RS2

2D finite element program for stress analysis and support design
around excavations in soil and rock

Slope Stability Verification Manual

Part II

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Introduction

This problem is taken from Figure 6.27 on page 88 of Duncan and Wright (2005).

Description

Verification problem #70 for Slide2– a submerged slope with water table at 30 feet above the crest – is shown in Figure 1. The slope is homogeneous with soil properties given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

c' (psf)	ϕ' (^{0})	γ (pcf)
100	20	128

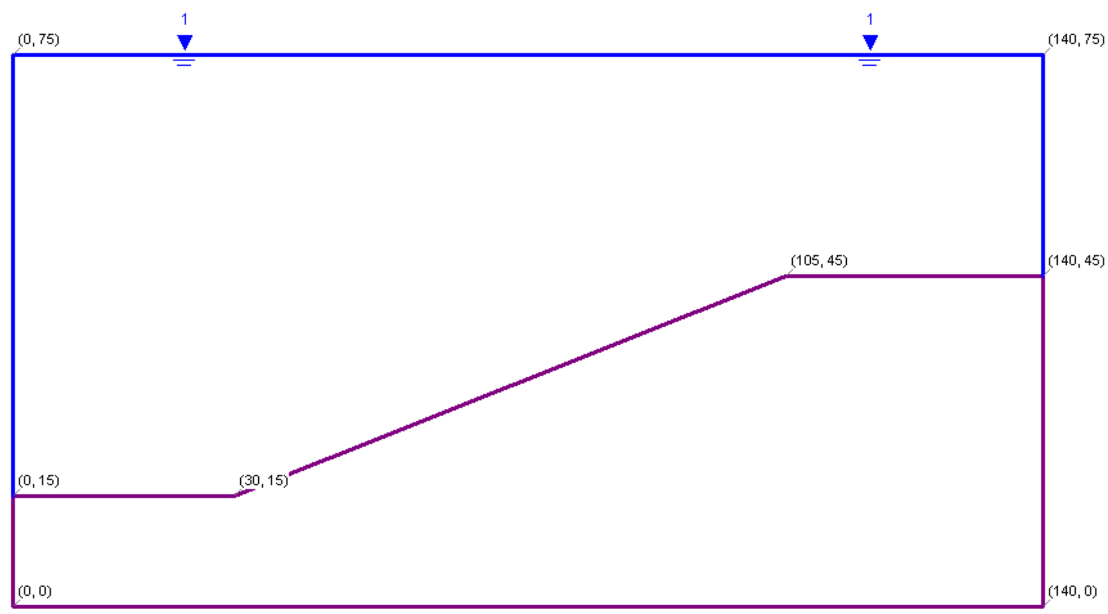


Figure 1 - Geometry

Results

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
0SSR	1.64	
Bishop	1.60	1.56
Spencer	1.60	1.62
GLE	1.60	1.62

Note: Referee Factor of Safety = 1.60 [Duncan and Wright]

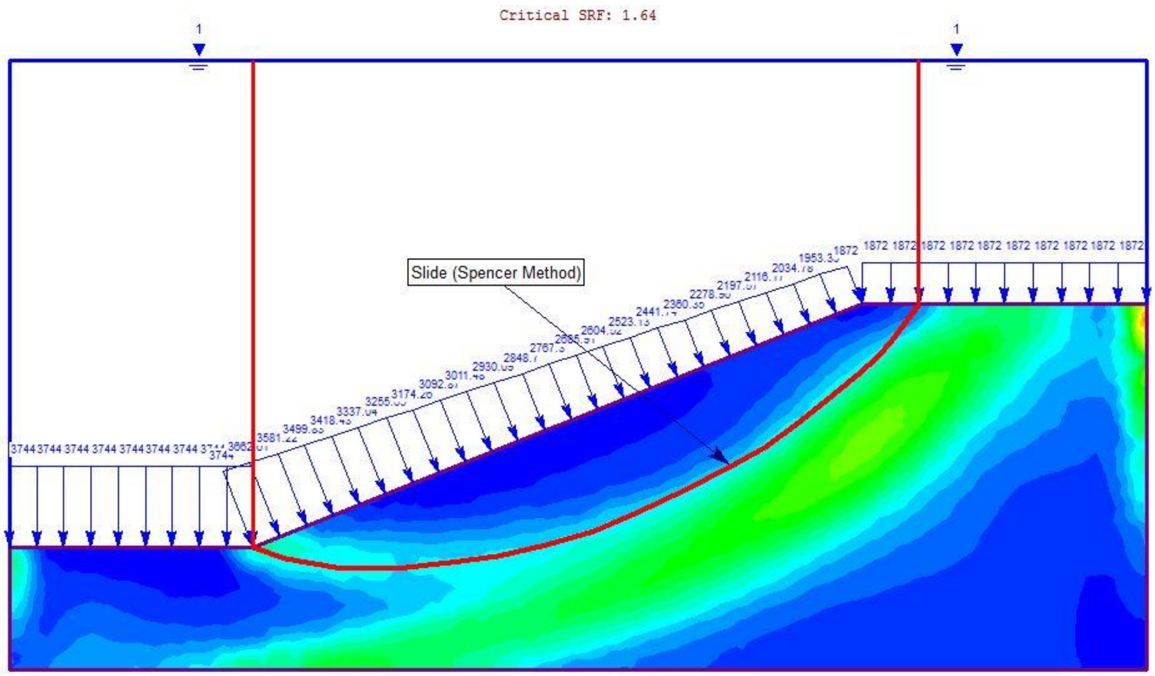


Figure 2 – Maximum Shear Strain Plot

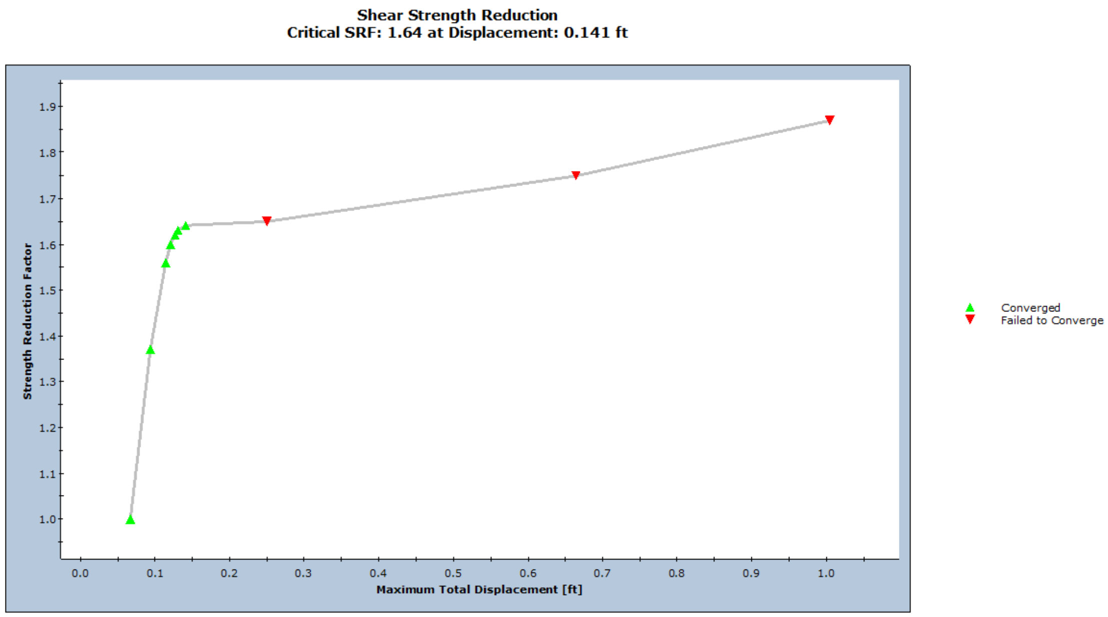


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from Figure 6.37 on page 100 of Duncan and Wright (2005).

