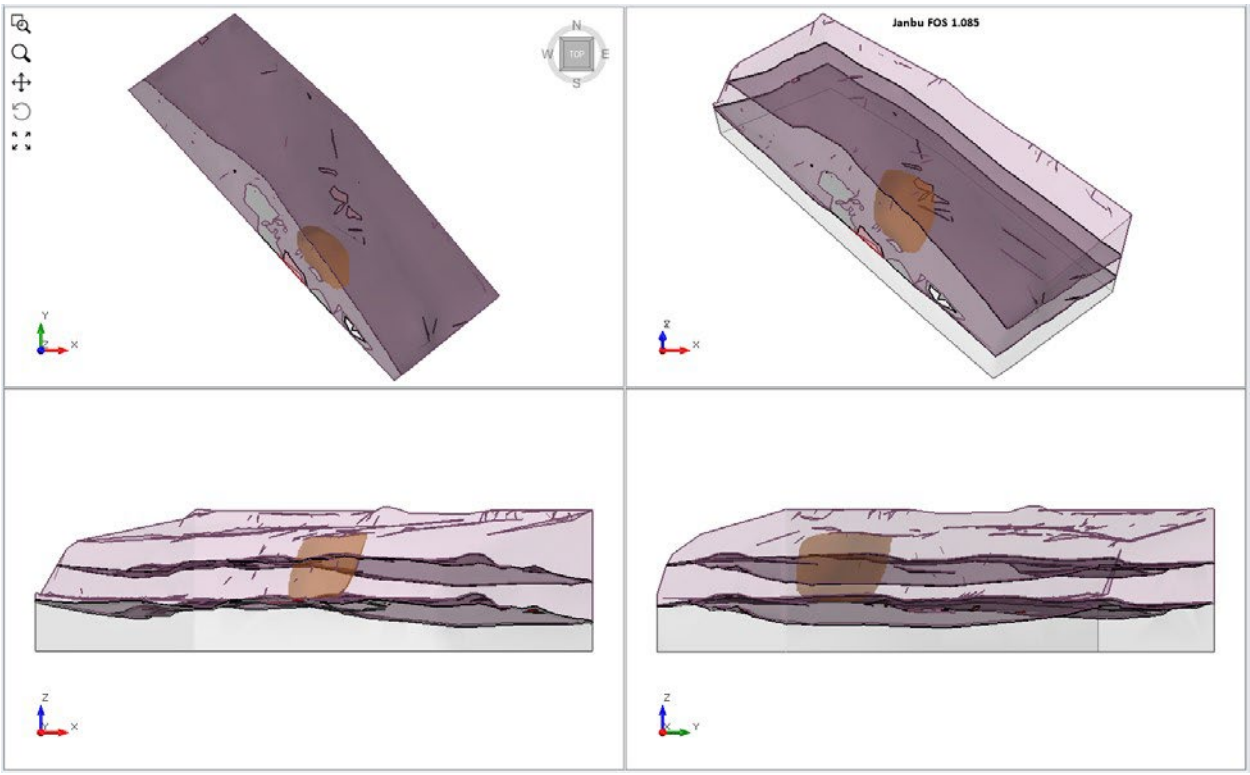

Figure 20.5 – *Slide3* Solution Using the Janbu Method

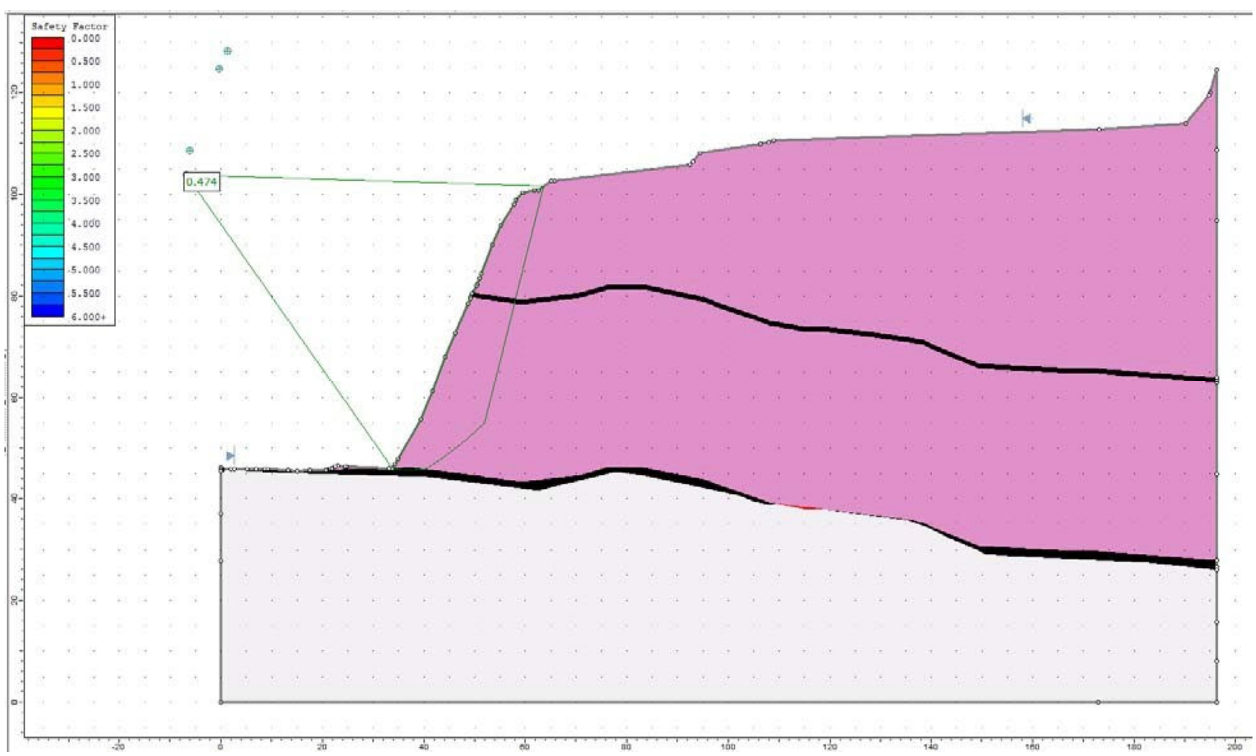

Figure 20.6 – *Slide3* Solution Using the Janbu Method

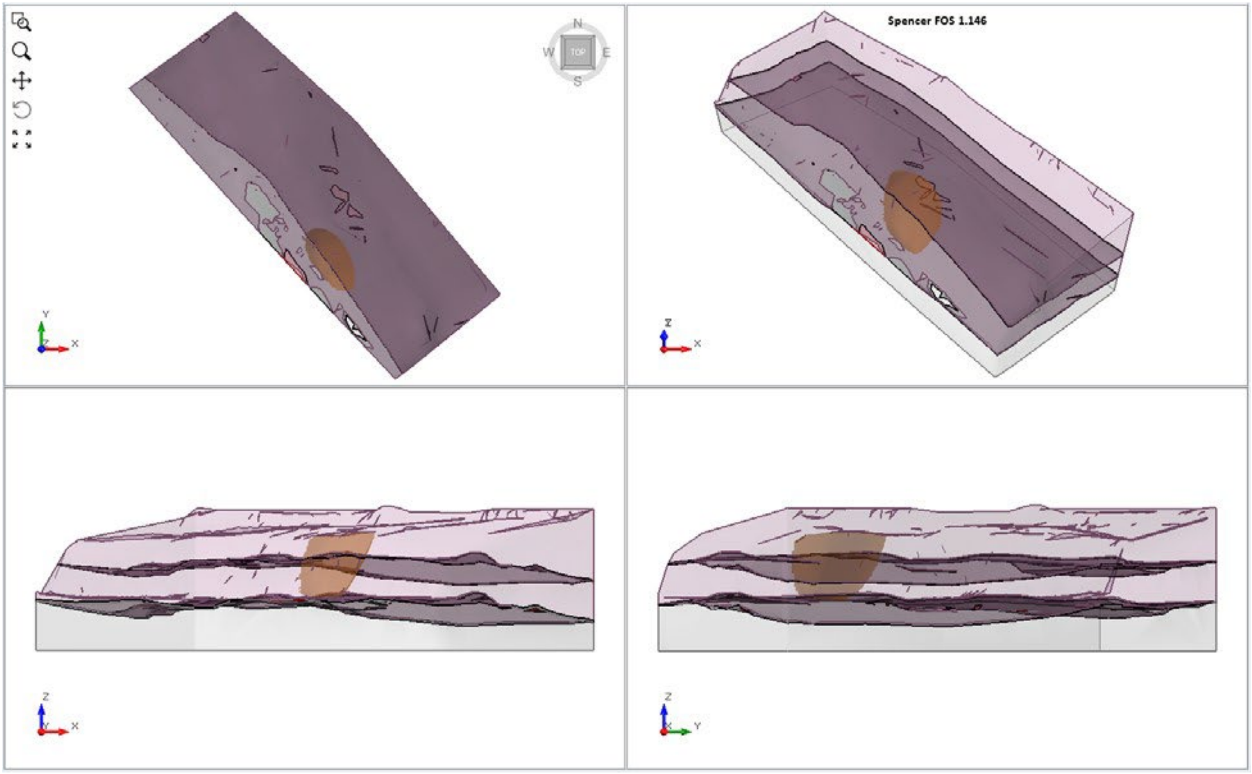

Figure 20.7 – *Slide3* Solution Using the Spencer Method

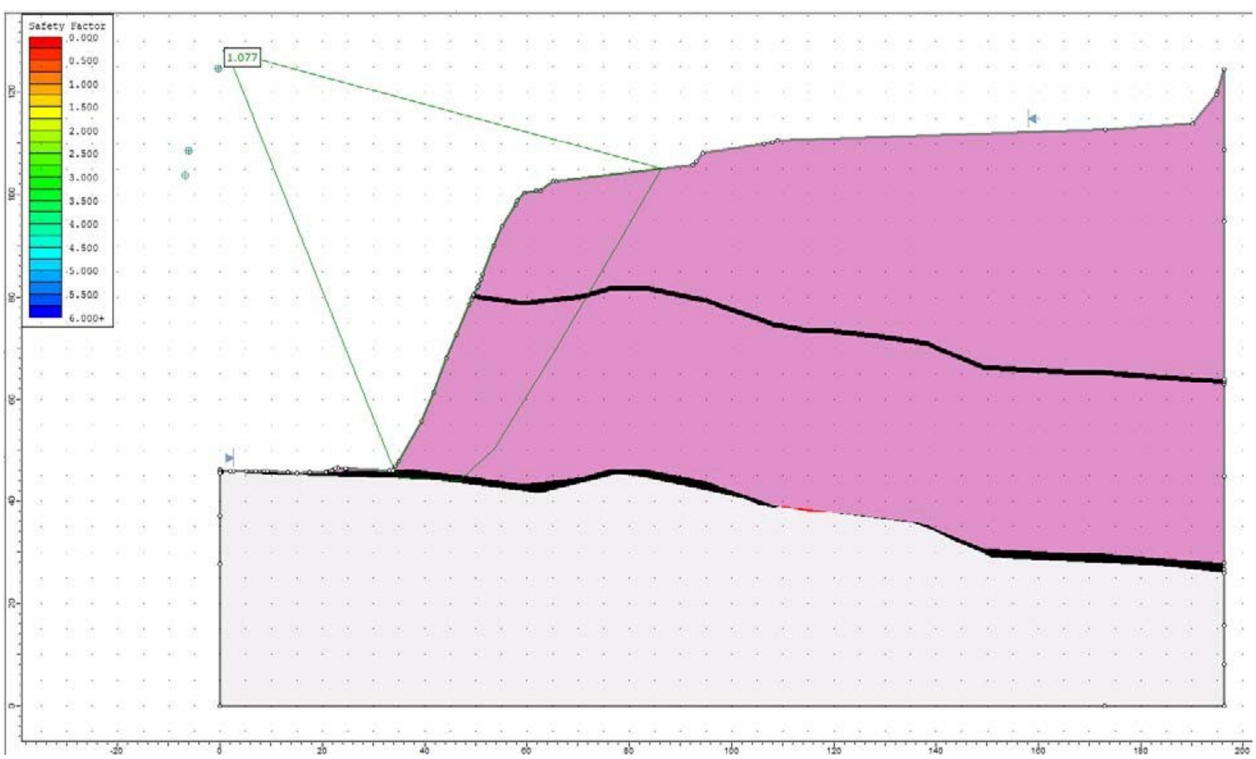

Figure 20.8 – *Slide3* Solution Using the Spencer Method

21. 3D Verification #21

21.1. 3D slope with embankment, (5) materials, ellipsoidal with SA

21.1.1. Introduction

This example is a model of a slope with an embankment. Searching for the failure surface is limited to the embankment using slope limits.

21.1.2. Problem Description

The material properties for this problem can be found in Table 21.1. There is no groundwater in this problem. The slope limits for this problem are defined as the surfaces of the embankment. The ellipsoidal slip surface and corresponding safety factor is required.

21.1.3. Properties

Table 21.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Embankment Fill	10.5	35	18
Sand Fill	0	28	18
Silty Sand	0	33	18
Dense Silty Sand	0	35	18
Silty Clay	15	25	18

21.1.4. Results

Table 21.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.417</td><td>1.204</td><td rowspan="4">1.58</td><td rowspan="4">1.26</td></tr>
<tr><td>GLE</td><td>1.616</td><td>1.261</td></tr>
<tr><td>Janbu</td><td>1.369</td><td>1.164</td></tr>
<tr><td>Spencer</td><td>1.663</td><td>1.291</td></tr>
</table>

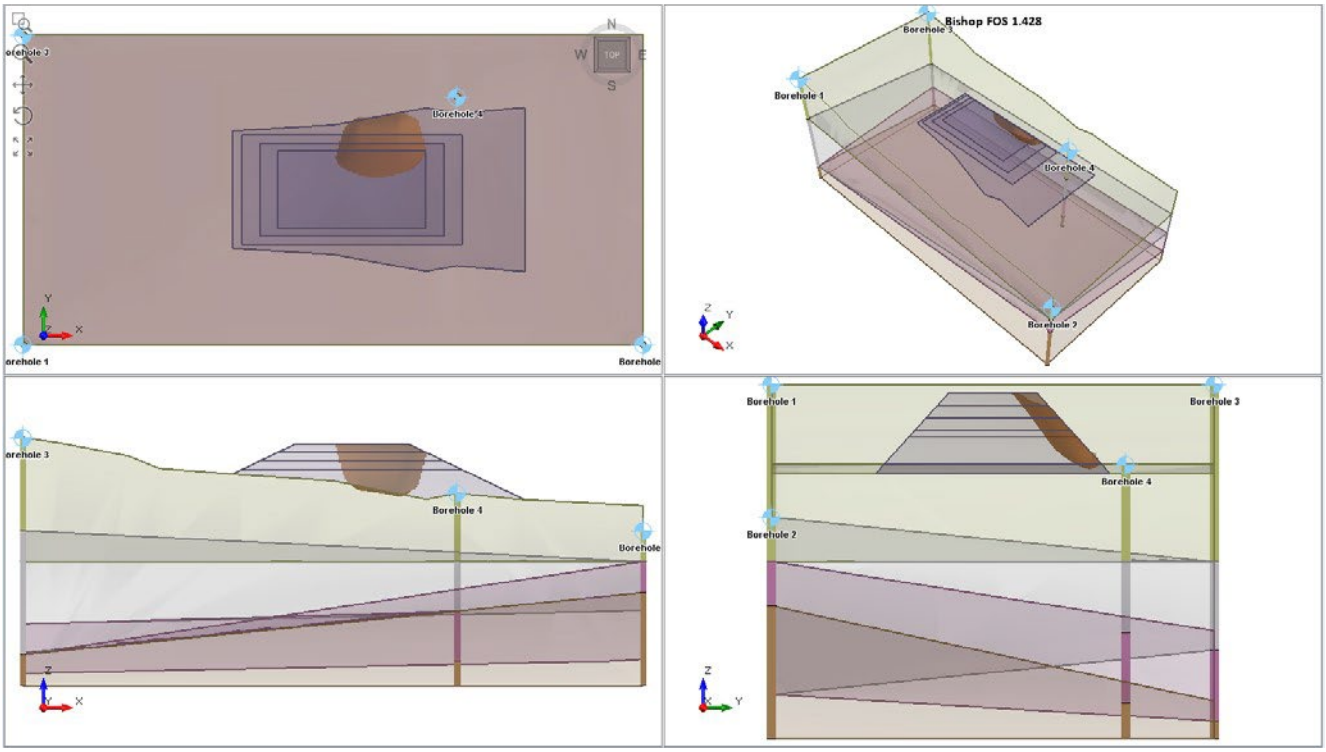

Figure 21.1 – *Slide3* Solution Using the Bishop Method

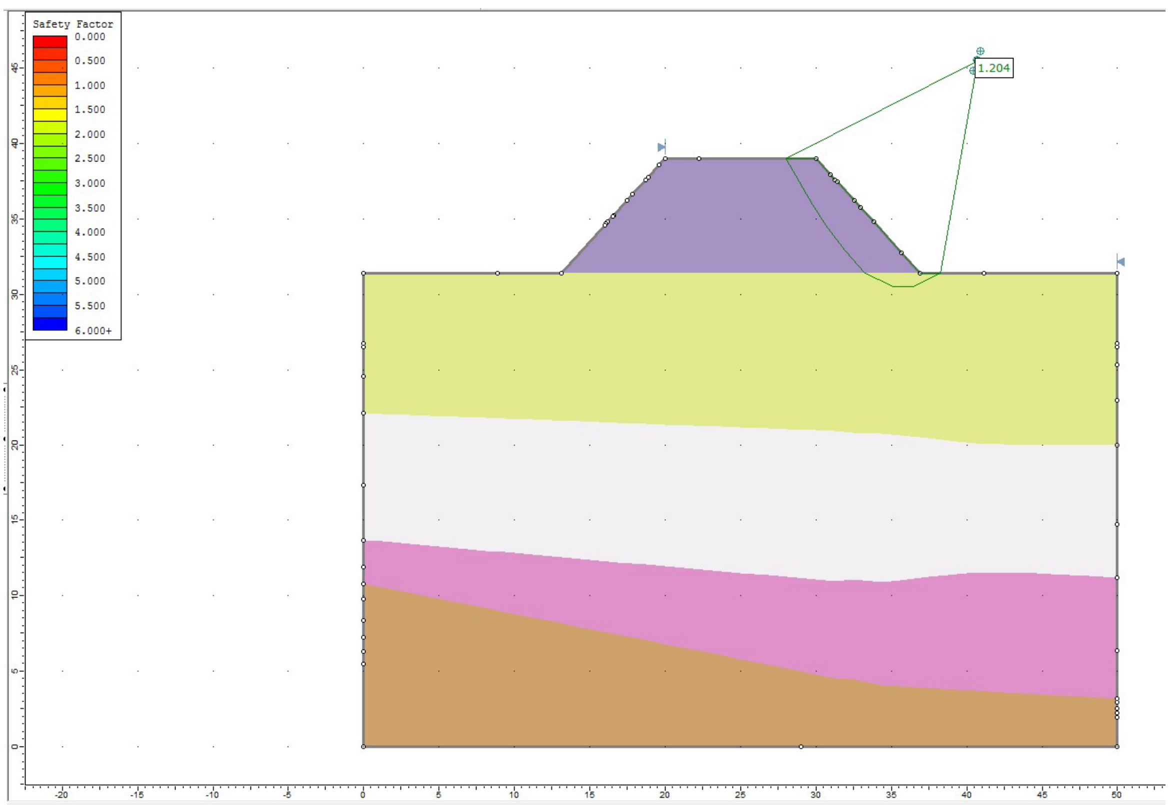

Figure 21.2 – *Slide2* Solution Using the Bishop method

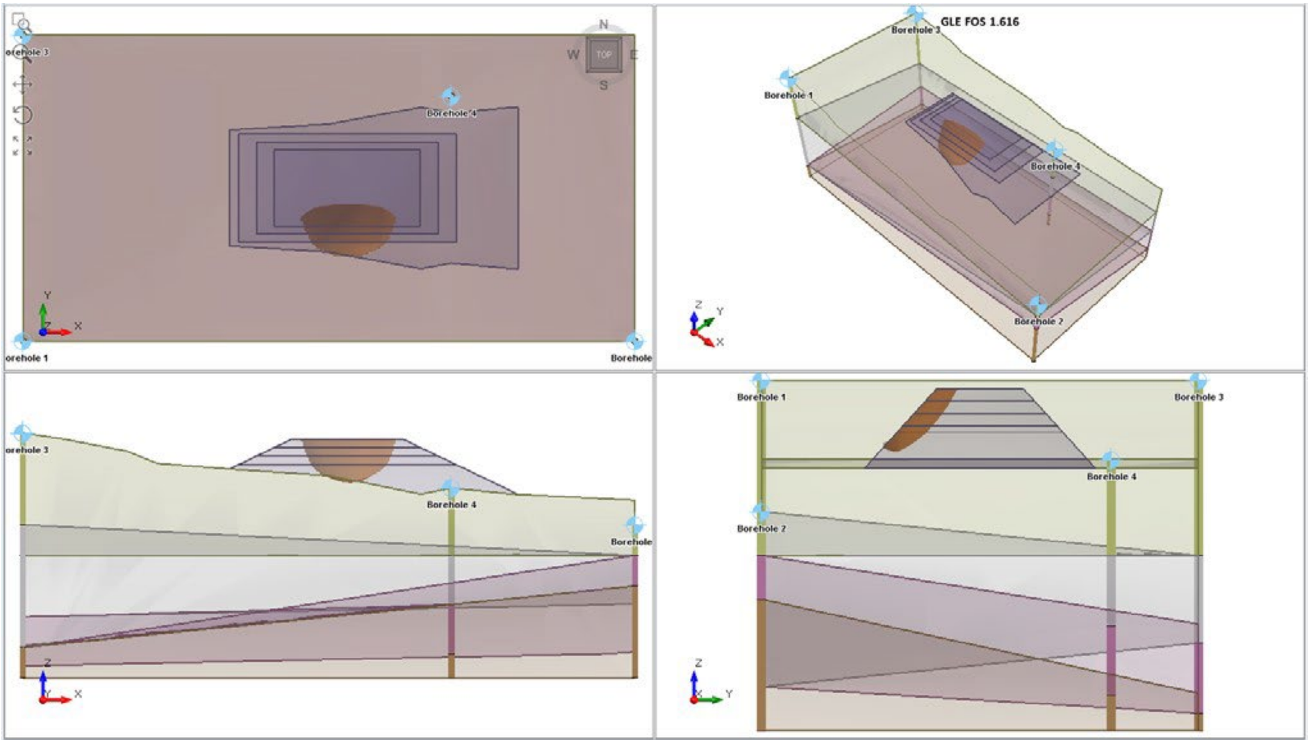

Figure 21.3 – *Slide3* Solution Using the GLE Method

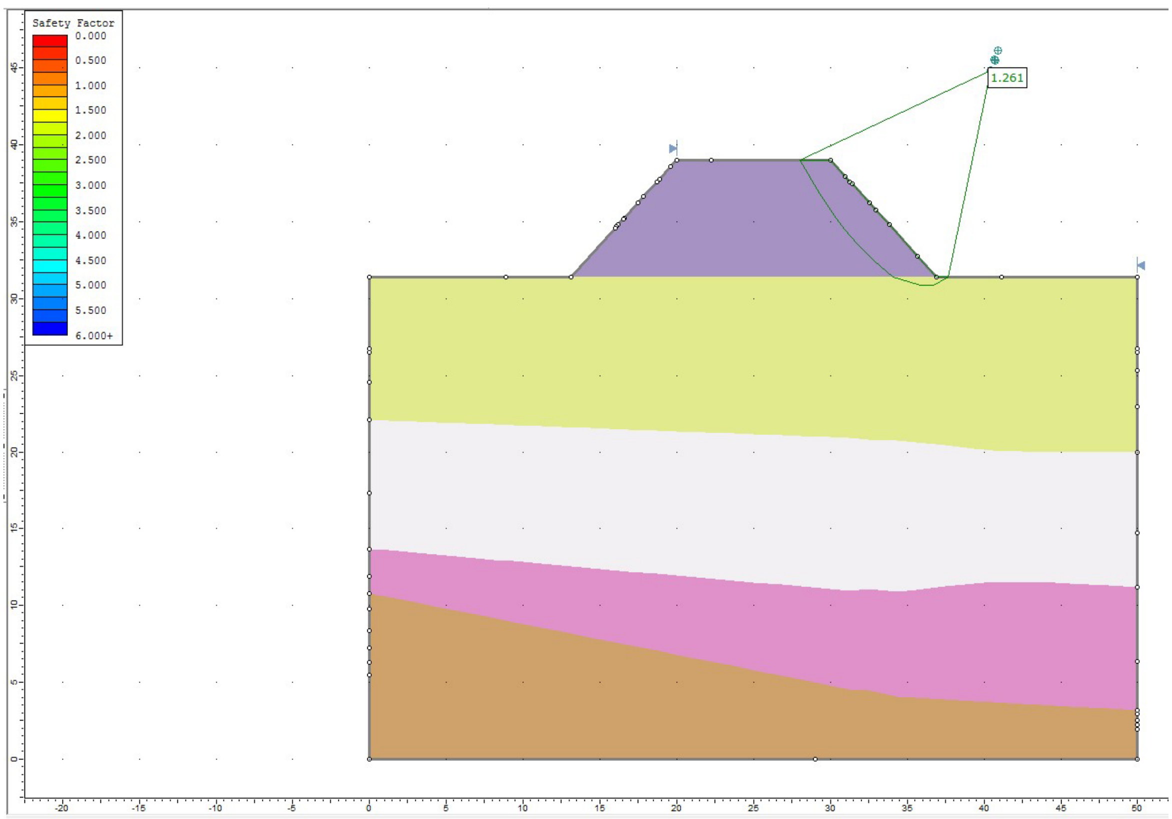

Figure 21.4 – *Slide2* Solution Using the GLE Method

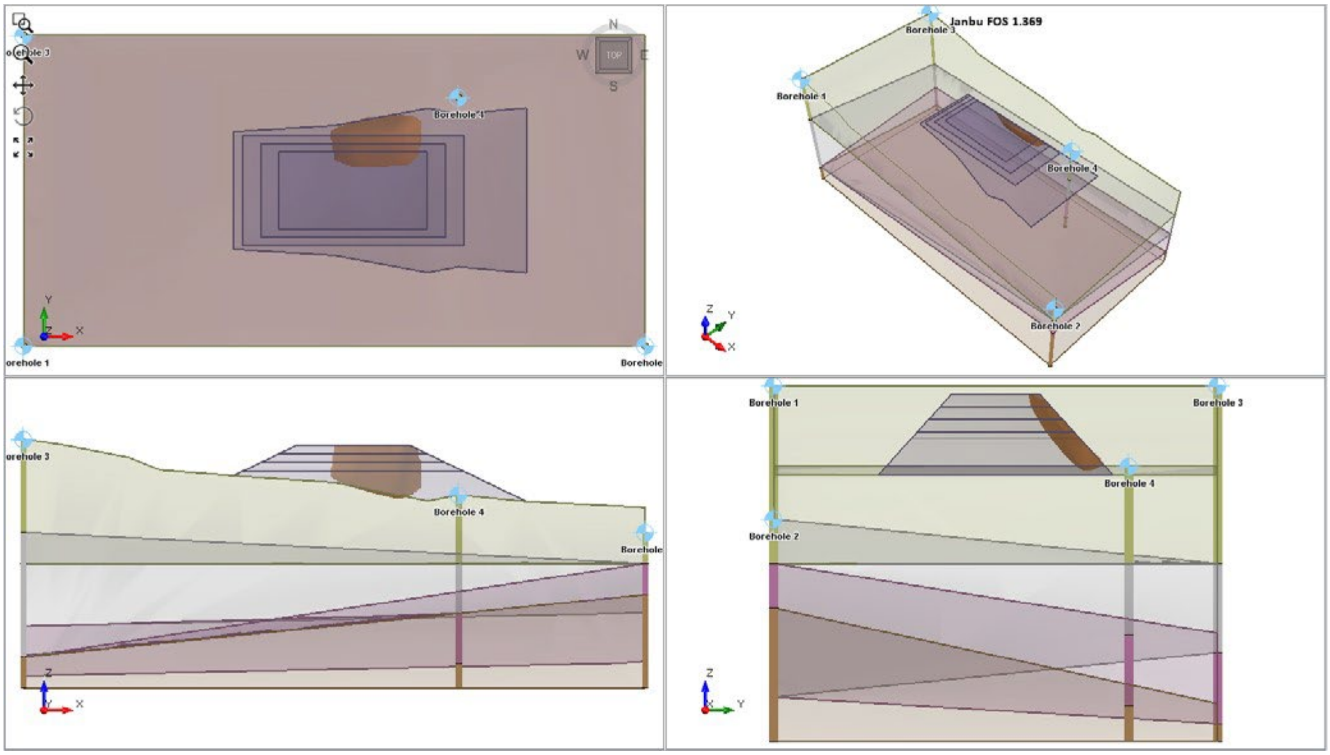

Figure 21.5 – *Slide3* Solution Using the Janbu Method

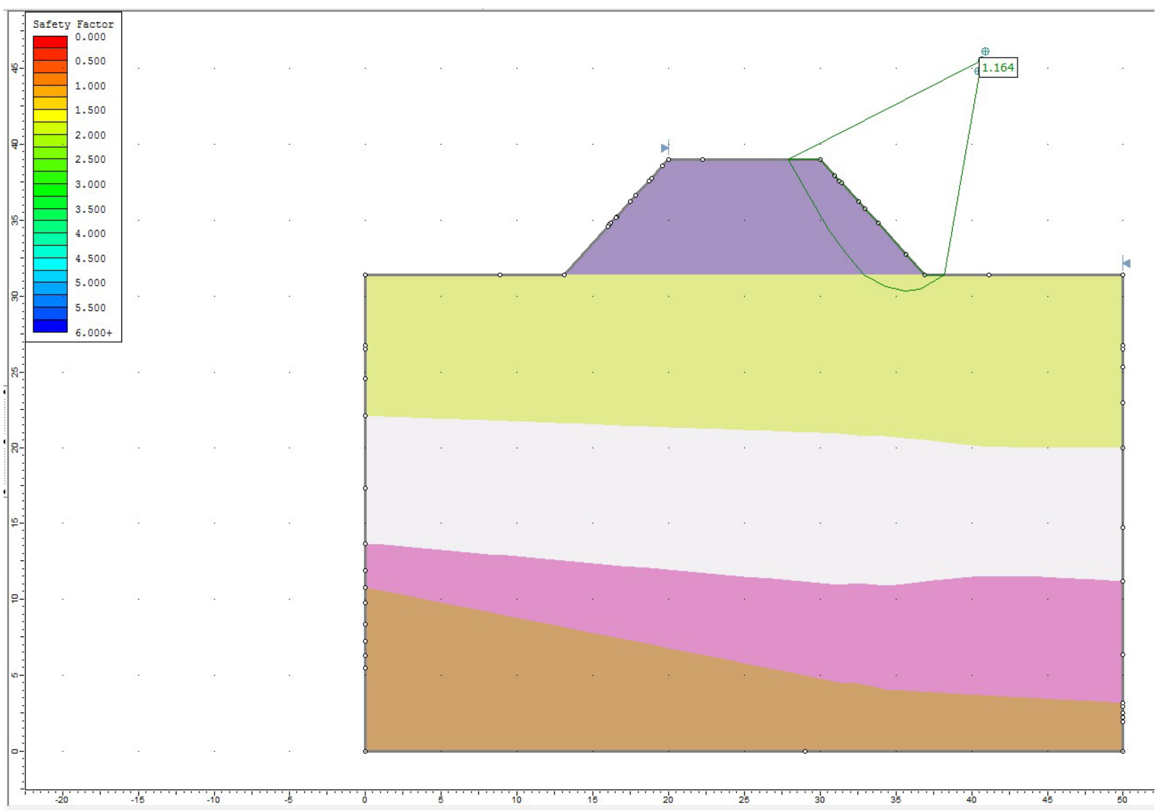

Figure 21.6 – *Slide2* Solution Using the Janbu Method

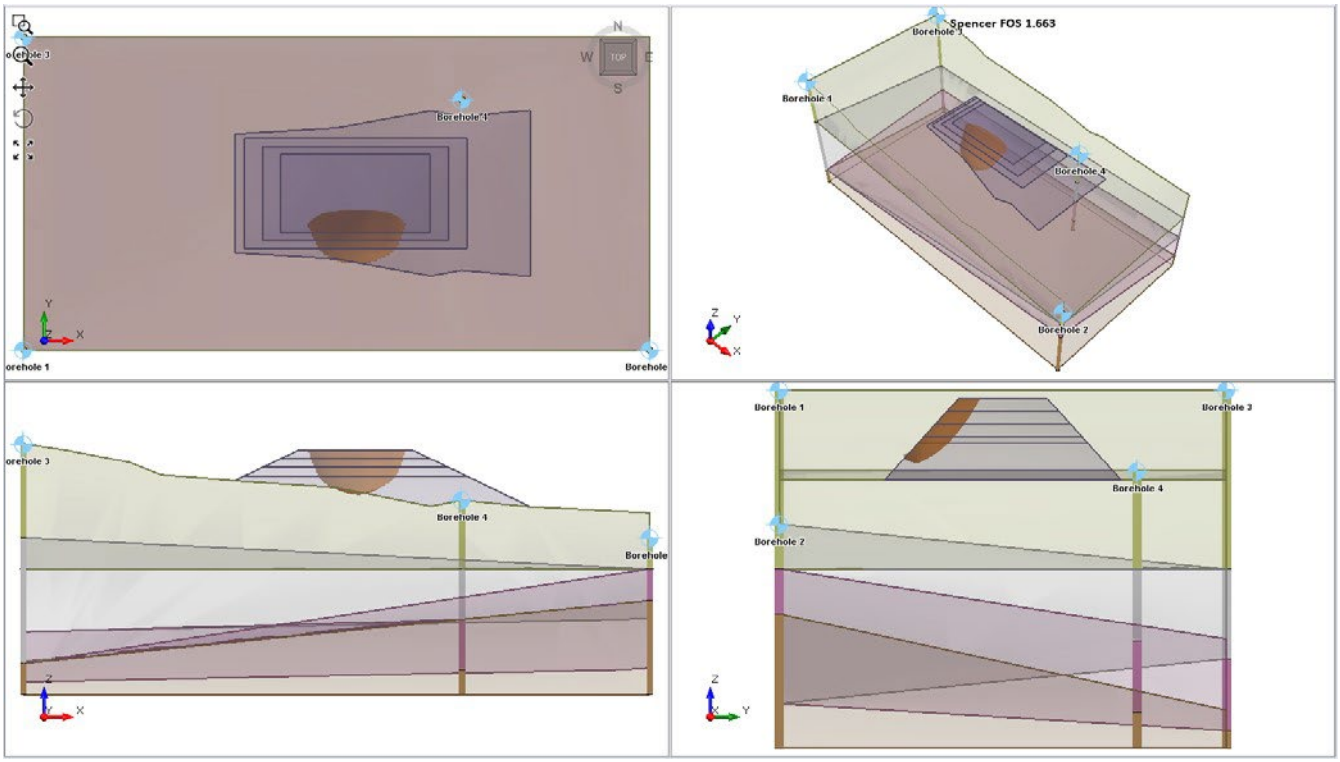

Figure 21.7 – *Slide3* Solution Using the Spencer Method

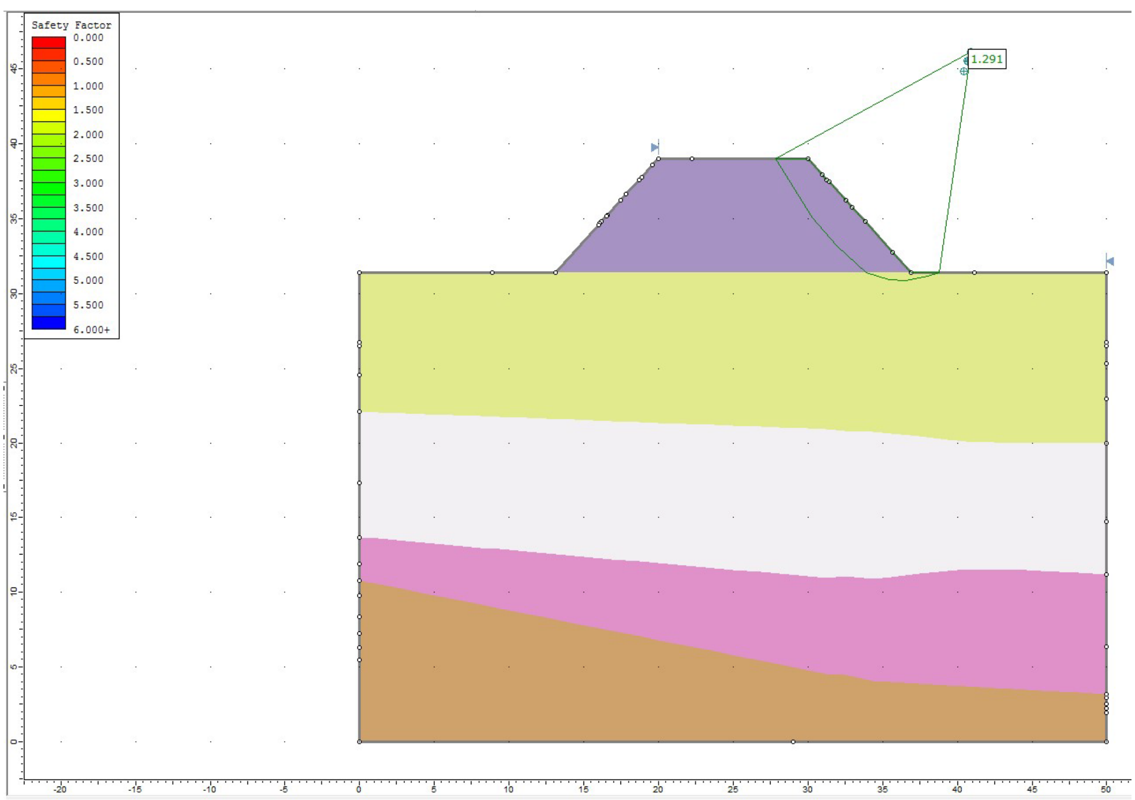

Figure 21.8 – *Slide2* Solution Using the Spencer Method

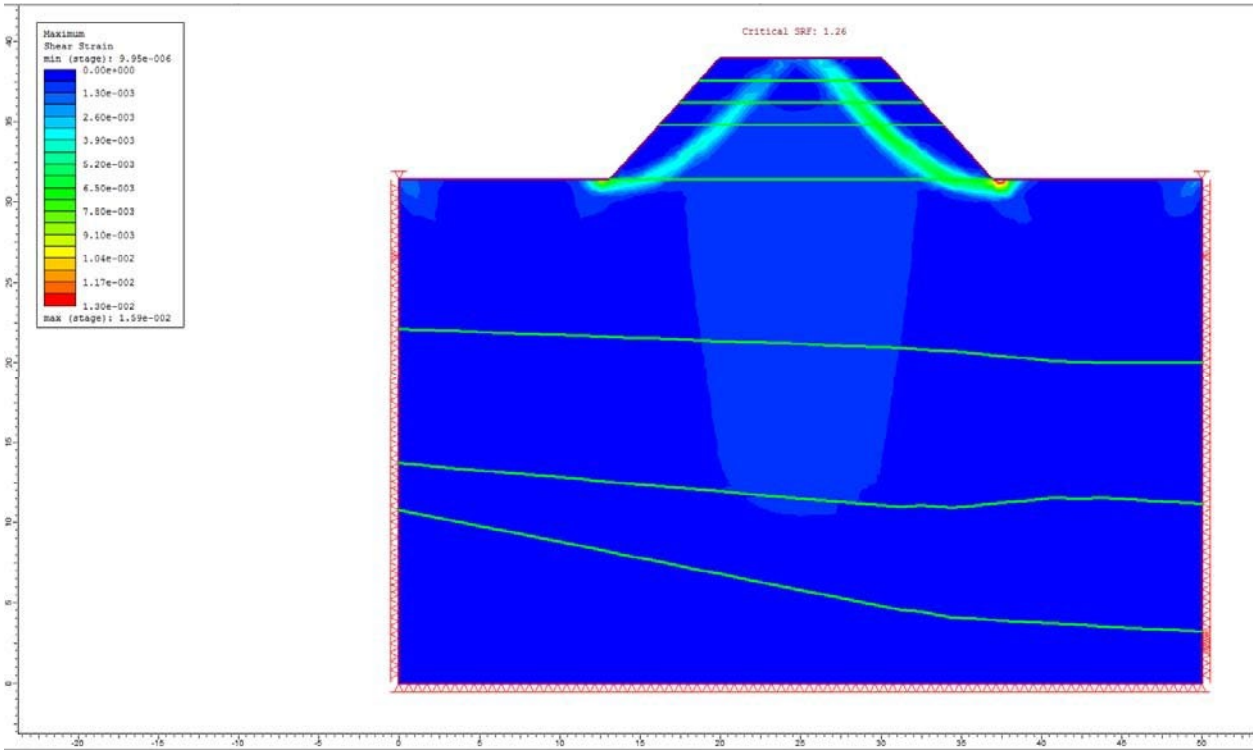

Figure 21.9 – *RS2* Maximum Shear Strain

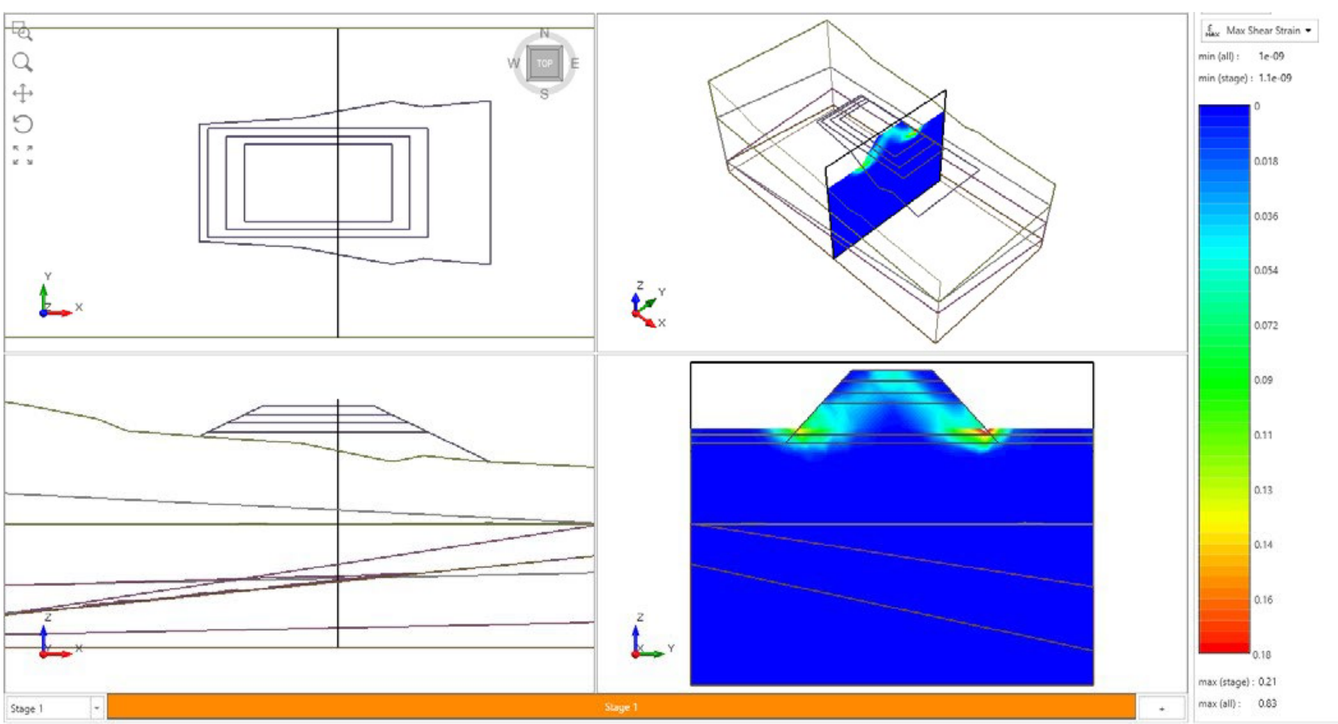

Figure 21.10 – *RS3* Maximum Shear Strain

22. 3D Verification #22

22.1. 3D slope, (6) materials, anisotropic materials, ellipsoidal with SA

22.1.1. Introduction

This model is a non-homogenous slope with anisotropic materials.

22.1.2. Problem Description

The material properties for all the materials used in the slope, as well as the materials used to create the anisotropic materials can be found in Table 22.1. Table 22.2 are the properties of the two anisotropic materials used in the slope. The ellipsoidal slip surface is required.

22.1.3. Properties

Table 22.1: Material Properties

	c´ (kN/m²)	φ´ (deg.)	γ (kN/m³)
M CONG	90	50	30
XT	Infinite Strength		20
IT Classe IV - Paral. Foliação	30	32	25
IT Classe IV - Obliq. Foliação	50	36	25
QTZ XT Classe V - Paral. Foliação	15	22	20
QTZ XT Classe V - Obliq. Foliação	20	32	20

Table 22.2: Anisotropic Properties

Material	γ (kN/m³)	Base Material	Material	Dip	Dip Direction	A	B
IT Class IV - Maciço	25	IT Classe IV - Paral. Foliação	IT Classe IV - Paral. Foliação	27	90	5	10
QTZ XT Classe V - Maciço	20	QTZ XT Classe V - Obliq. Foliação	QTZ XT Classe V - Paral. Foliação	27	90	5	10

22.1.4. Results

Table 22.3: Safety Factors Safety Factors Using *Slide3* and *Slide2* 7.0

Method	*Slide3*	*Slide2* 7.0
Bishop	1.254	1.1
GLE	1.301	1.095
Janbu	1.228	1.053
Spencer	1.285	1.135

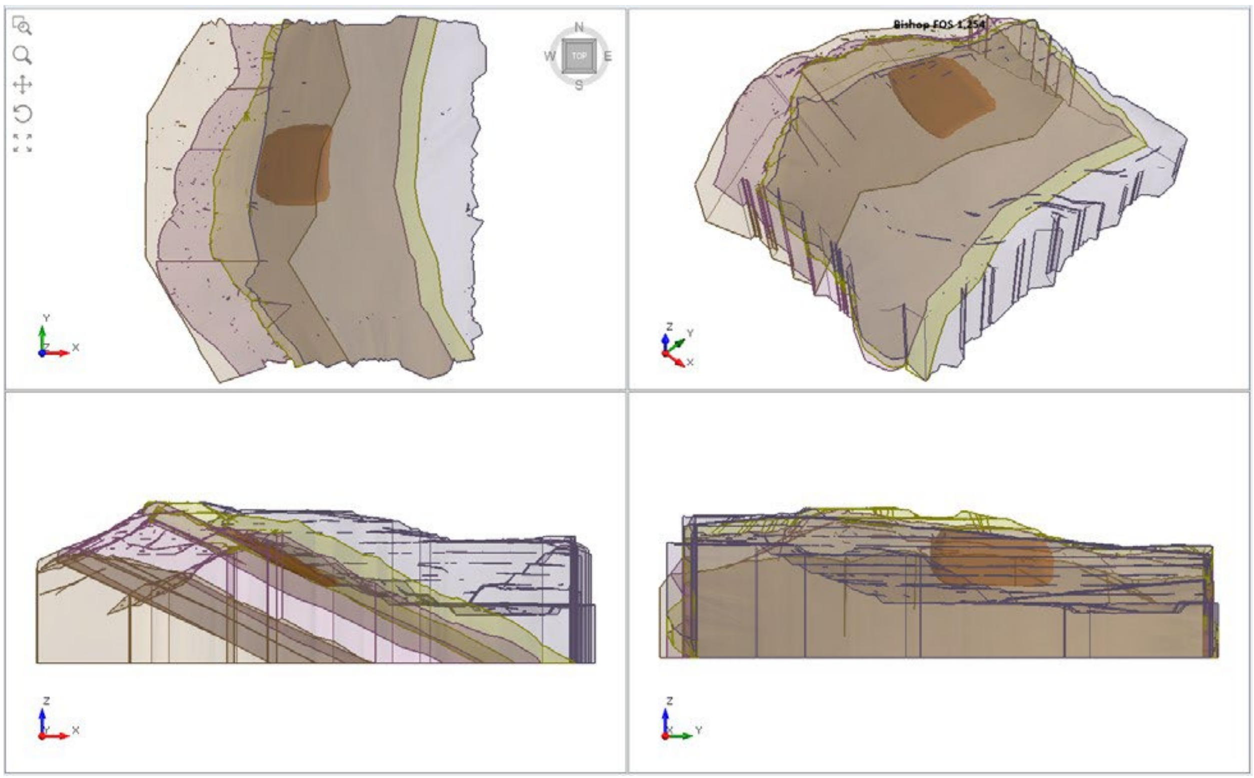

Figure 22.1 – *Slide3* Solution Using the Bishop Method

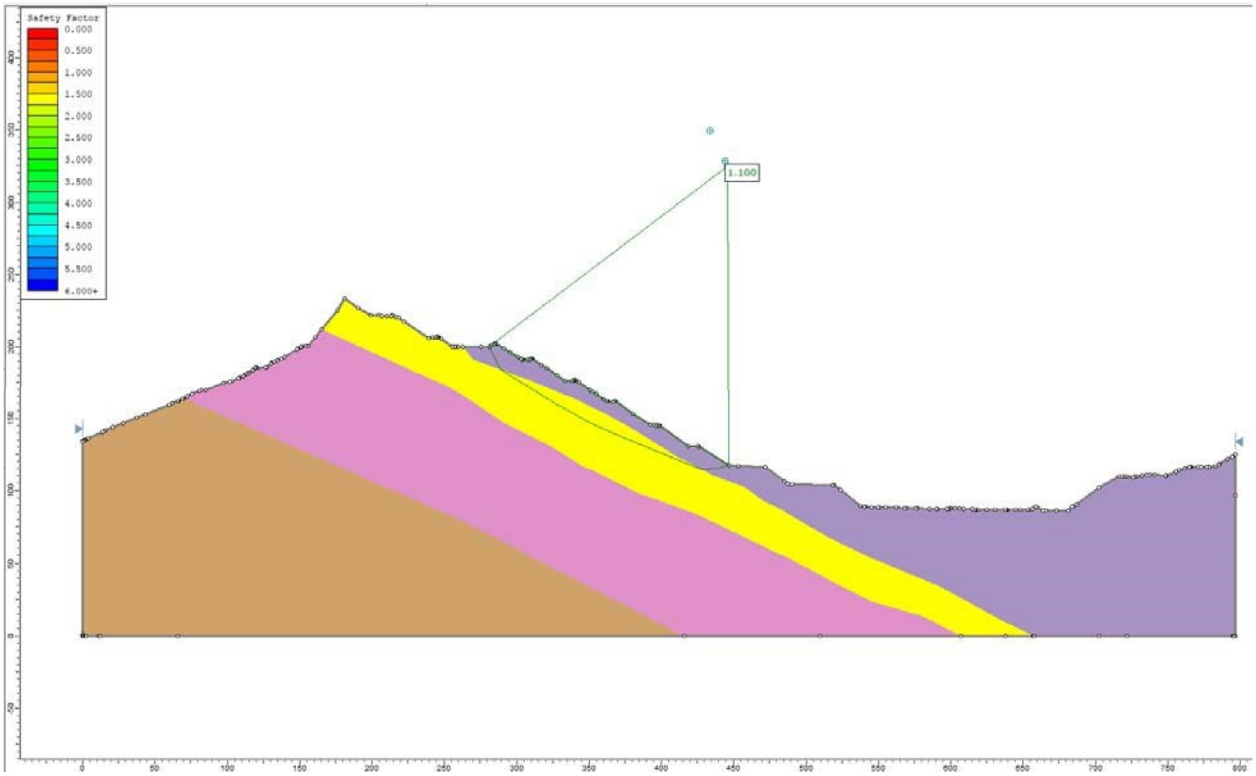

Figure 22.2 – *Slide2* Solution using the Bishop Method

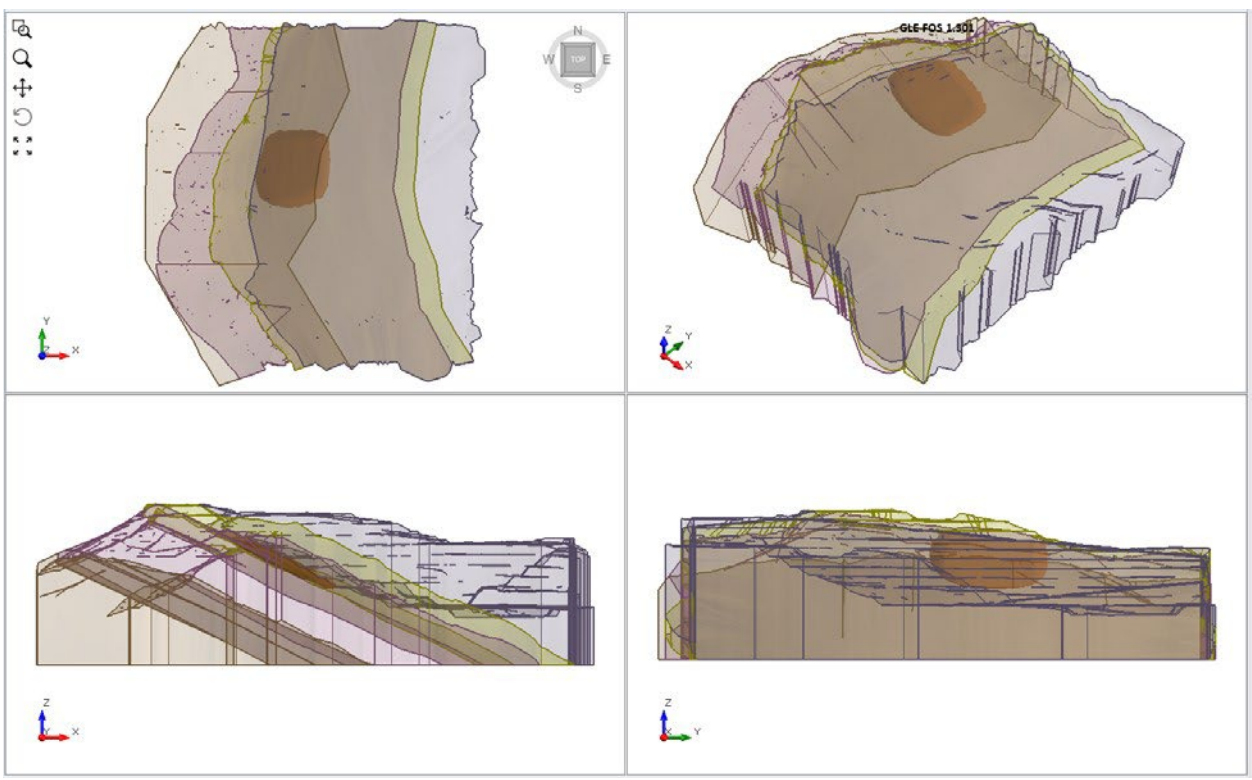

Figure 22.3 – *Slide3* Solution using the GLE Method

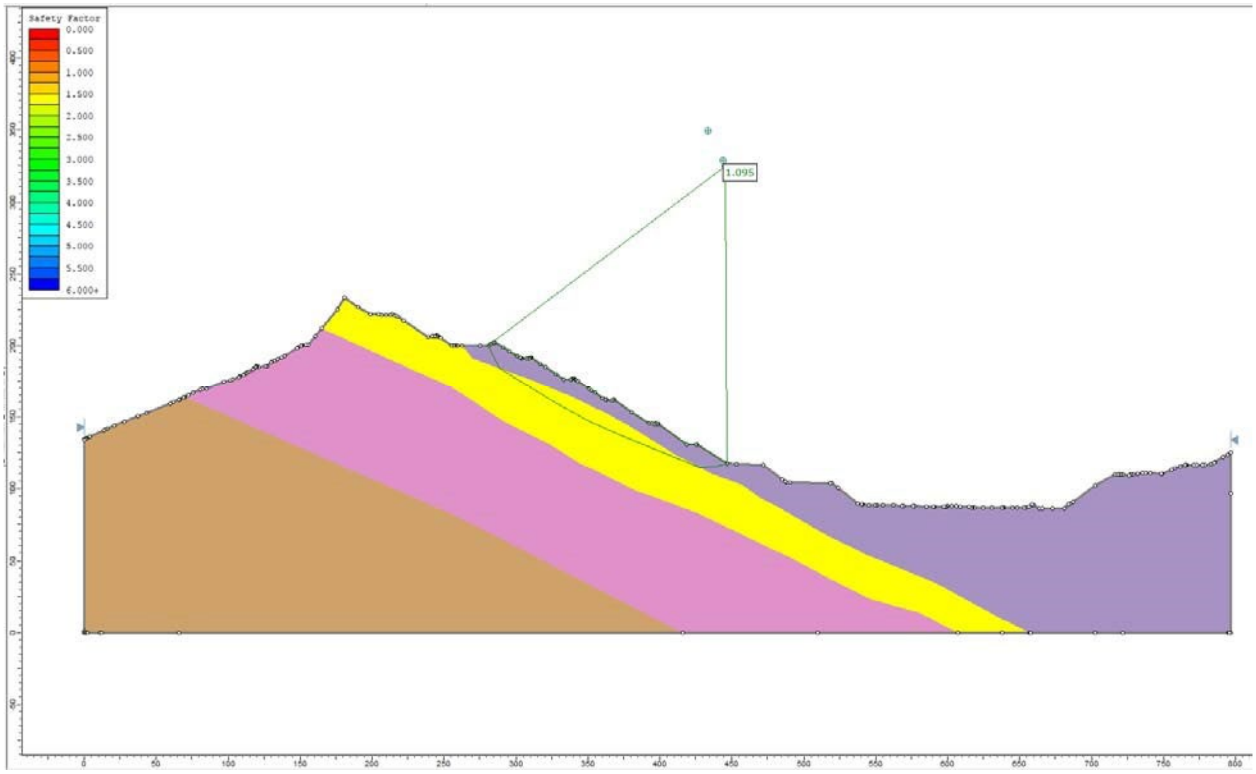

Figure 22.4 – *Slide2* Solution Using the GLE Method

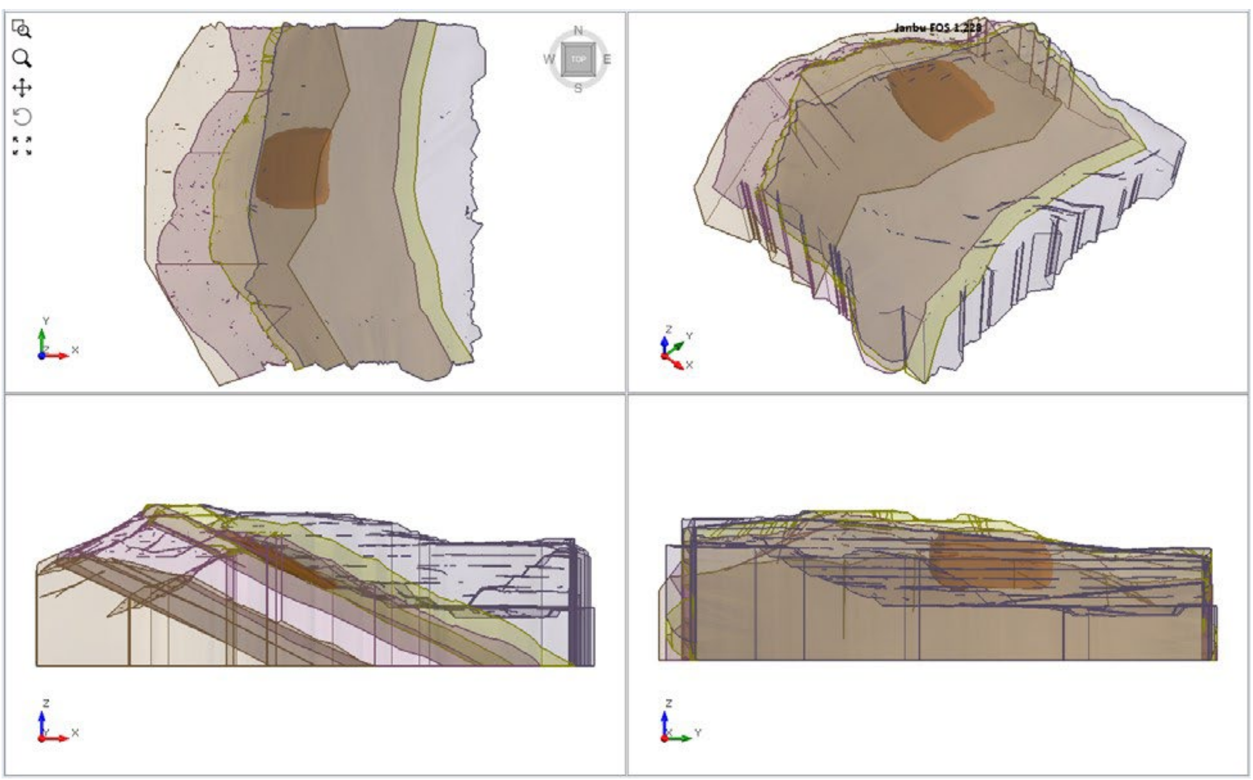

Figure 22.5 – *Slide3* Solution Using the Janbu Method

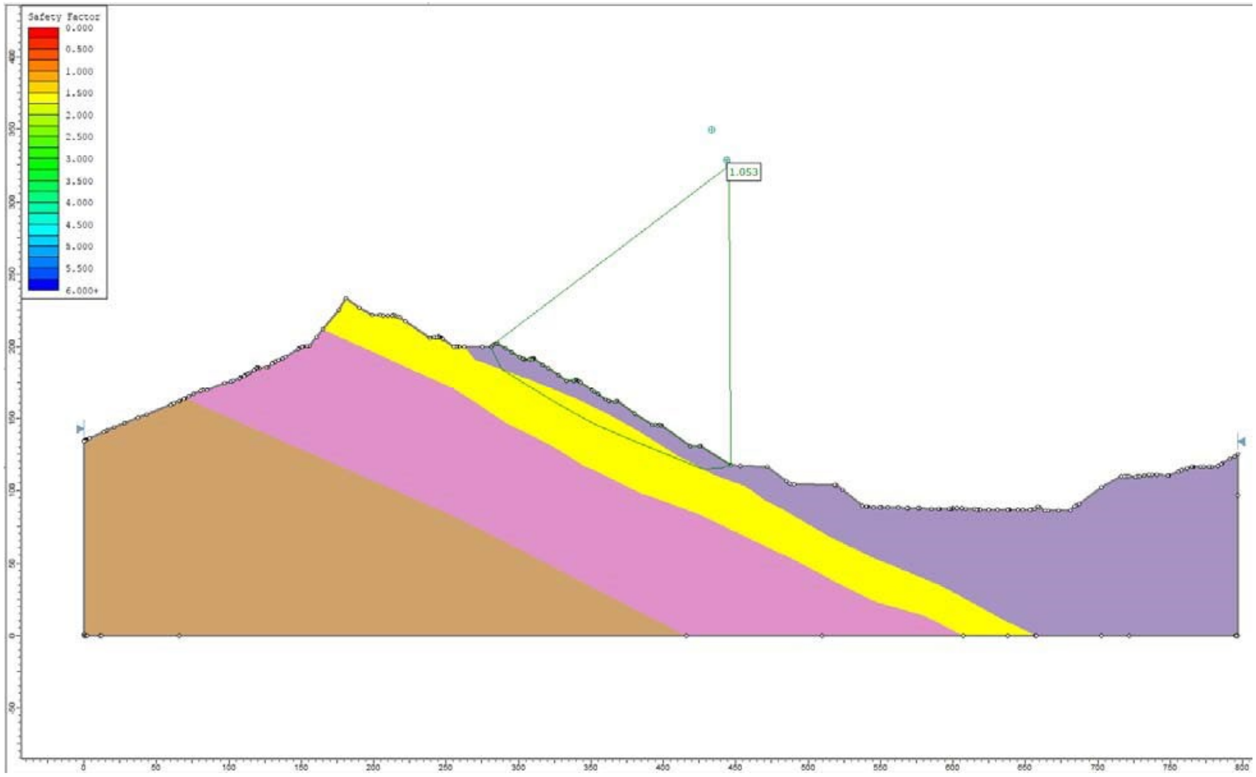

Figure 22.6 – *Slide2* Solution Using the Janbu Method

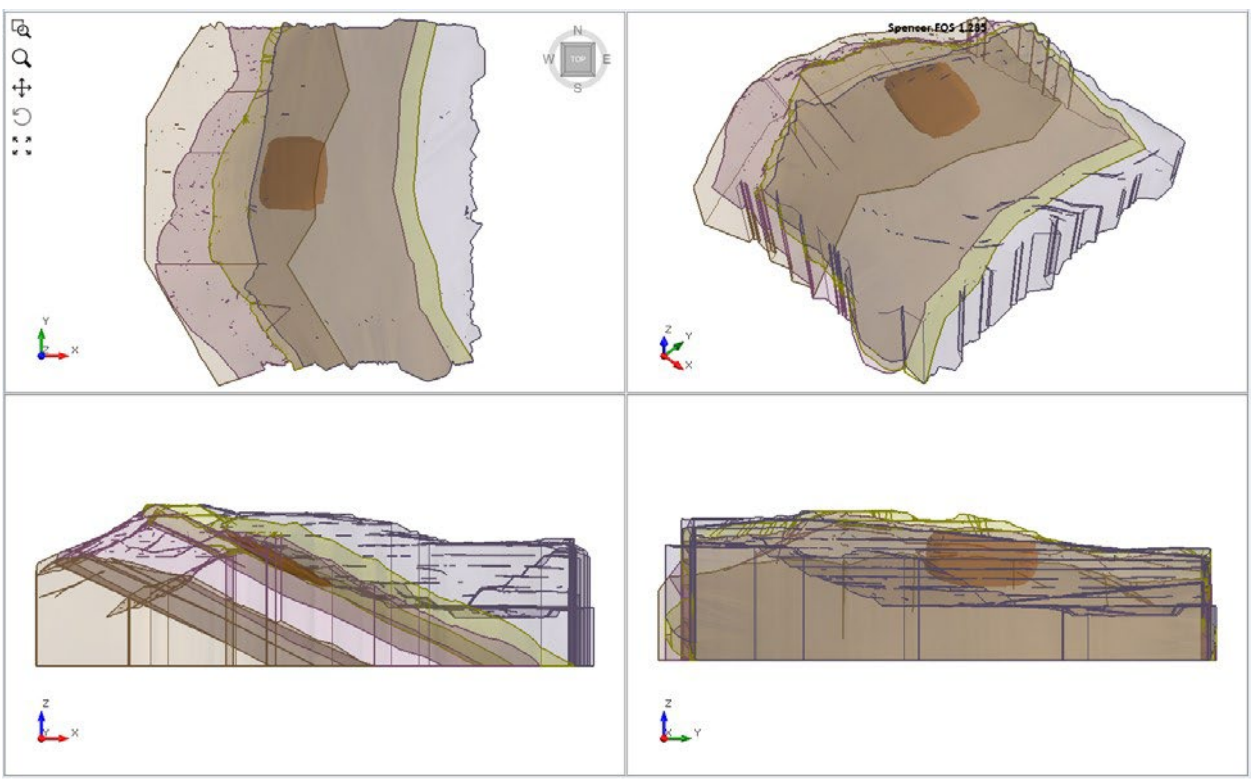

Figure 22.7 – *Slide3* Solution Using the Spencer Method

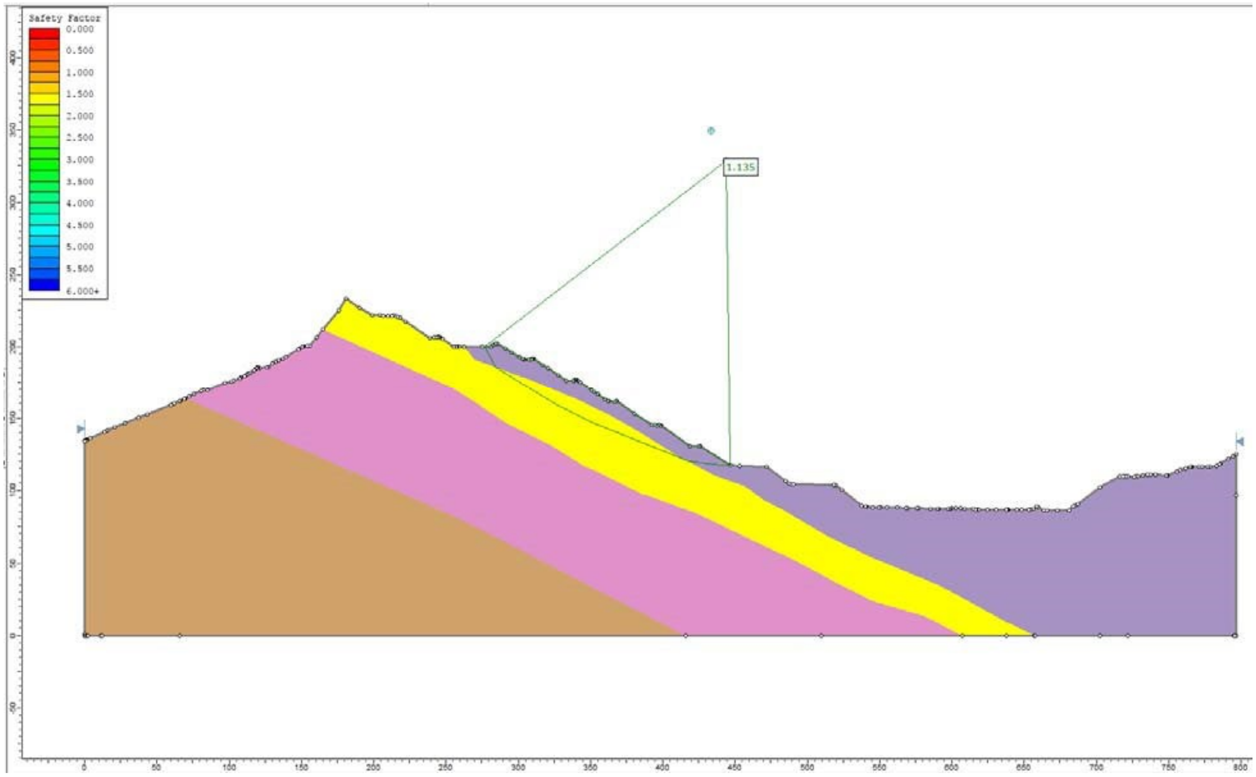

Figure 22.8 – *Slide2* Solution Using the Spencer Method

23. 3D Verification #23

23.1. 3D slope, (4) materials, ellipsoidal with SA

23.1.1. Introduction

This model is taken from Jiang et al. (2009). The Qiaotou Land*Slide2* was caused by drawdown of the Three Gorges Reservoir. This model is the slope that collapsed, however it is initially modeled as a completely dry slope, prior to the collapse, therefore the safety factor should be greater than 1.

23.1.2. Problem Description

The slope was created by lofting seven 2D cross sections to each other. The slope in this problem is made of four materials, the bedrock is modeled as an infinite strength material and the land*Slide2* material is where the failure occurs, therefore there are slope limits confining the slip surface to the surface of the land*Slide2* material. The material properties can be found in Table 23.1. The ellipsoidal slip surface is required.

23.1.3. Properties

Table 23.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Land*Slide2* Deposits	36	22	17.658
Alluvial Deposits	0	25	20.601
Cataclasite	0	25	20.601
Bedrock (Infinite Strength)	10000	65	23.544

23.1.4. Results

Table 23.1: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.175</td><td>1.129</td><td rowspan="4">1.12</td><td rowspan="4">1.1</td></tr>
<tr><td>GLE</td><td>1.174</td><td>1.120</td></tr>
<tr><td>Janbu</td><td>1.135</td><td>1.092</td></tr>
<tr><td>Spencer</td><td>1.184</td><td>1.128</td></tr>
</table>