Description

Verification problem #71 for Slide2 – a homogeneous slope with water level located at 75 feet at the right end – is shown in Figure 1. The soil properties are given in Table 1. Seepage analysis was carried out using two different methods in this verification problem. The first method was using Finite Element seepage analysis and the second method was using piezometric line approximation. The location of the approximated piezometric line is shown in Figure 2. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

c (psf)	ϕ (^{0})	γ (pcf)
200	20	125

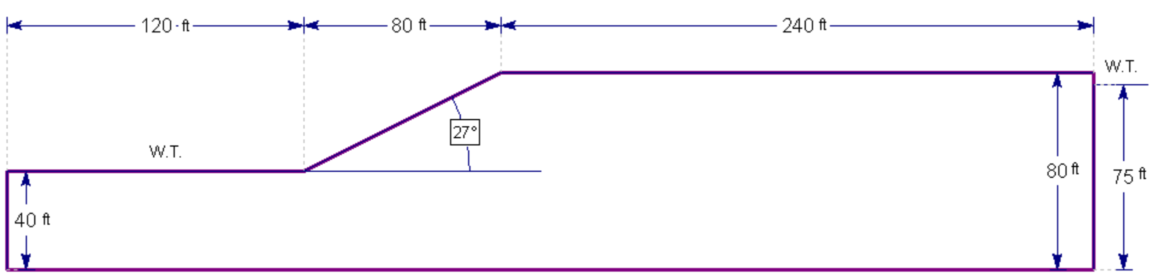


Figure 1 - Geometry

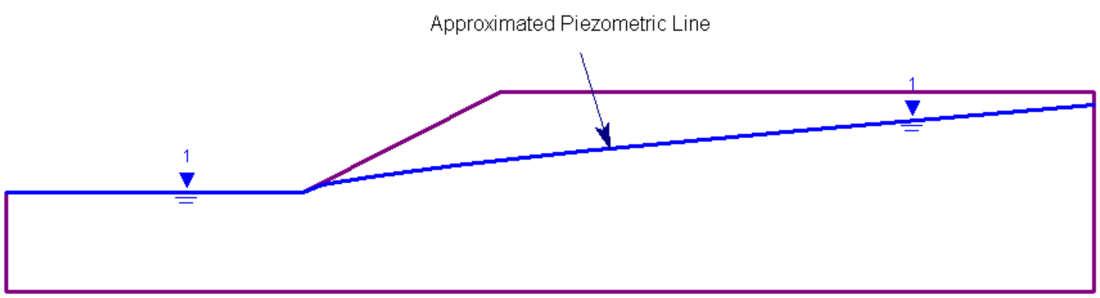


Figure 2 – Approximated Piezometric Line Location

Results

Case 1: Finite Element Seepage Analysis

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.12	
Bishop	1.139	1.046
Spencer	1.138	1.128
GLE	1.140	1.109

Note: Referee Factor of Safety = 1.138 [Duncan and Wright]