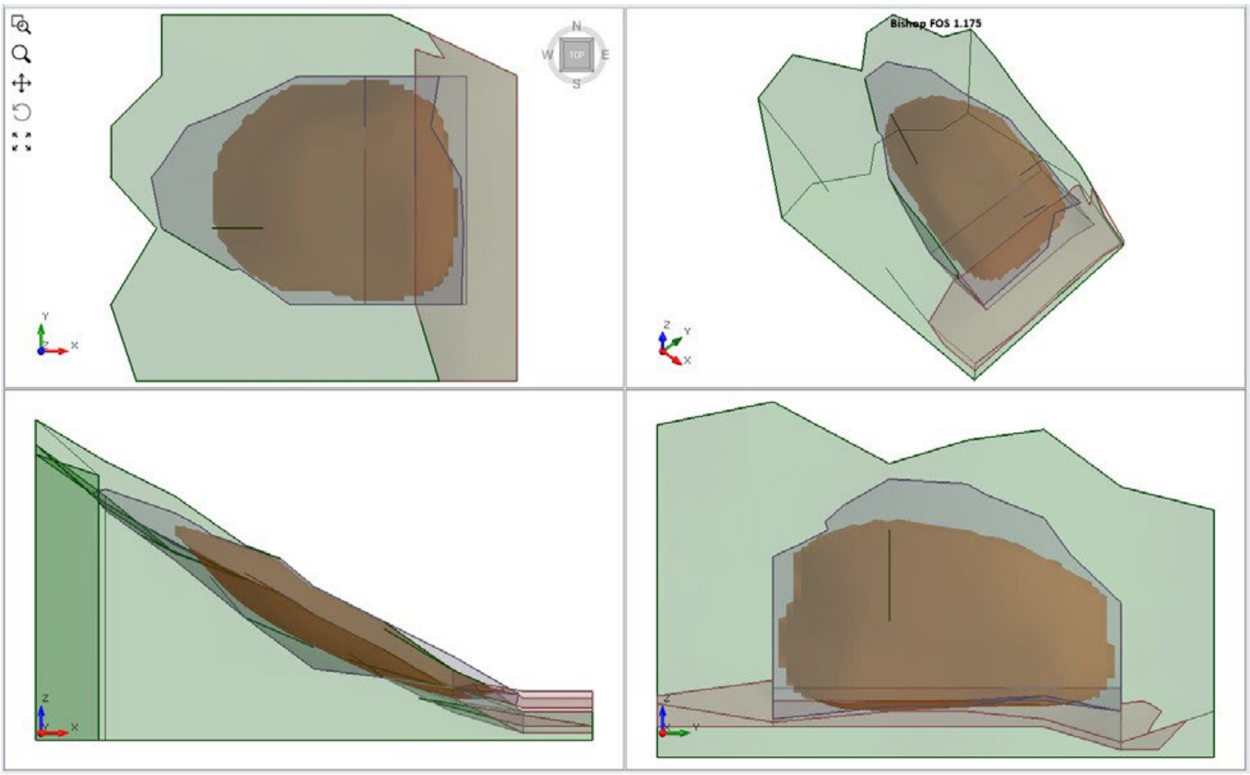

Figure 23.1 – *Slide3* Solution Using the Bishop Method

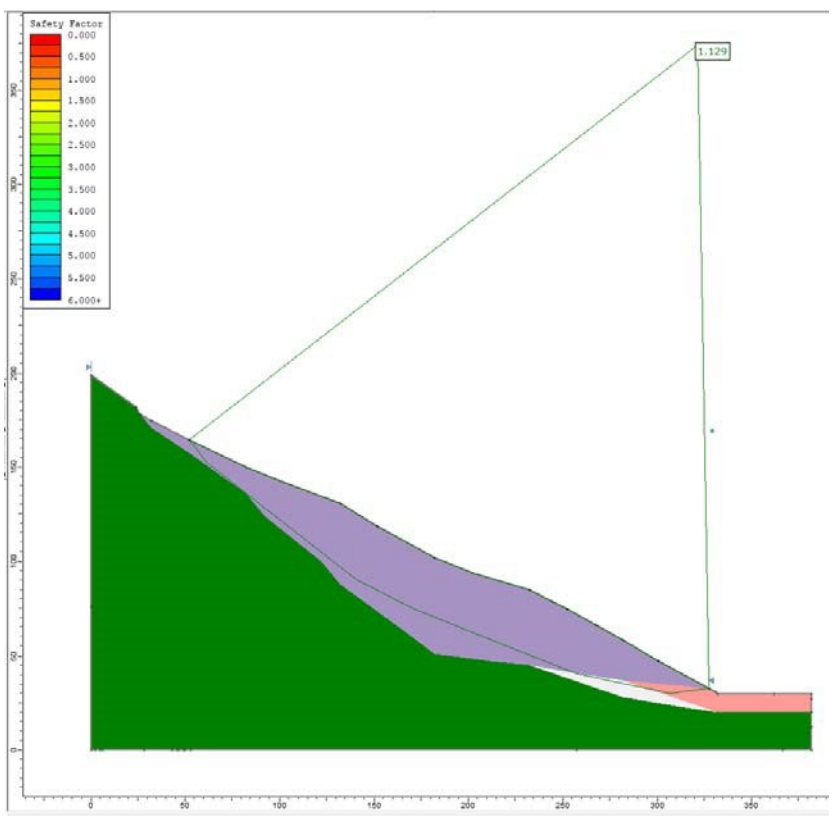

Figure 23.2 – *Slide2* Solution using the Bishop Method

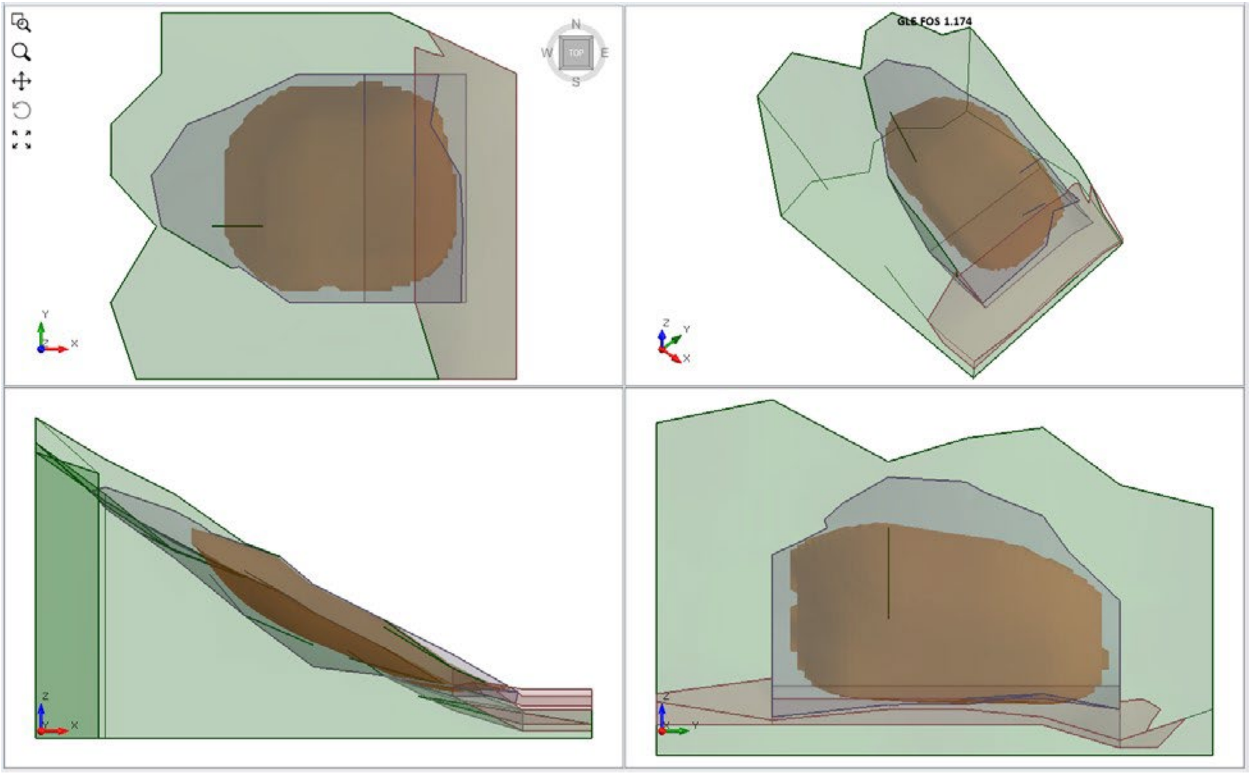

Figure 23.3 – *Slide3* Solution Using the GLE Method

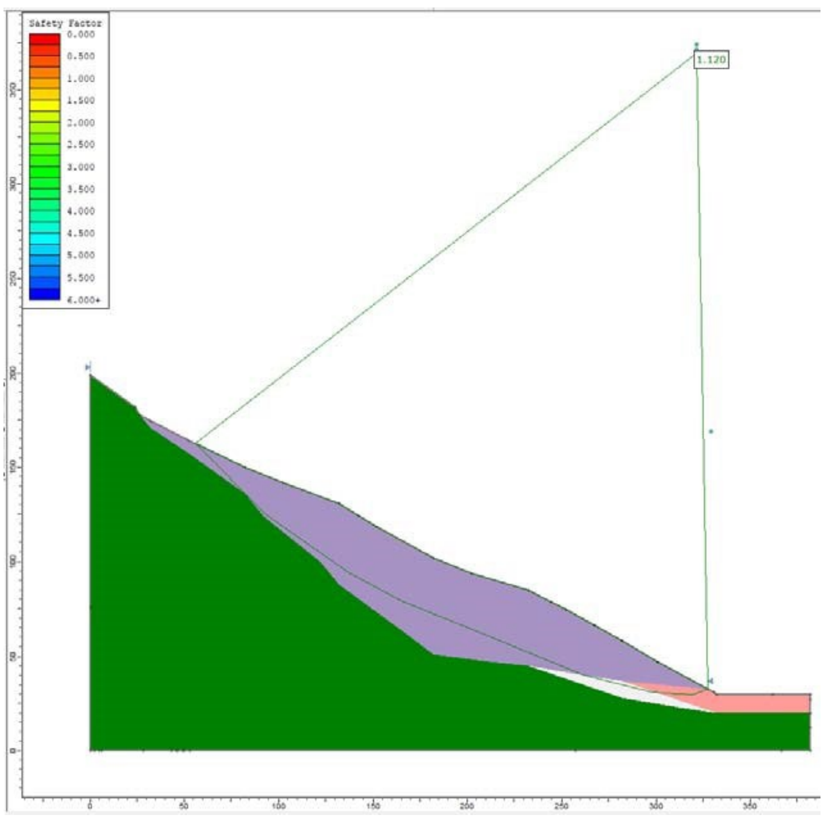

Figure 23.4 – *Slide2* Solution Using the GLE Method

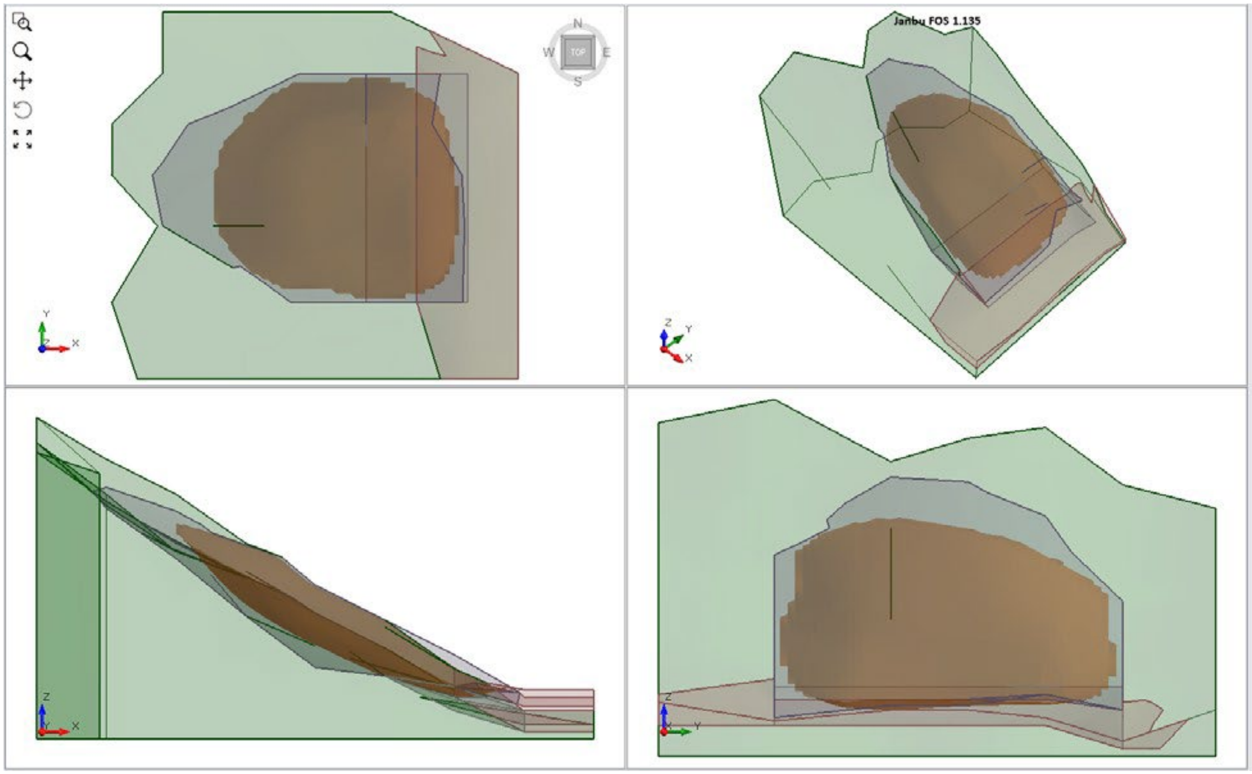

Figure 23.5 – *Slide3* Solution Using the Janbu Method

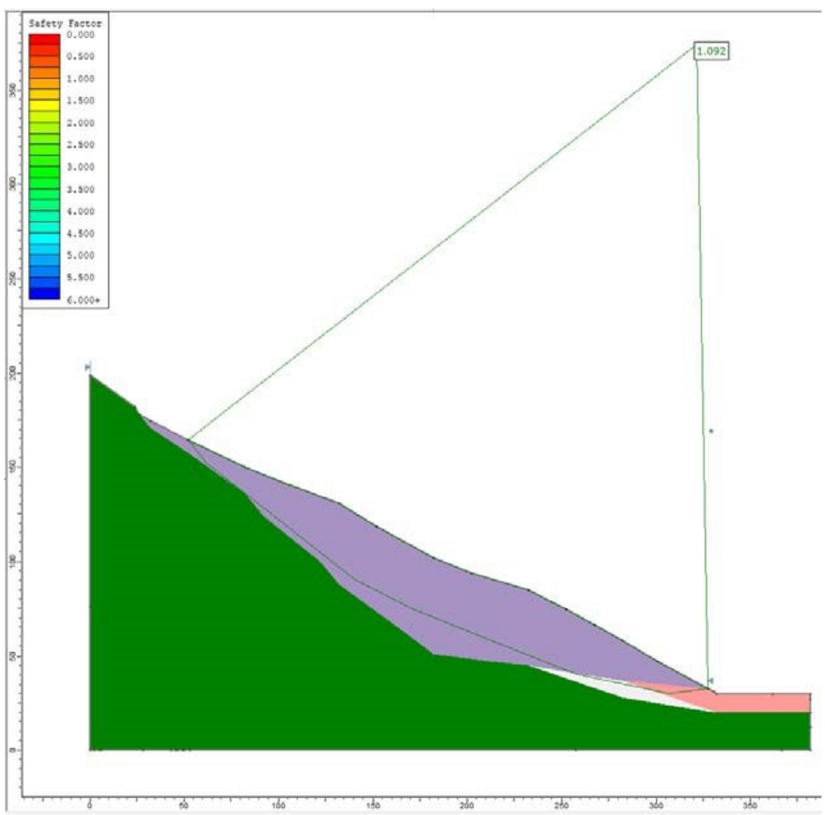

Figure 23.6 – *Slide2* Solution Using the Janbu Method

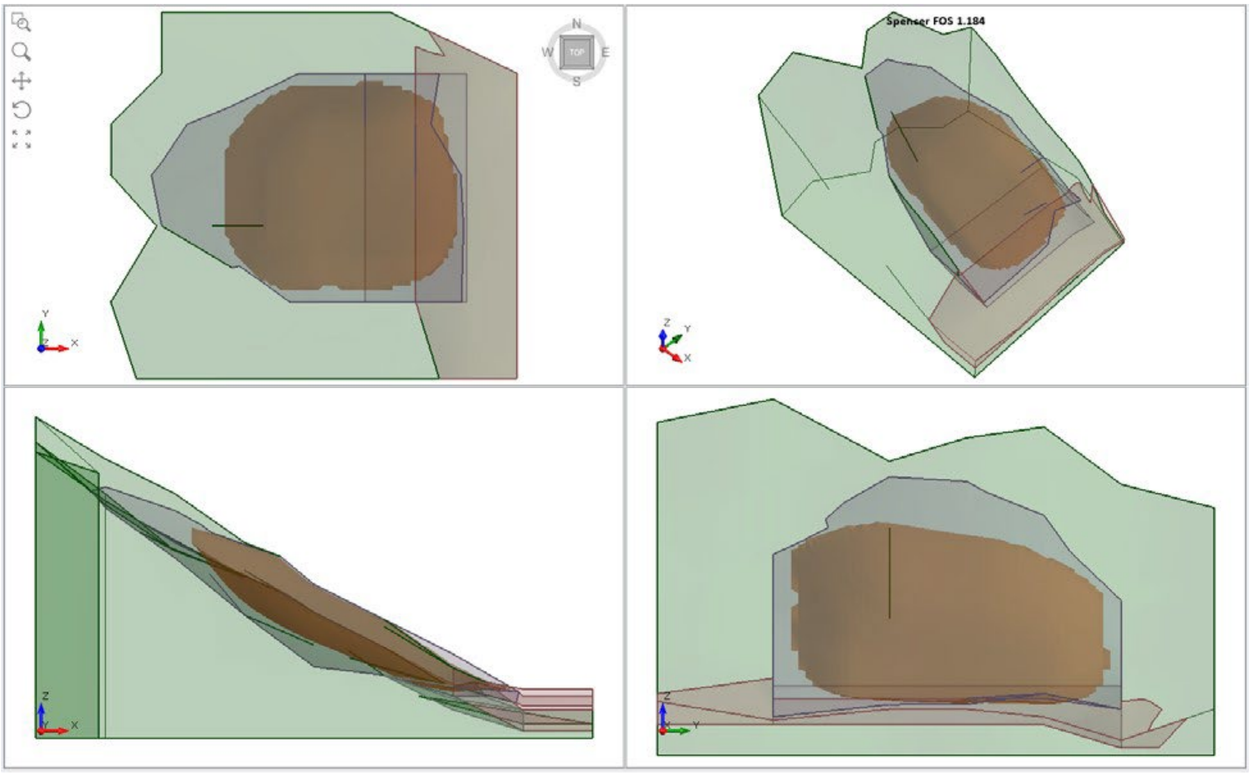

Figure 23.7 – *Slide3* Solution Using the Spencer Method

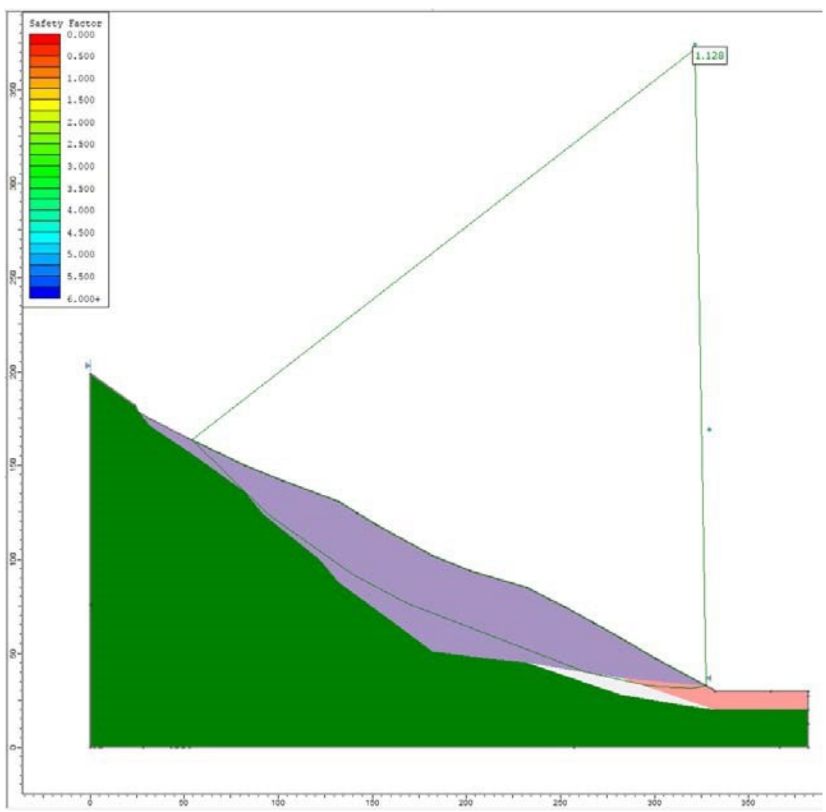

Figure 23.8 – *Slide2* Solution Using the Spencer Method

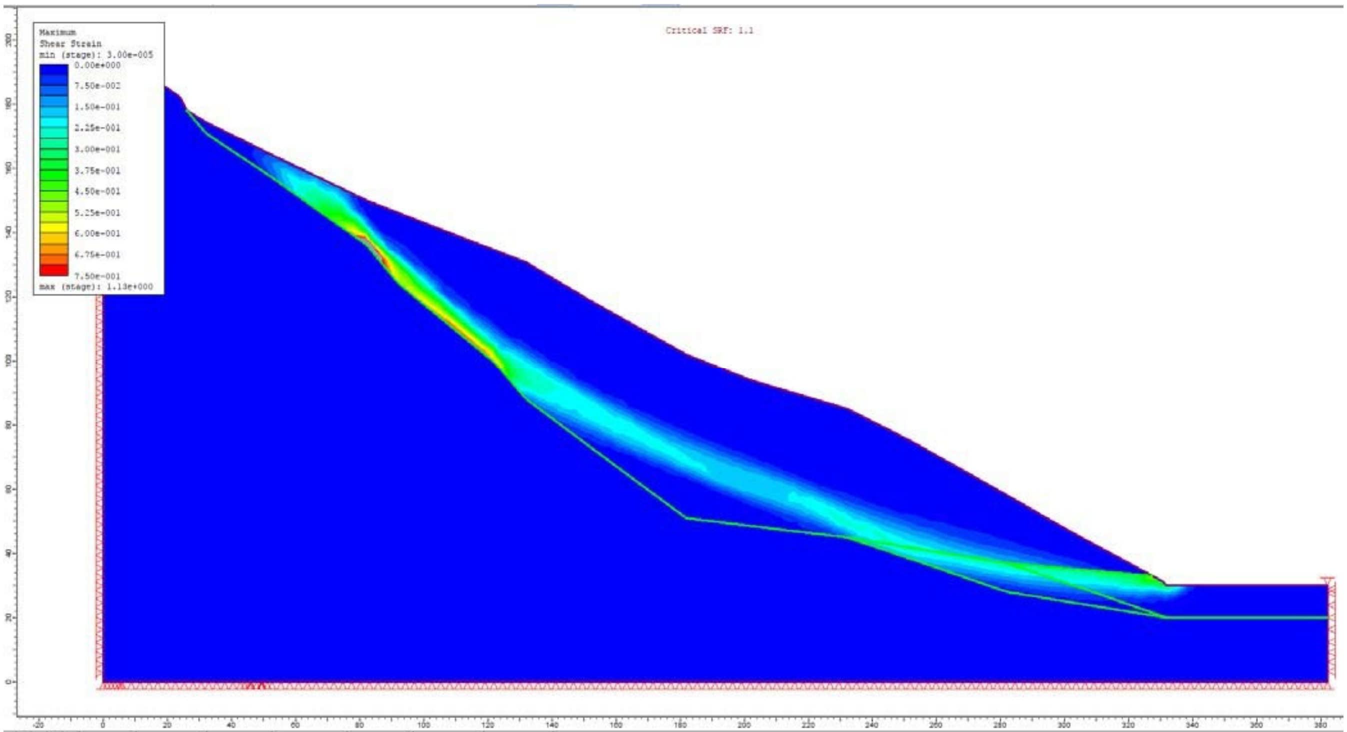

Figure 23.9 – *RS2* Maximum Shear Strain

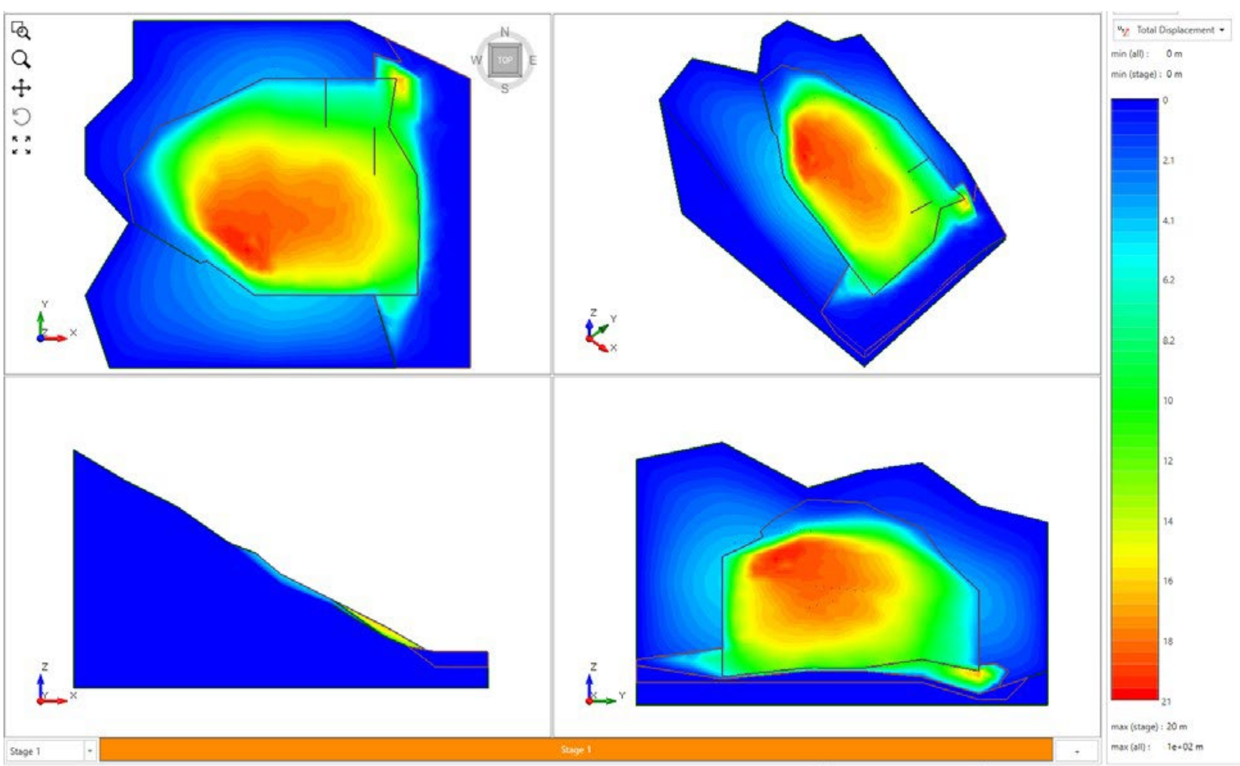

Figure 23.10 – *RS3* Total Displacement

24. 3D Verification #24

24.1. 3D slope, (4) materials + (2) saturated materials, water table, ellipsoidal with SA

24.1.1. Introduction

This model is taken from Jiang et al. (2009). The Qiaotou Land*Slide2* was caused by drawdown of the Three Gorges Reservoir. This model is the slope that collapsed, however it is initially modeled as a slope with a steady water table, at the initial height of the drawdown, Z = 175m.

24.1.2. Problem Description

The slope was created by lofting seven 2D cross sections to each other. The slope in this problem is made of four materials, the bedrock is modeled as an infinite strength material and the land*Slide2* material is where the failure occurs, therefore there are slope limits confining the slip surface to the surface of the land*Slide2* material. The slope has been cut at Z = 175m, the same height as the water table, so the materials below the water table can take on different properties (as they are now saturated.) Only the land*Slide2* deposit and bedrock take on these characteristics, the other materials are already underneath the water table. The material properties for both the saturated and unsaturated materials can be found in Table 24.1. The ellipsoidal slip surface is required.

24.1.3. Properties

Table 24.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Land*Slide2* Deposits	36	22	17.658
Alluvial Deposits	0	25	23.544
Cataclasite	0	25	22.563
Bedrock (Infinite Strength)	10000	65	23.544
Wet Land*Slide2*	29	18	21.582
Sat Bedrock (Infinite Strength)	10000	65	24.525

24.1.4. Results

Table 24.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	0.993	0.941	0.9	0.92
GLE	1.002	0.944		
Janbu	0.956	0.899		

Spencer	1.002	0.947		

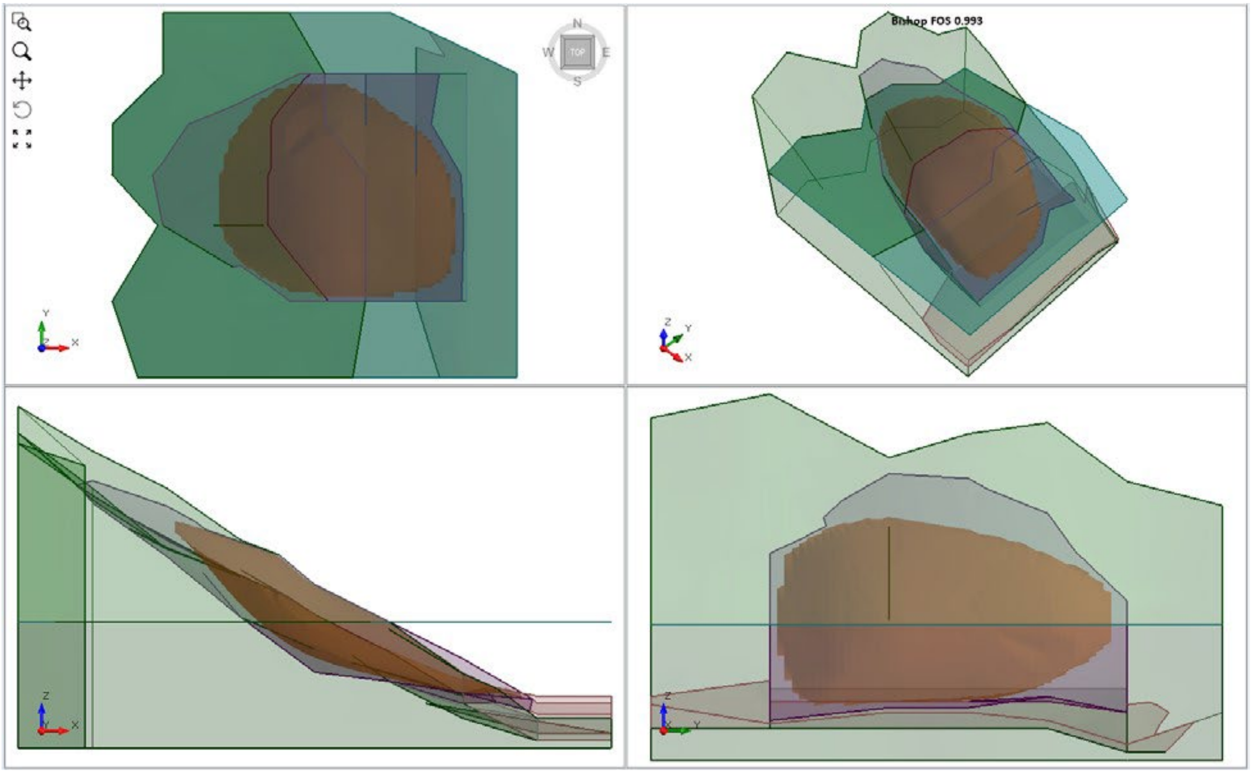

Figure 24.1 – *Slide3* Solution Using the Bishop Method

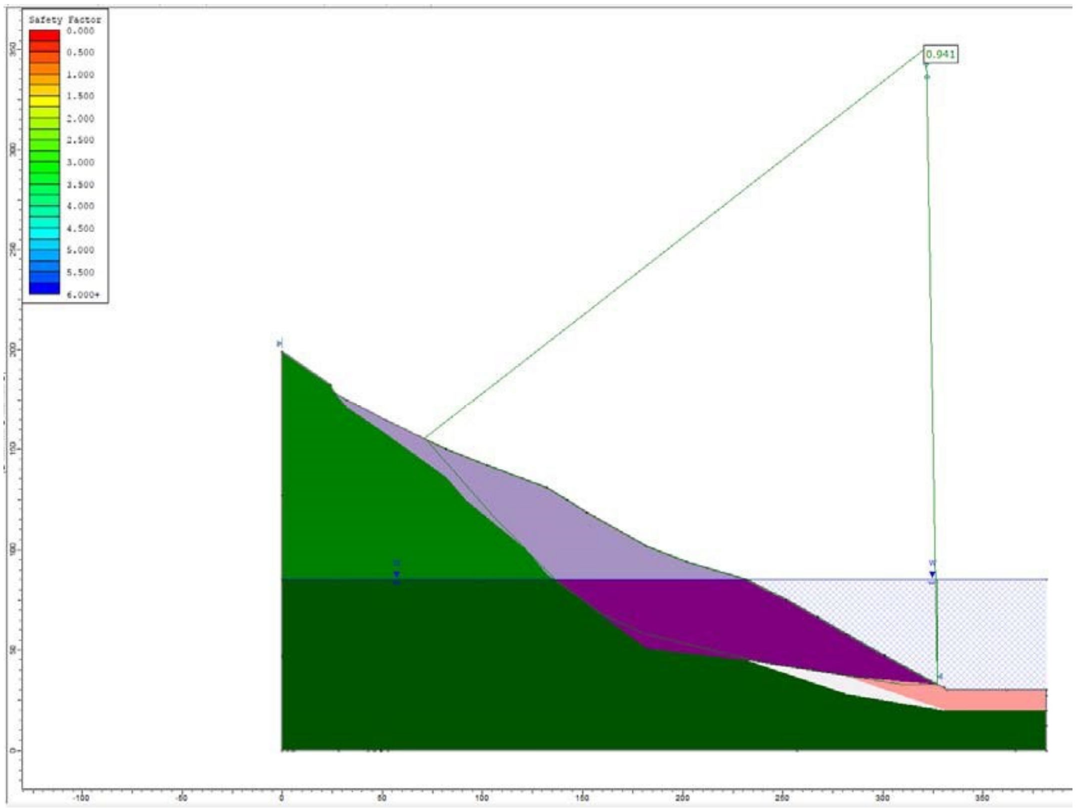

Figure 24.2 – *Slide2* Solution using the Bishop Method

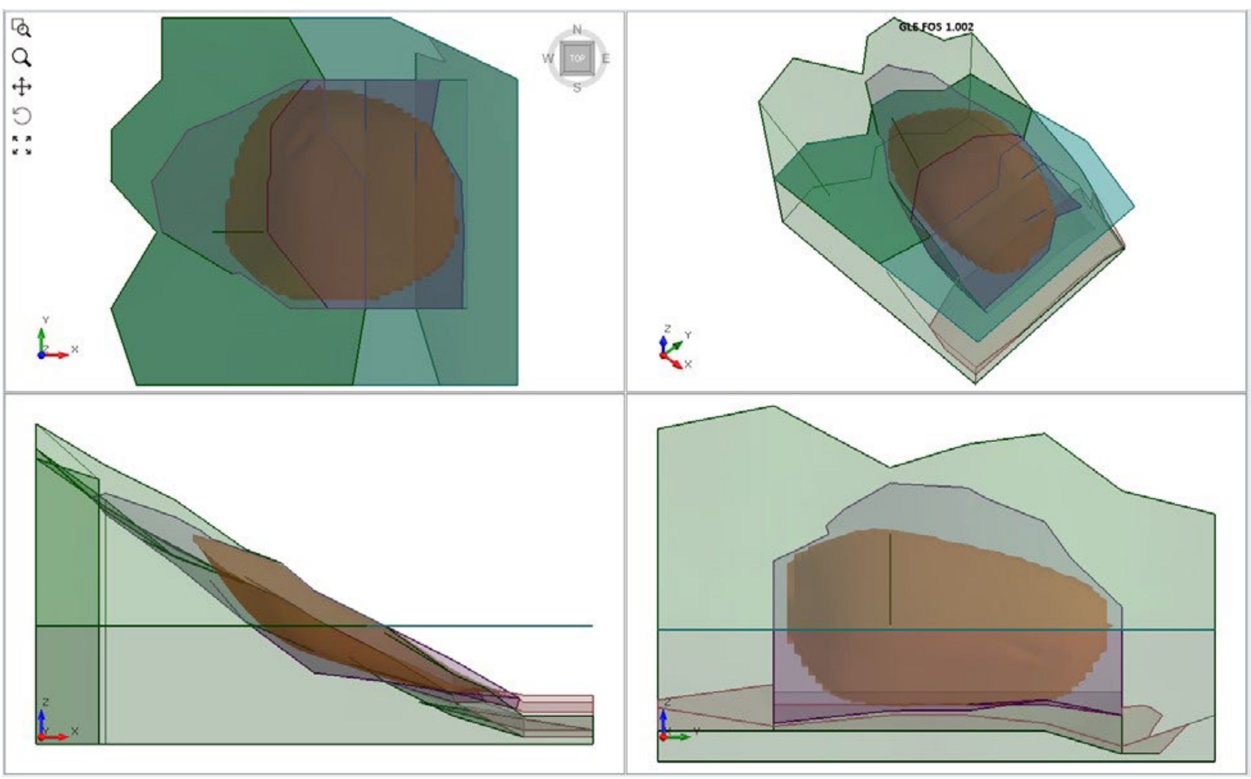

Figure 24.3 – *Slide3* Solution Using the GLE Method

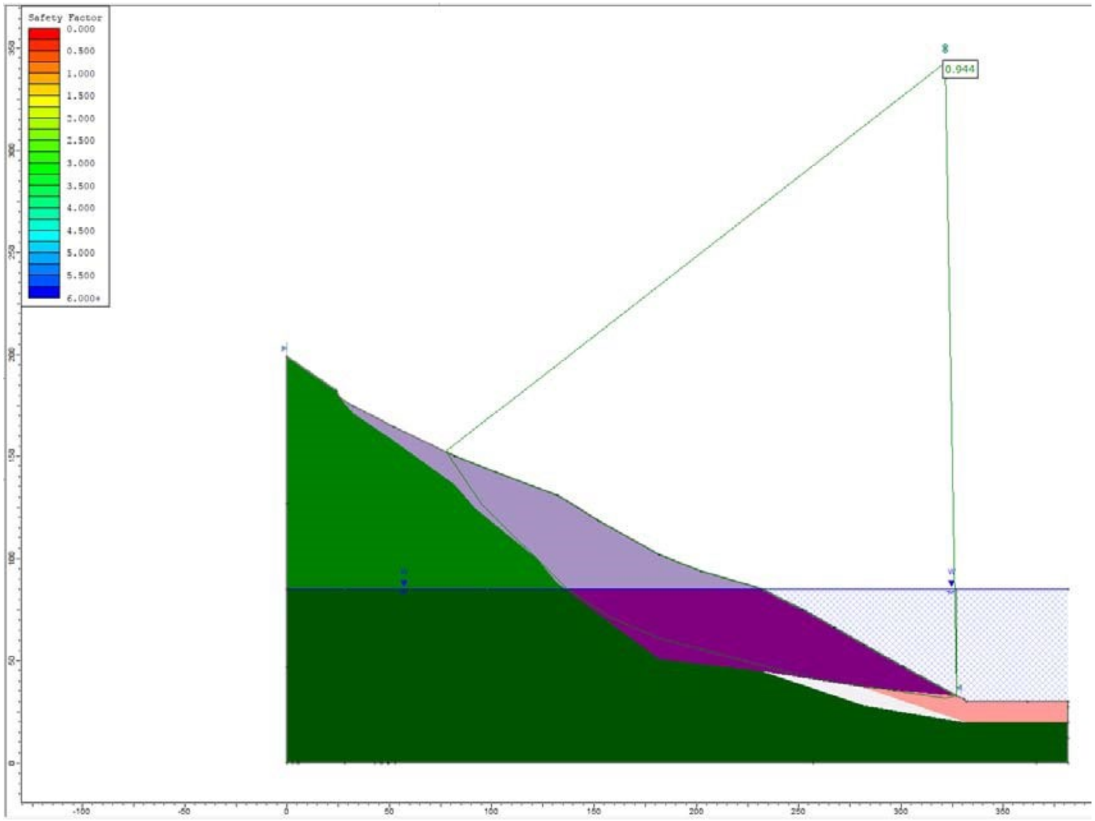

Figure 24.4 – *Slide2* Solution Using the GLE Method

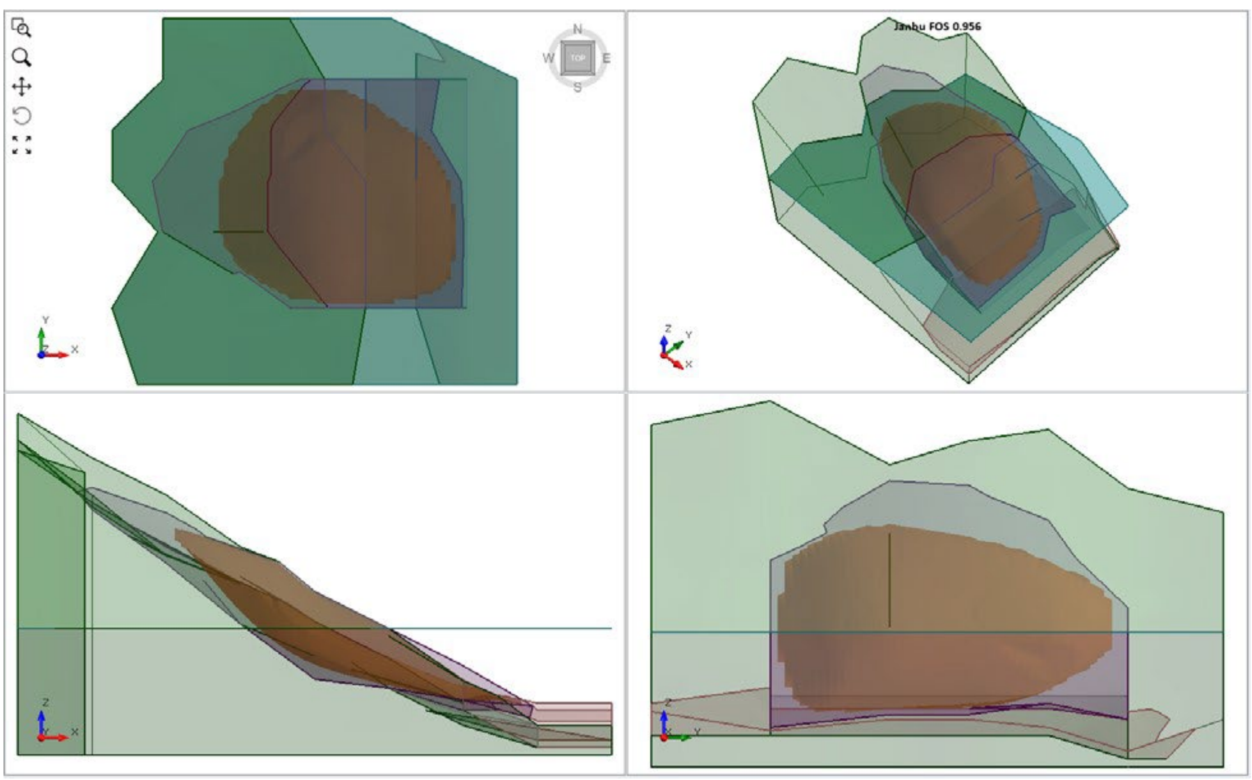

Figure 24.5 – *Slide3* Solution Using the Janbu Method

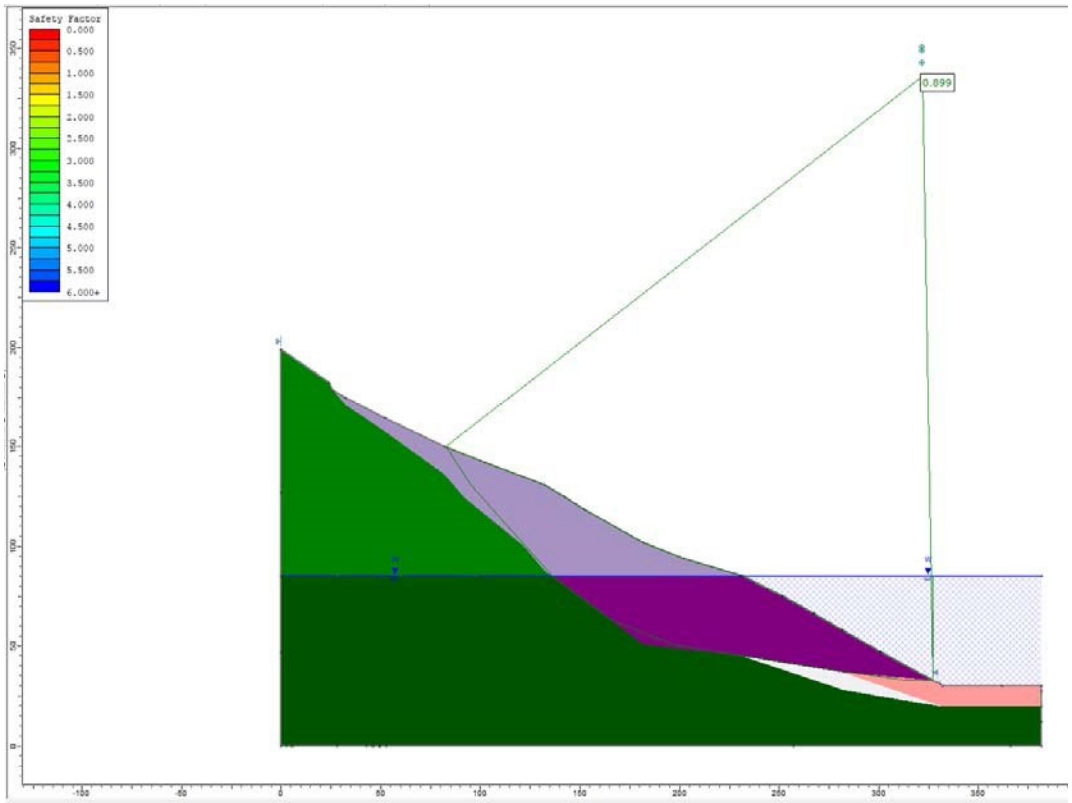

Figure 24.6 – *Slide2* Solution Using the Janbu Method

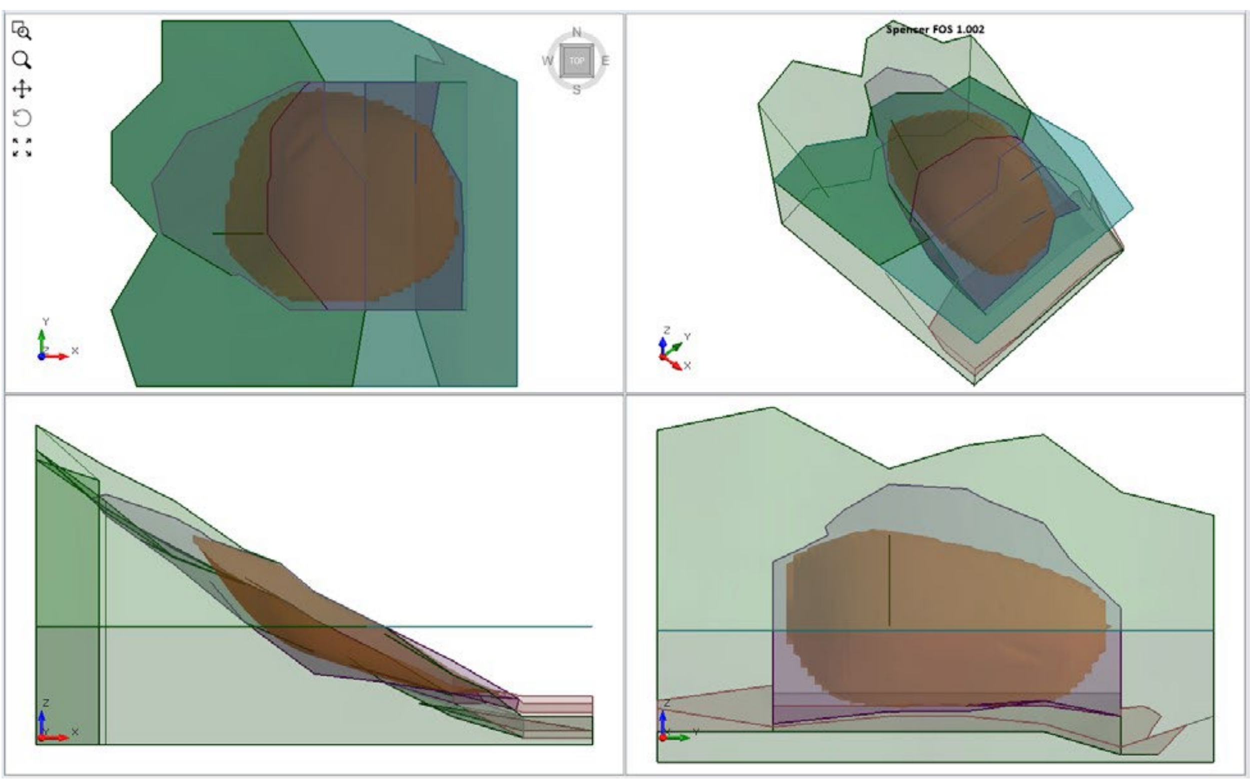

Figure 24.7 – *Slide3* Solution Using the Spencer Method

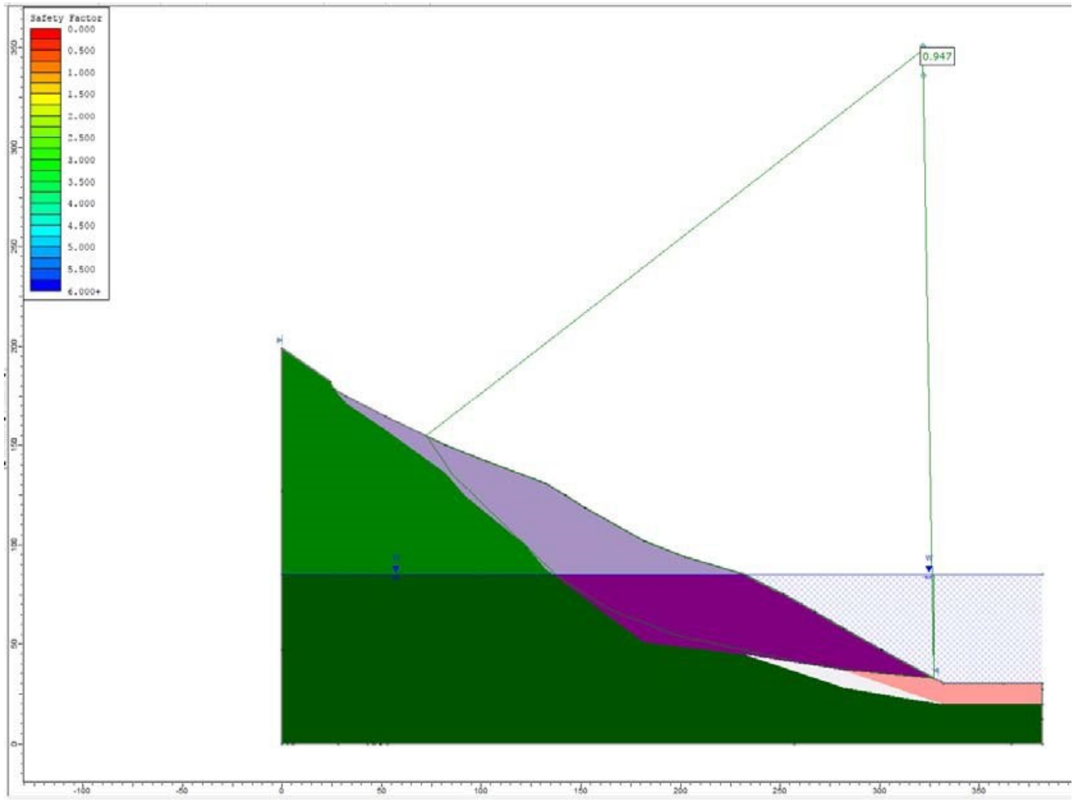

Figure 24.8 – *Slide2* Solution Using the Spencer Solution

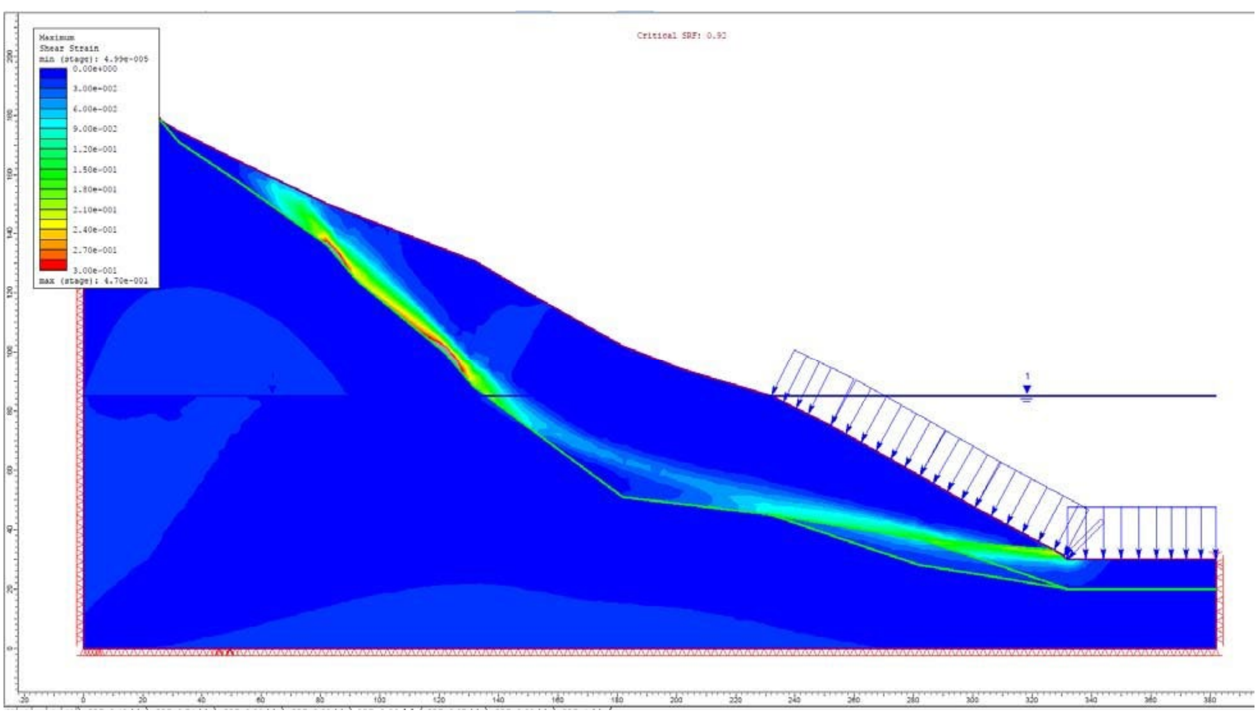

Figure 24.9 – *RS2* Maximum Shear Strain

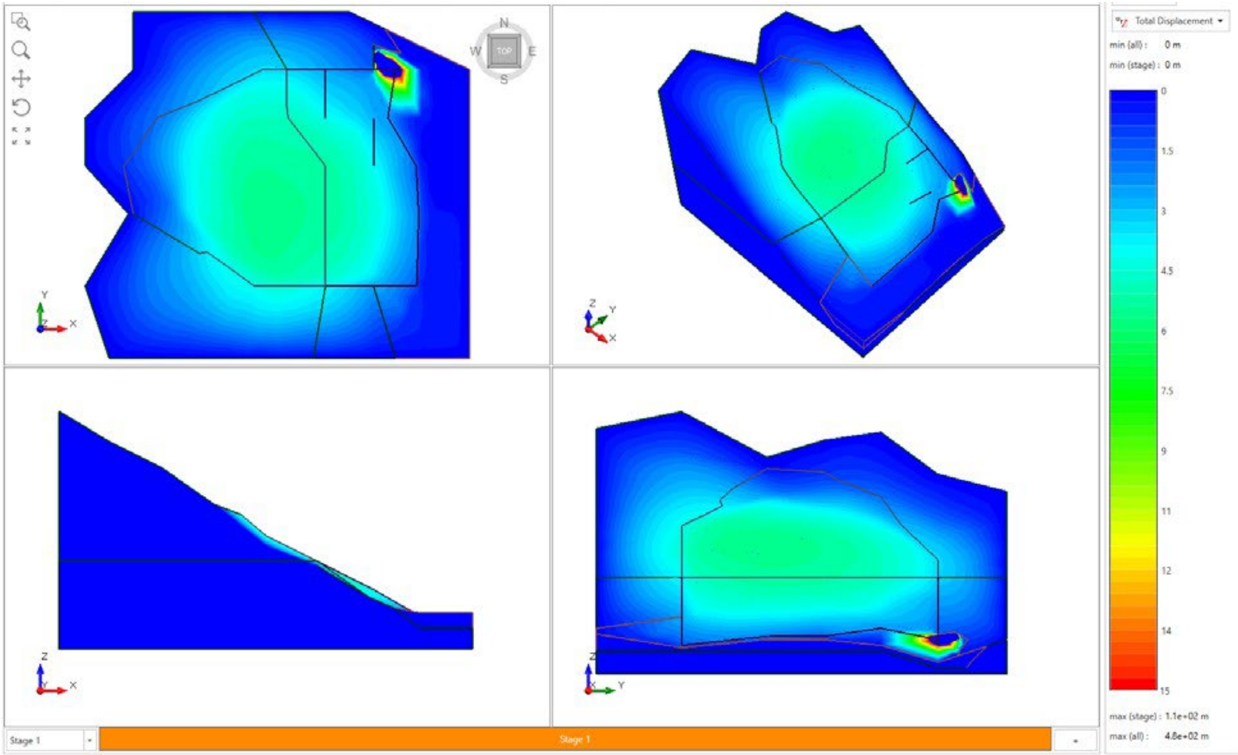

Figure 24.10 – *RS3* Total Displacement

25. 3D Verification #25

25.1. 3D slope, (2) materials, ellipsoidal with SA

25.1.1. Introduction

This example is taken from Qi et al. (2015). The model is a slope at Xiari in southwestern China. The slope modeled by Qi et al. is a series of 2D cross sections take from a 3D slope, the lowest of the three cross sections will be taken as the referee value for the entire slope. For this example, these cross sections have been lofted together. Qi et al also analyzed the slope stability of the rock portion of the slope, while *Slide3* and *RS3* analyze the slope stability of the soil portion, which explains the higher referee values compared to the lower calculated values.

25.1.2. Problem Description

This problem was modeled by lofting three 2D cross sections together. The slope is nonhomogenous, and the properties for both materials can be found in Table 25.1. The ellipsoidal slip surface is required.