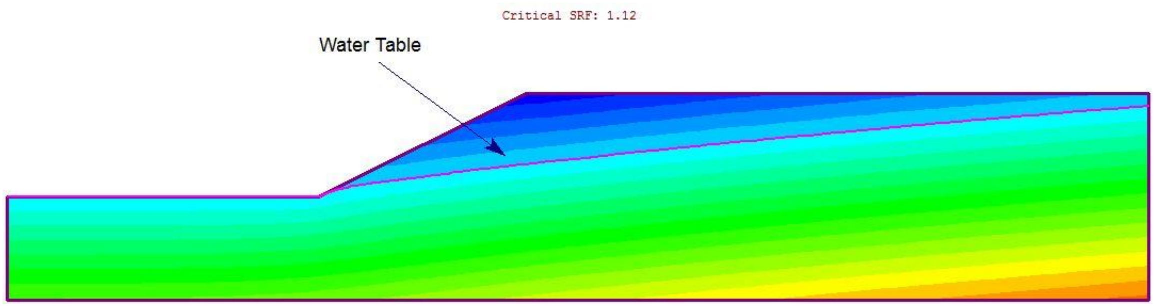


Figure 3 – Pore Water Pressure Plot

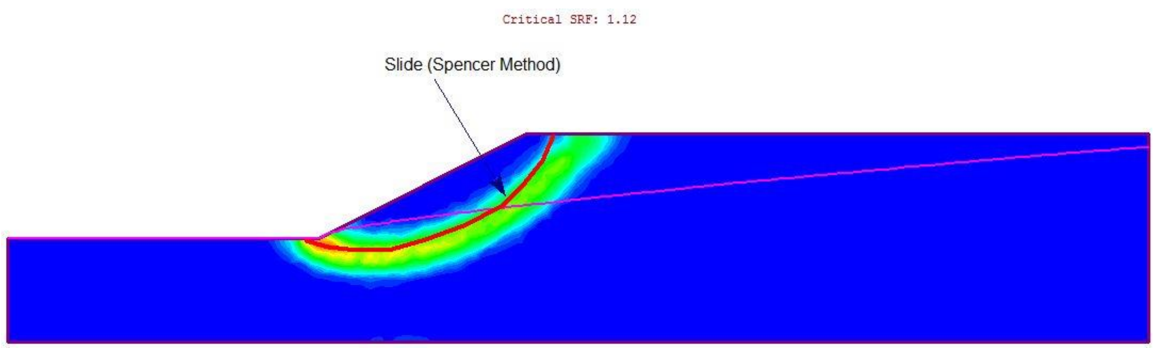


Figure 4 – Maximum Shear Strain Plot

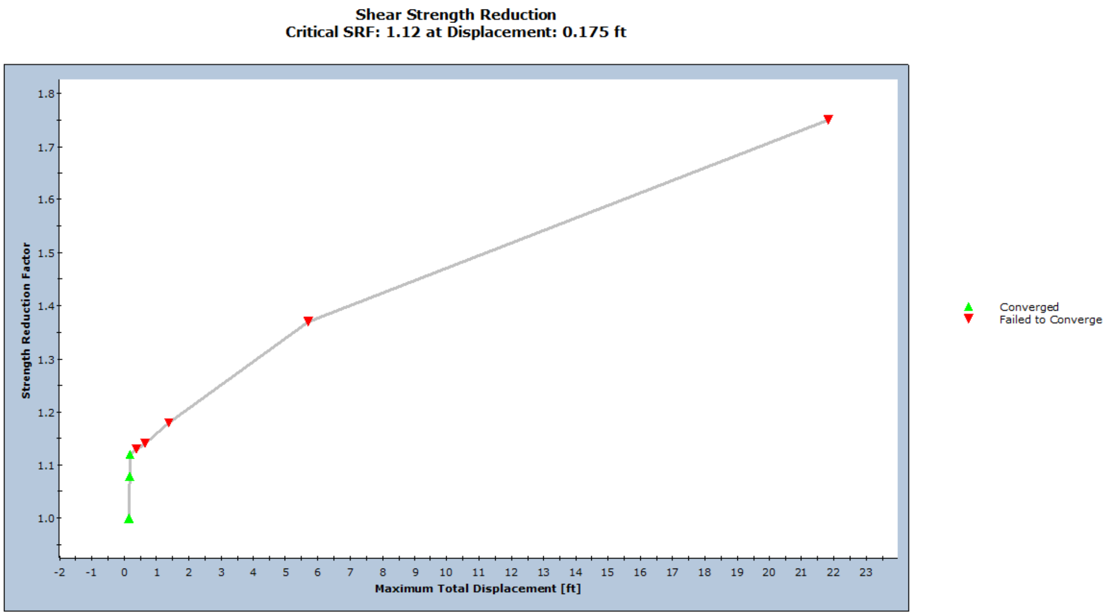


Figure 5 – SSR Convergence Graph

Case 2: Piezometric Line Approximation Seepage Analysis

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.12	
Bishop	1.142	1.081
Spencer	1.140	1.147
GLE	1.141	1.154

Note: Referee Factor of Safety = 1.141 [Duncan and Wright]

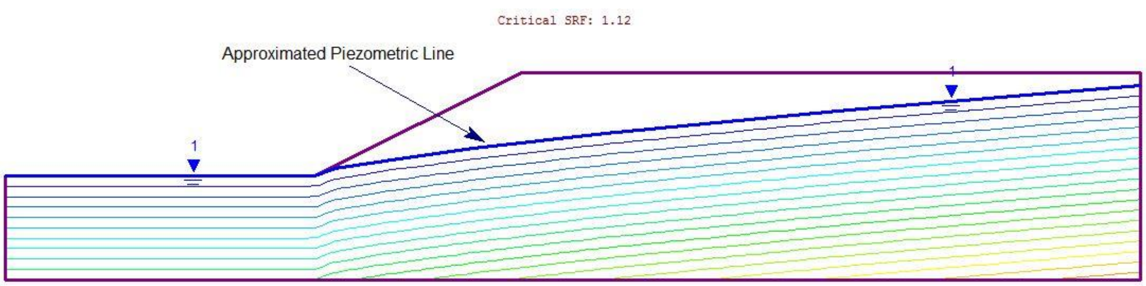


Figure 6 – Pore Water Pressure Plot

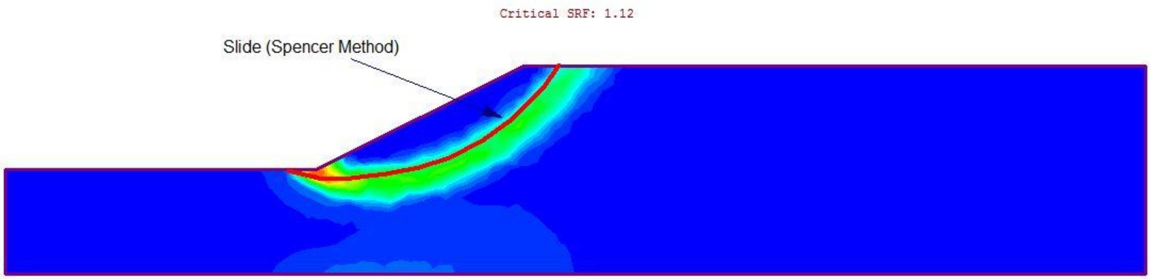


Figure 7 – Maximum Shear Strain Plot

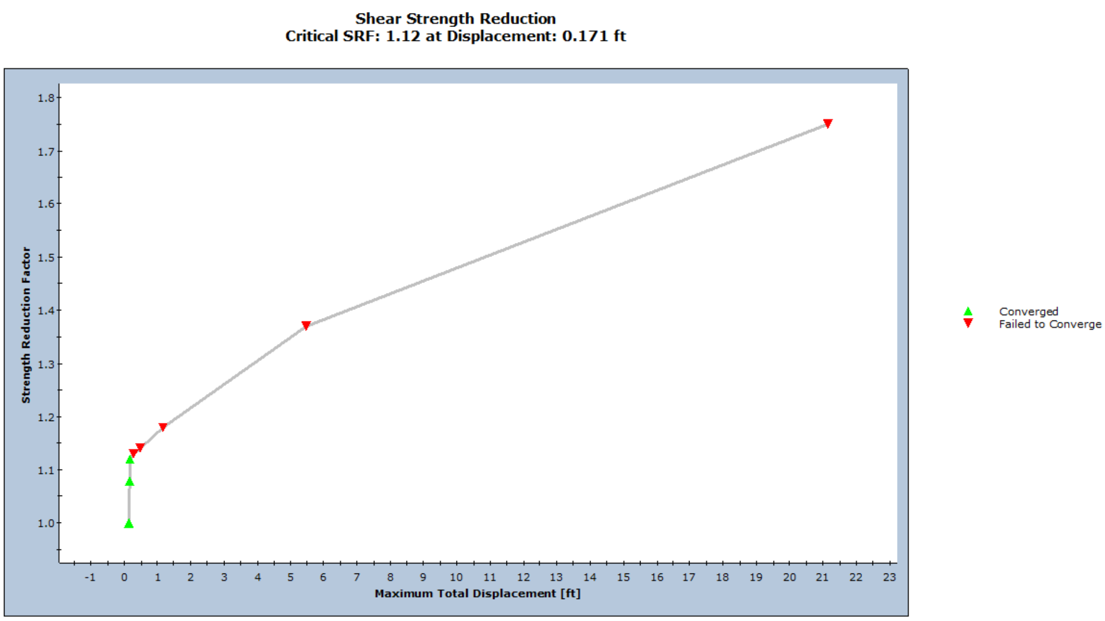


Figure 8 – SSR Convergence Graph

Introduction

This problem is taken from Figure 6.39 on page 101 of Duncan and Wright (2005).

Description

Verification problem #72 – a symmetric earth embankment dam resting on a layered soil foundation with ponded water of elevation 302 feet on the left side – is shown in Figure 1. Both left face and right face are constructed using shell material. Seepage analysis was performed in this verification problem. The material strength properties and permeability values are given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Material	k (ft/s)	c' (psf)	ϕ' (^{0})	γ (pcf)
Outer Shell	1.67×10^{-4}	0	34	125
Clay Core	1.67×10^{-8}	100	26	122
Foundation Clay	1.67×10^{-7}	0	24	123
Foundation Sand	1.67×10^{-5}	0	32	127

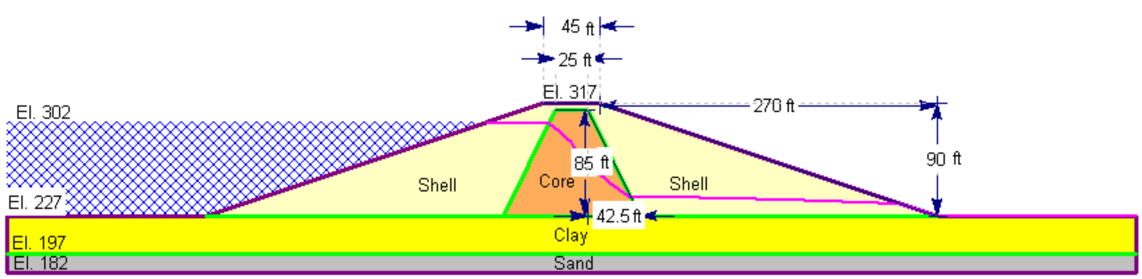


Figure 1 - Geometry

Results

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	0.95	
Bishop	1.15	1.05
Spencer	1.16	1.20
GLE	1.16	1.21

Note: Referee Factor of Safety = 1.11 [Duncan and Wright]

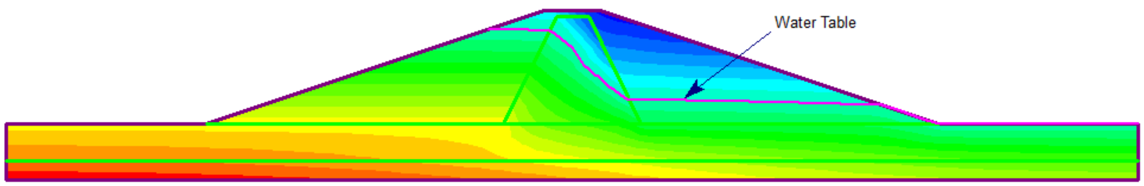


Figure 2 – Pore Water Pressure Plot

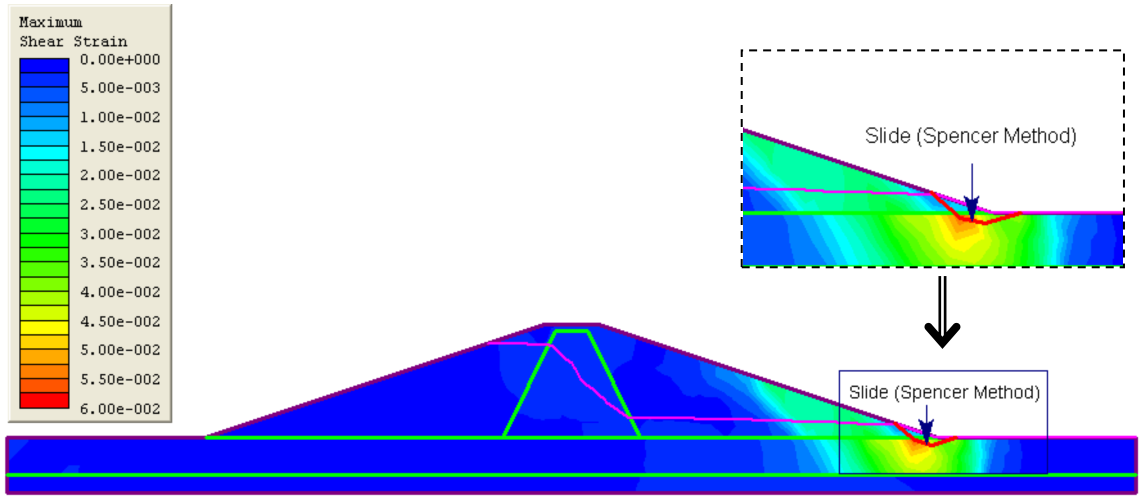


Figure 3 – Maximum Shear Strain Plot

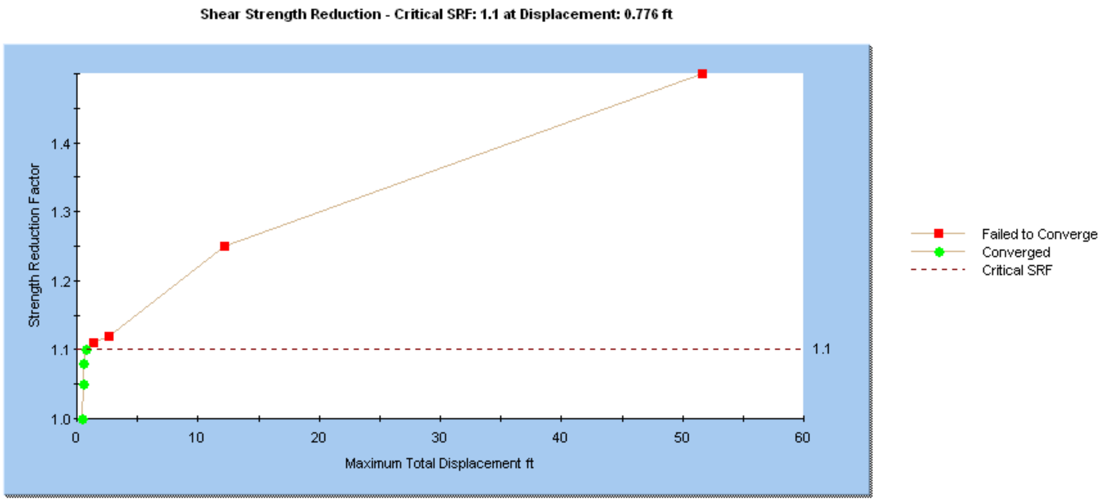


Figure 4 – SSR Convergence Graph

38 Cohesionless Earth Embankment with Saturated Clay Foundation

Introduction

This problem is taken from Figure 7.12 on page 120 of Duncan and Wright (2005).

Description

Verification problem #74 for Slide2 – an embankment of cohesionless material resting on saturated clay foundation – is shown in Figure 1. The material properties are given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Material	c (psf)	ϕ (^{0})	γ (pcf)
Embankment (Sand)	0	40	140
Foundation (Saturated Clay)	2500	0	140

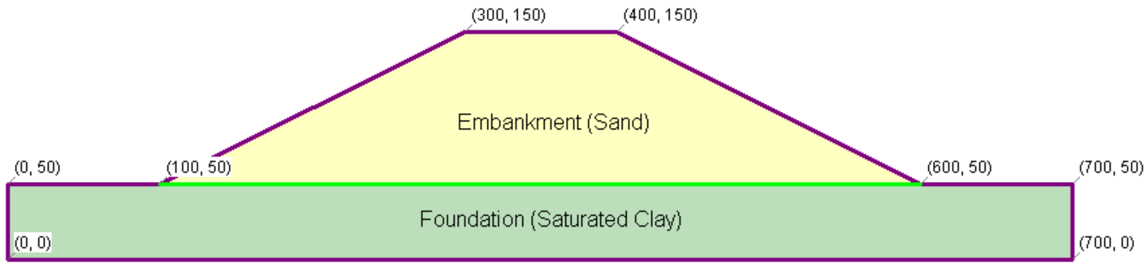


Figure 1 - Geometry

Results

Method	Factor of Safety (circular)	Factor of Safety (non-circular)	Referee Factor of Safety [Duncan and Wright]
SSR	1.21		
Bishop	1.23	1.09	1.22
Janbu Simplified	1.08	1.04	1.07
Janbu Corrected	1.18	1.13	1.16
Spencer	1.20	1.18	1.19