25.1.3. Properties

Table 25.1: Material Properties

	c′ (kN/m^2)	φ′ (deg.)	γ (kN/m^3)
Rock	540	31.3	25.506
Soil	45	26	19.8162

25.1.4. Results

Table 25.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.156	1.157	1.28	1.26
GLE	1.209	1.155		
Janbu	1.127	1.095		
Spencer	1.22	1.160		

Referee: FS 1.575 [Qi et al., 2015]

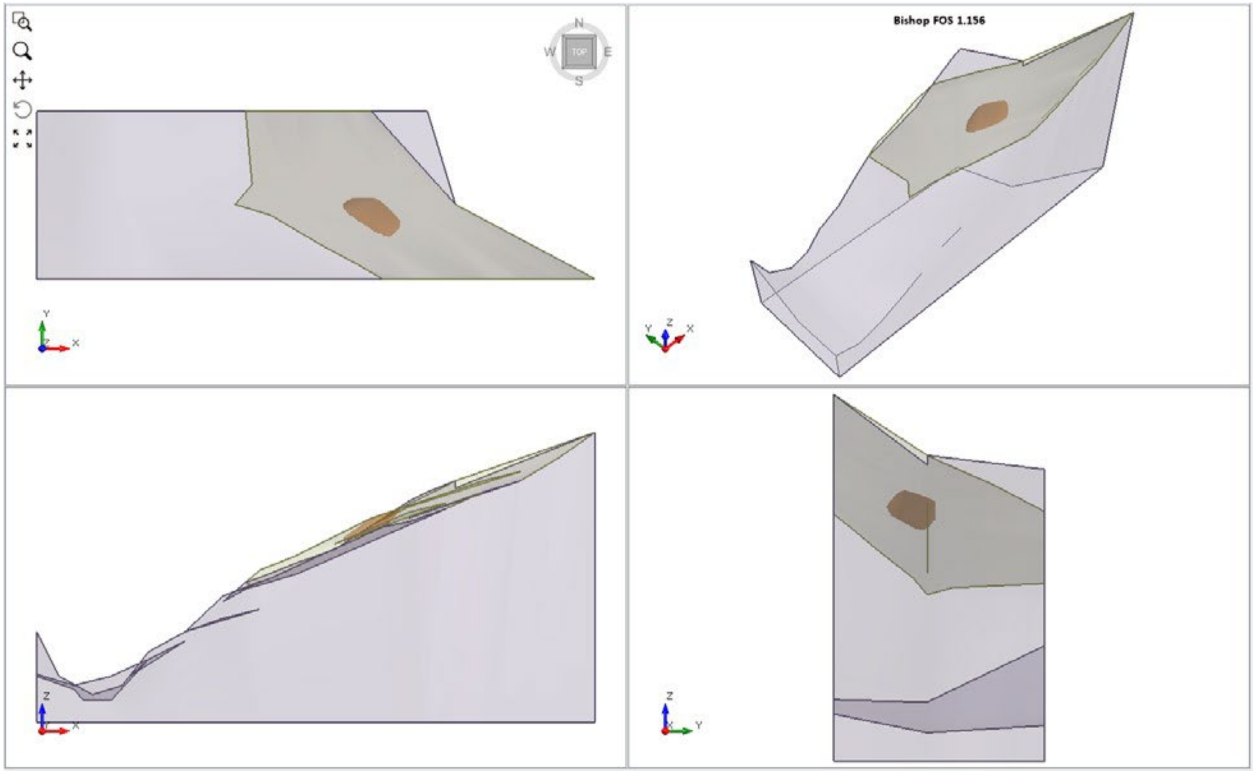

Figure 25.1 – *Slide3* Solution Using the Bishop Method

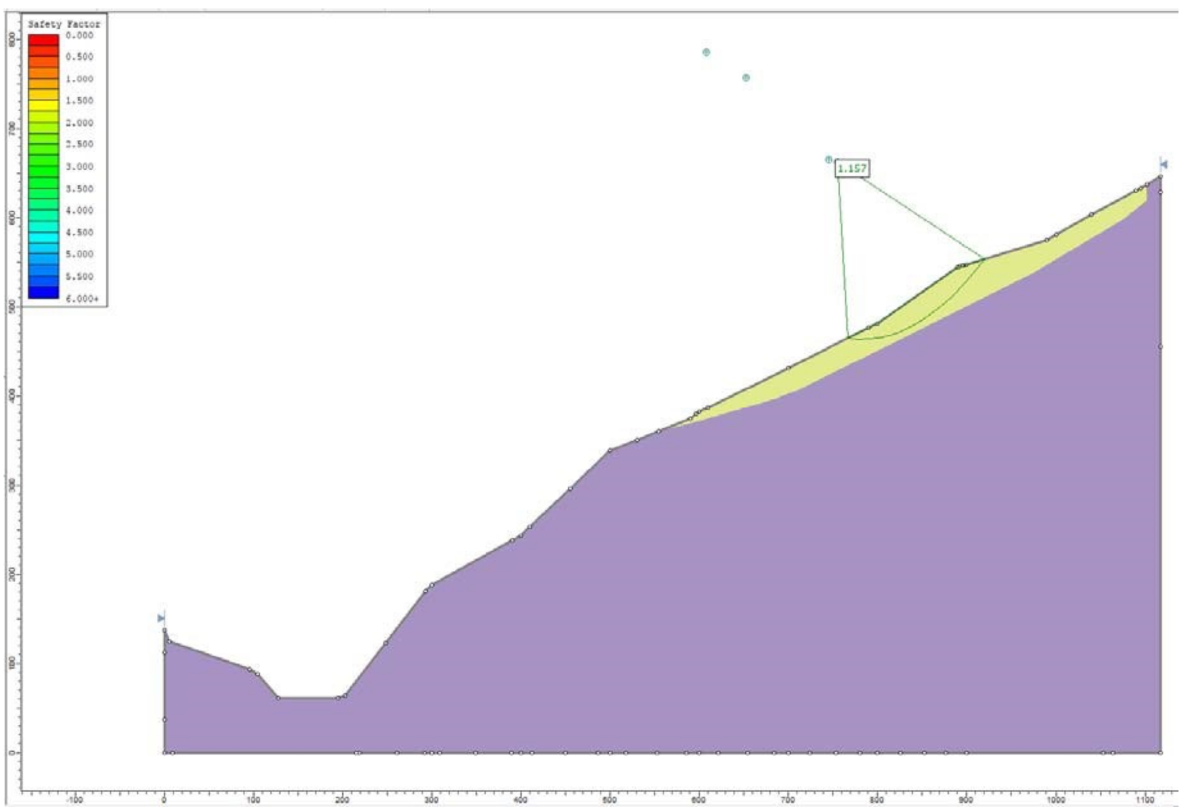

Figure 25.4.2 – *Slide2* Solution using the Bishop Method

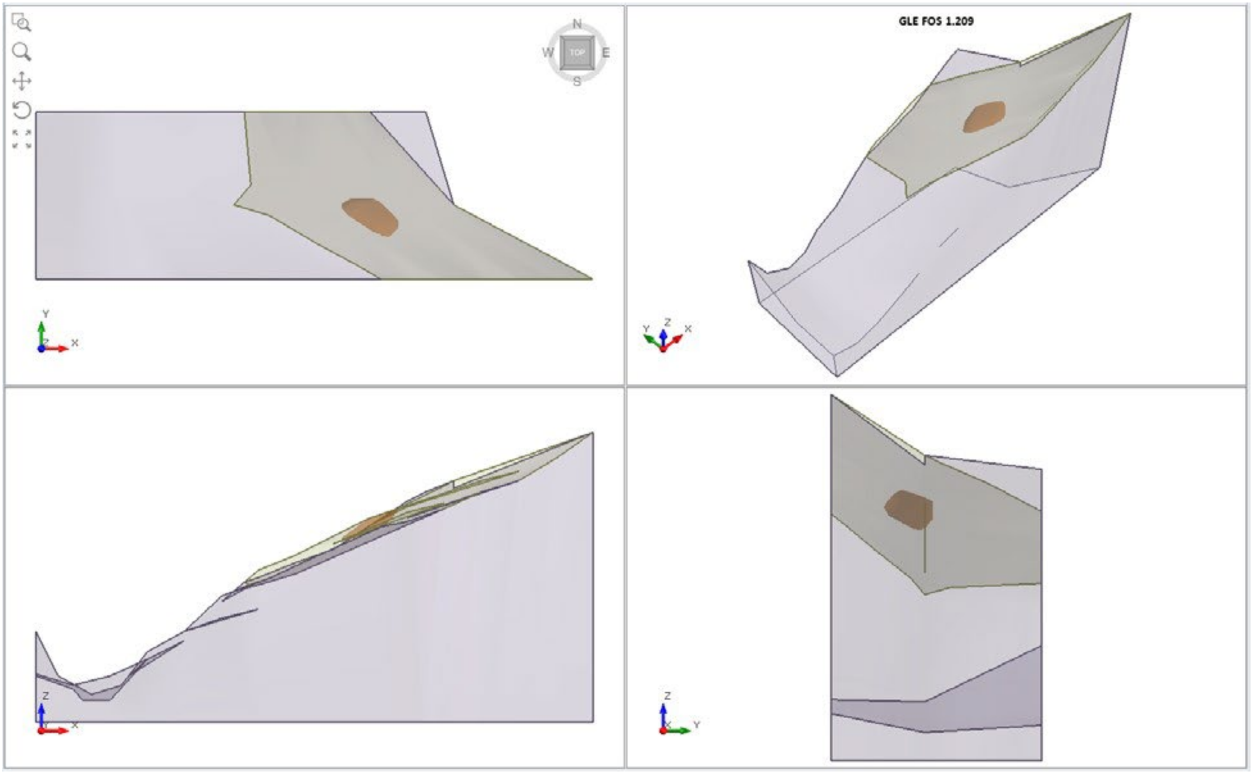

Figure 25.3 – *Slide3* Solution Using the GLE Method

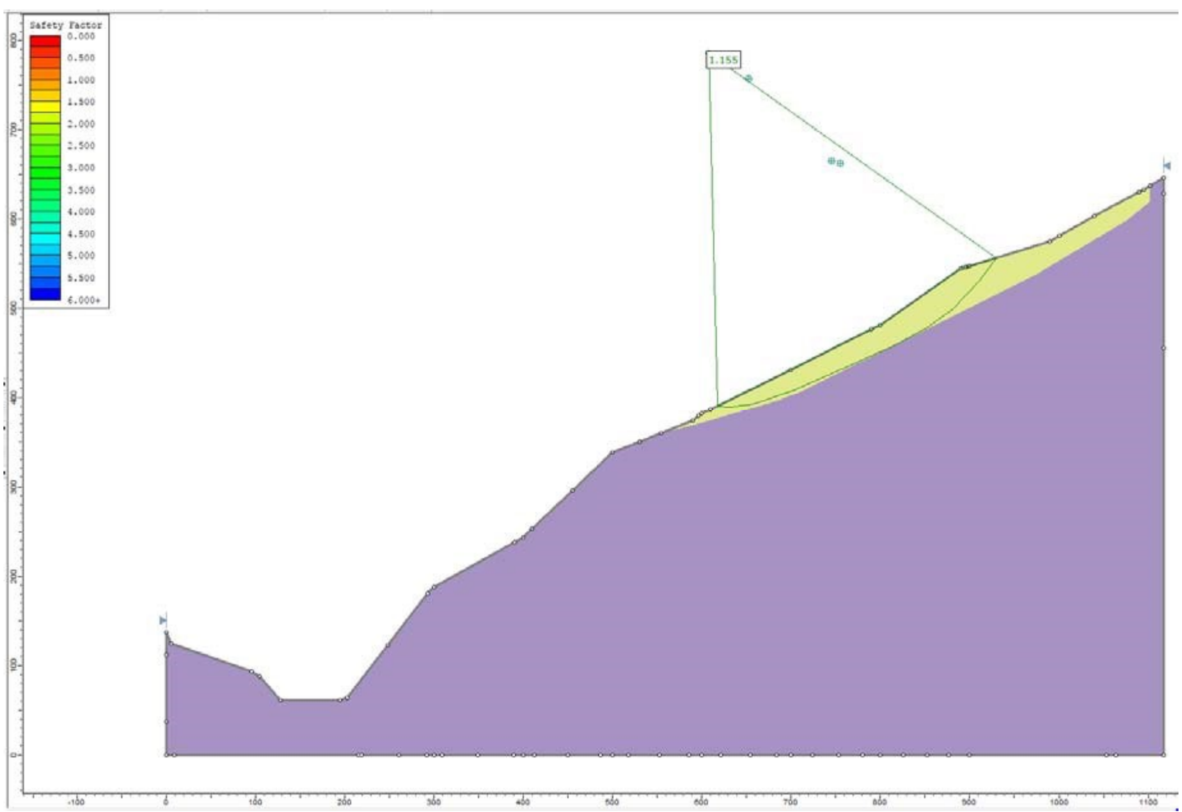

Figure 25.4 – *Slide2* Solution Using the GLE Method

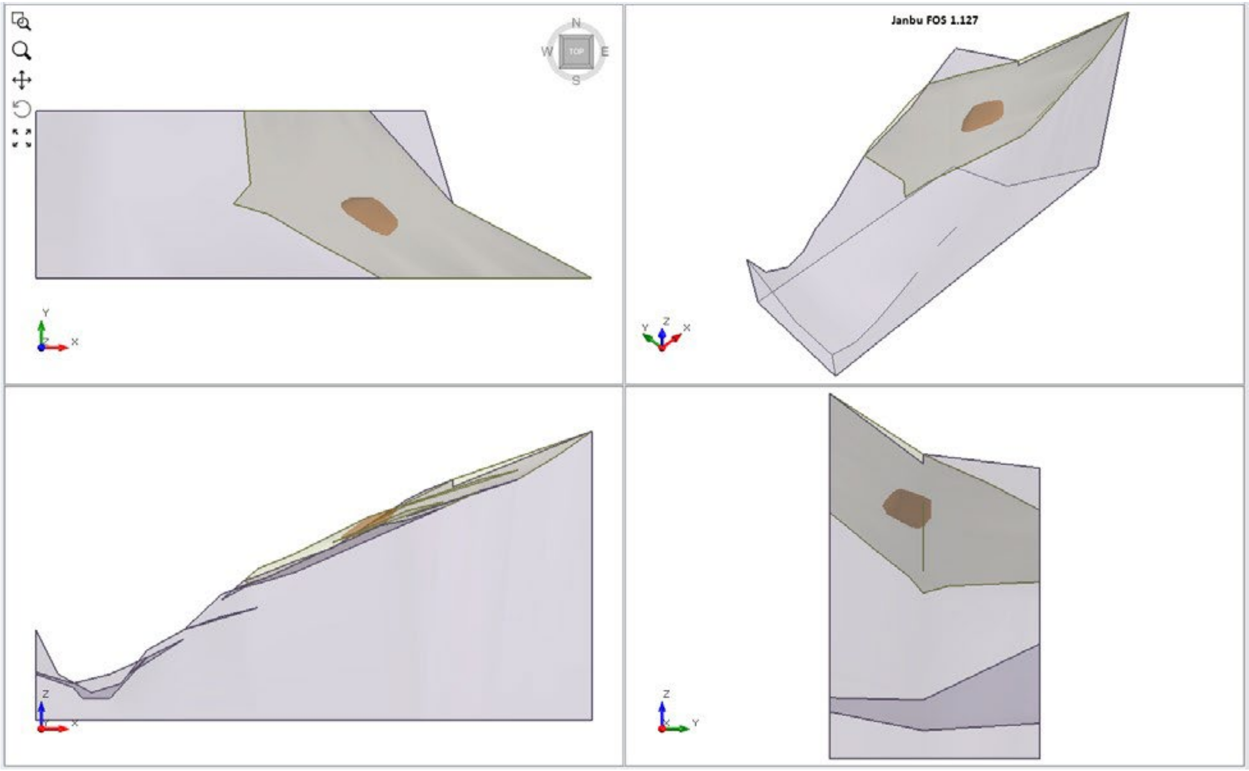

Figure 25.5 – *Slide3* Solution Using the Janbu Method

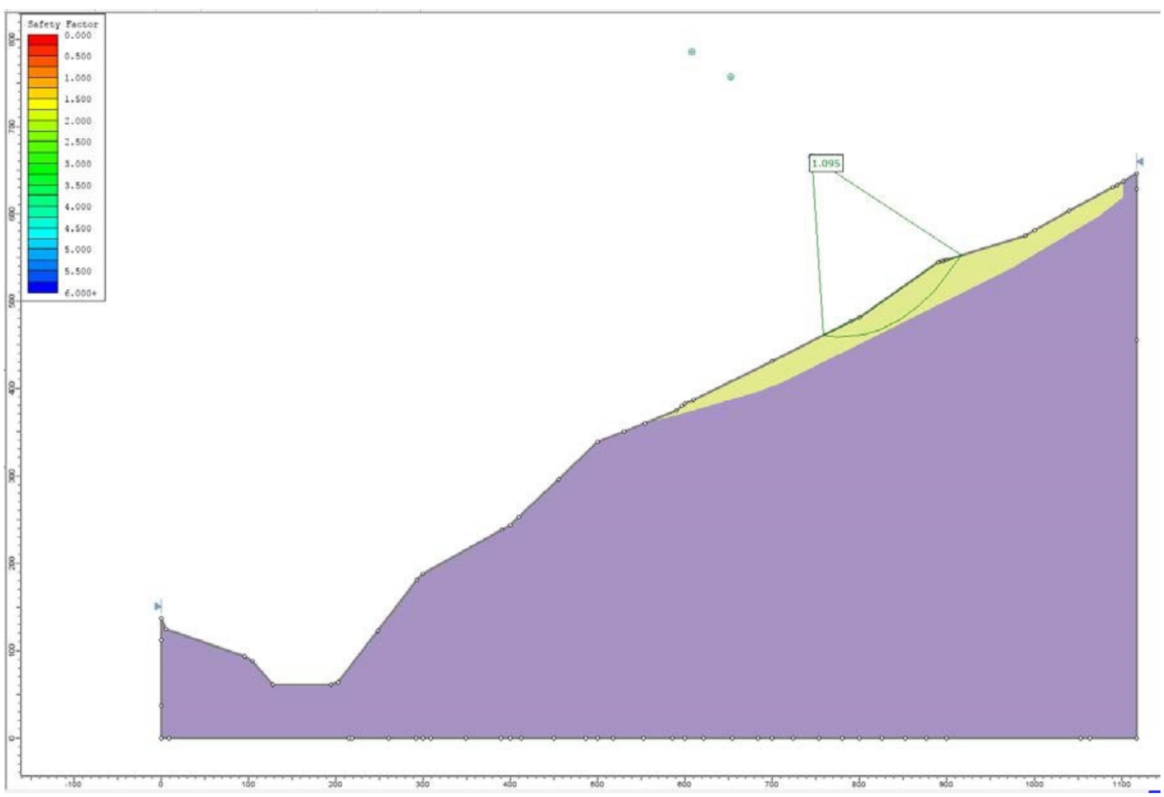

Figure 25.6 – *Slide2* Solution Using the Janbu Method

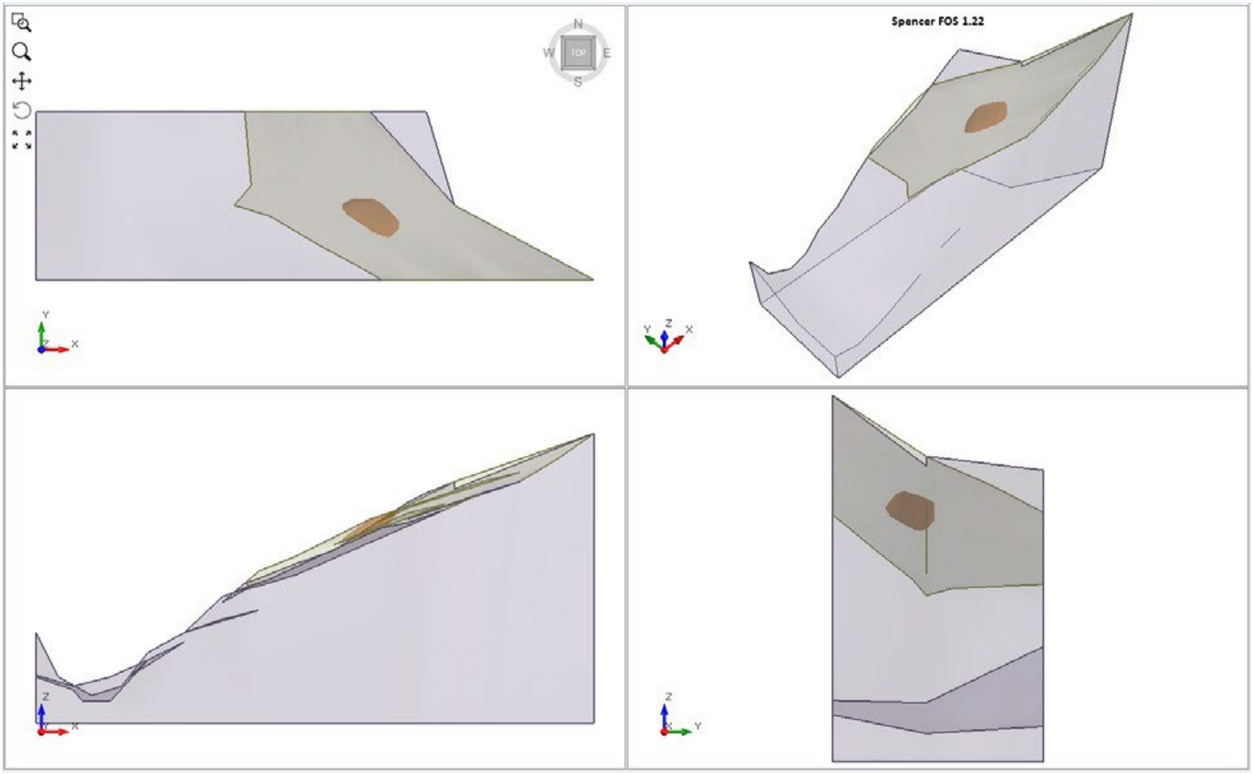

Figure 25.7 – *Slide3* Solution Using the Spencer Method

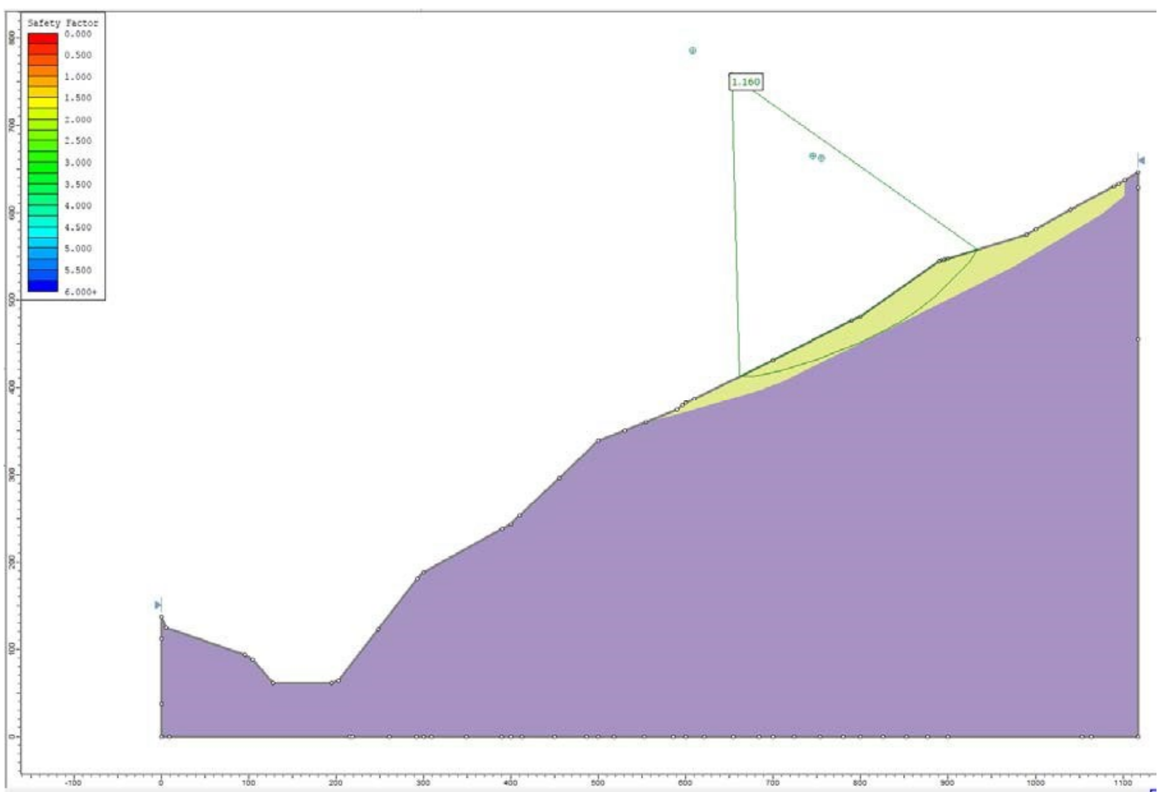

Figure 25.8 – *Slide2* Solution Using the Spencer Method

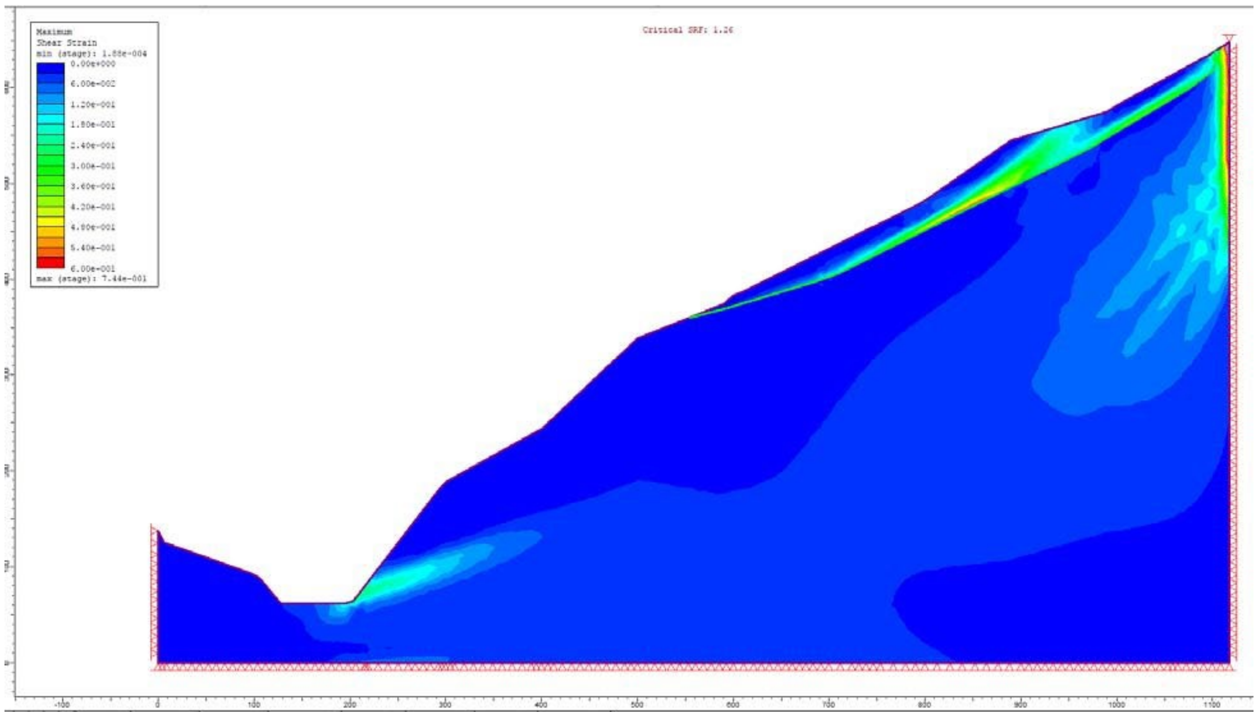

Figure 25.9 – *RS2* Maximum Shear Strain

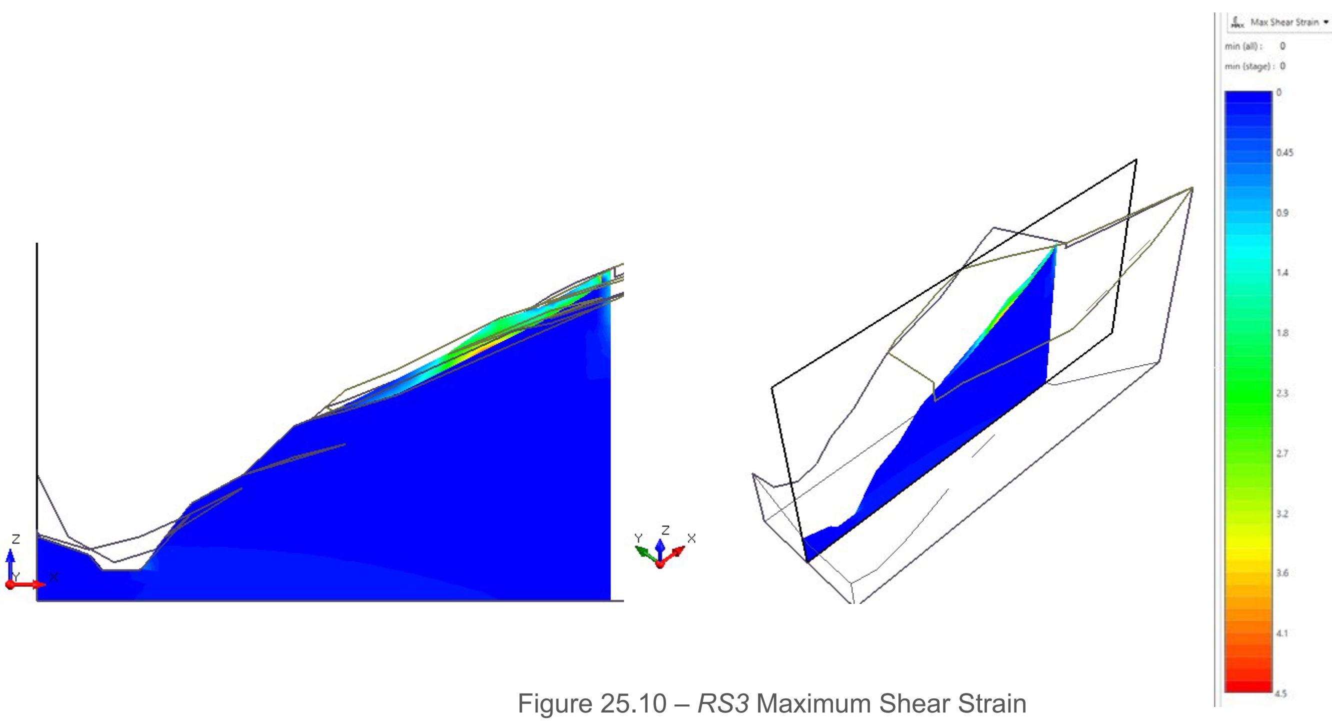

Figure 25.10 – *RS3* Maximum Shear Strain

26. 3D Verification #26

26.1. 3D slope, (2) materials, water table, ellipsoidal with SA

26.1.1. Introduction

This example is a fully 3D slope with a water table.

26.1.2. Problem Description

The material properties for both materials used to create the 3D slope analyzed in this problem can be found in Table 26.1. The water table is located just under the surface and is applied to all the materials. The ellipsoidal slip surface and corresponding safety factor is required.

26.1.3. Properties

Table 26.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Bed Rock	500	42	23
Weathered Rock	100	19	18

26.1.4. Results

Table 26.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	0.961	0.784	0.95	0.78
GLE	1.173	0.793		
Janbu	0.893	0.748		
Spencer	1.173	0.815		

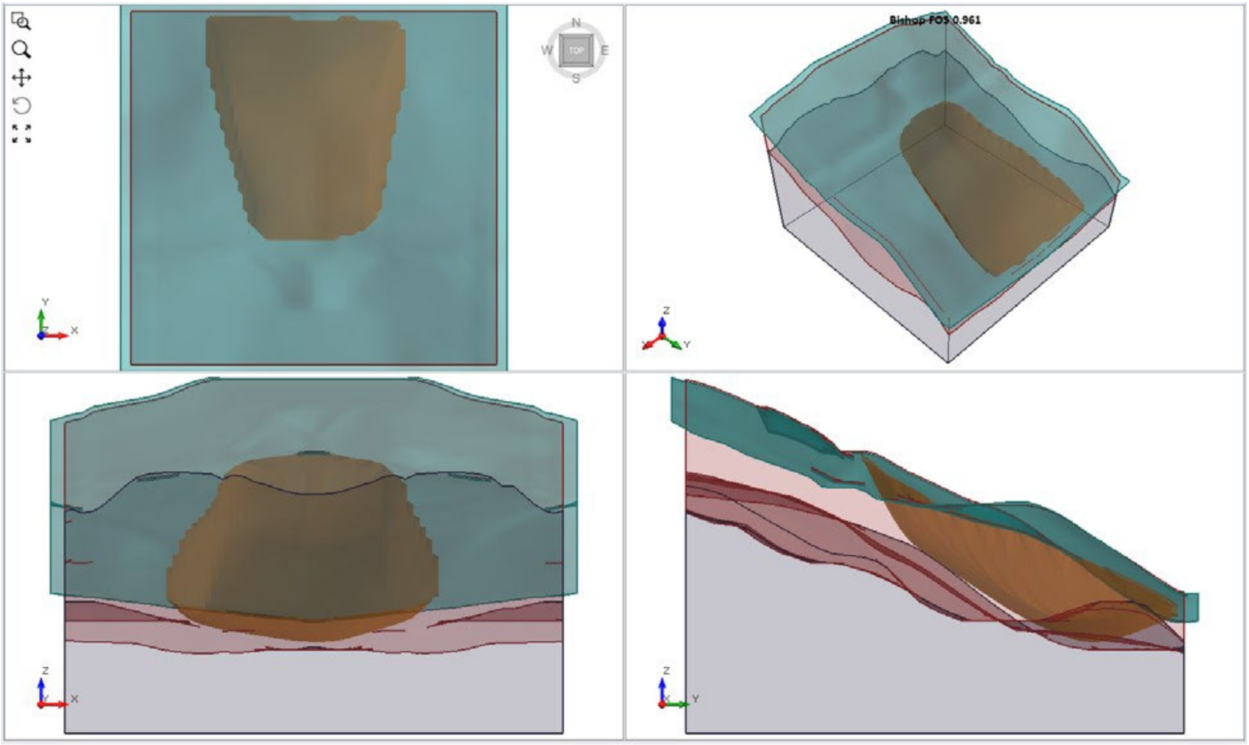

Figure 26.1 – *Slide3* Solution Using the Bishop Method

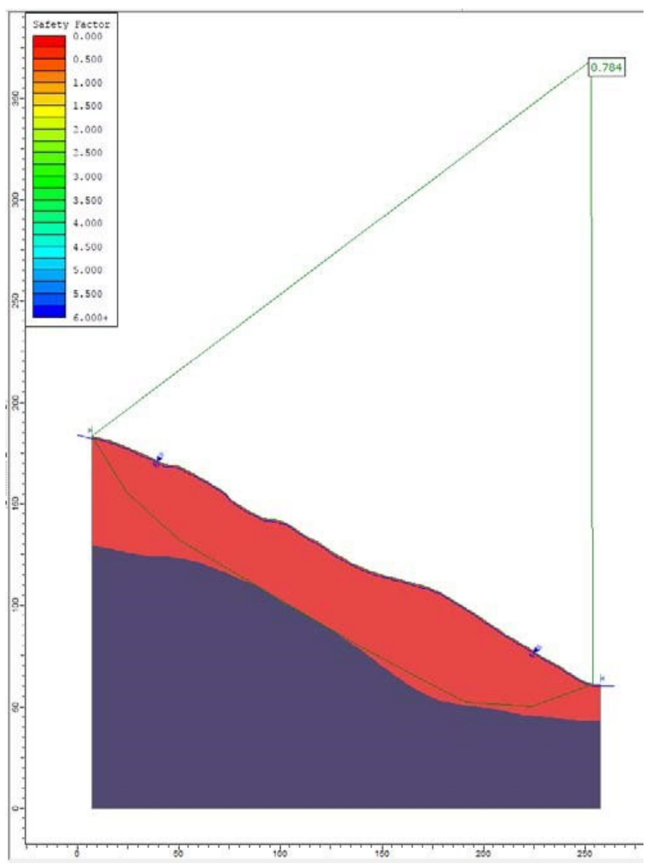

Figure 26.2 – *Slide2* Solution Using the Bishop Method

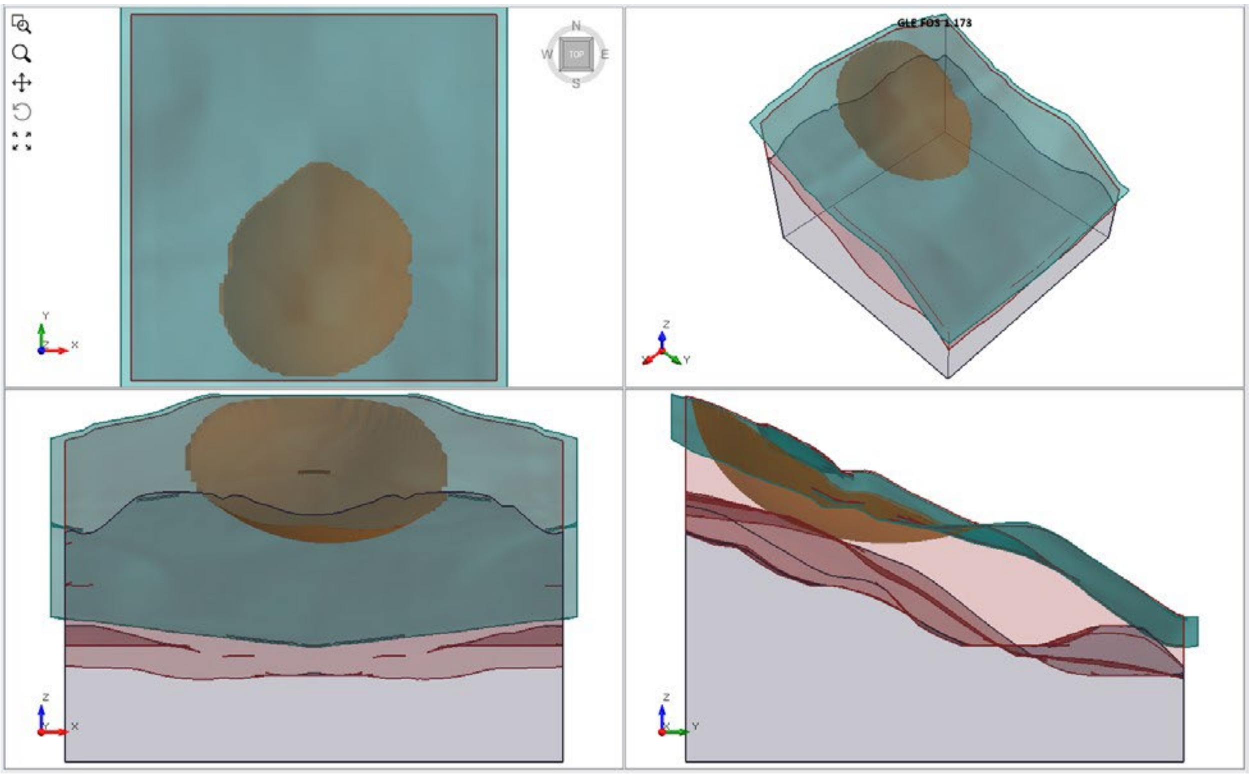

Figure 26.3 – *Slide3* Solution Using the GLE Method

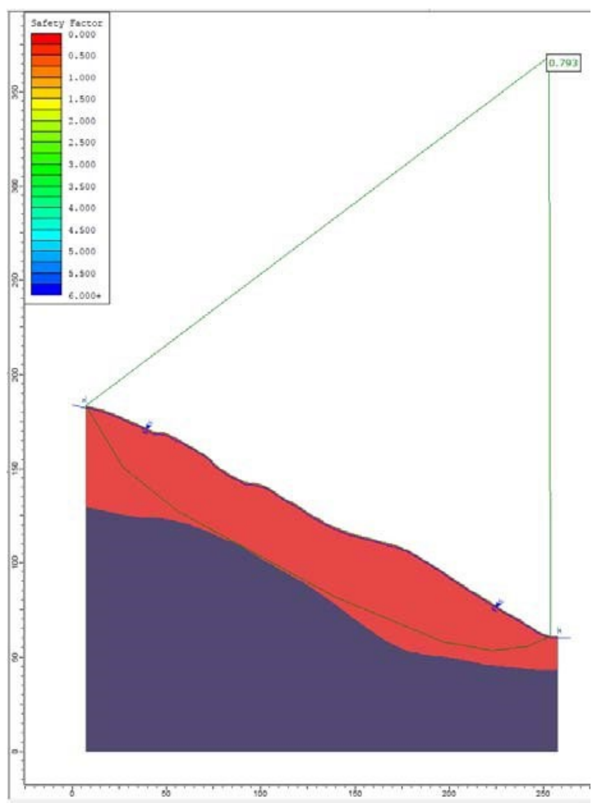

Figure 26.4 – *Slide2* Solution Using the GLE Method

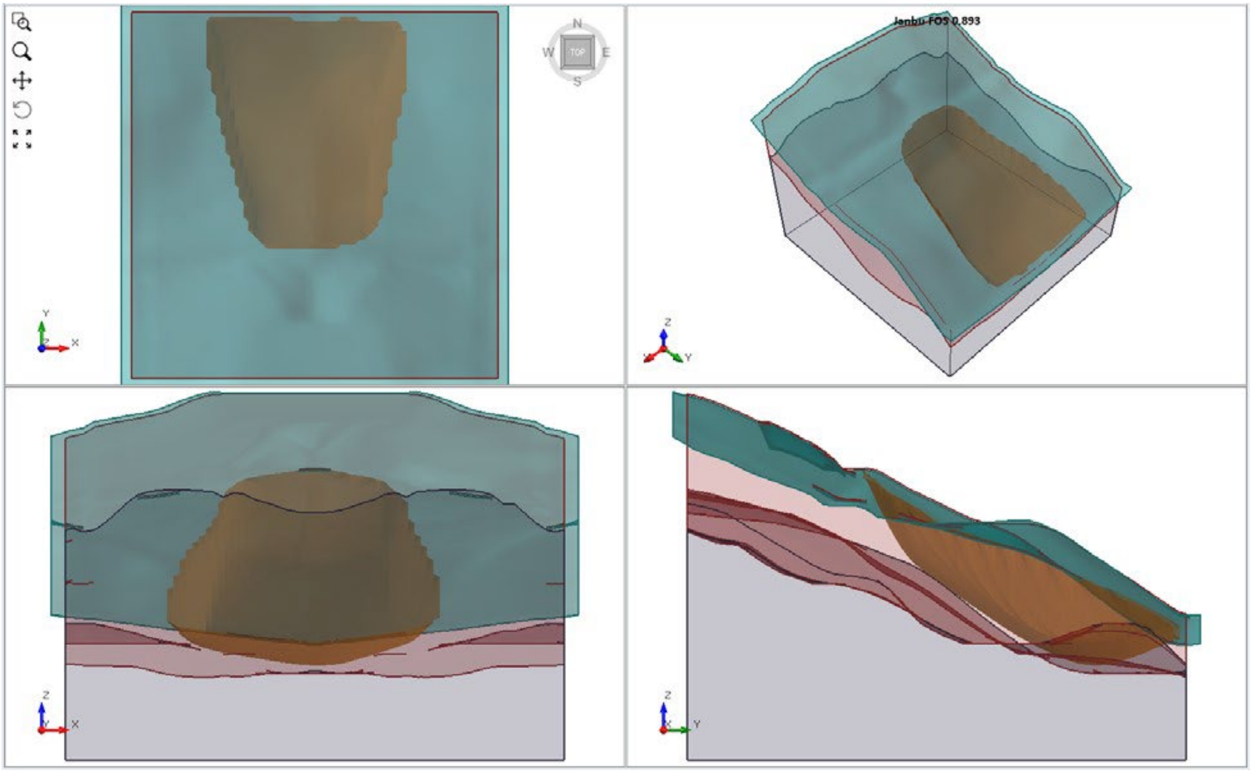

Figure 26.5 – *Slide3* Solution Using the Janbu Method

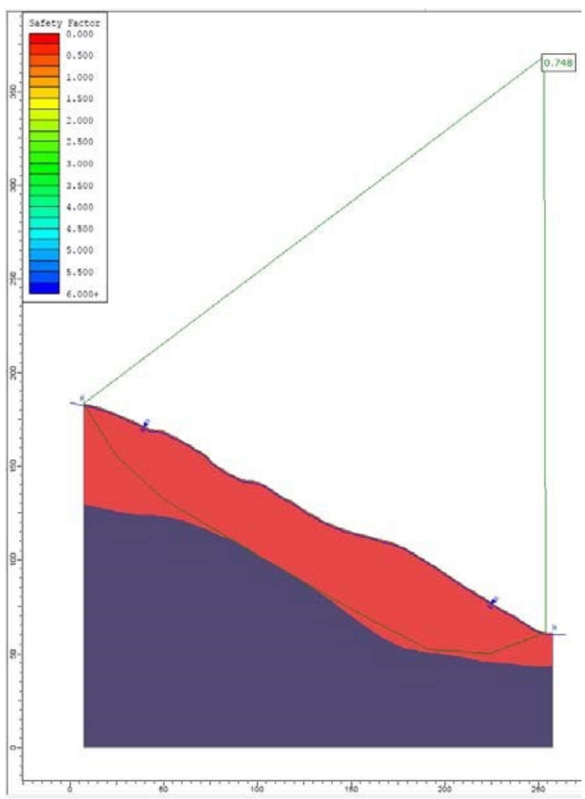

Figure 26.6 – *Slide2* Solution Using the Janbu Method

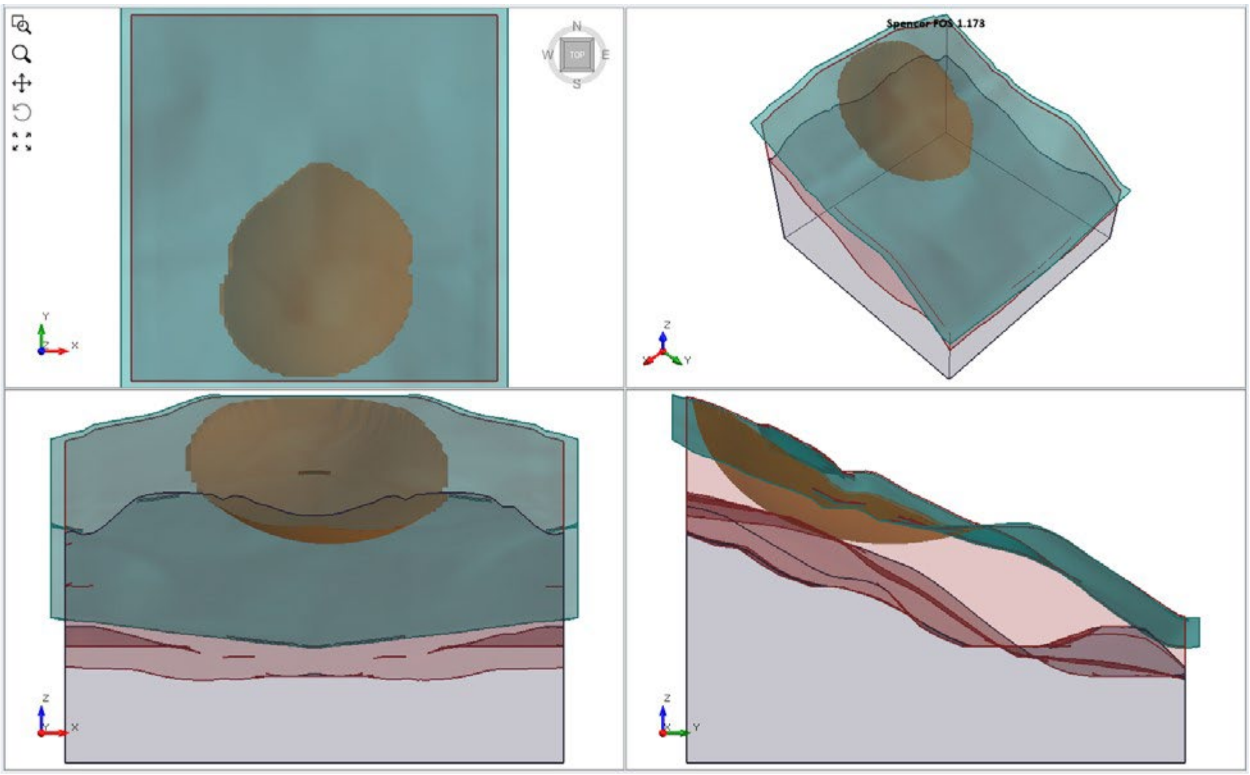

Figure 26.7 – *Slide3* Solution Using the Spencer Method

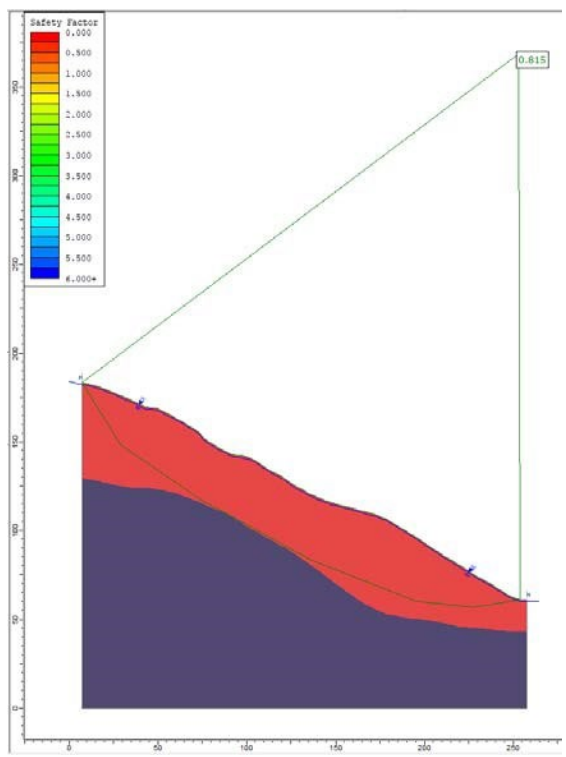

Figure 26.8 – *Slide2* Solution Using the Spencer Method

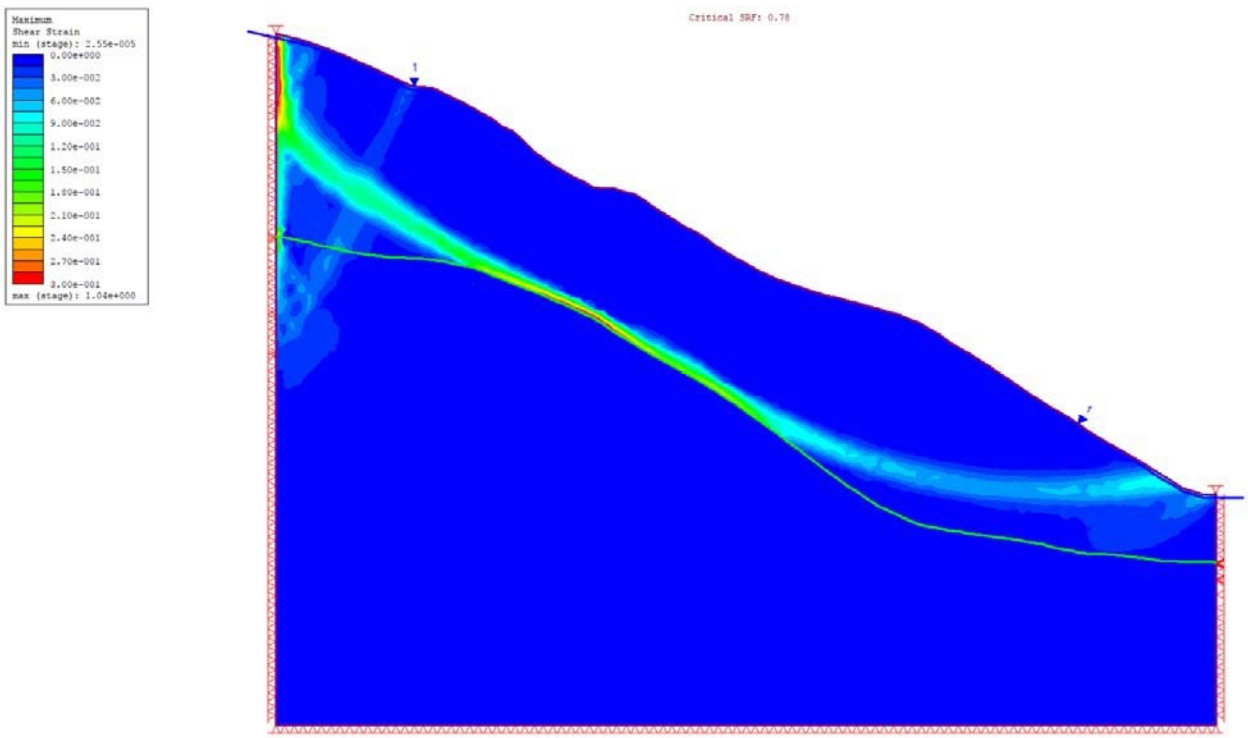

Figure 26.9 – *RS2* Maximum Shear Strain

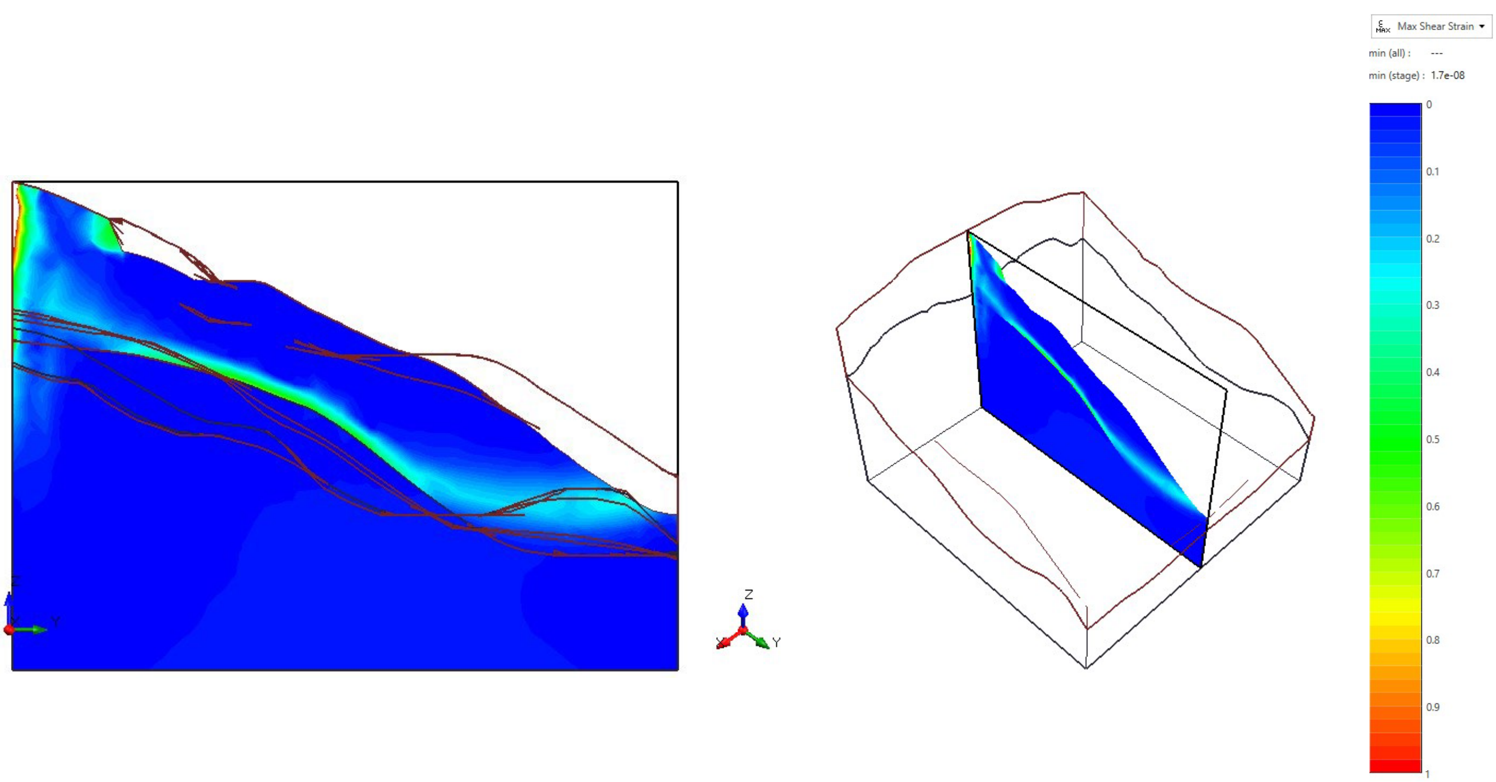

Figure 26.10 – *RS3* Maximum Shear Strain

27. 3D Verification #27

27.1. 3D tailings facility, homogeneous, ellipsoidal with SA

27.1.1. Introduction

This example is a fully 3D model of a tailings facility.

27.1.2. Problem Description

The material properties for the fully 3D homogeneous tailings facility can be found in Table 27.1. There is no groundwater in this problem. The ellipsoidal slip surface and corresponding safety factor is required.

27.1.3. Properties

Table 27.1: Material Properties

c′ (kN/m^2)	φ′ (deg.)	γ (kN/m^3)
10	38	20

27.1.4. Results

Table 27.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.773	1.750	1.84	1.74
GLE	1.765	1.722		
Janbu	1.731	1.684		
Spencer	1.772	1.729		

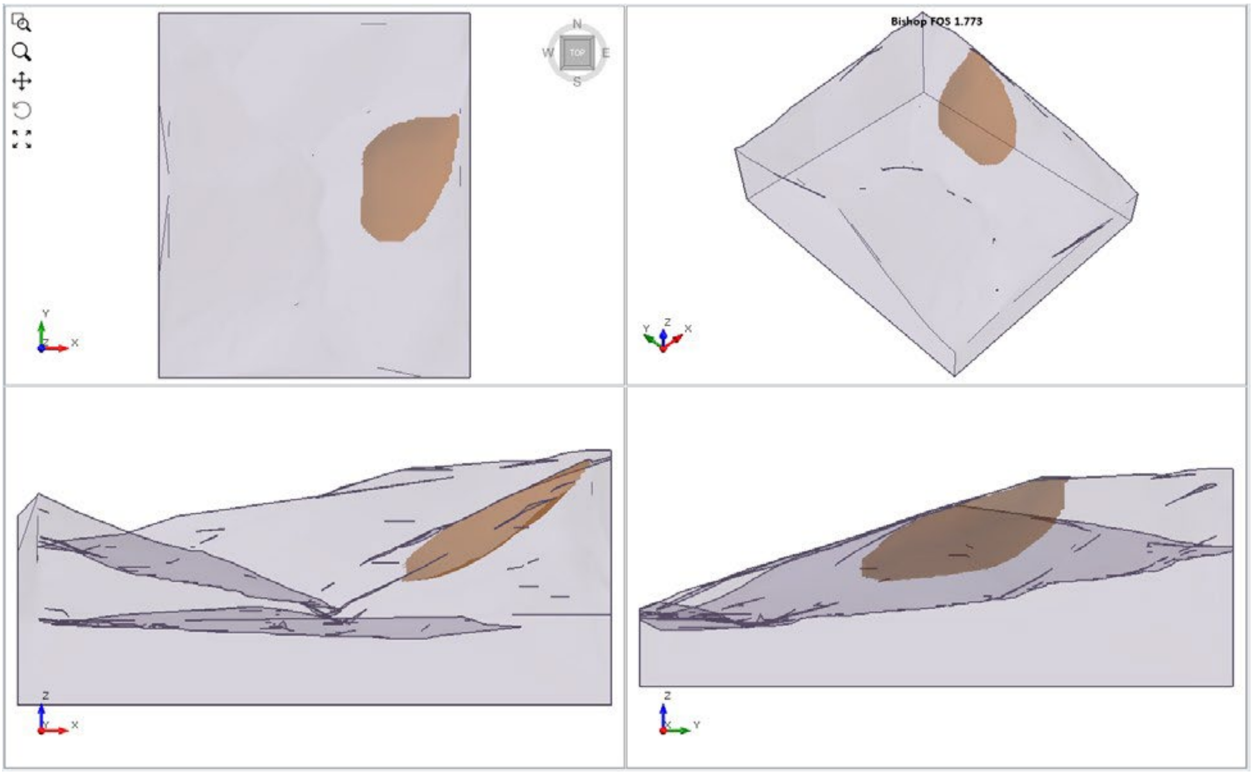

Figure 27.1 – *Slide3* Solution Using the Bishop Method

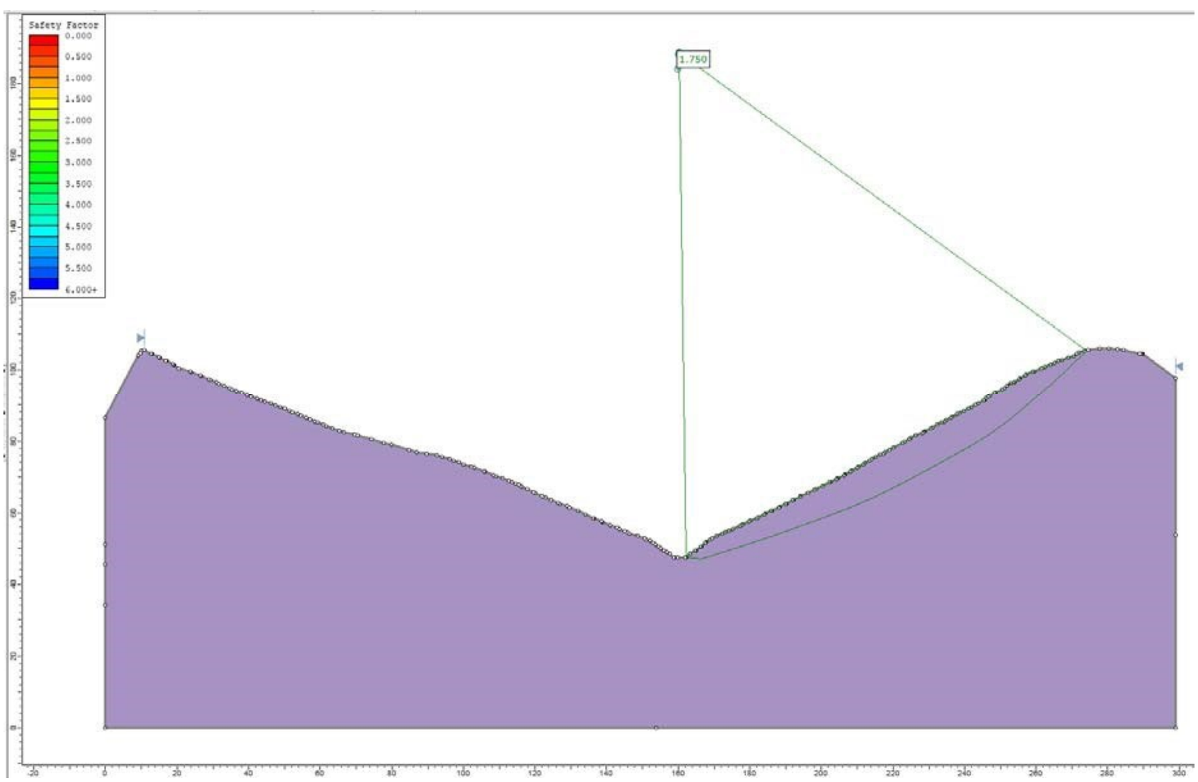

Figure 27.2 – *Slide2* Solution Using the Bishop Method

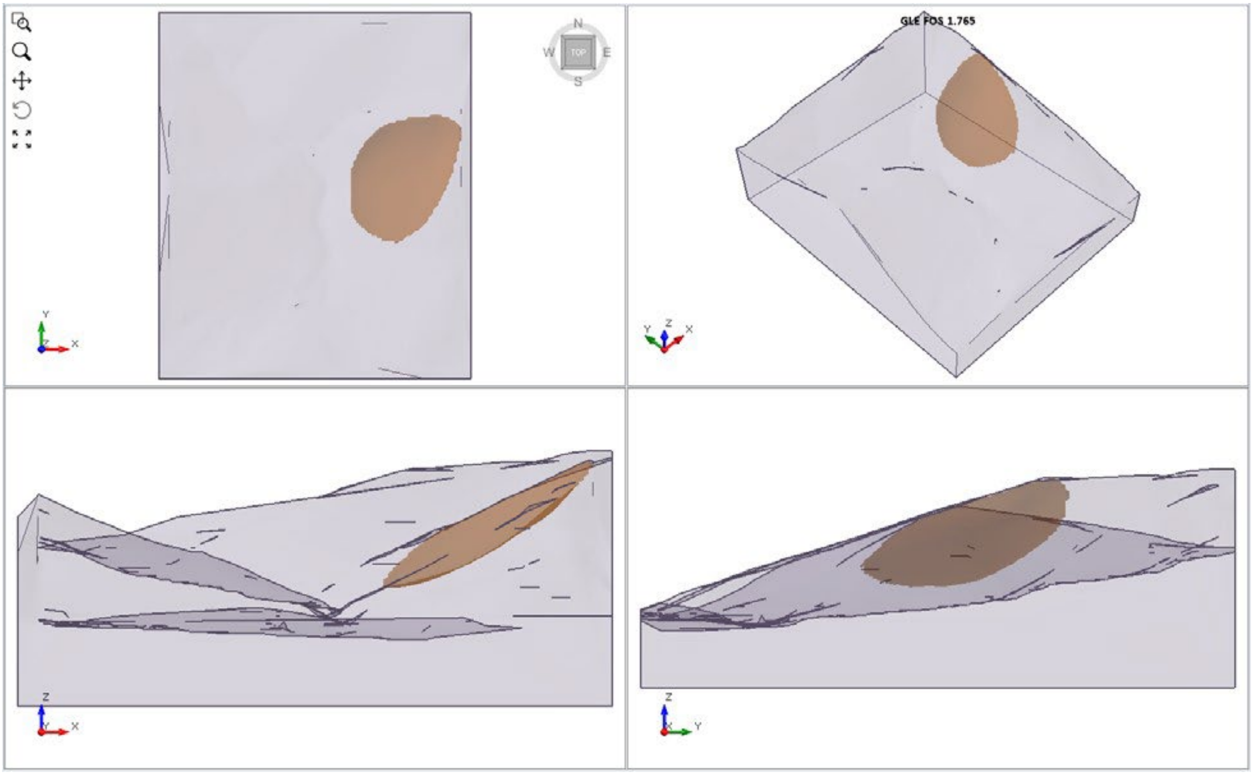

Figure 27.3 – *Slide3* Solution Using the GLE Method

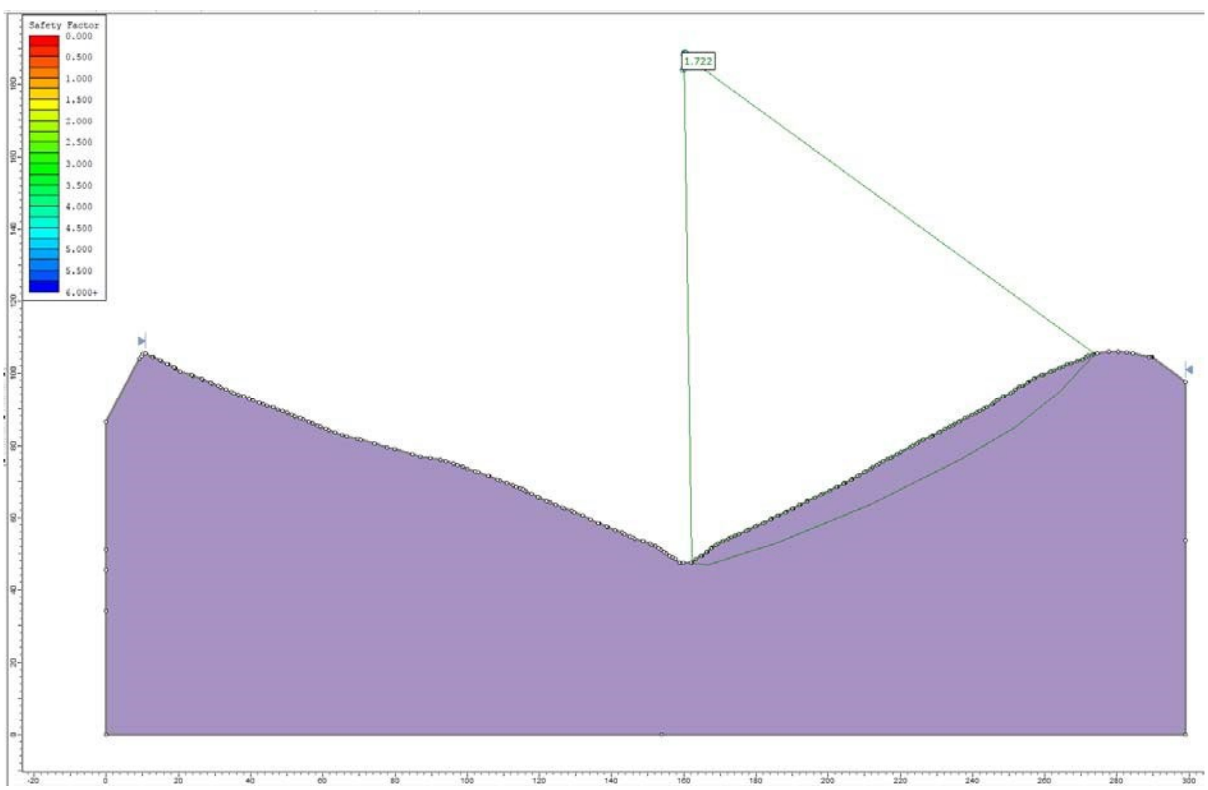

Figure 27.4 – *Slide2* Solution Using the GLE Method

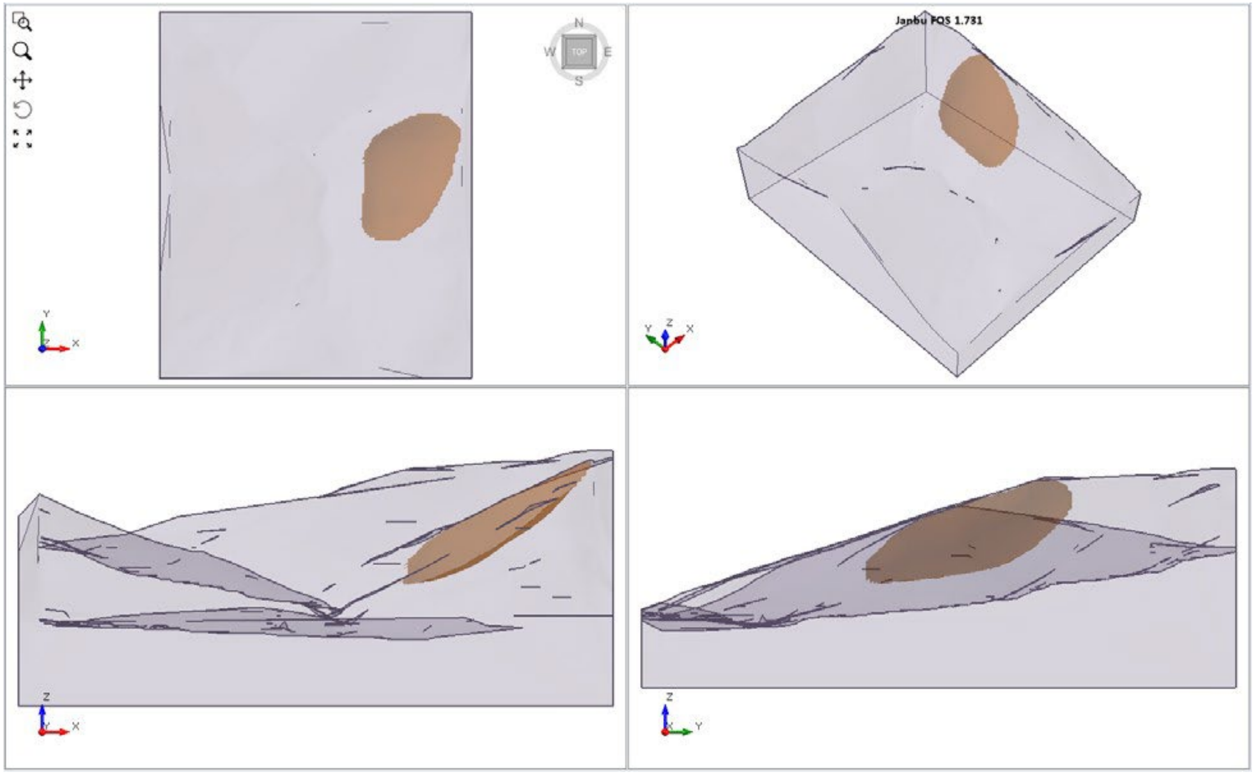

Figure 27.5 – *Slide3* Solution Using the Janbu Method

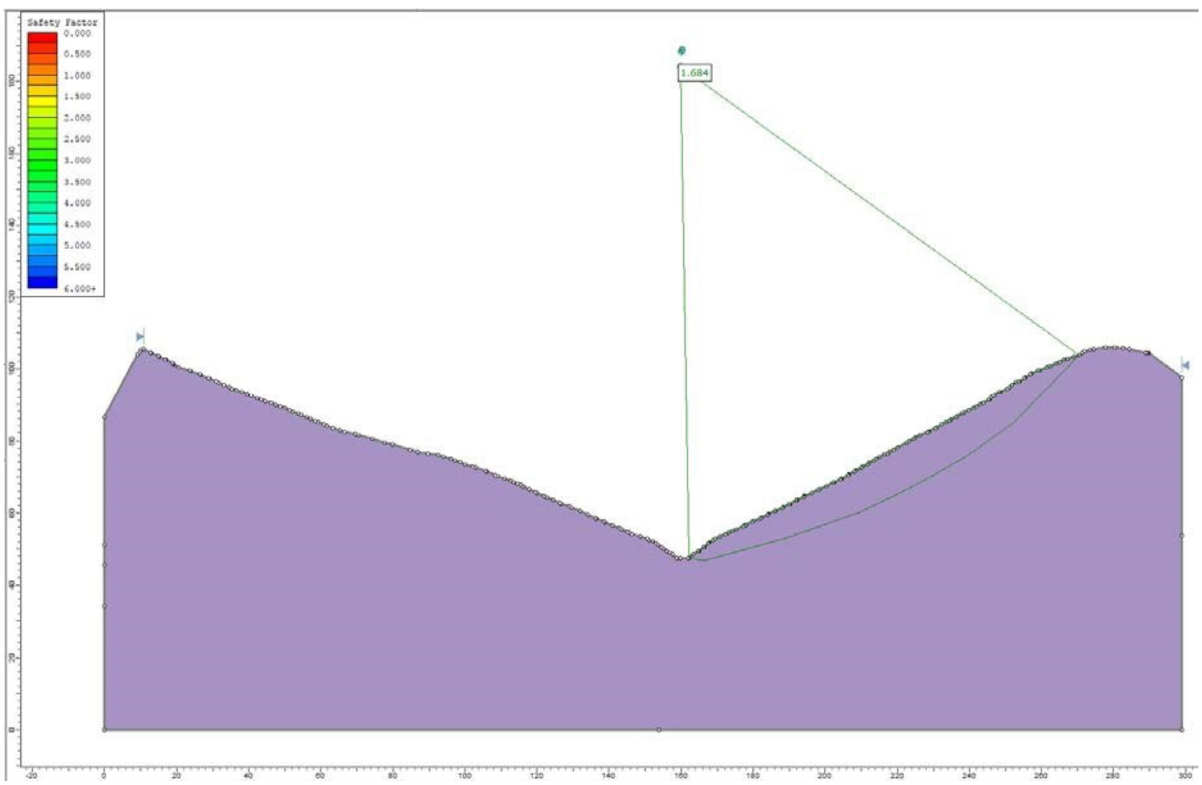

Figure 27.6 – *Slide2* Solution Using the Janbu Method

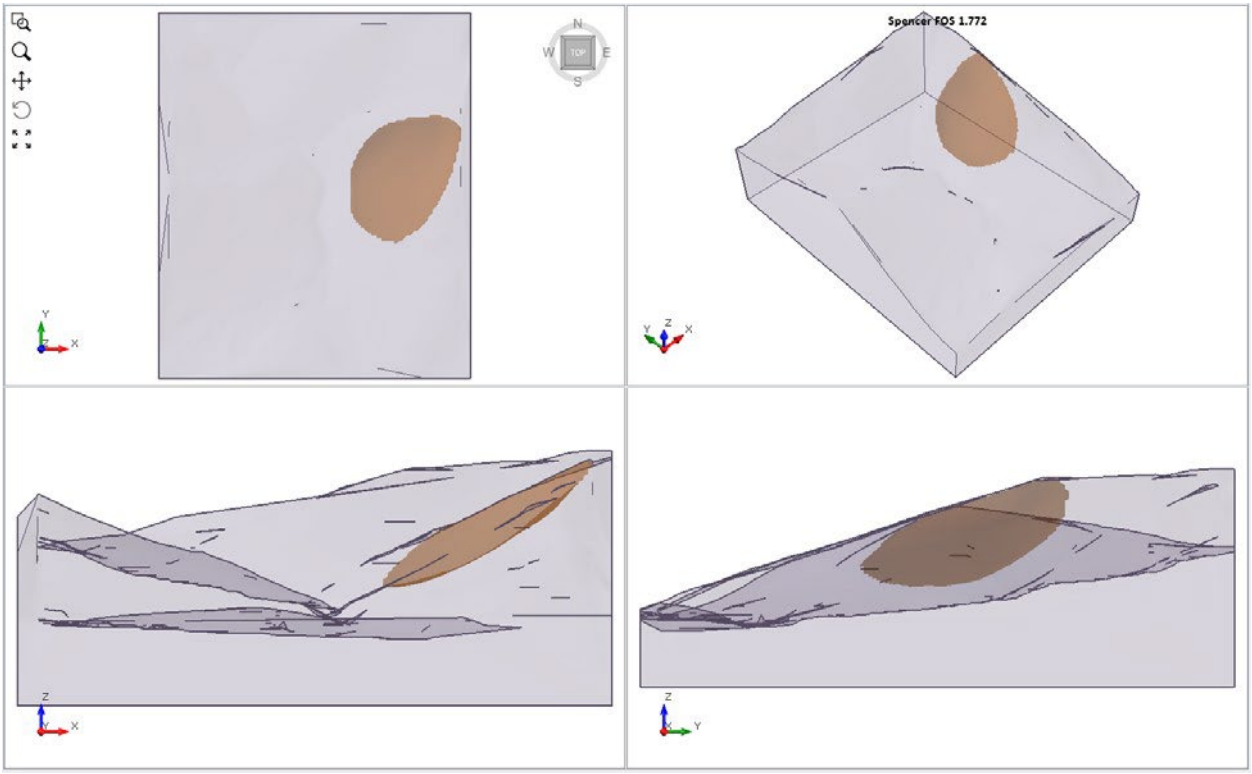

Figure 27.7 – *Slide3* Solution Using the Spencer Method

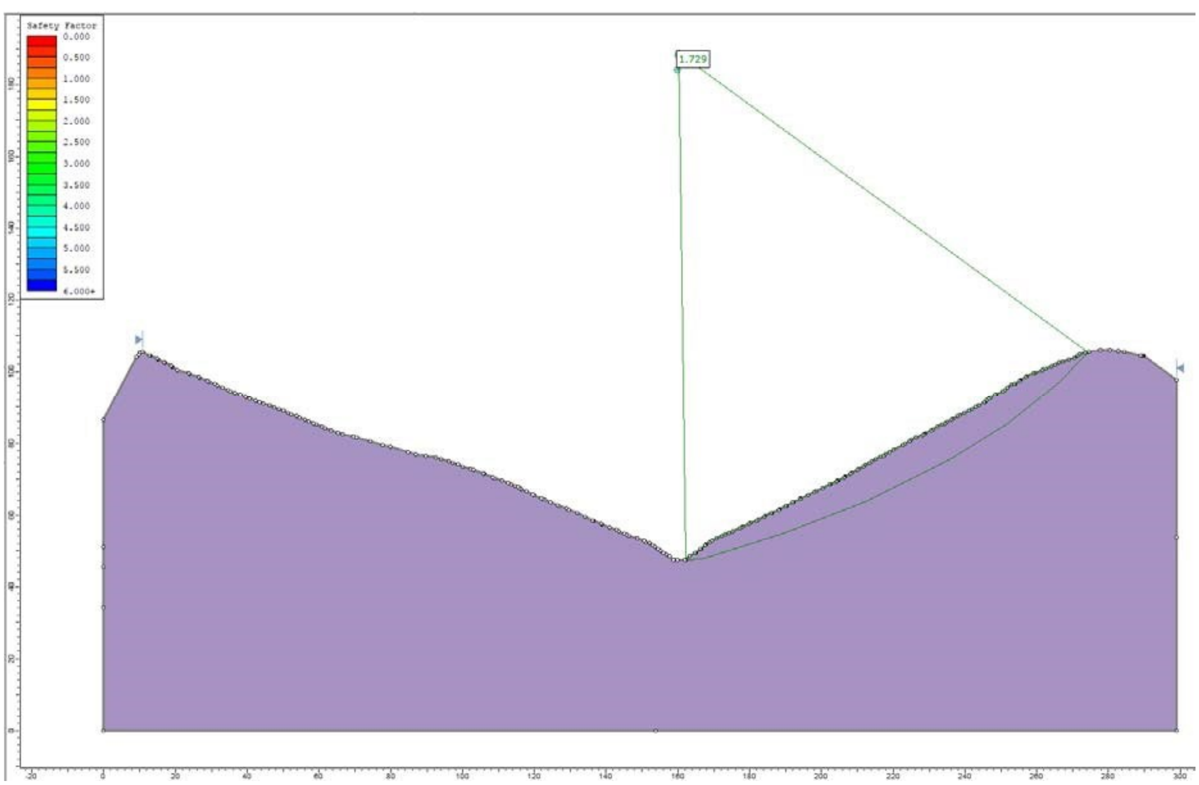

Figure 27.8 – *Slide2* Solution Using the Spencer Method

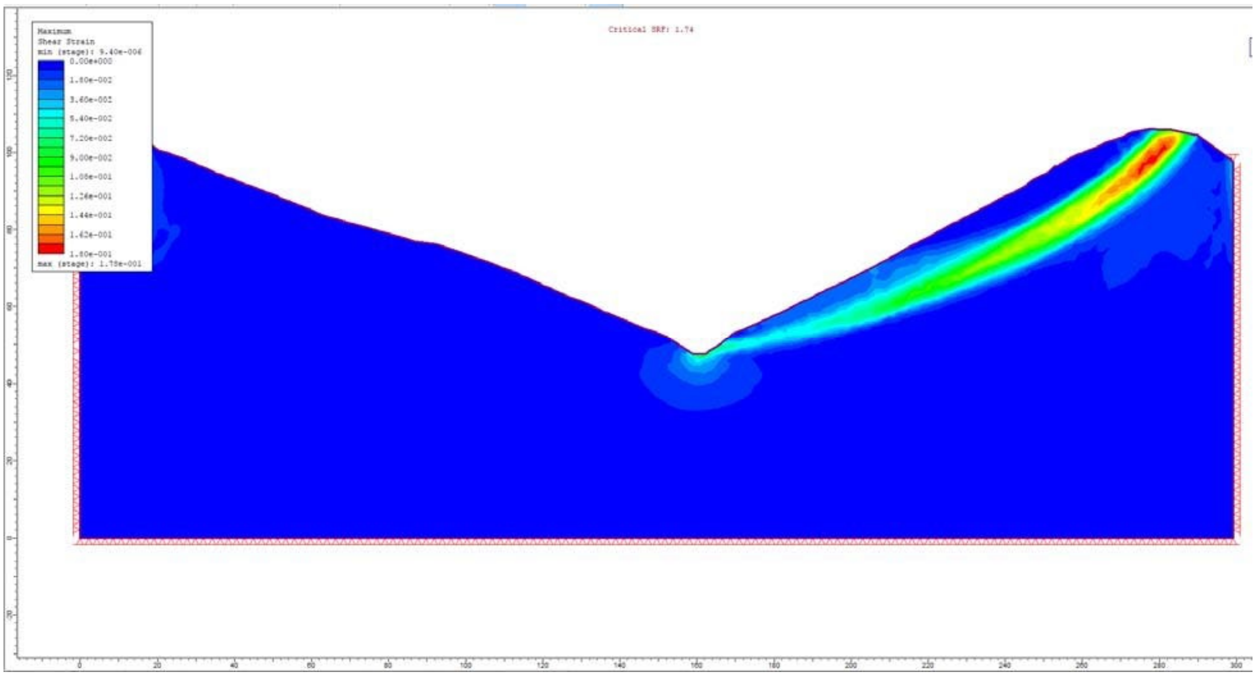

Figure 27.9 – *RS2* Maximum Shear Strain

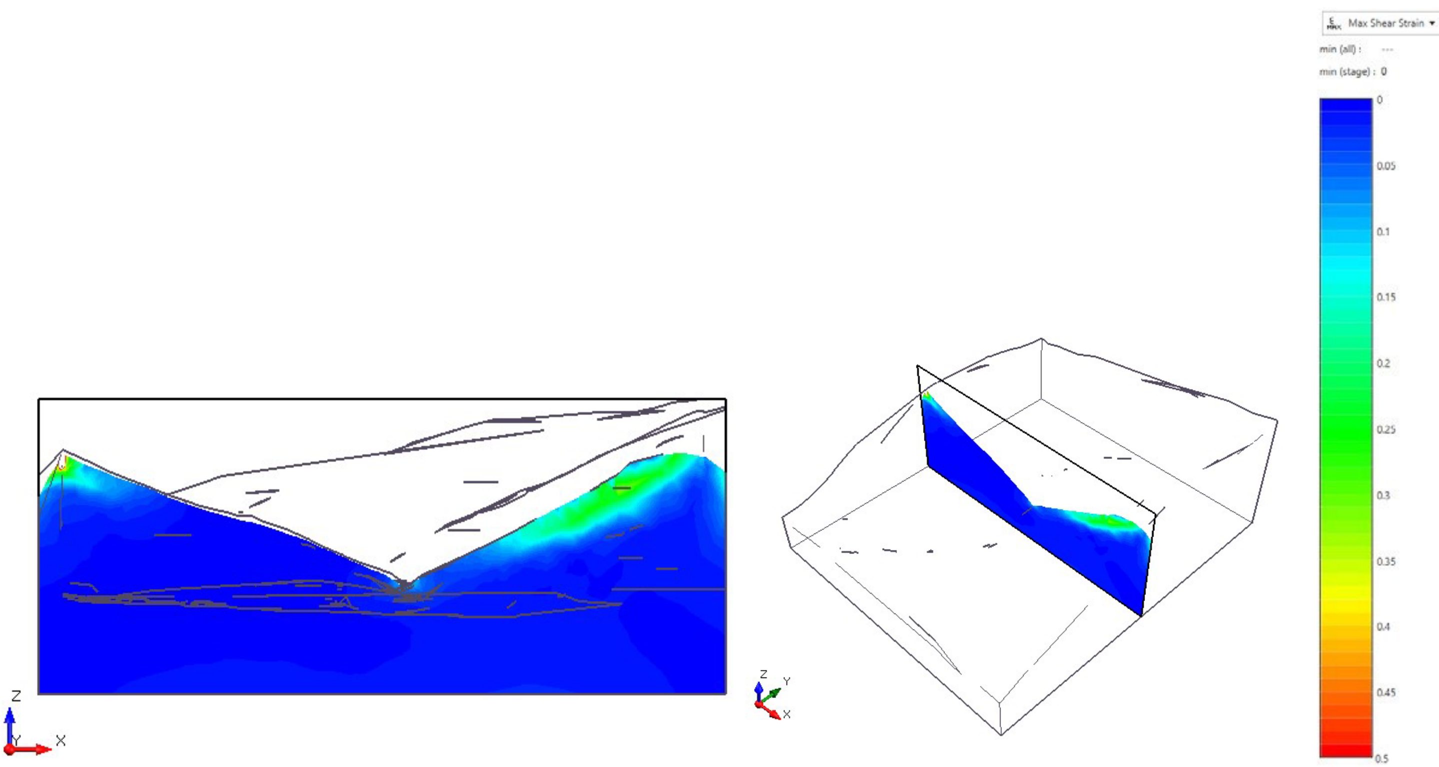

Figure 27.10 – *RS3* Maximum Shear Strain

28. 3D Verification #28

28.1. 3D tailings facility, (2) materials, ellipsoidal with SA

28.1.1. Introduction

This example has the same geometry as the previous example, except half of the slope is made of a different material.

28.1.2. Problem Description

The material properties for both materials can be found in Table 28.1. There is no groundwater in this problem. The ellipsoidal slip surface and corresponding safety factor is required.