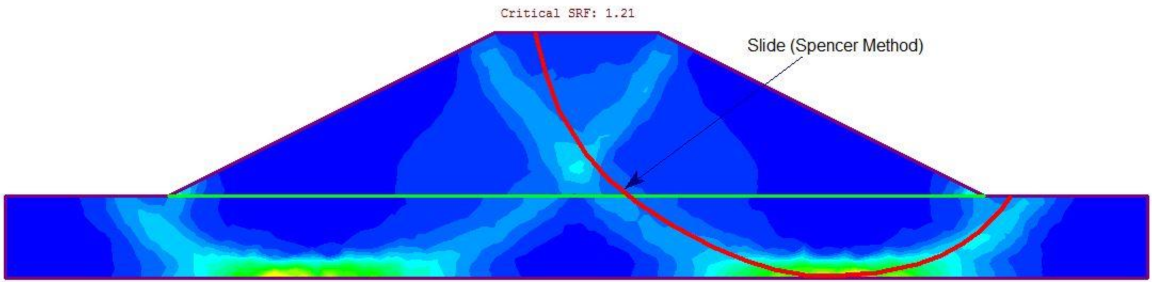


Figure 2 – Maximum Shear Strain Plot

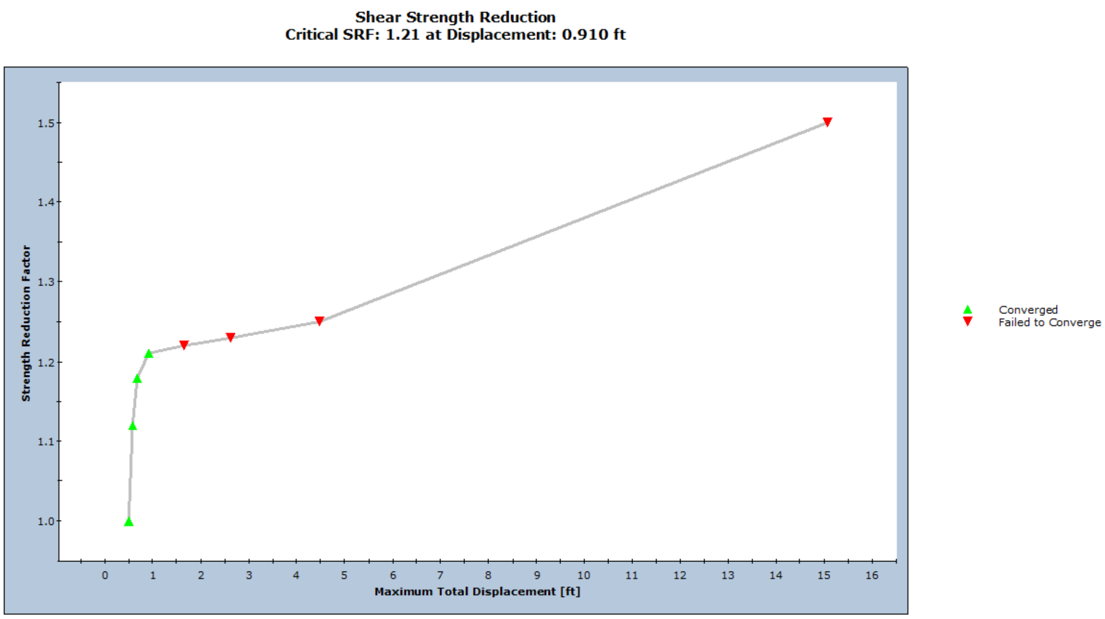


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from Figure 7.19 on page 128 of Duncan and Wright (2005).

Description

Verification problem #76 for Slide2 – a symmetric homogeneous earth embankment resting on an impermeable foundation with a ponded water of elevation 40 feet on its left side – is shown in Figure 1. The material properties and permeability values are given in Table 1. Seepage analysis was conducted in this verification problem. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

c' (psf)	ϕ' (^{0})	γ (pcf)	k_{sat} (ft/s)	k_{unsat} (ft/s)
100	30	100	1.67×10^{-7}	1.67×10^{-10}

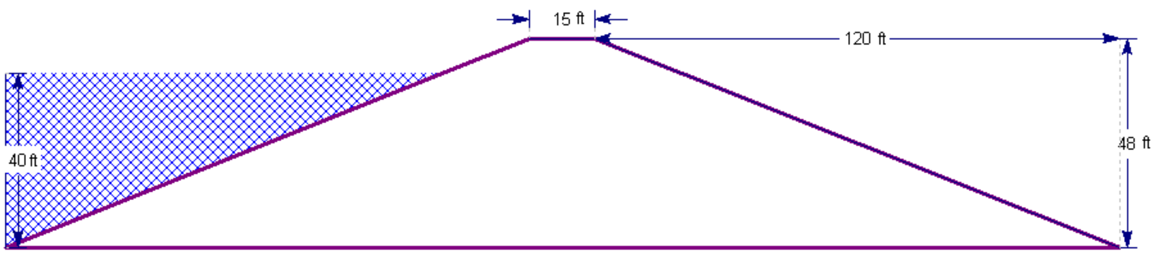


Figure 1 - Geometry

Results

Method	Factor of Safety (circular)
SSR	0.97
Bishop	1.07
Spencer	1.08
GLE	1.08

Note: Referee Factor of Safety = 1.08 - 1.19 [Duncan and Wright]