28.1.3. Properties

Table 28.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
1	38	10	20
2	100	45	20

28.1.4. Results

Table 28.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

<table>
<tr><th>Method</th><th>Slide3</th><th>Slide2 7.0</th><th>RS3</th><th>RS2</th></tr>
<tr><td>Bishop</td><td>1.836</td><td>1.856</td><td rowspan="4">1.9</td><td rowspan="4">1.84</td></tr>
<tr><td>GLE</td><td>1.8358</td><td>1.834</td></tr>
<tr><td>Janbu</td><td>1.781</td><td>1.779</td></tr>
<tr><td>Spencer</td><td>1.846</td><td>1.841</td></tr>
</table>

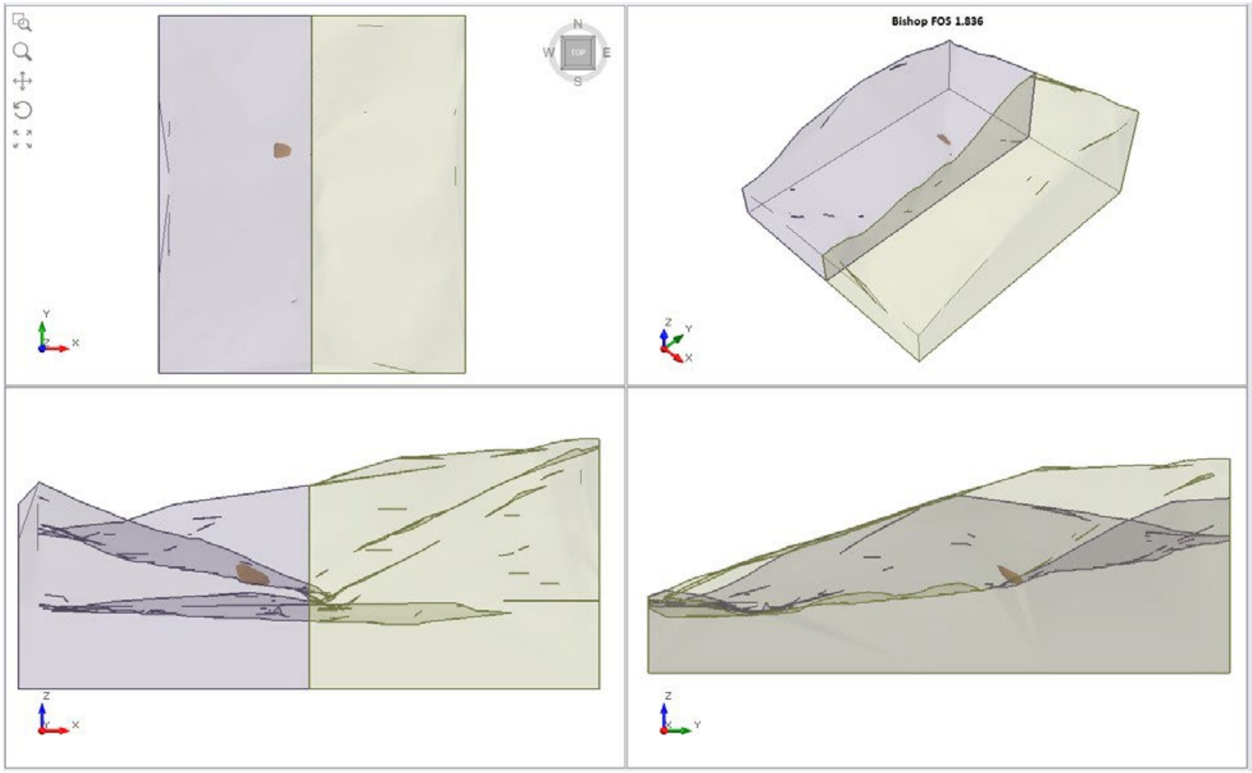

Figure 28.1 – *Slide3* Solution Using the Bishop Method

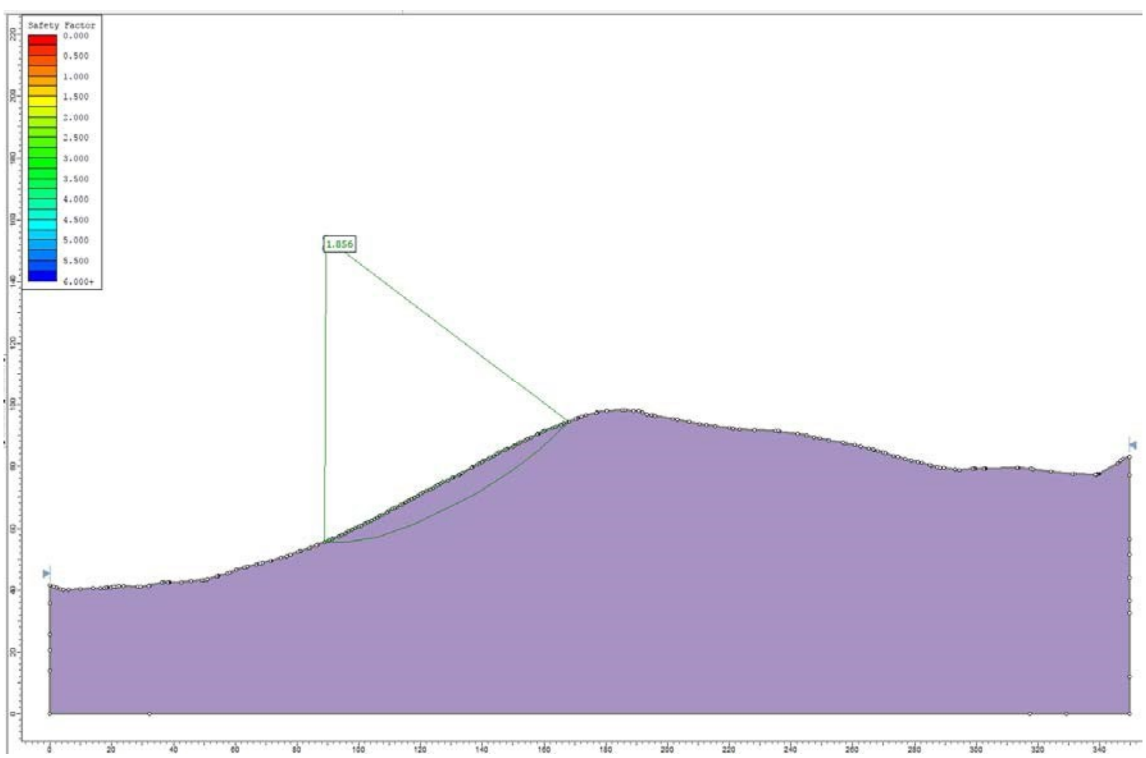

Figure 28.2 – *Slide2* Solution Using the Bishop Method

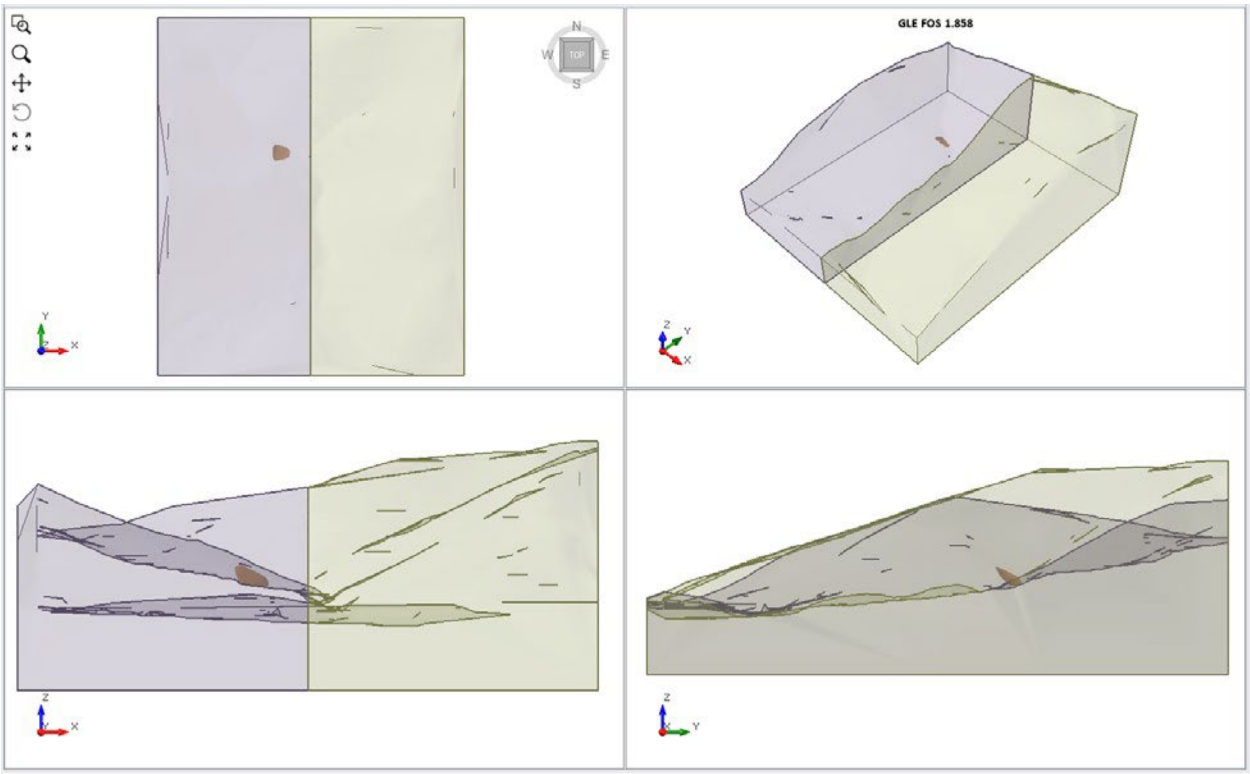

Figure 28.3 – *Slide3* Solution Using the GLE Method

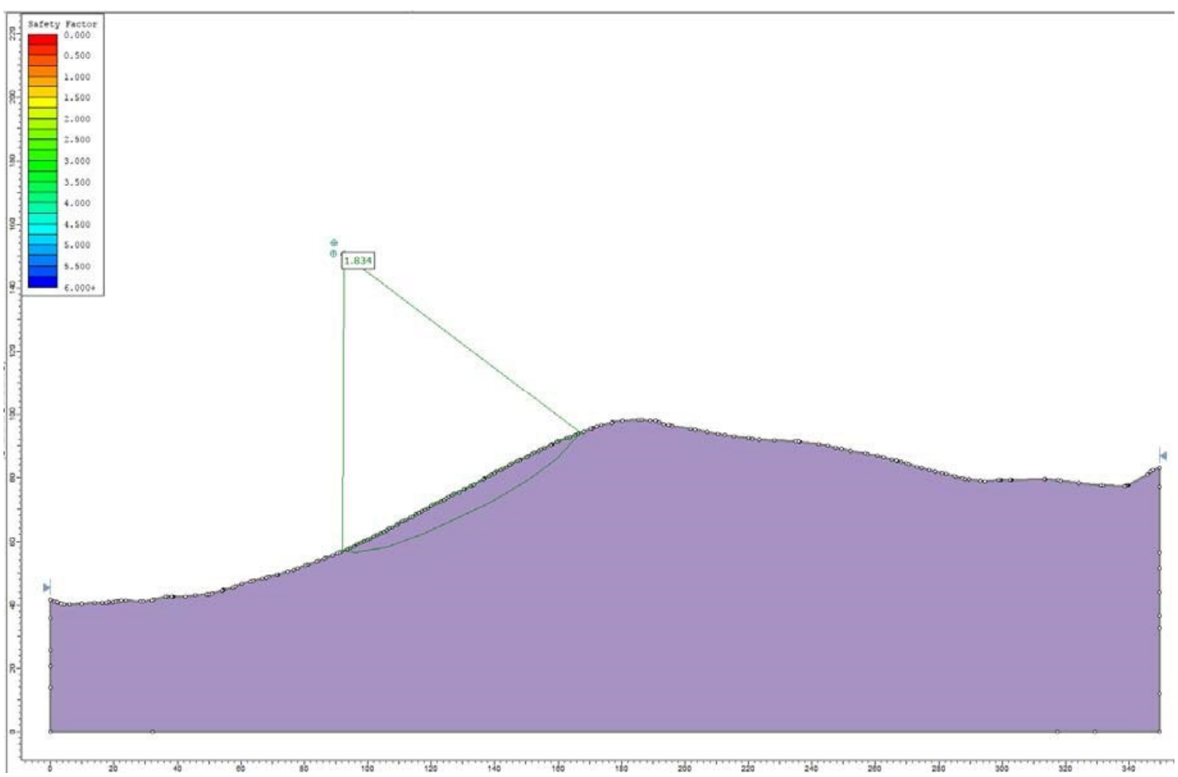

Figure 28.4 – *Slide2* Solution Using the GLE Method

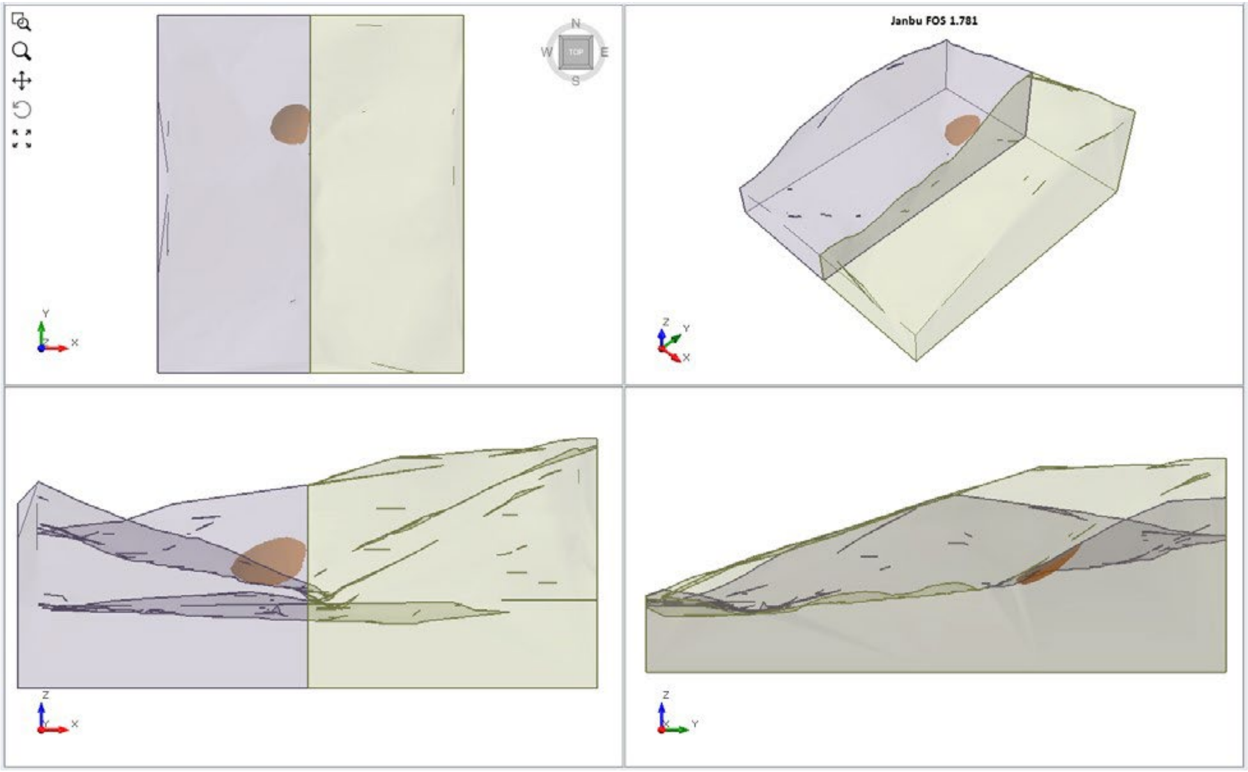

Figure 28.5 – *Slide3* Solution Using the Janbu Method

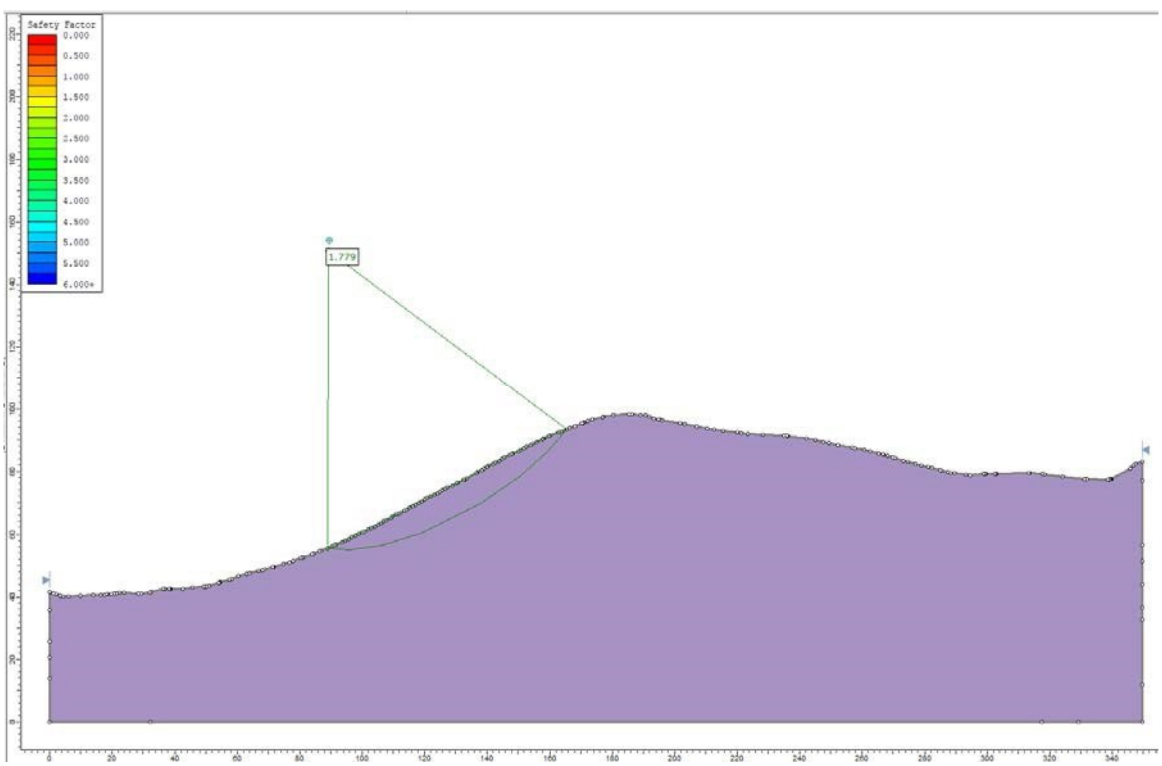

Figure 28.6 – *Slide2* Solution Using the Janbu Method

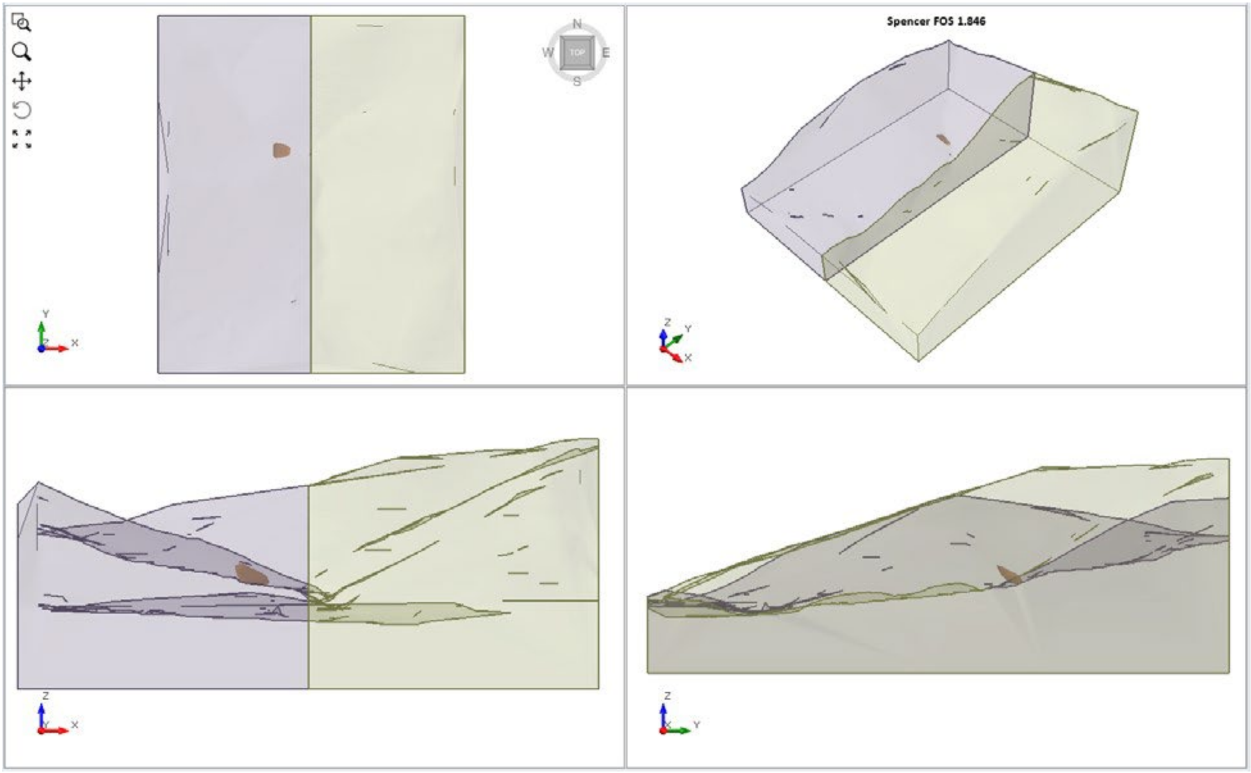

Figure 28.7 – *Slide3* Solution Using the Spencer Method

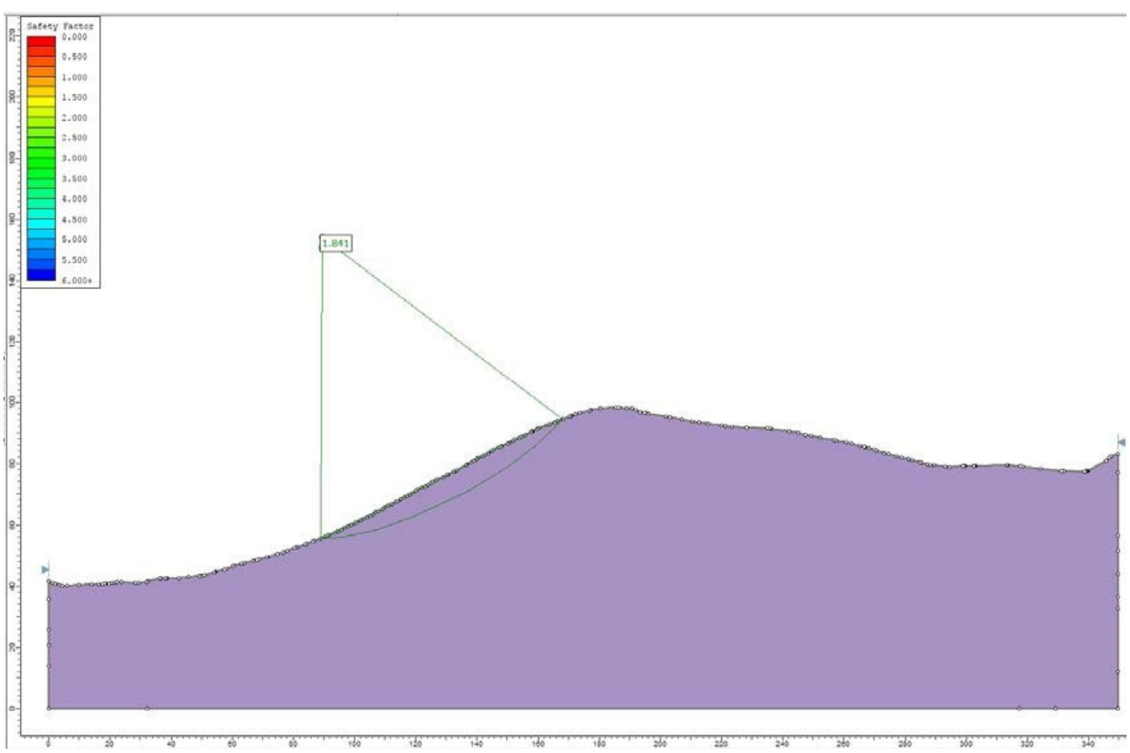

Figure 28.8 – *Slide2* Solution Using the Spencer Method

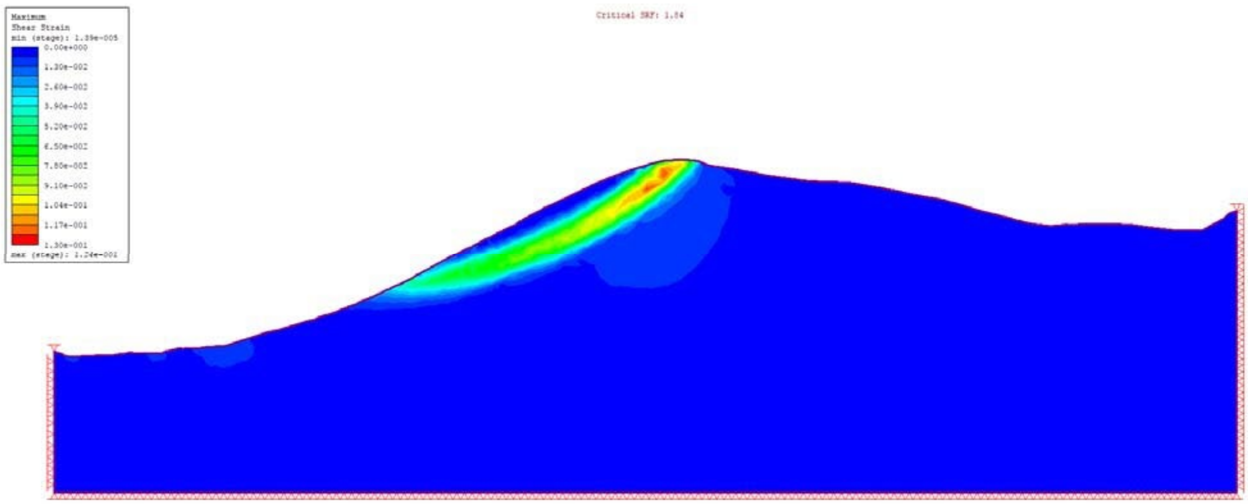

Figure 28.9 – *RS2* Maximum Shear Strain

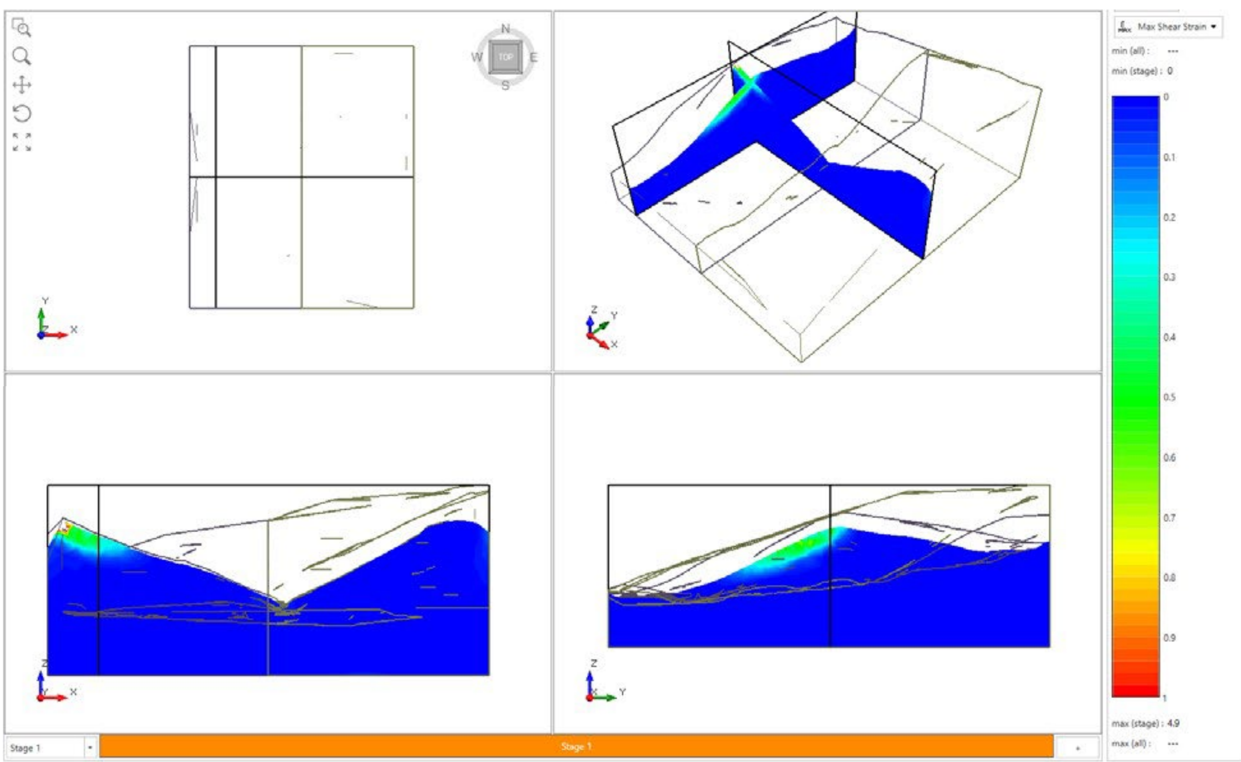

Figure 28.10 – *RS3* Maximum Shear Strain

29. 3D Verification #29

29.1. 3D open pit, homogeneous, ellipsoidal with SA

29.1.1. Introduction

This example is a fully 3D model of an open pit.

29.1.2. Problem Description

The material properties for the fully 3D homogeneous open pit can be found in Table 29.1. There is no groundwater in this problem. The ellipsoidal slip surface and corresponding safety factor is required.

29.1.3. Properties

Table 29.1: Material Properties

c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
1	35	20

29.1.4. Results

Table 29.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	0.807	0.746	0.87	0.73
GLE	0.899	0.734		
Janbu	0.785	0.704		
Spencer	0.843	0.736		