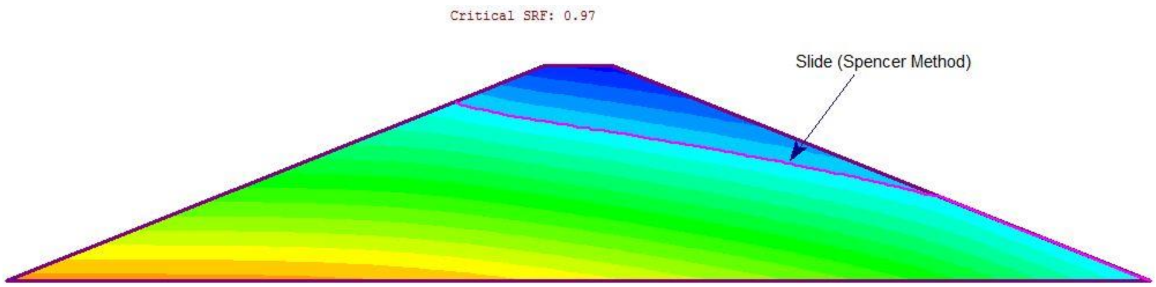


Figure 2 – Pore Water Pressure Plot

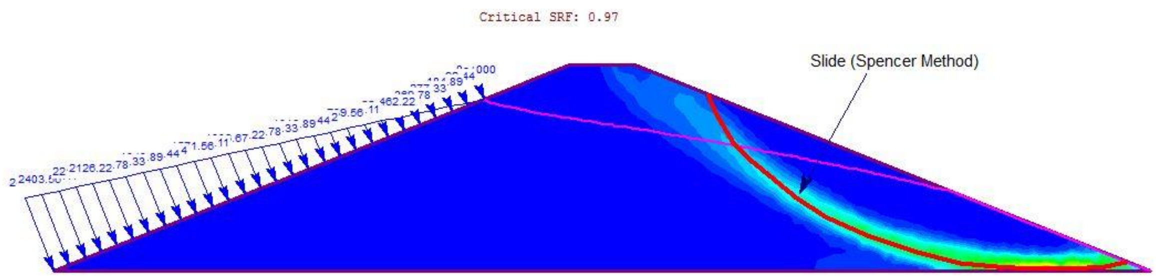


Figure 3 – Maximum Shear Strain Plot

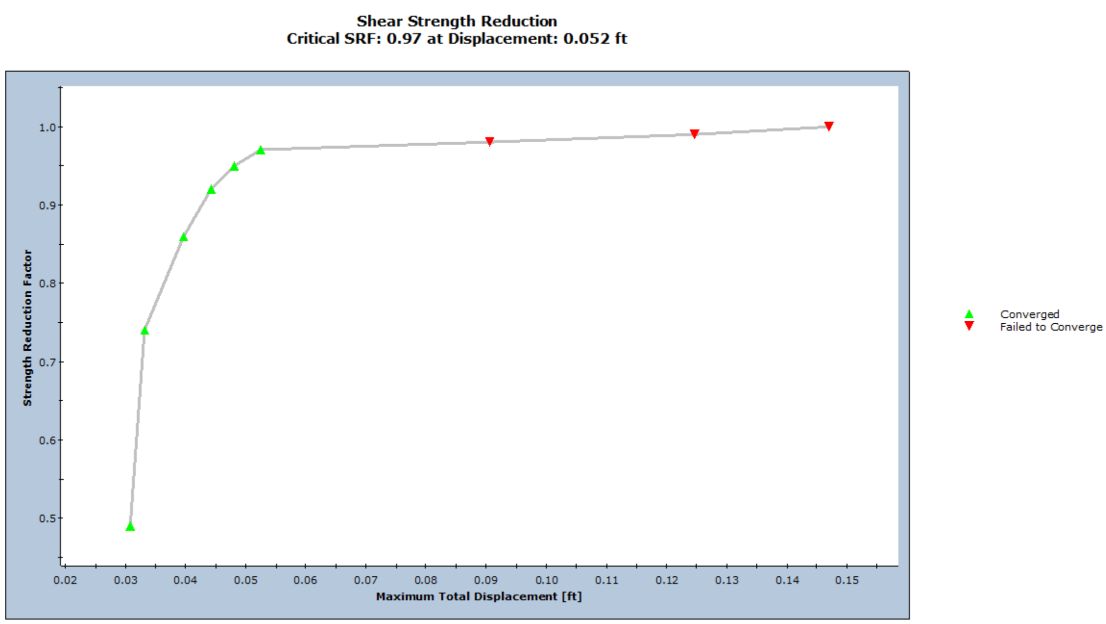


Figure 4 – SSR Convergence Graph

Introduction

This problem is taken from Figure 7.24 on page 131 of Duncan and Wright (2005).

Description

Verification problem #77 for Slide2 – a symmetric earth dam with thick core and with ponded water of elevation 315 on its left side resting on an impervious foundation – is shown in Figure 1. The material properties are given in Table 1. Seepage analysis was performed using two different techniques in this verification problem. The first technique was using Finite Element seepage analysis and the second technique was using piezometric line approximation. The location of the approximated piezometric line is shown in Figure 2. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Zone	c' (psf)	ϕ' (^{0})	γ (pcf)	k (ft/s)
Core	0	20	120	$1.67\text{x } 10^{-7}$
Shell	0	38	140	$1.67\text{x } 10^{-5}$

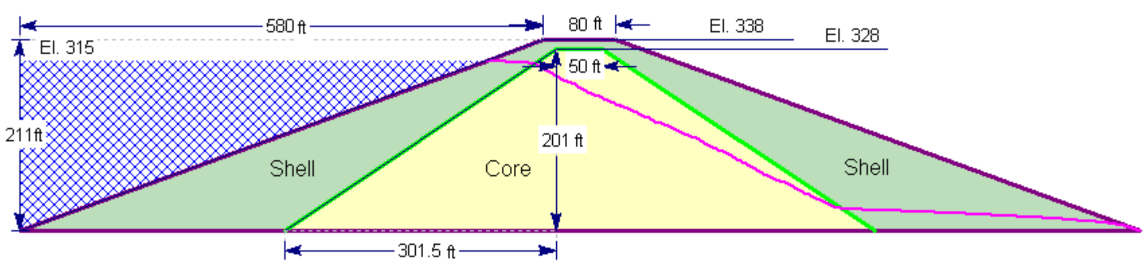


Figure 1 - Geometry

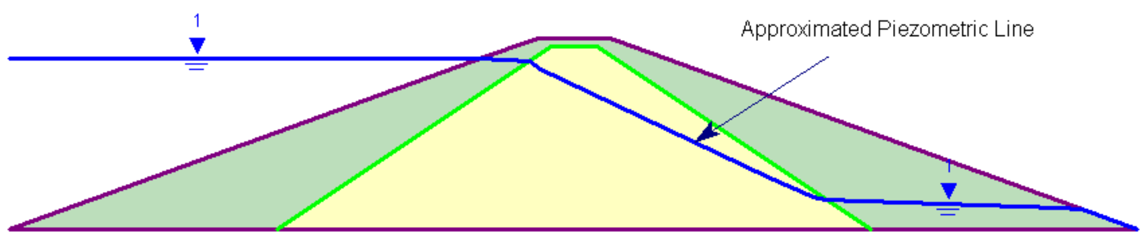


Figure 2 – Approximated Piezometric Line Location

Results

Case 1: Finite Element Seepage Analysis

Method	Factor of Safety (circular)	Factor of Safety (non-circular)	Referee Factor of Safety [Duncan and Wright]
SSR	1.52		
Bishop	1.58	1.49	1.62
Spencer	1.64	1.57	1.69