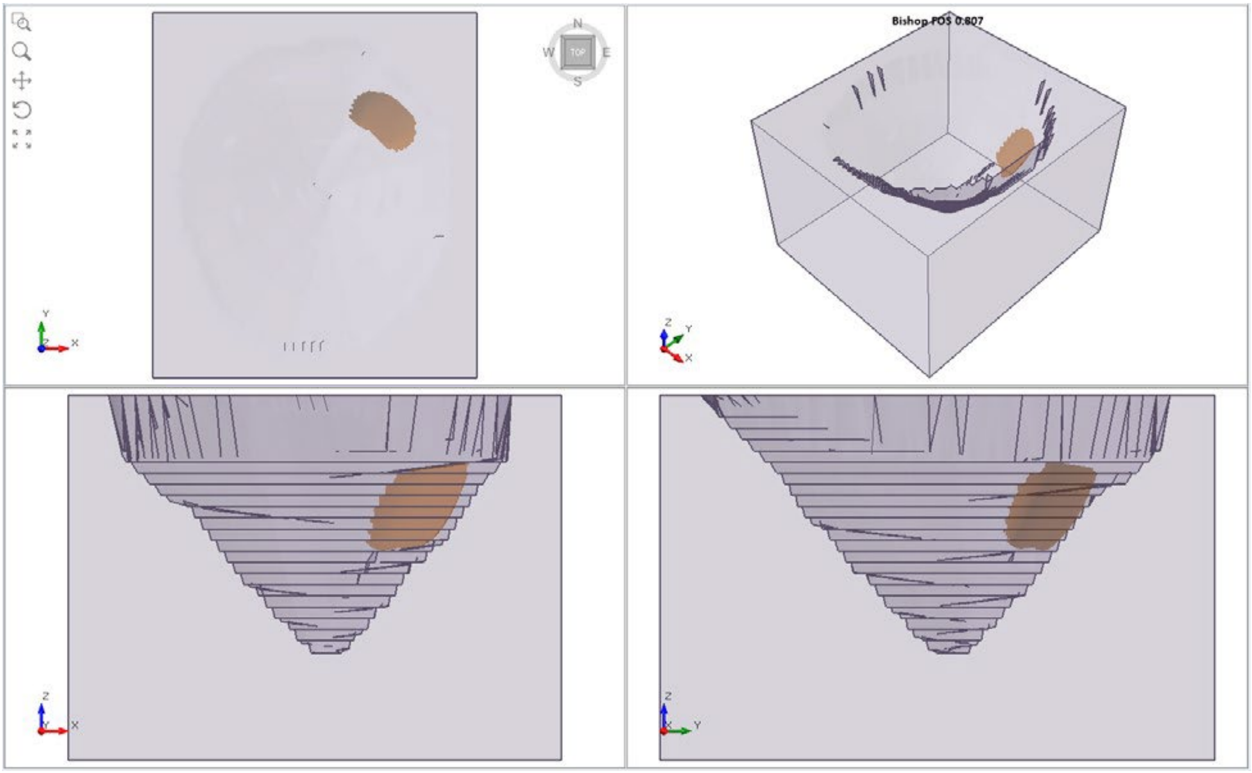

Figure 29.1 – *Slide3* Solution Using the Bishop Method

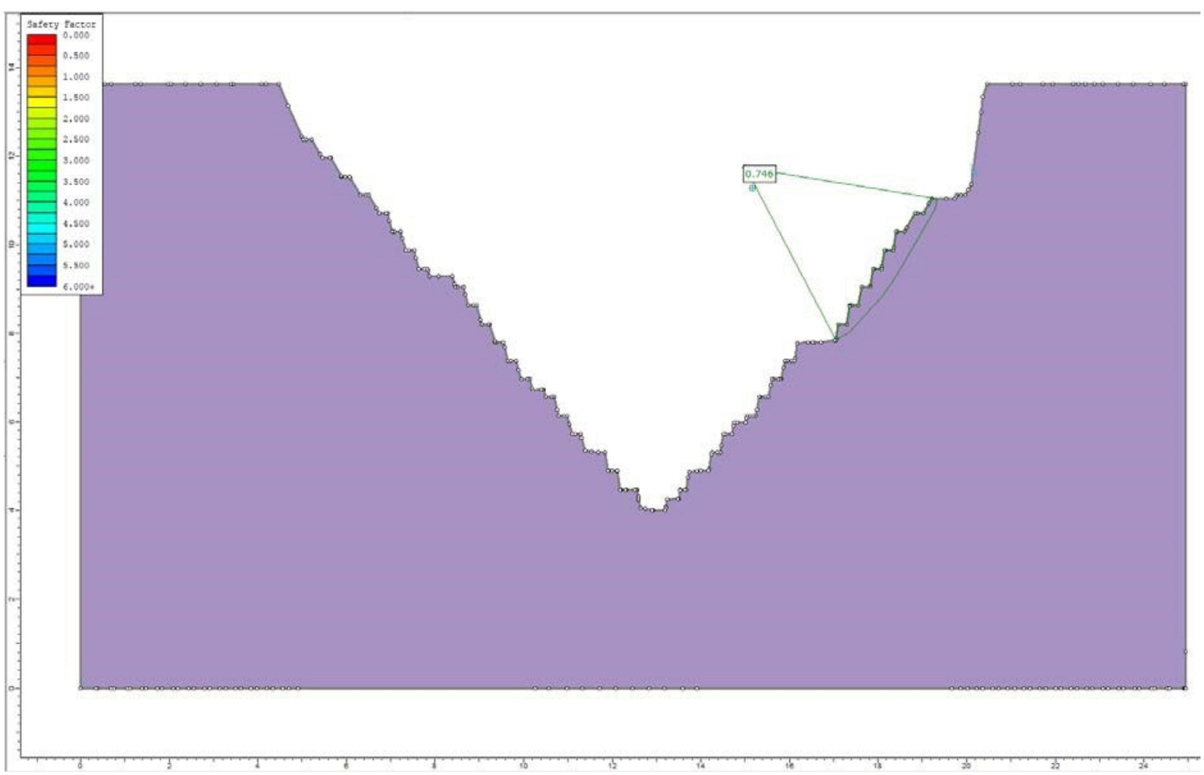

Figure 29.2 – *Slide2* Solution Using the Bishop Method

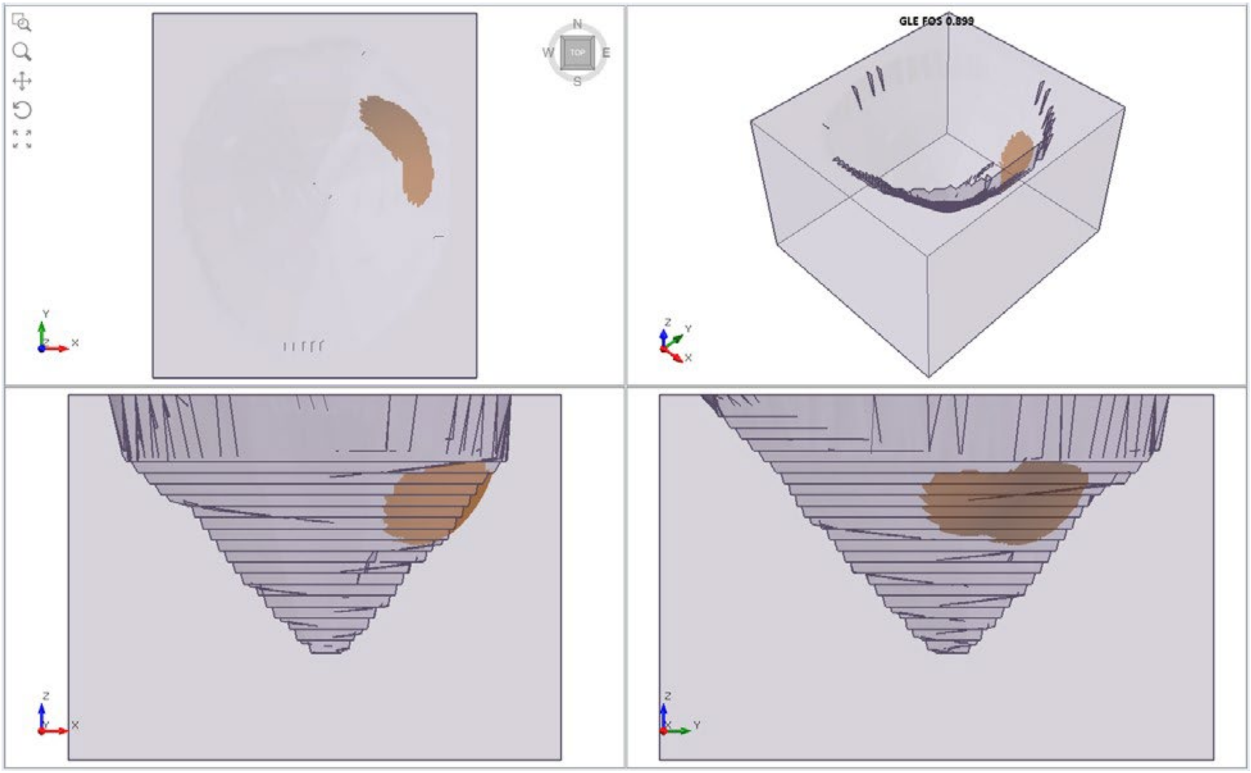

Figure 29.3 – *Slide3* Solution Using the GLE Method

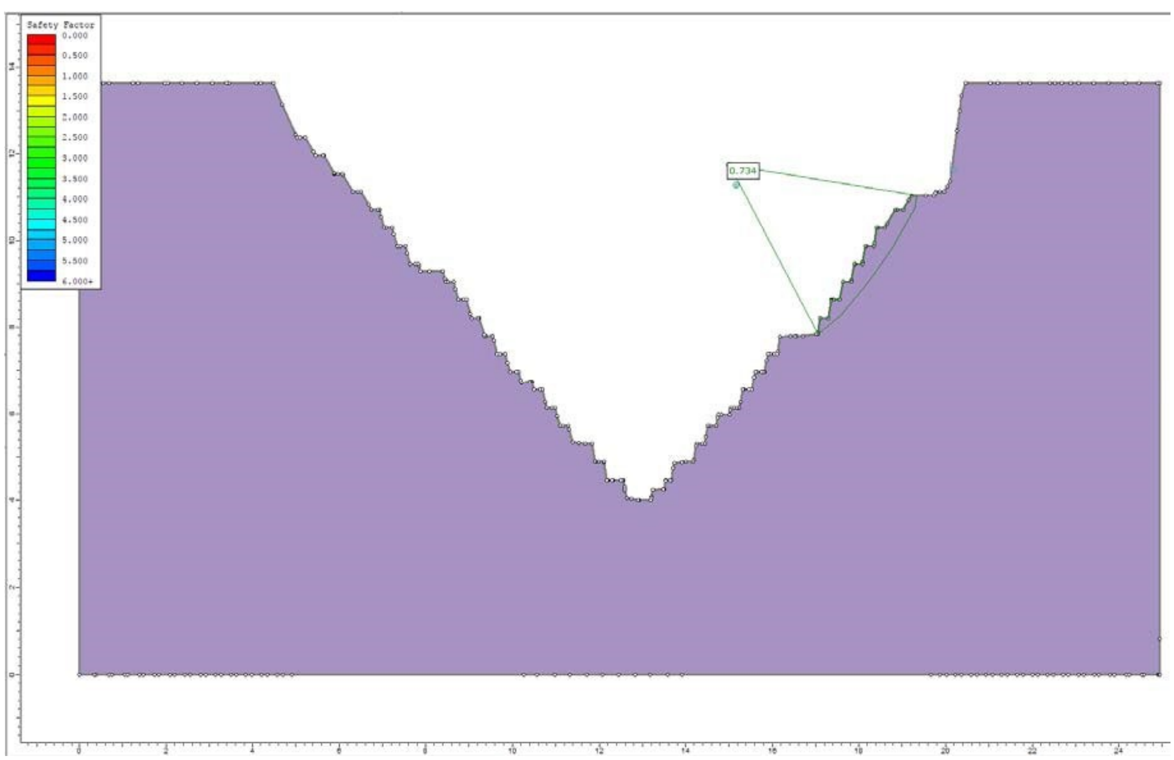

Figure 29.4 – *Slide2* Solution Using the GLE Method

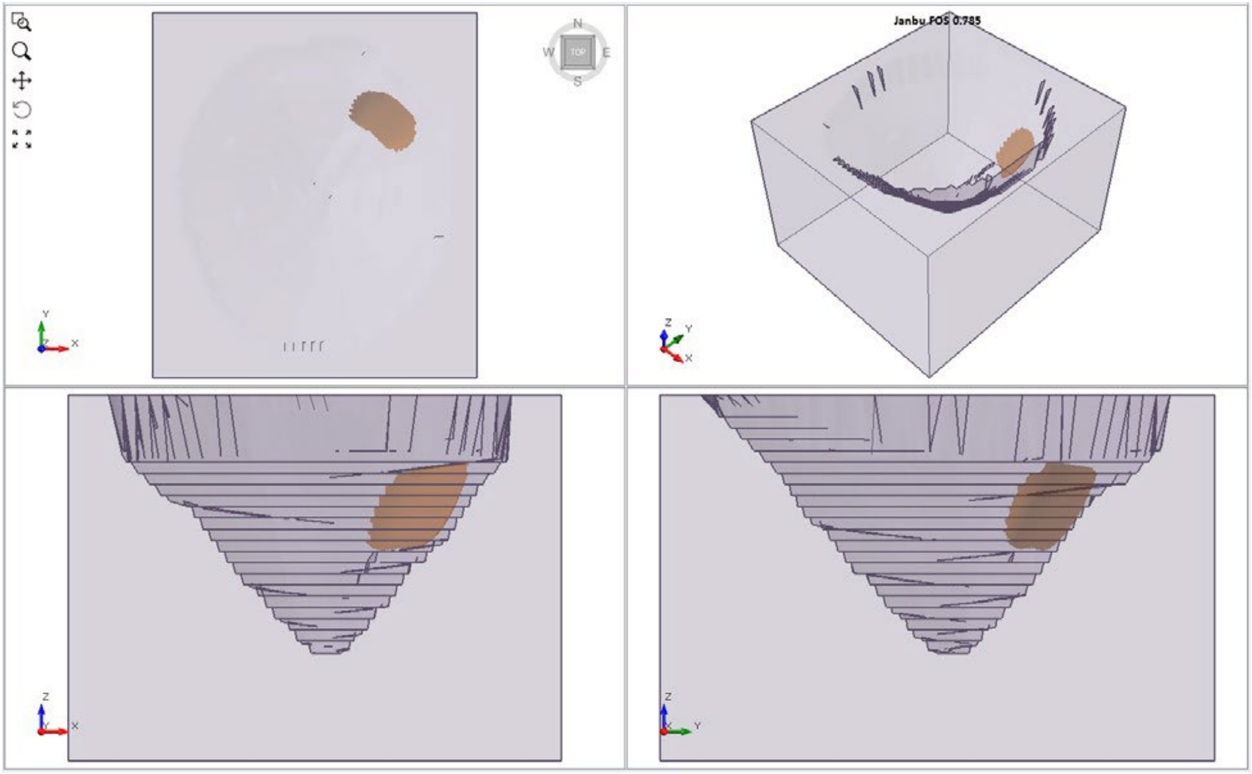

Figure 29.5 – *Slide3* Solution Using the Janbu Method

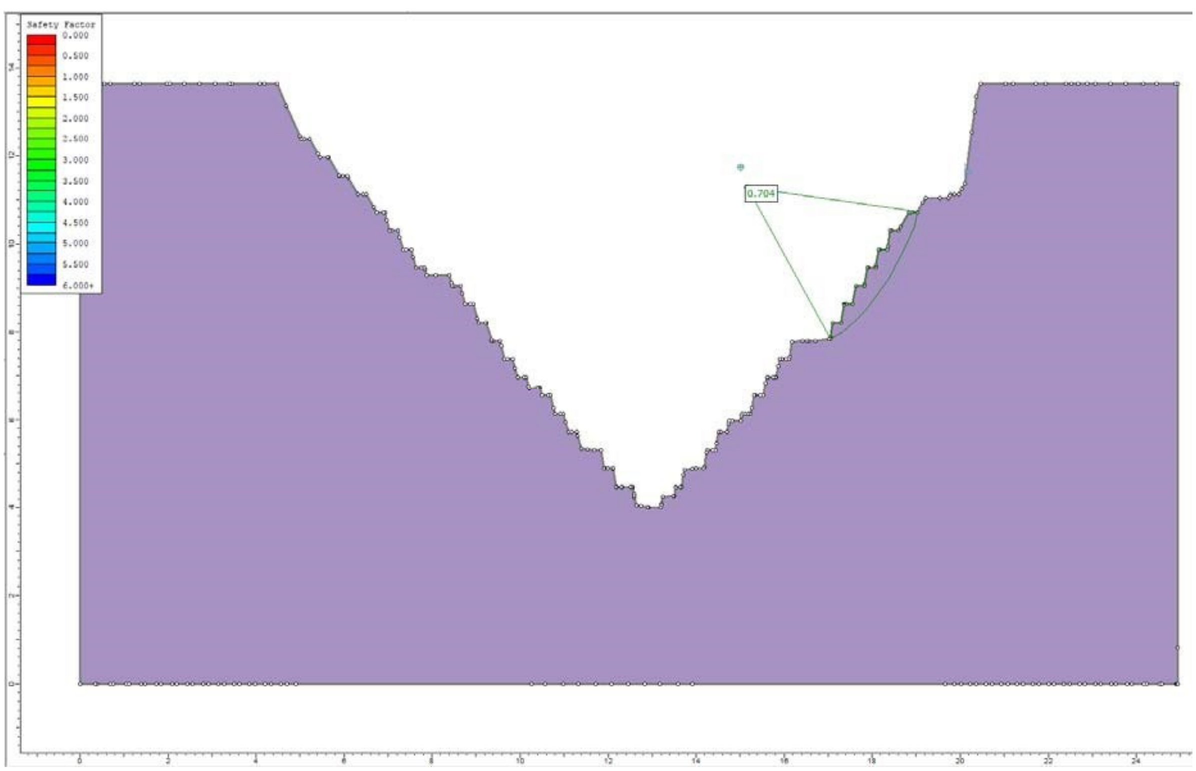

Figure 29.6 – *Slide2* Solution Using the Janbu Method

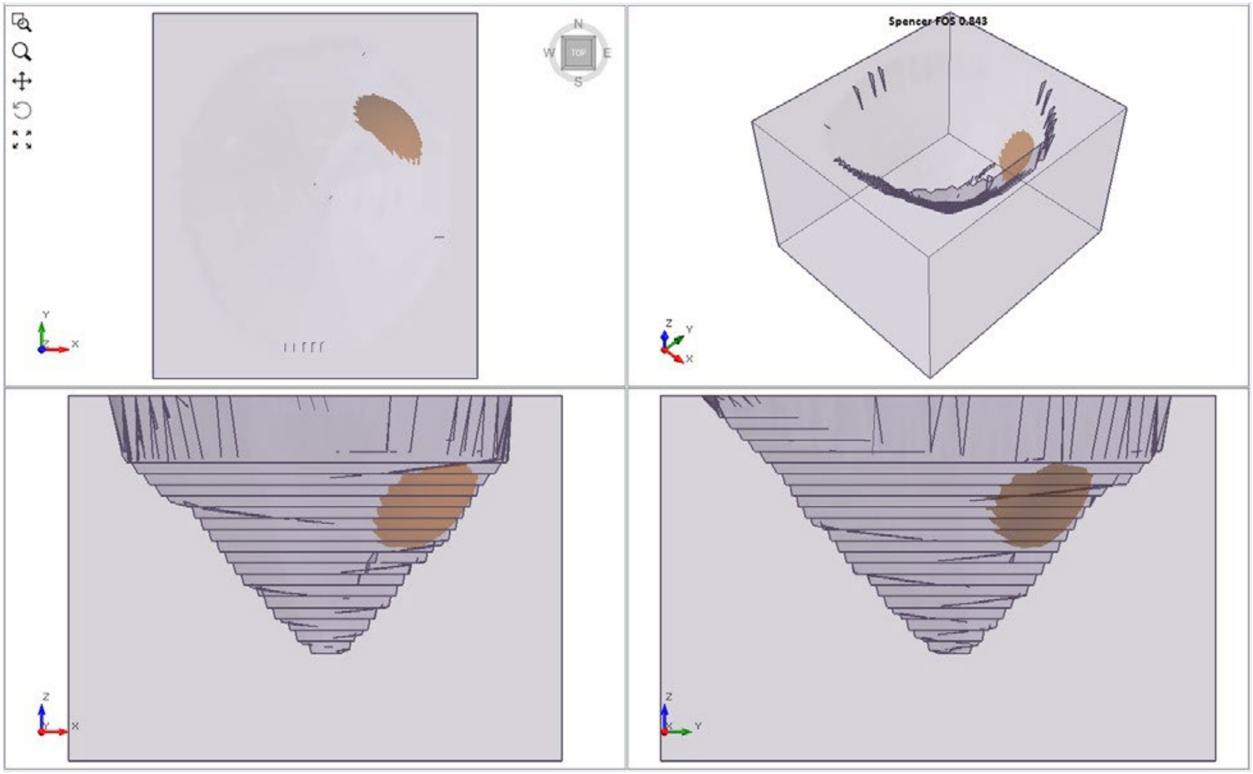

Figure 29.7 – *Slide3* Solution Using the Spencer Method

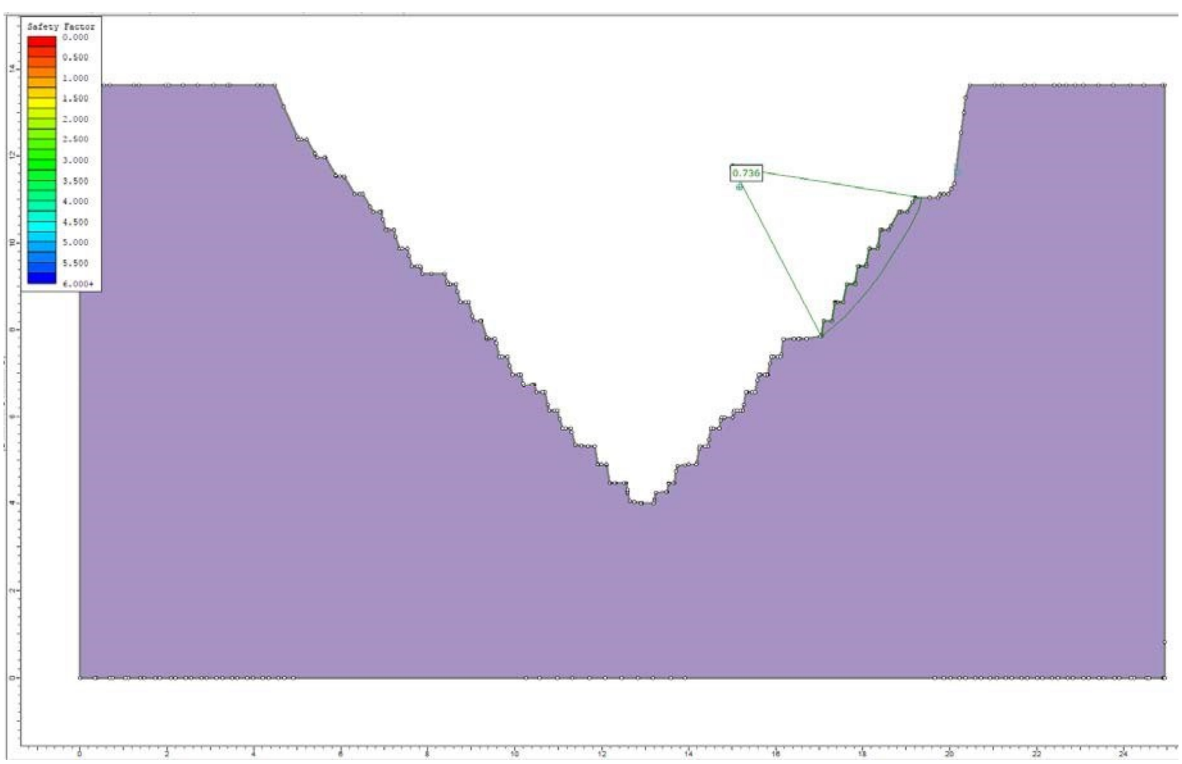

Figure 29.8 – *Slide2* Solution Using the Spencer Method

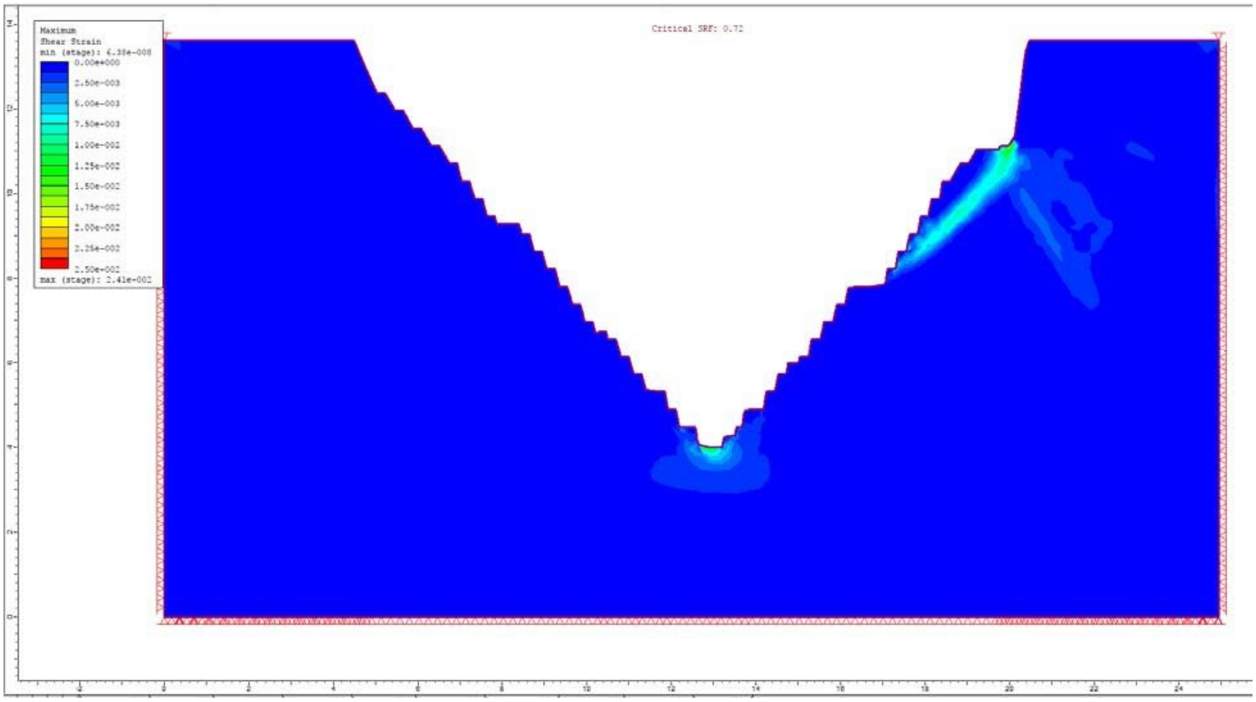

Figure 29.9 – *RS2* Maximum Shear Strain

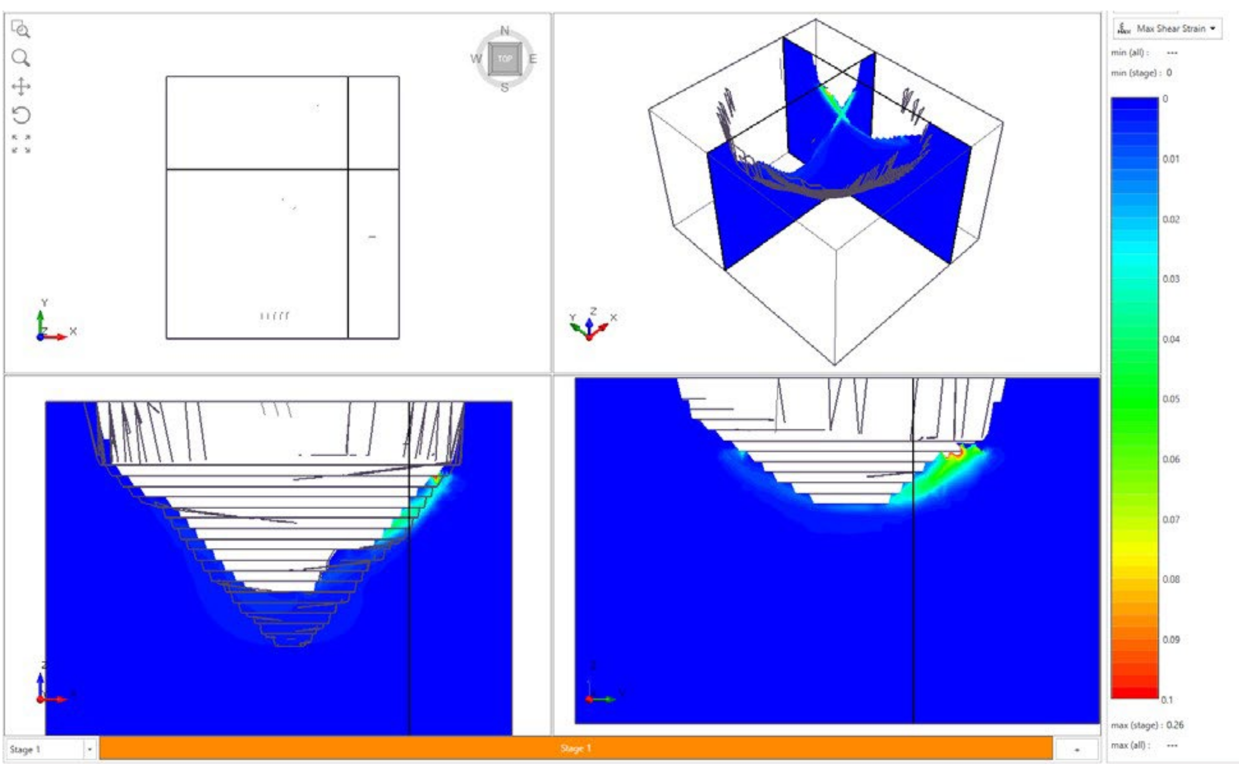

Figure 29.10 – *RS3* Maximum Shear Strain

30. 3D Verification #30

30.1. 3D open pit, (2) materials, ellipsoidal with SA

30.1.1. Introduction

This model is a 3D open pit with a weaker material running through the center of the pit.

30.1.2. Problem Description

The material properties for both materials can be found in Table 30.1. There is no groundwater in this problem. The ellipsoidal slip surface and corresponding safety factor is required.

30.1.3. Properties

Table 30.1: Material Properties

	Strength Type	UCS of intact rock (kPa)	mb	s	a	c′ (kN/m^2)	φ′ (deg.)	γ (kN/m^3)
1	Generalized Hoek-Brown	50000	1.67677	0.0038659	0.505938	X	X	20
2	Mohr-Coulomb	X	X	X	X	300	25	20

30.1.4. Results

Table 30.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	0.999	0.903	1.03	0.88
GLE	1.006	0.895		
Janbu	0.958	0.847		
Spencer	1.005	0.902		

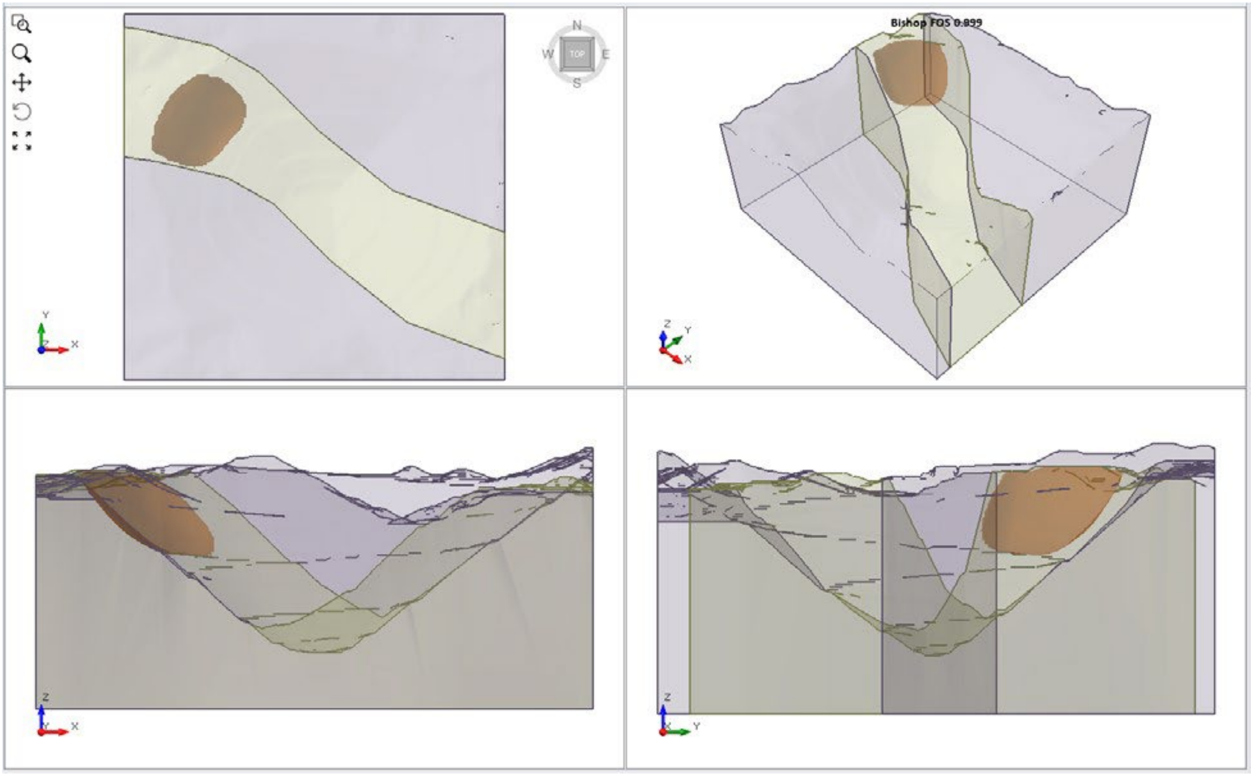

Figure 30.1 – *Slide3* Solution Using the Bishop Method

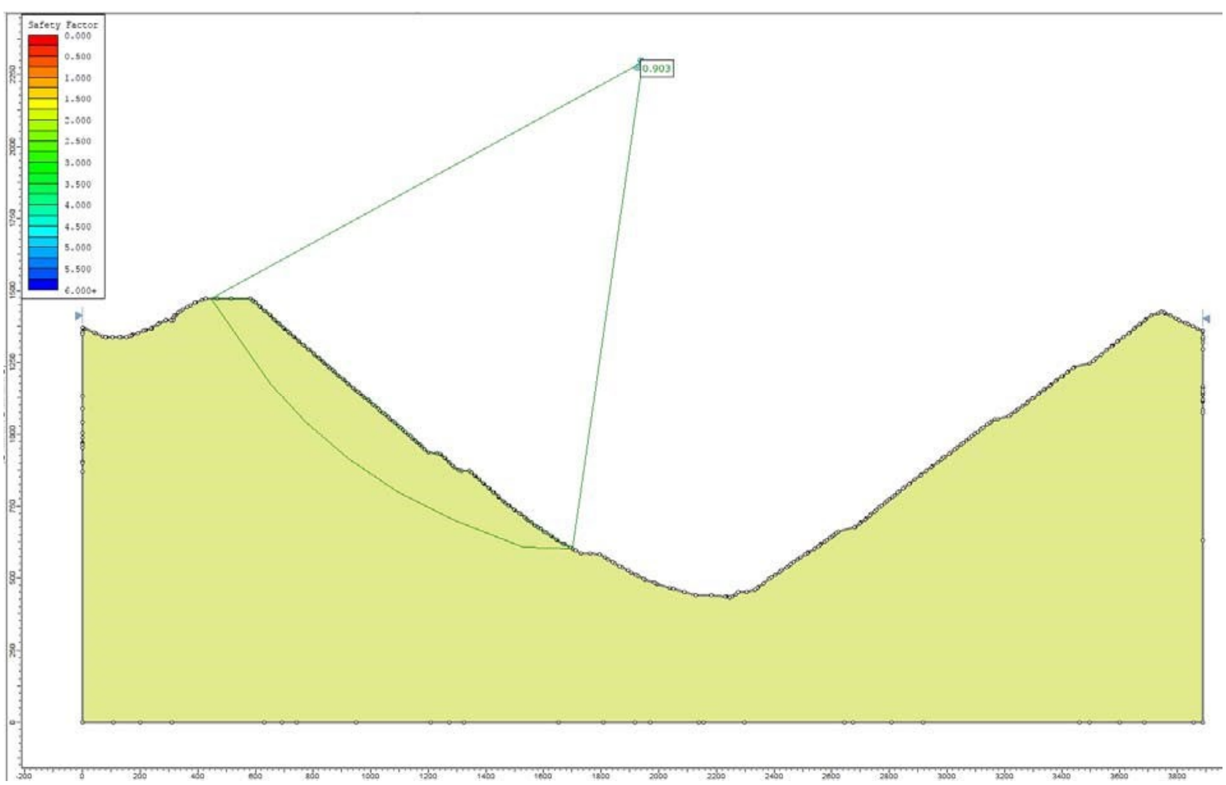

Figure 30.2 – *Slide2* Solution Using the Bishop Method

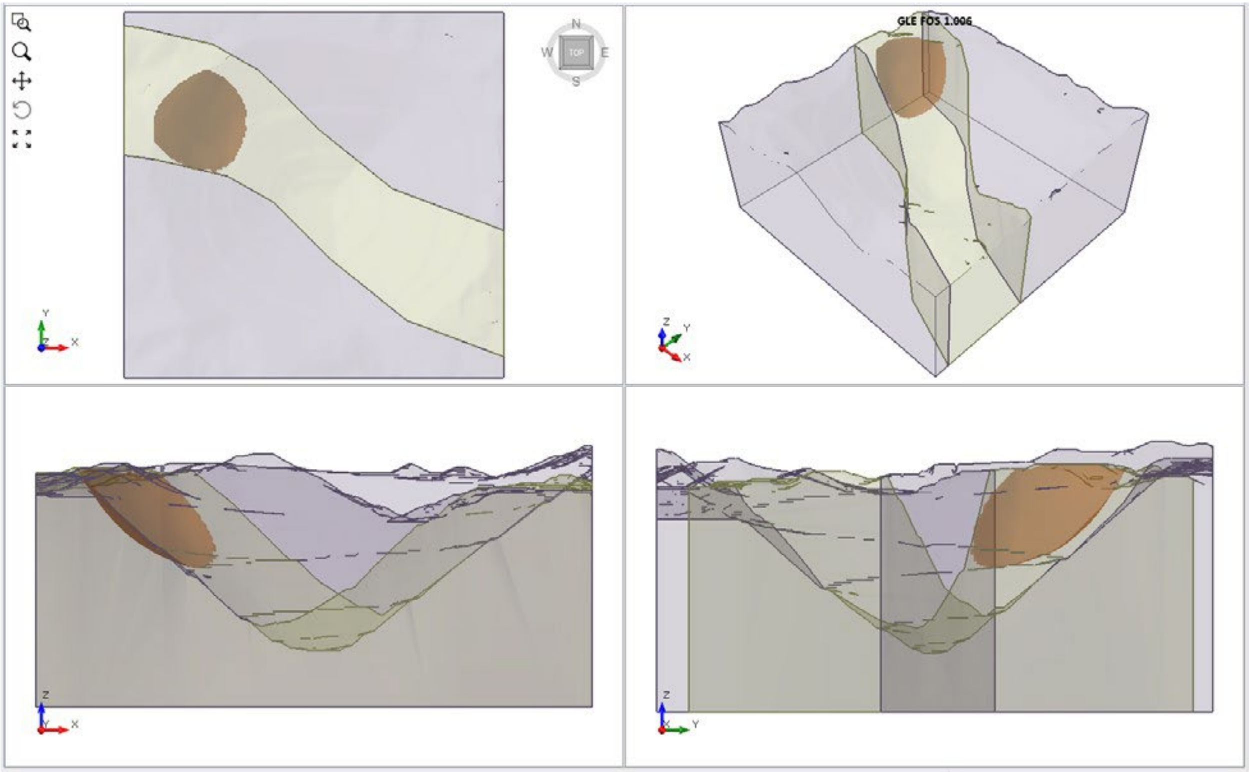

Figure 30.3 – *Slide3* Solution Using the GLE Method

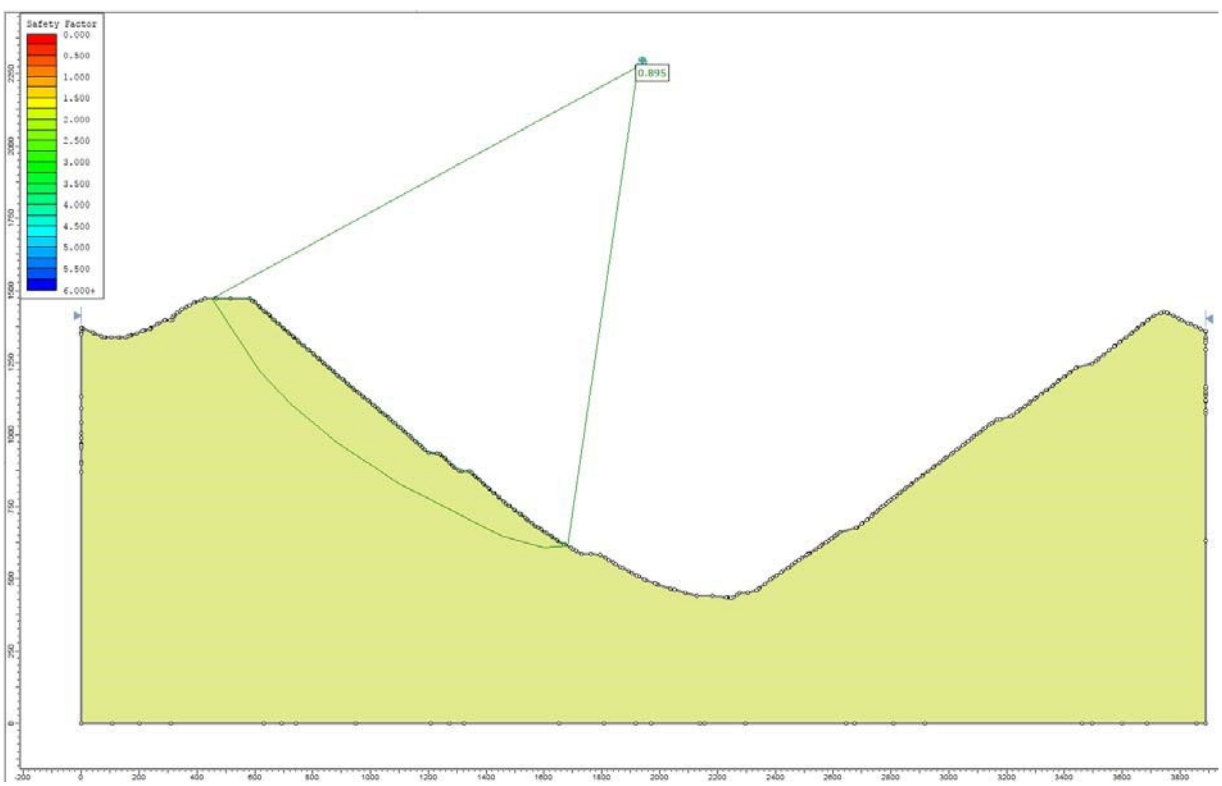

Figure 30.4 – *Slide2* Solution Using the GLE Method

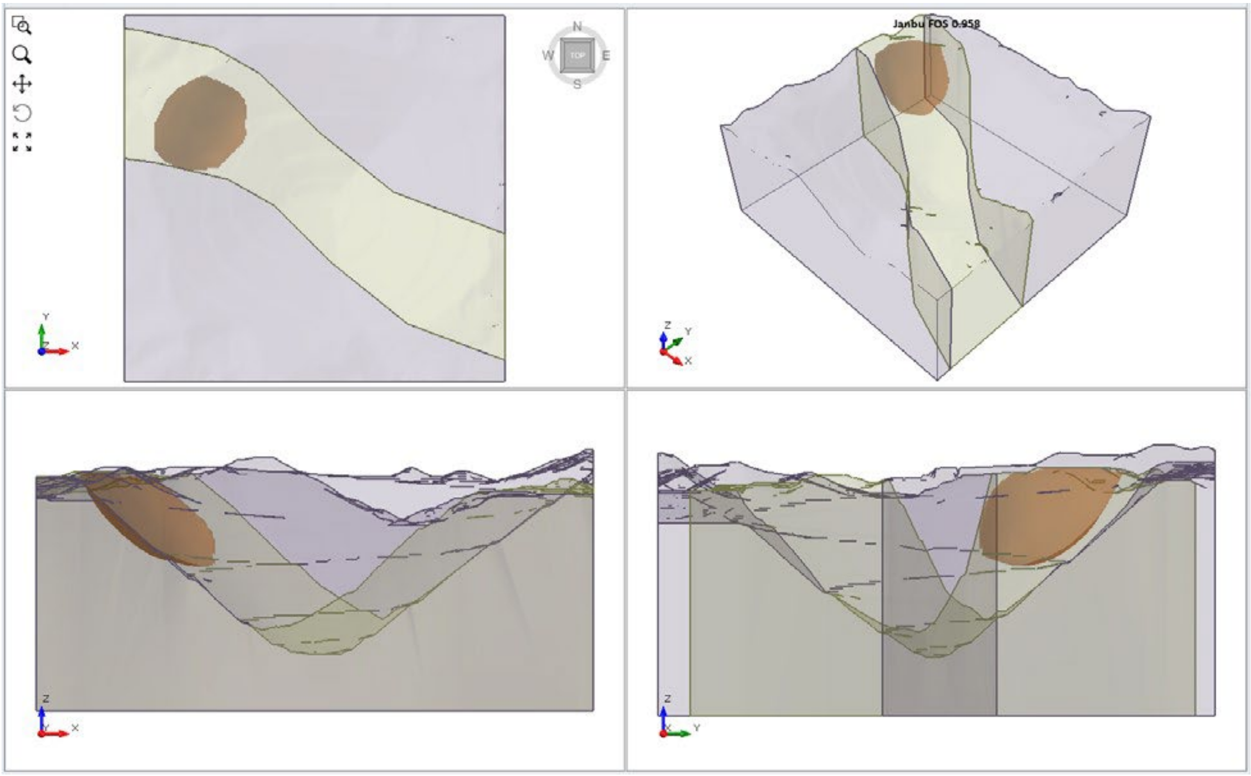

Figure 30.5 – *Slide3* Solution Using the Janbu Method

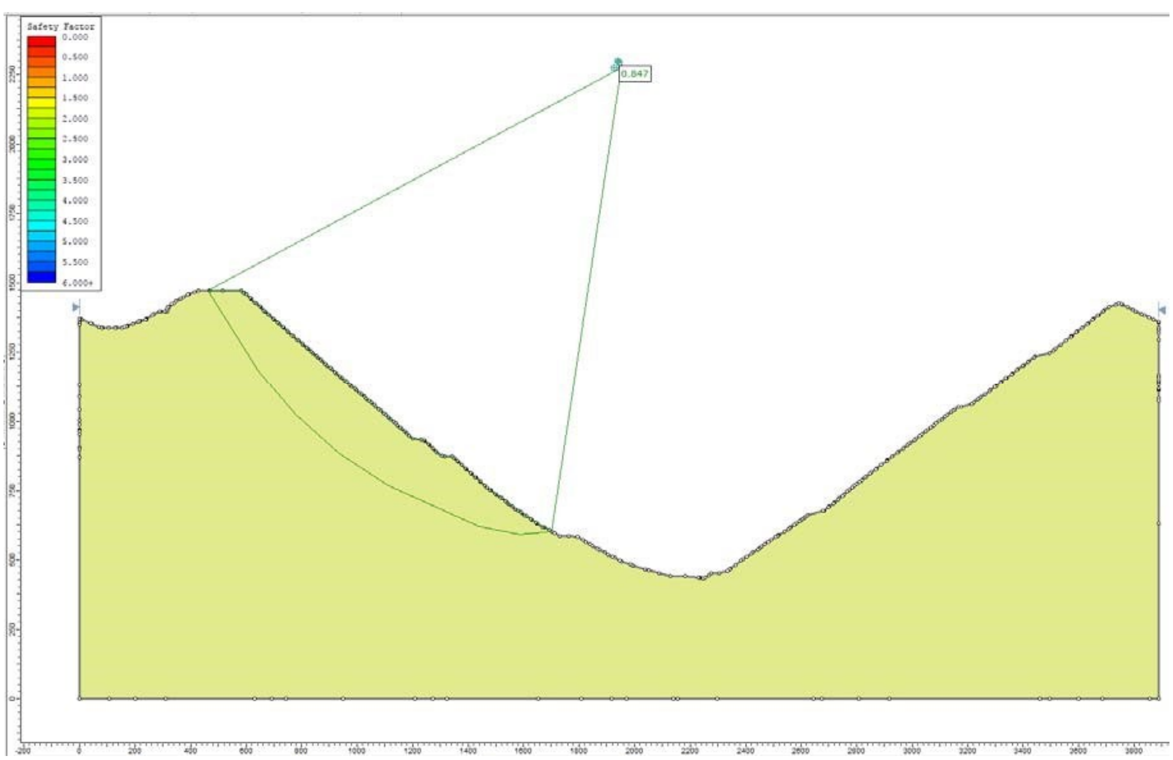

Figure 30.6 – *Slide2* Solution Using the Janbu Method

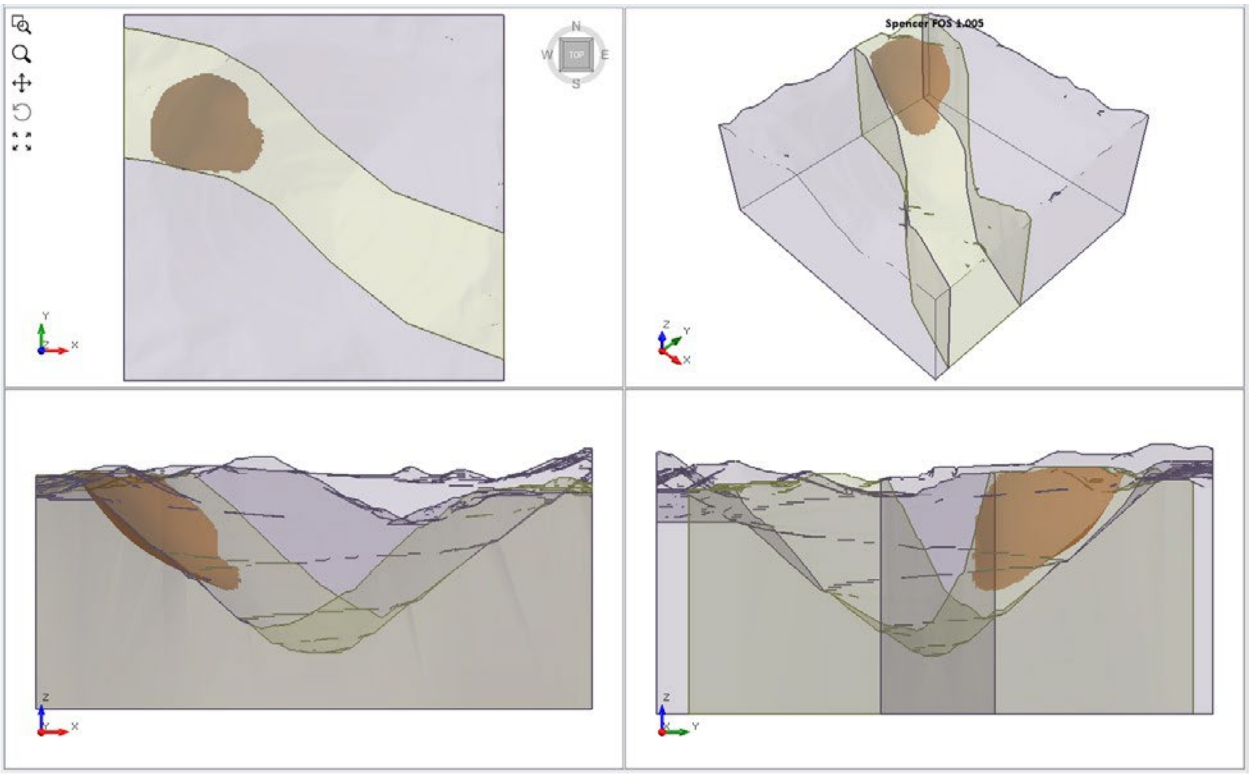

Figure 30.7 – *Slide3* Solution Using the Spencer Method

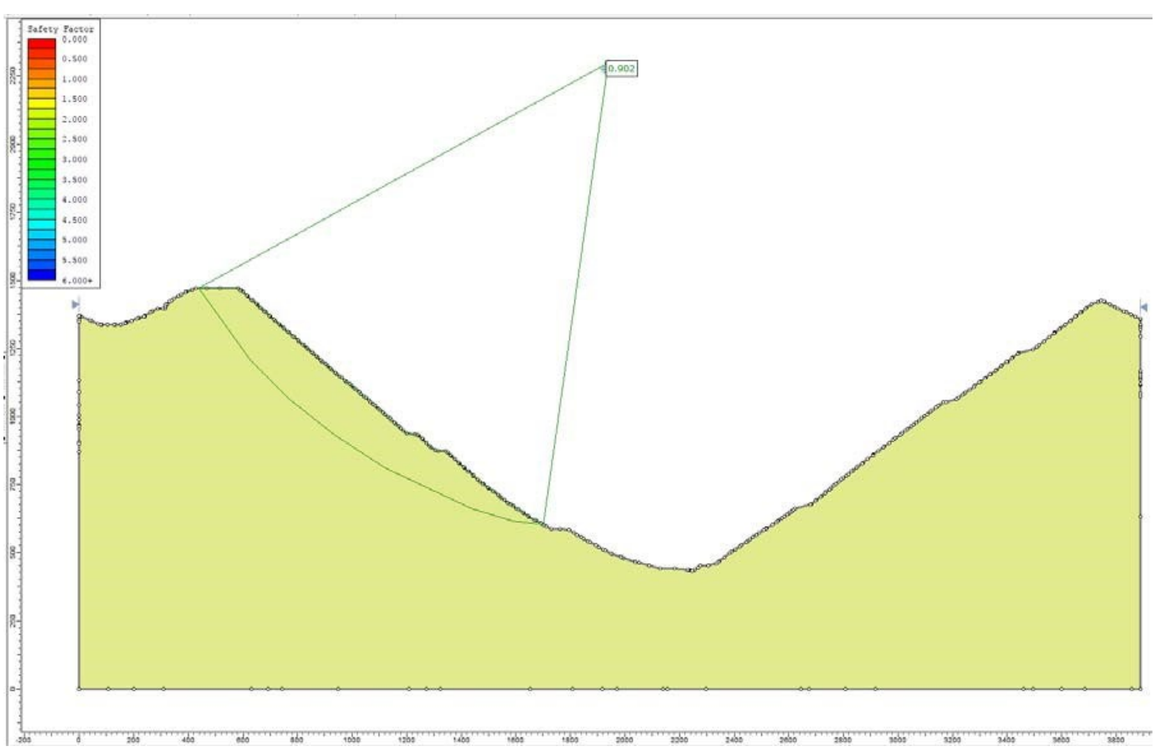

Figure 30.8 – *Slide2* Solution Using the Spencer Method

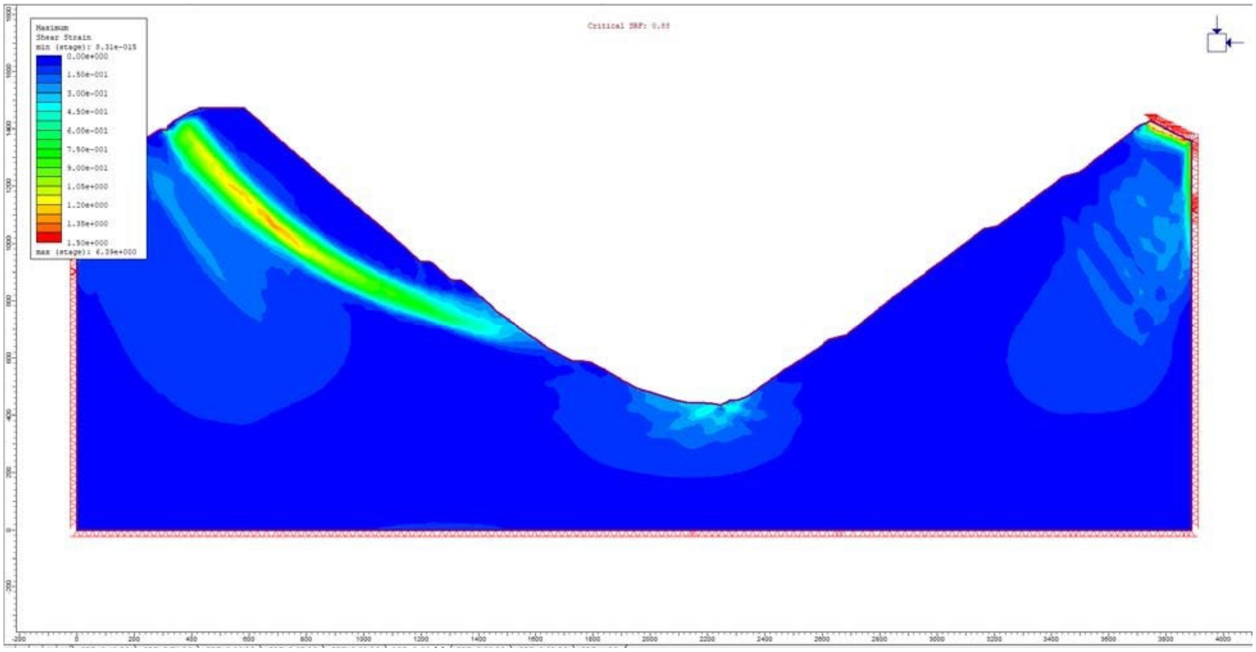

Figure 30.9 – *RS2* Maximum Shear Strain

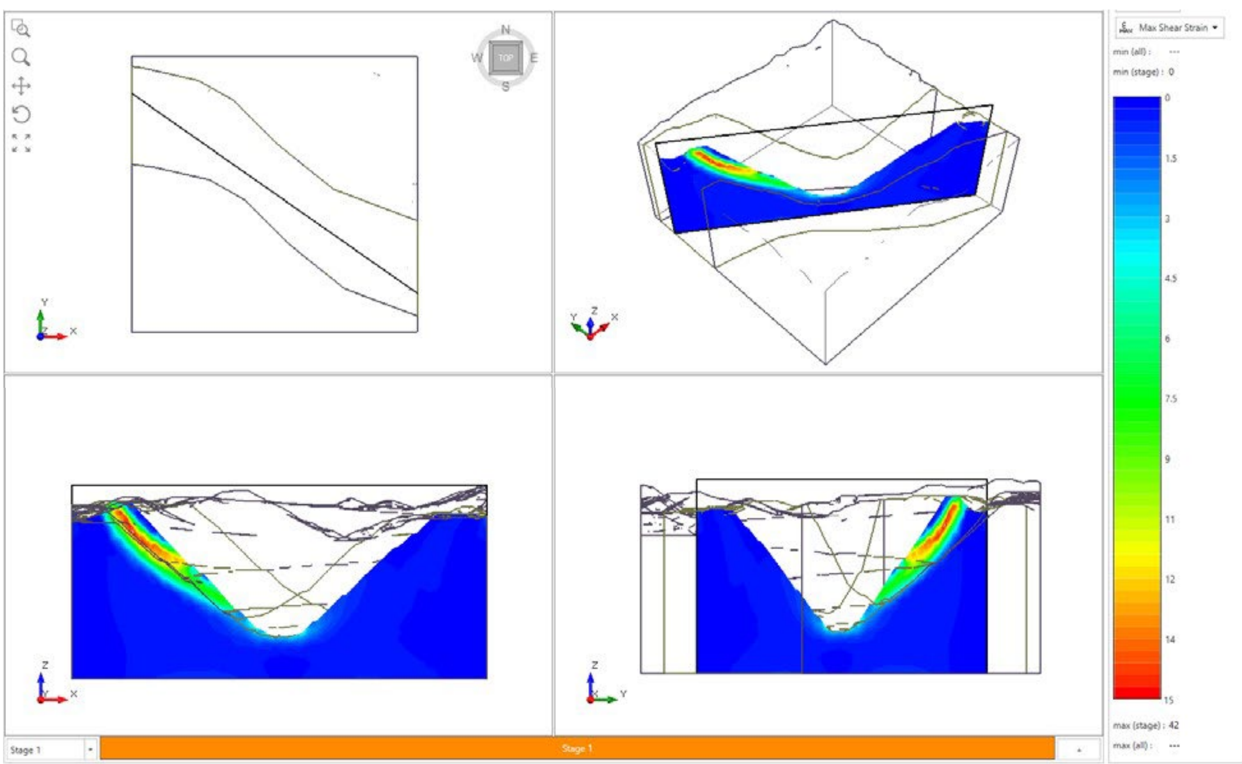

Figure 30.10 – *RS3* Maximum Shear Strain

31. 3D Verification #31

31.1. 3D coal mine, (3) materials, ellipsoidal with SA

31.1.1. Introduction

This example is a model of a 3D coal mine made of three materials.

31.1.2. Problem Description

The material properties for this problem are in Table 31.1. This is a fully 3D model with no groundwater. The ellipsoidal slip surface and corresponding safety factor is required.