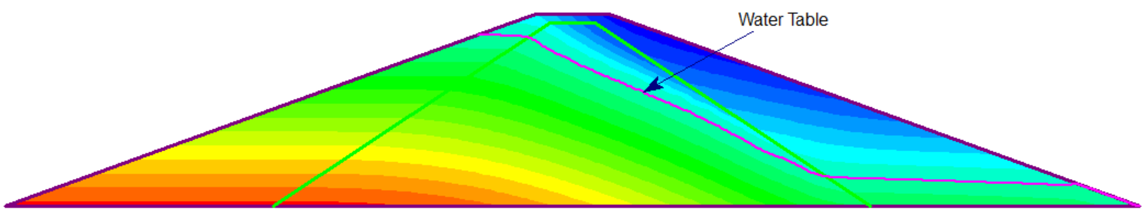


Figure 3 – Pore Water Pressure Plot

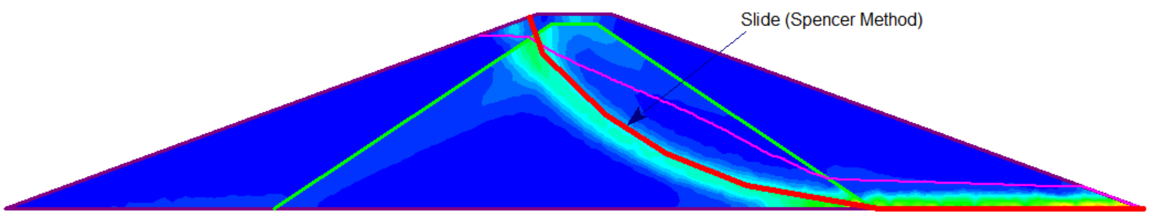


Figure 4 – Maximum Shear Strain Plot

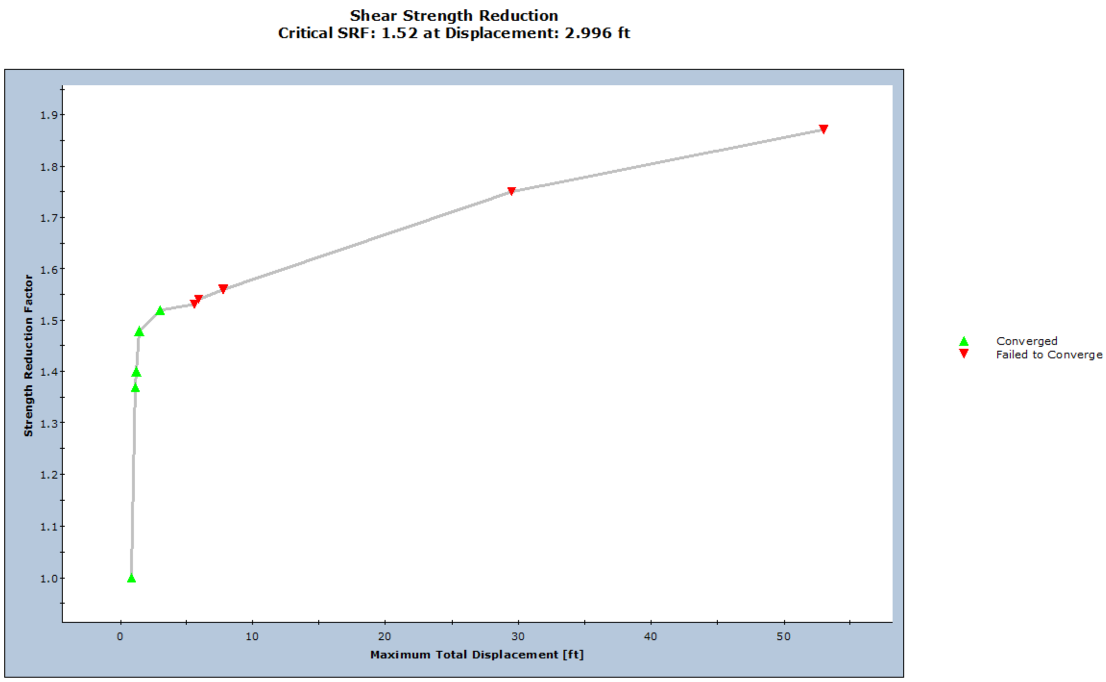


Figure 5 – SSR Convergence Graph

Case 2: Piezometric Line Approximation Seepage Analysis

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.53	
Bishop	1.58	1.48
Spencer	1.65	1.57
GLE	1.66	1.57

Note: Referee Factor of Safety = 1.67 [Duncan and Wright]

Figure 6 – Pore Water Pressure Plot

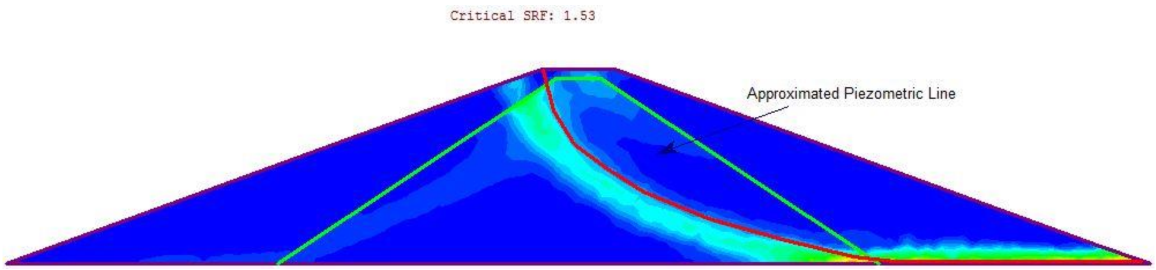


Figure 7 – Maximum Shear Strain Plot

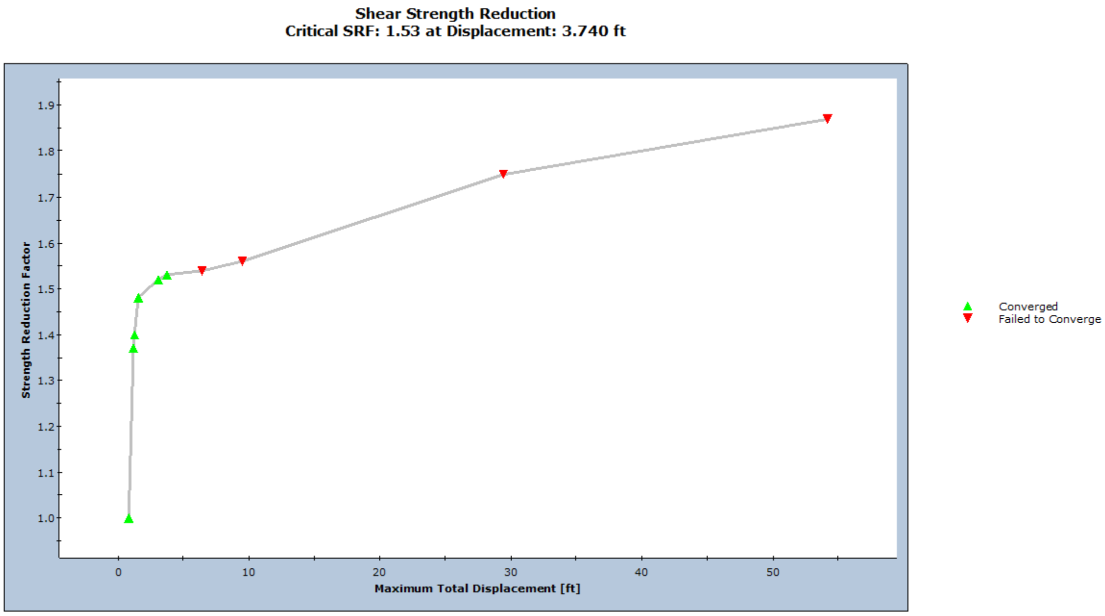


Figure 8 – SSR Convergence Graph

Introduction

This problem is taken from Figure 14.4 on page 217 of Duncan and Wright (2005).