31.1.3. Properties

Table 31.1: Material Properties

	UCS of intact rock (kPa)	mb	s	a	γ (kN/m^3)
Mist (D=0)	70000	0.8832	0.00073	0.51595	24
Coal (D=0)	5000	1.40783	0.001273	0.511368	14
Rock Mass Below Coal (D=0)	88000	2.01213	0.003866	0.505734	24

31.1.4. Results

Table 31.2: Safety Factors Safety Factors Using *Slide3*, *Slide2* 7.0, *RS3*, and *RS2*

Method	*Slide3*	*Slide2* 7.0	*RS3*	*RS2*
Bishop	1.933	1.447	2.43	1.55
GLE	2.249	1.586		
Janbu	1.849	1.381		
Spencer	2.085	1.569		

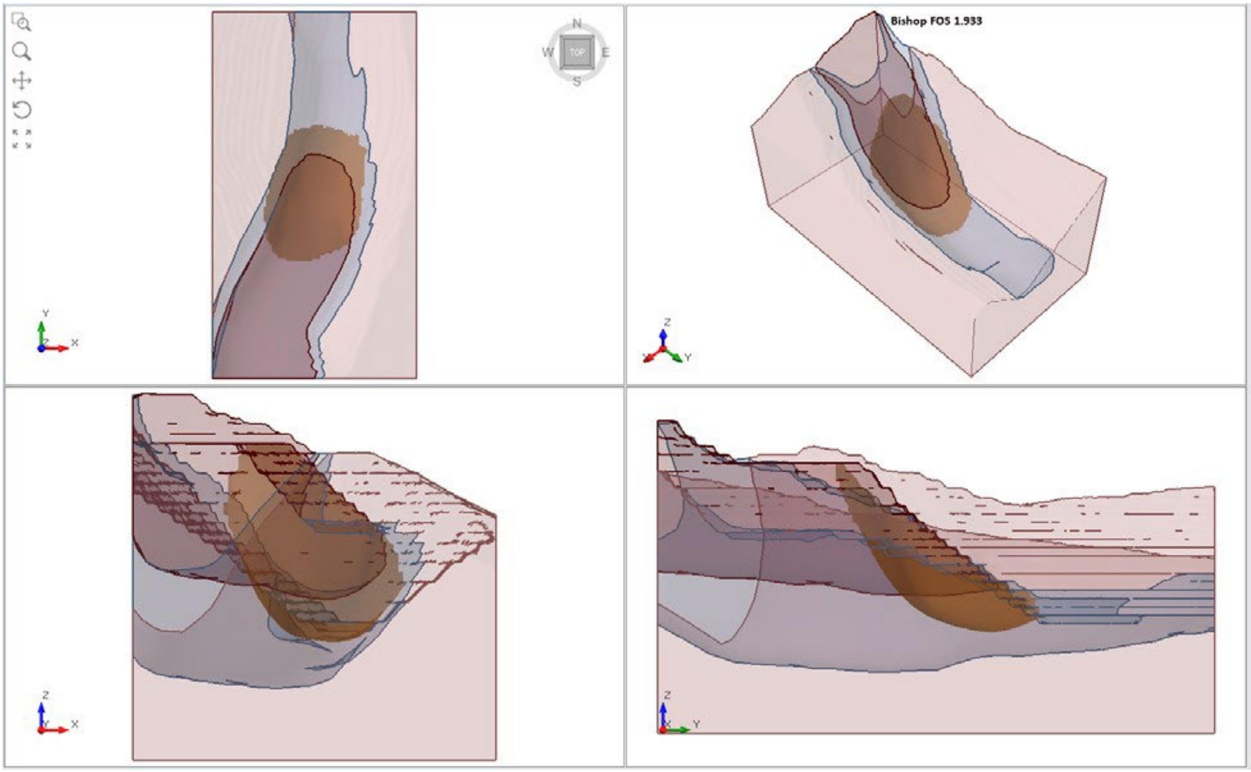

Figure 31.1 – *Slide3* Solution Using the Bishop Method

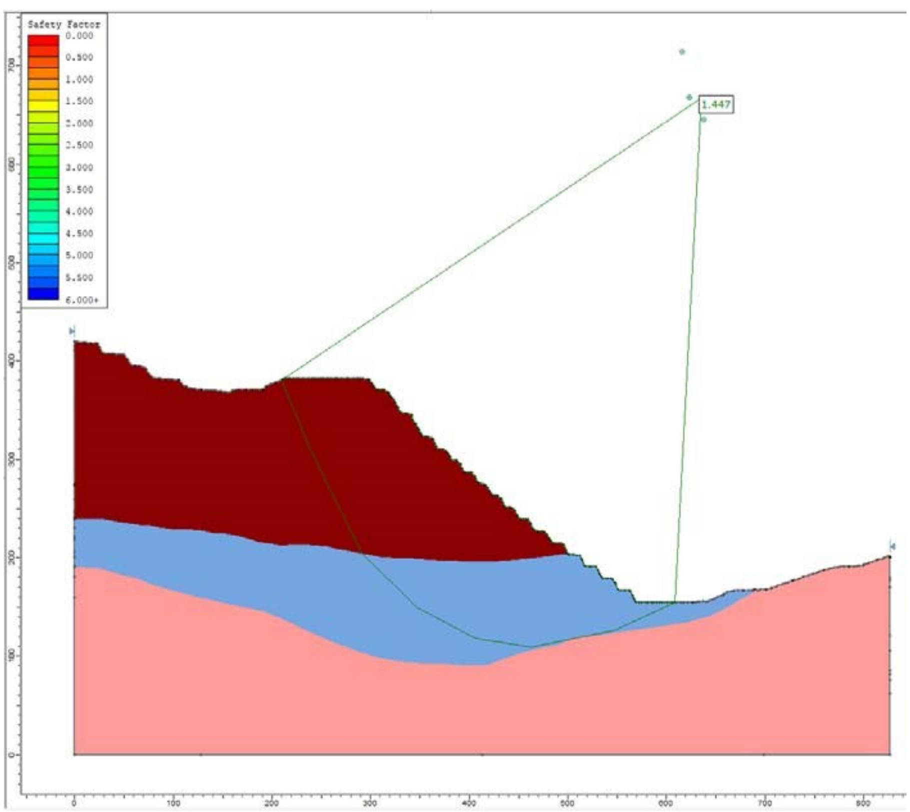

Figure 31.2 – *Slide2* Solution Using the Bishop Method

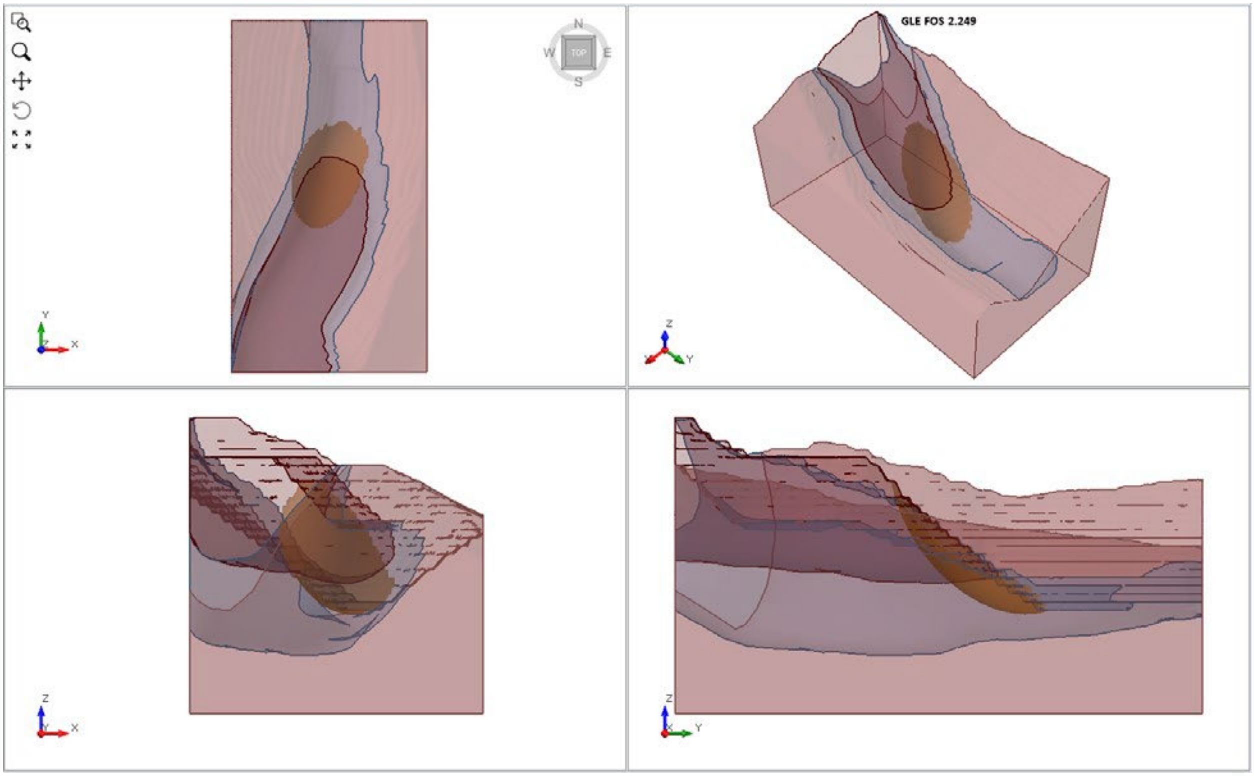

Figure 31.3 – *Slide3* Solution Using the GLE Method

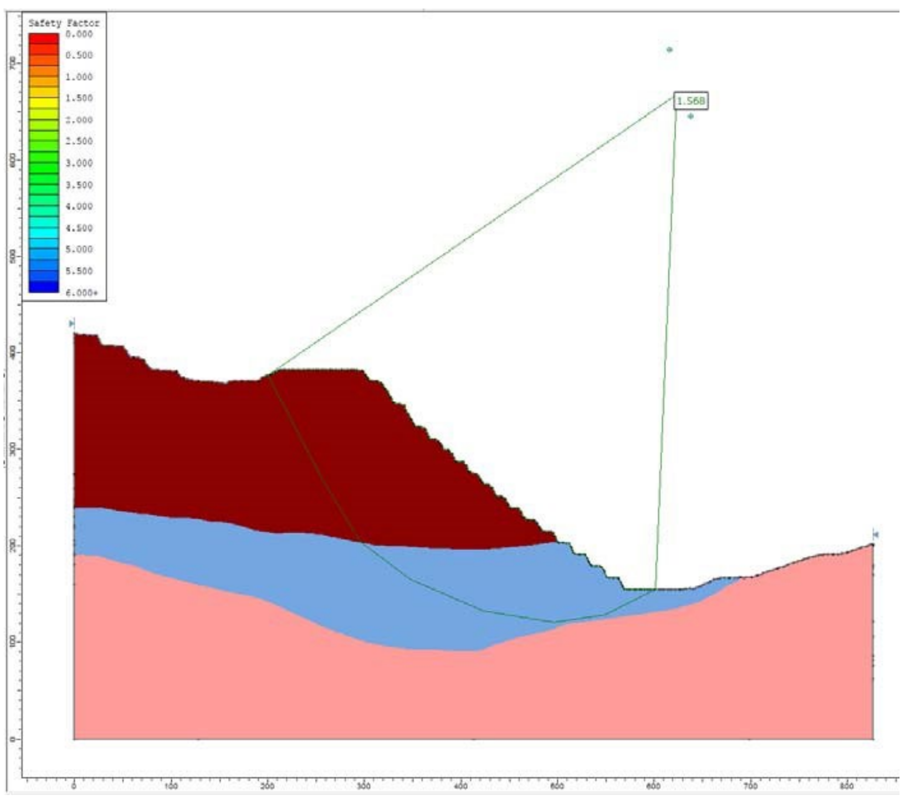

Figure 31.4 *Slide2* Solution Using the GLE Method

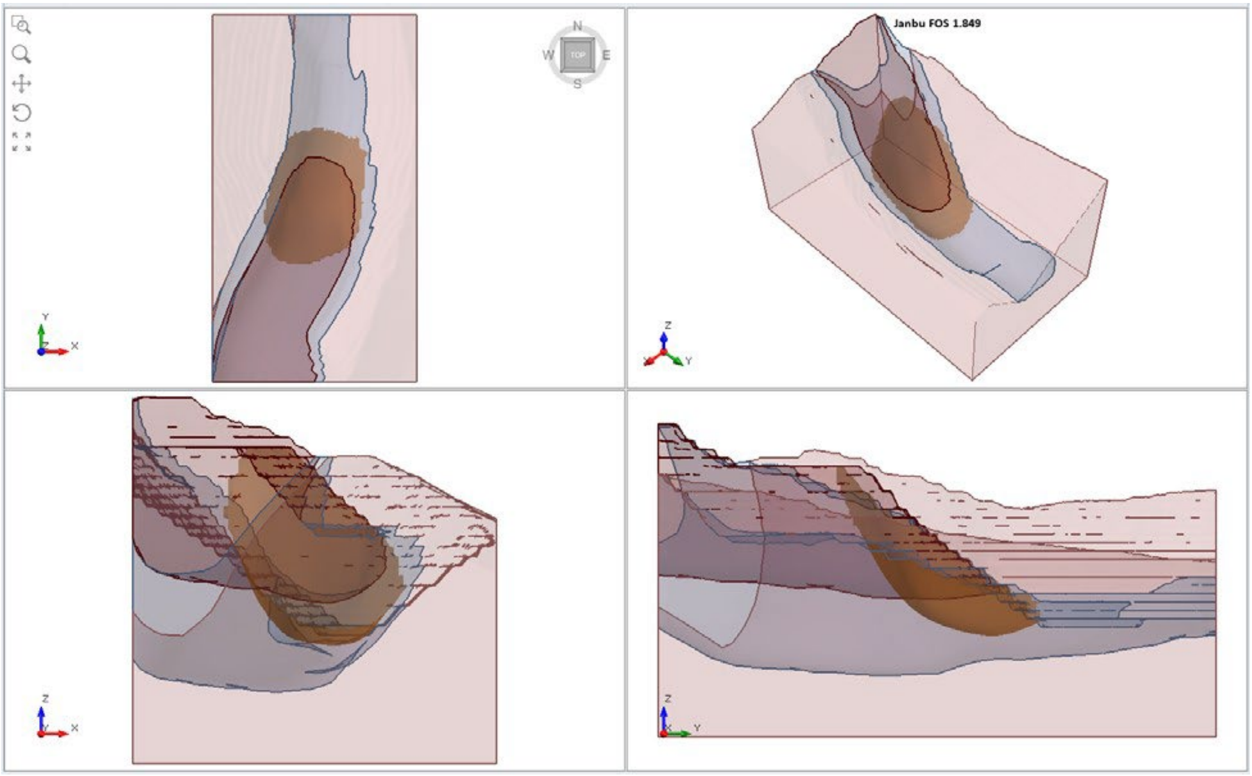

Figure 31.5 – *Slide3* Solution Using the Janbu Method

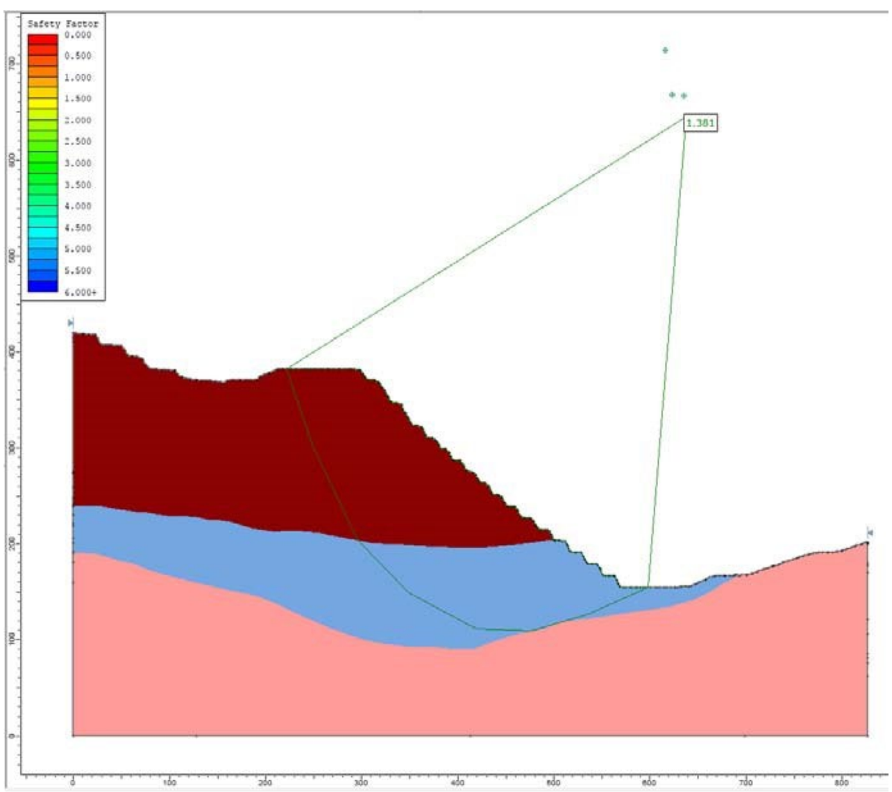

Figure 31.6 – *Slide2* Solution Using the Janbu Method

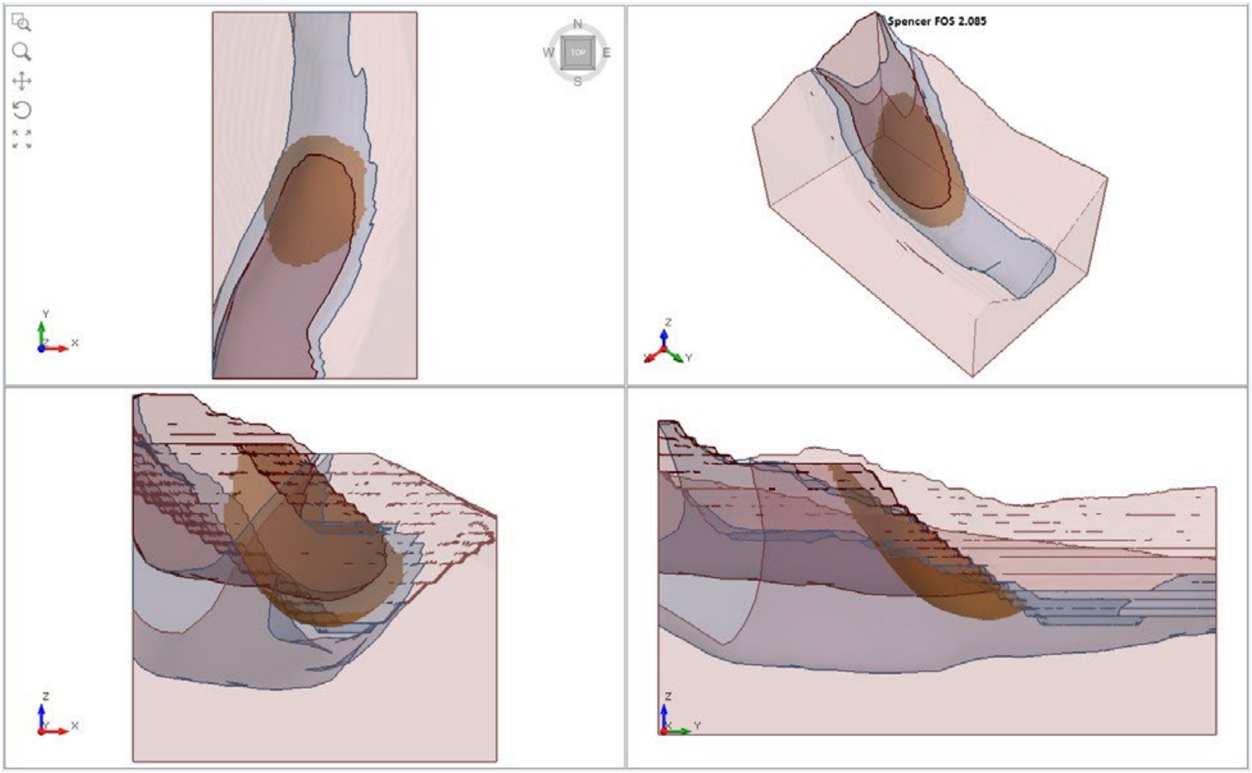

Figure 31.7 – *Slide3* Solution Using the Spencer Method

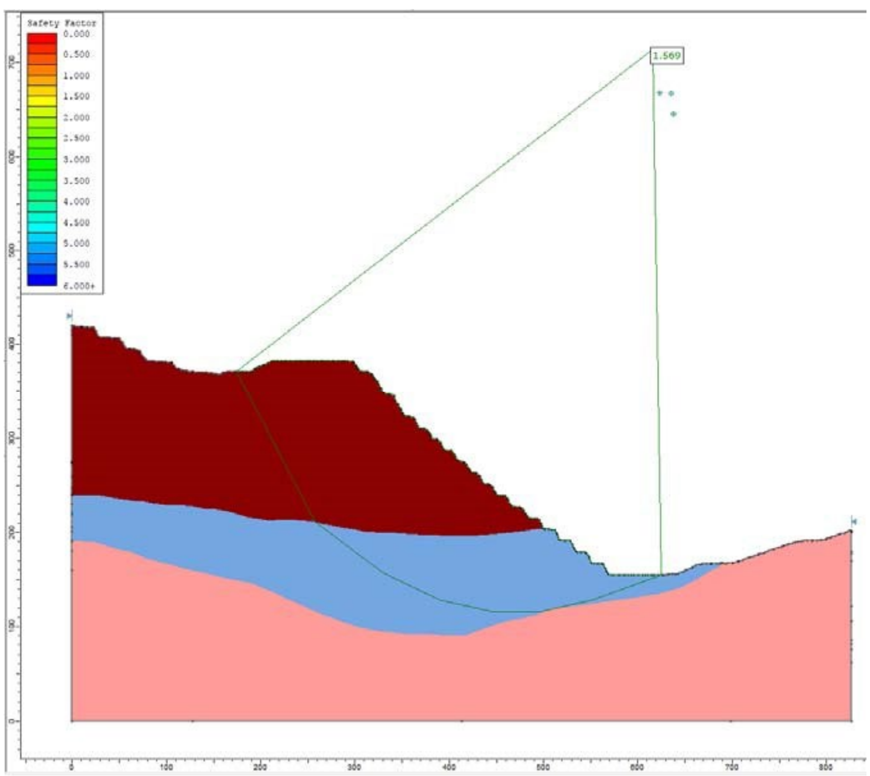

Figure 31.8 – *Slide2* Solution Using the Spencer Method

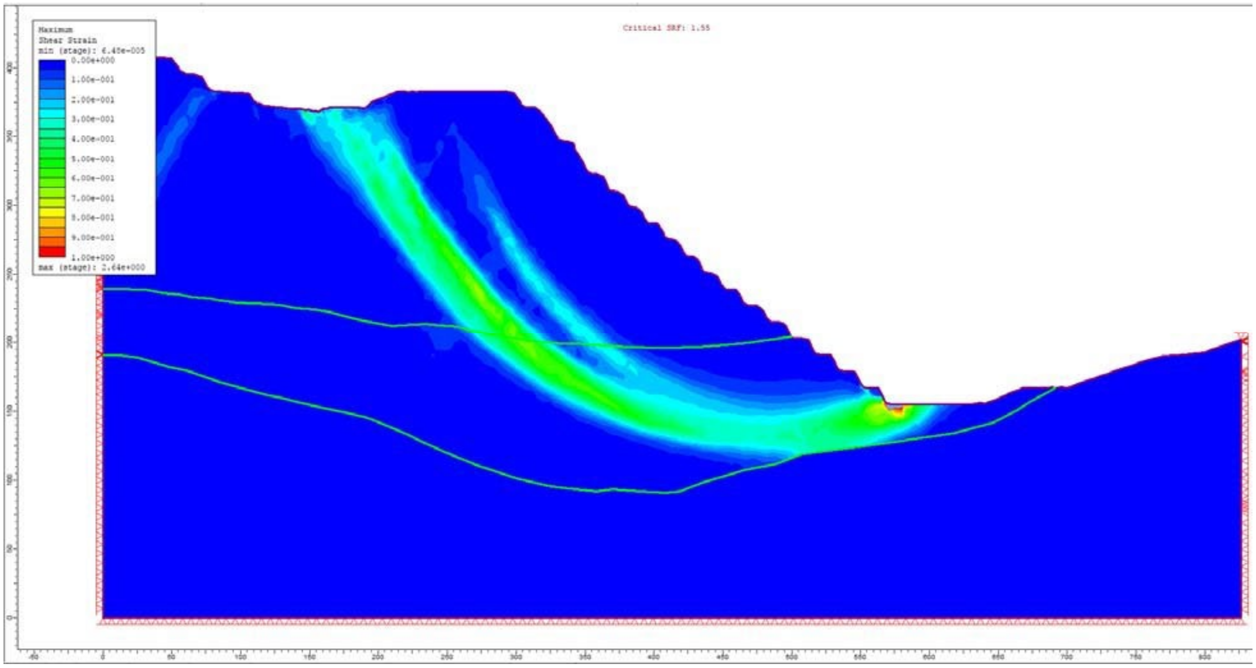

Figure 31.9 – *RS2* Maximum Shear Strain

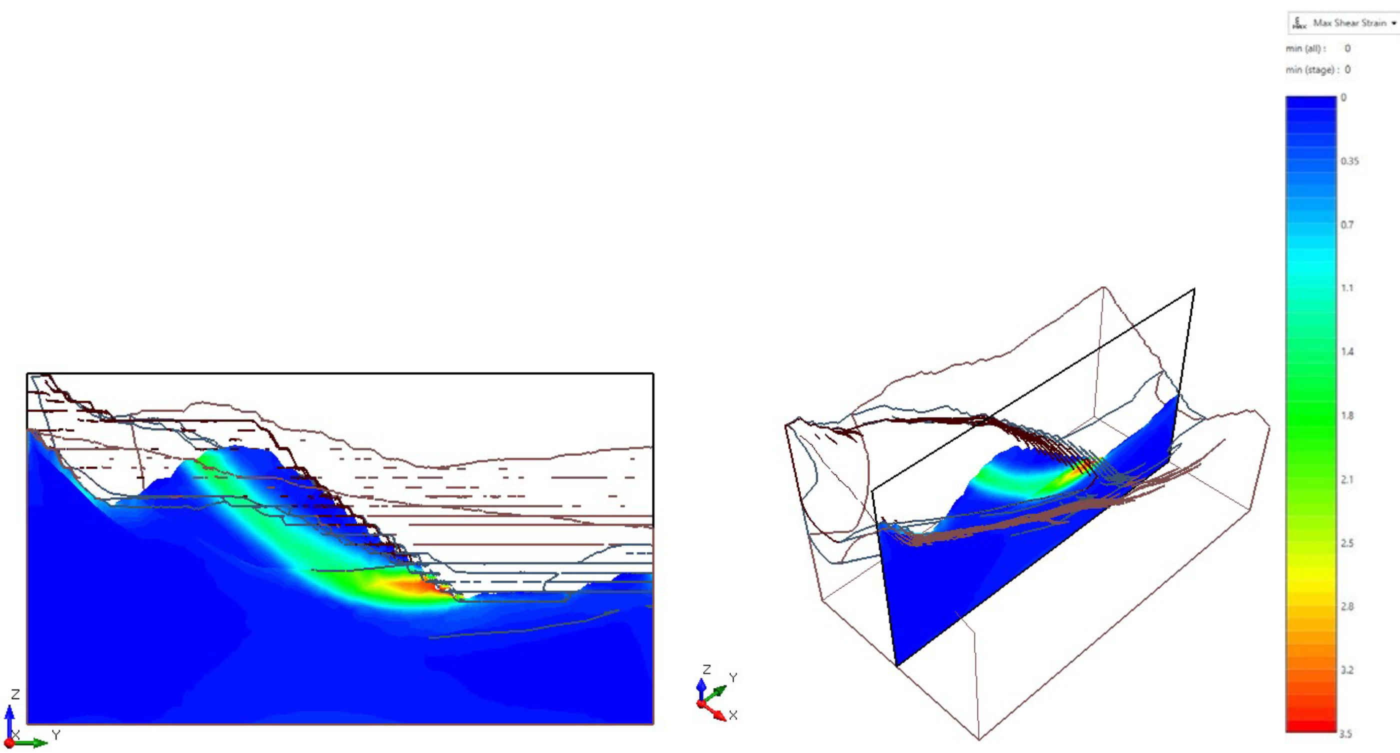

Figure 31.10 – *RS3* Maximum Shear Strain

32. 3D Verification #32

32.1. *RSPile* model, homogeneous, ellipsoidal with SA

32.1.1. Introduction

This example compares the force computations for multiple embedded piles at varying orientations and ground slope. Comparisons were made for the force analysis in both *Slide3* and *RSPile*.

32.1.2. Problem Description

The model for this hypothetical example can be seen in Figure 32.1. The elliptical surface has a center of (13,33,33) with principal radii in directions X,Y,Z of 20, 20, and 24 m respectively, and then rotated 45º clockwise about the Z axis. There is no water table present in this problem and only one material layer was used. Material properties are shown in Table 32.1 while pile properties are shown in Figure 32.2. The piles are numbered from 0 to 44 as shown in Figure 32.3 and every pile is identical. Although the factor of safety isn't the focus of this example, it is nonetheless shown in Section 32.4. The purpose of this example is to compare the pile forces calculated during the *Slide3*-*RSPile* integration against the result from *RSPile* itself and show their overall agreement with one another. The specific orientation, ground slope, and soil displacement for each pile can be found in Table 32.4.

32.1.3. Properties

Table 32.1: Material Properties

	c´ (kN/m^2)	φ´ (deg.)	γ (kN/m^3)
Material 1	20	18	20

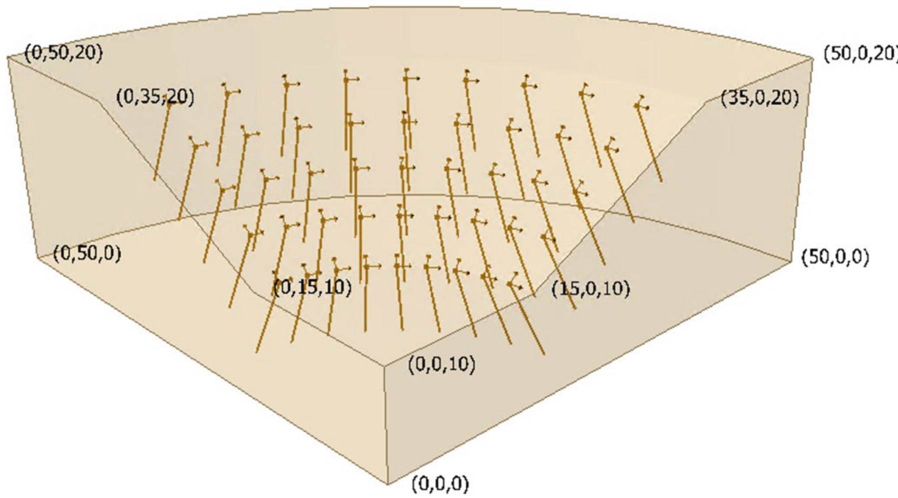

Figure 32.1 – *Slide3* Model containing *RSPile* Anchors

Pile Name	Color	Pile Type	Pile Cross Section	Section Depth (m)	Section Width (m)	Young's Modulus (kPa)
Pile Section 1		Elastic	Rectangular	1	0.5	2.2e+07

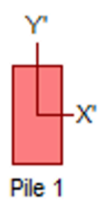

Figure 32.2 – Cross Section of the *RSPile*

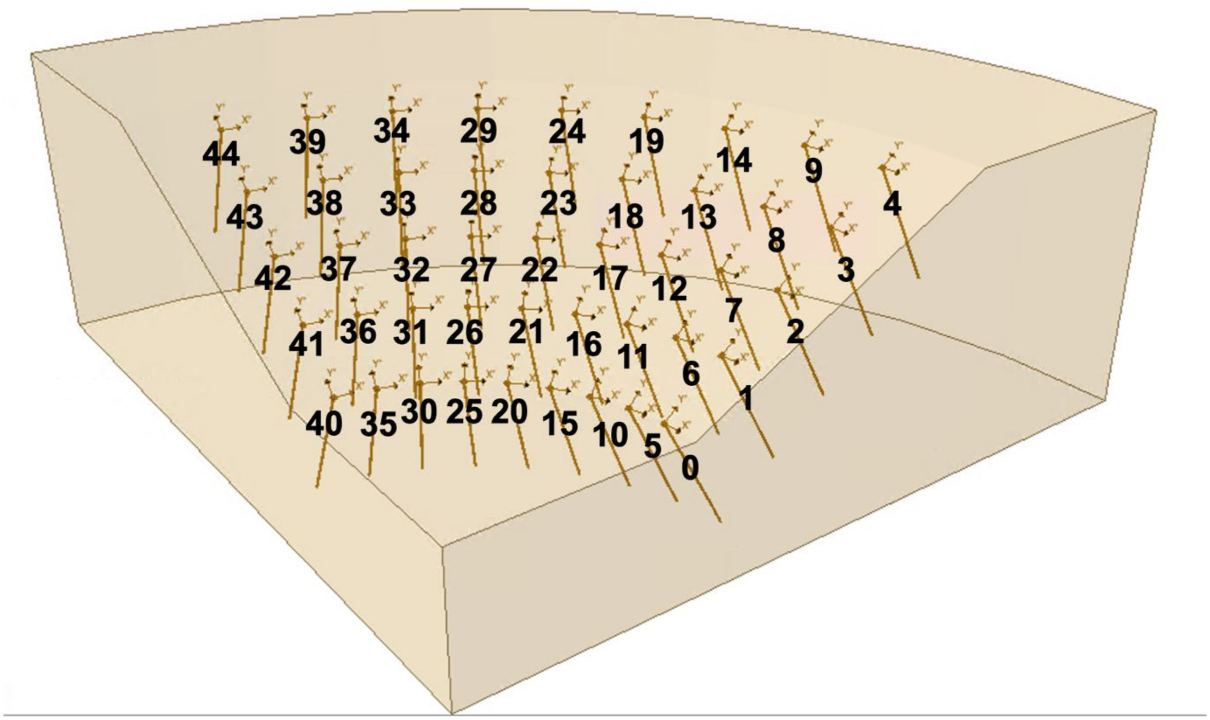

Figure 32.3 – Numbering of *RSPile*s Inputted in *Slide3*

32.1.4. Results

Due to the symmetry of the problem, the sliding direction of the slip surface has a trend of 225 degrees.

Table 32.2: Safety Factor Values with *Slide3*

Method	Safety Factor *Slide3*
Bishop	2.551
GLE	2.539
Janbu	2.398
Spencer	2.522

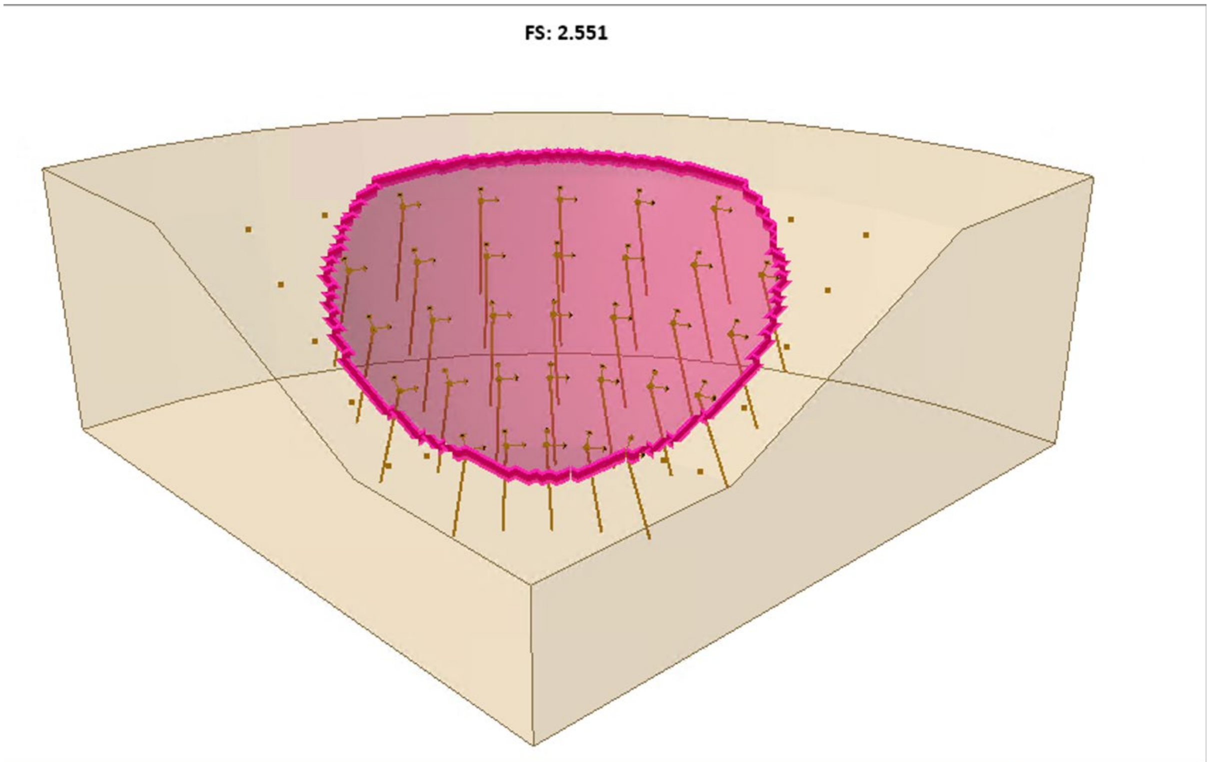

Figure 32.4 – *Slide3* Factor of Safety Solution using the Bishop Method

Table 32.3: *Slide3* and *RSPile* Pile Force Comparison

	Slide3				*RSPile*				
Pile Index	Beam Shear Force X' (kN)	Beam Shear Force Y' (kN)	Beam Axial Force (kN)	Resultant Force (kN)	Beam Shear Force X' (kN)	Beam Shear Force Y' (kN)	Beam Axial Force (kN)	Resultant Force (kN)	% Difference between Resultant (%)
0	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
6	-19.83	15.11	7.93	26.16	-19.10	14.50	7.99	25.28	3%
7	-33.35	28.10	20.23	48.07	32.00	26.90	18.90	45.88	5%
8	-13.00	10.47	2.36	16.86	-13.40	10.80	2.49	17.39	3%
9	-	-	-	-	-	-	-	-	-
10	-1.38	0.96	0.11	1.68	-1.03	0.70	0.00	1.25	35%*
11	-47.86	56.21	64.21	97.85	-47.20	54.50	61.10	94.51	4%
12	-54.63	73.19	123.97	153.98	-54.10	72.70	121.00	151.17	2%
13	-50.46	71.73	10.95	88.39	-49.70	70.50	10.40	86.88	2%
14	-30.86	35.66	-27.42	54.55	-29.10	34.30	-25.80	51.85	5%
15	-12.55	11.96	6.95	18.68	-13.10	12.40	6.99	19.35	4%
16	-40.23	72.67	129.12	153.53	-39.80	72.40	127.00	151.51	1%
17	-47.42	71.32	235.17	250.28	-46.80	70.10	230.00	244.96	2%
18	-45.46	71.83	-44.08	95.76	-44.80	70.70	-43.10	94.14	2%
19	-35.60	74.67	-136.62	159.71	-35.40	74.10	-137.00	159.73	0%
20	0.00	17.00	11.71	20.64	0.00	16.30	11.20	19.78	4%
21	0.00	73.58	155.59	172.11	0.00	72.20	153.00	169.18	2%
22	0.00	70.43	281.95	290.61	0.00	69.20	280.00	288.42	1%
23	0.00	70.55	-38.93	80.57	0.00	69.60	-37.80	79.20	2%
24	0.00	72.73	-192.00	205.32	0.00	71.80	-190.00	203.11	1%
25	12.70	11.96	6.95	18.79	13.20	12.40	6.99	19.41	3%

26	40.23	72.67	129.12	153.53	39.80	72.40	127.00	151.51	1%
27	47.42	71.32	235.17	250.28	46.80	70.10	230.00	244.96	2%
28	45.46	71.83	-44.08	95.76	44.80	70.70	-44.00	94.56	1%
29	35.60	74.67	-136.62	159.71	35.40	74.10	-137.00	159.73	0%
30	1.40	0.96	0.11	1.70	1.04	0.70	0.00	1.25	36%*
31	47.87	56.22	64.23	97.87	47.20	54.50	61.10	94.51	4%
32	54.63	73.19	123.98	153.99	54.10	72.70	121.00	151.17	2%
33	50.46	71.74	10.95	88.39	49.70	70.50	10.40	86.88	2%
34	30.85	35.66	-27.42	54.55	29.10	34.30	-25.80	51.85	5%
35	-	-	-	-	-	-	-	-	-
36	19.81	15.10	7.92	26.14	19.10	14.50	6.99	24.98	5%
37	33.33	28.07	20.21	48.03	32.00	26.90	18.90	45.88	5%
38	12.96	10.44	2.35	16.81	13.40	10.80	2.49	17.39	3%
39	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	-

Note that empty cells indicate that the pile and slip surface did not intersect.

*The large percent difference between pile 10 and 30 can be attributed to a shallow depth and very small forces.

The slight discrepancies between *Slide3* and *RSPile* computations can be attributed to linear interpolation methods used in *Slide3*, which estimate the reactions based on precomputed reaction forces for various sliding depths and soil displacement magnitudes, whereas in *RSPile* there is exact control over the sliding depth and soil displacement. Nonetheless, the 0-5% difference between *Slide3* and *RSPile* is within acceptable tolerances.

Table 32.4: Individual Pile Orientation, Ground Slope, and Soil Displacement

	Orientation		Ground Slope		Soil Displacement			
Pile Index	Trend (Alpha)	Plunge (Beta)	Dip	Direction	Depth	dX	dY	dZ
0	81	60	16	262.5	-	-	-	-
1	81	60	26.6	261	-	-	-	-
2	81	60	26.6	261	-	-	-	-
3	81	60	26.6	261	-	-	-	-
4	81	60	26.6	261	-	-	-	-
5	72	60	16	253.5	-	-	-	-
6	72	60	26.6	252	0.65	-17.67	-17.67	0.54
7	72	60	26.6	252	1.08	-17.41	-17.41	-4.29
8	72	60	26.6	252	0.45	-16.24	-16.24	-9.87
9	72	60	26.6	252	-	-	-	-
10	63	60	16	244.5	0.01	-17.61	-17.61	2.16
11	63	60	26.6	243	1.95	-17.66	-17.66	-1.20
12	63	60	26.6	243	2.73	-16.99	-16.99	-6.92
13	63	60	26.6	243	2.49	-15.60	-15.60	-11.77
14	63	60	26.6	243	1.28	-13.29	-13.29	-16.49
15	54	60	16	235.5	0.61	-17.52	-17.52	3.34
16	54	60	26.6	234	2.78	-17.57	-17.57	-2.79
17	54	60	26.6	234	3.76	-16.80	-16.80	-7.77
18	54	60	26.6	234	3.78	-15.16	-15.16	-12.85
19	54	60	26.6	234	2.86	-13.16	-13.16	-16.70
20	45	60	16	226.5	0.82	-17.52	-17.52	3.31
21	45	60	26.6	225	3.06	-17.54	-17.54	-3.15
22	45	60	26.6	225	4.12	-16.75	-16.75	-7.99
23	45	60	26.6	225	4.21	-15.17	-15.17	-12.84
24	45	60	26.6	225	3.40	-13.04	-13.04	-16.88
25	36	60	16	217.5	0.61	-17.52	-17.52	3.34
26	36	60	26.6	216	2.78	-17.57	-17.57	-2.79
27	36	60	26.6	216	3.76	-16.80	-16.80	-7.77

28	36	60	26.6	216	3.78	-15.16	-15.16	-12.85
29	36	60	26.6	216	2.86	-13.16	-13.16	-16.70
30	27	60	16	208.5	0.01	-17.61	-17.61	2.16
31	27	60	26.6	207	1.95	-17.66	-17.66	-1.20
32	27	60	26.6	207	2.73	-16.99	-16.99	-6.92
33	27	60	26.6	207	2.49	-15.60	-15.60	-11.77
34	27	60	26.6	207	1.28	-13.29	-13.29	-16.49
35	18	60	16	199.5	-	-	-	-
36	18	60	26.6	198	0.65	-17.67	-17.67	0.54
37	18	60	26.6	198	1.08	-17.41	-17.41	-4.29
38	18	60	26.6	198	0.45	-16.24	-16.24	-9.87
39	18	60	26.6	198	-	-	-	-
40	9	60	16	190.5	-	-	-	-
41	9	60	26.6	189	-	-	-	-
42	9	60	26.6	189	-	-	-	-
43	9	60	26.6	189	-	-	-	-
44	9	60	26.6	189	-	-	-	-

Note that empty cells indicate that the pile and slip surface did not intersect.

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