Description

Verification problem #79 for Slide2 – a cohesionless earth embankment – is shown in Figure 1. Two slip surfaces are of interest in this verification problem. The first is slip surface that is very shallow (infinite slope mechanism) and the second is deep slip surface. In order to get the first slip surface, it was assumed that the slip surface would not go through the boundary between the embankment and its foundation. To prevent the slip surface from crossing that boundary, the foundation was considered as elastic material in the analysis. The material properties are given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Zone	c' (psf)	ϕ' (^{0})	γ (pcf)
Embankment	0	30	120
Foundation	450	0	120

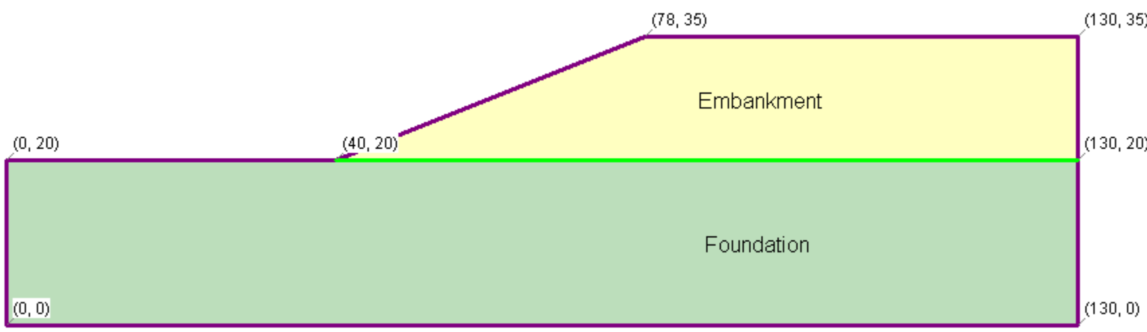


Figure 1 - Geometry

Results – Very Shallow Slip Surface (Infinite Slope Mechanism)

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.47	
Bishop	1.44	1.44
Spencer	1.44	1.44
GLE	1.44	1.44

Note: Referee Factor of Safety = 1.44 [Duncan and Wright]

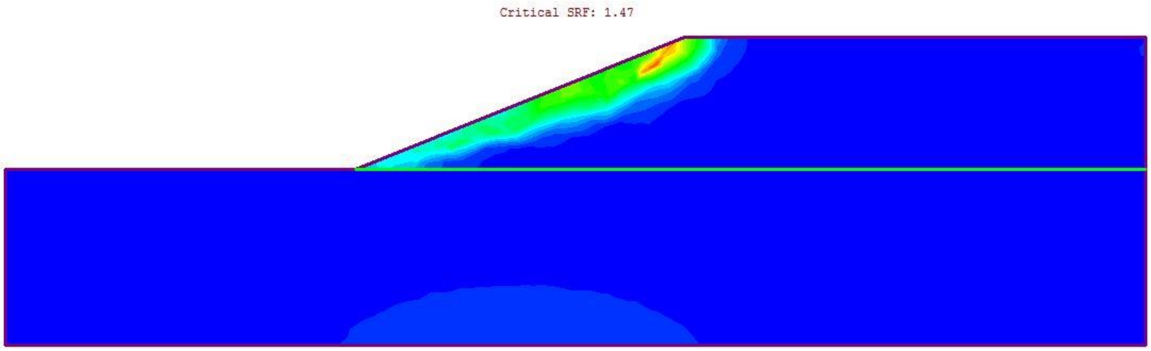


Figure 2 – Maximum Shear Strain Plot (Very Shallow Slip Surface)

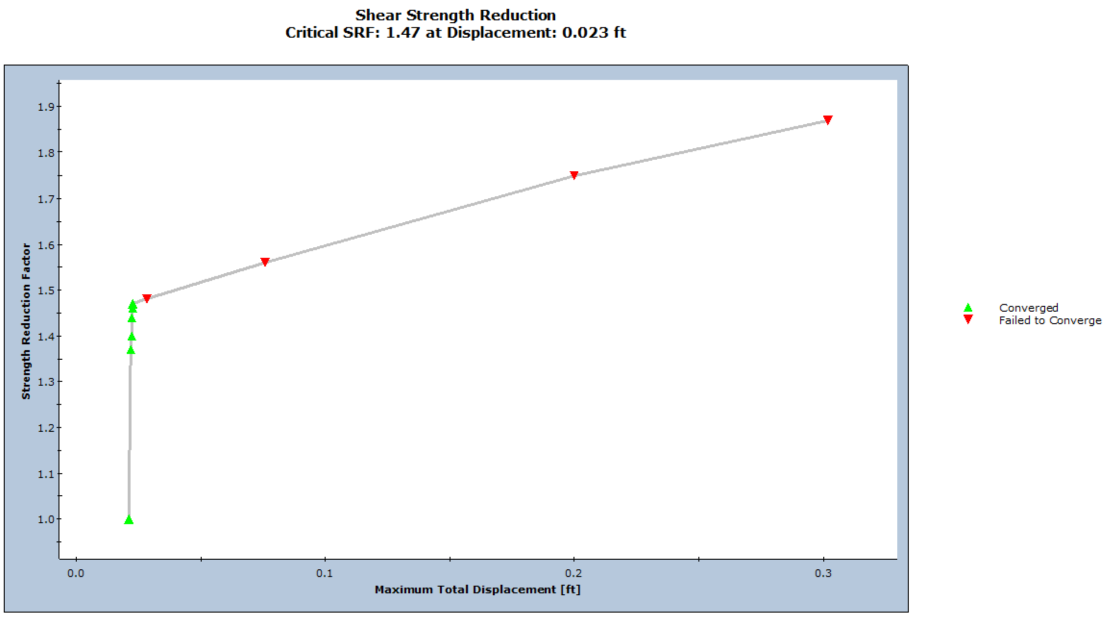


Figure 3 – SSR Convergence Graph (Very Shallow Slip Surface)

Results – Deep Slip Surface

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.43	
Bishop	1.41	1.23
Spencer	1.40	1.36
GLE	1.40	1.38

Note: Referee Factor of Safety = 1.40 [Duncan and Wright]

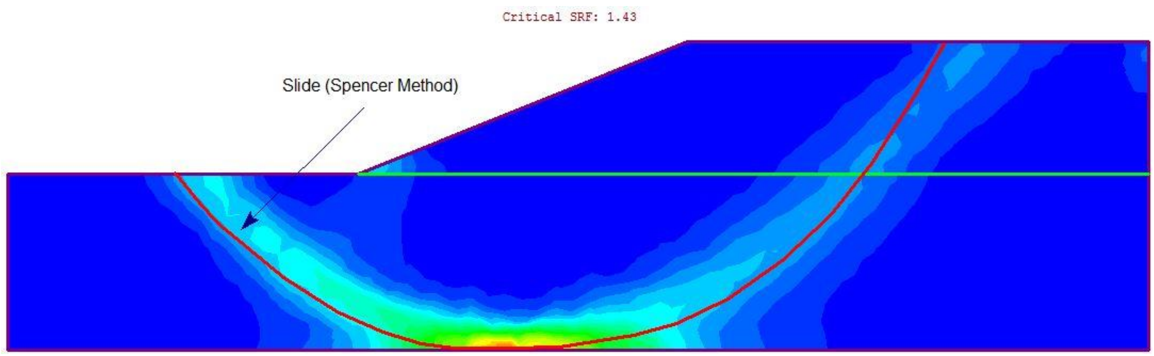


Figure 4 – Maximum Shear Strain Plot (Deep Slip Surface)

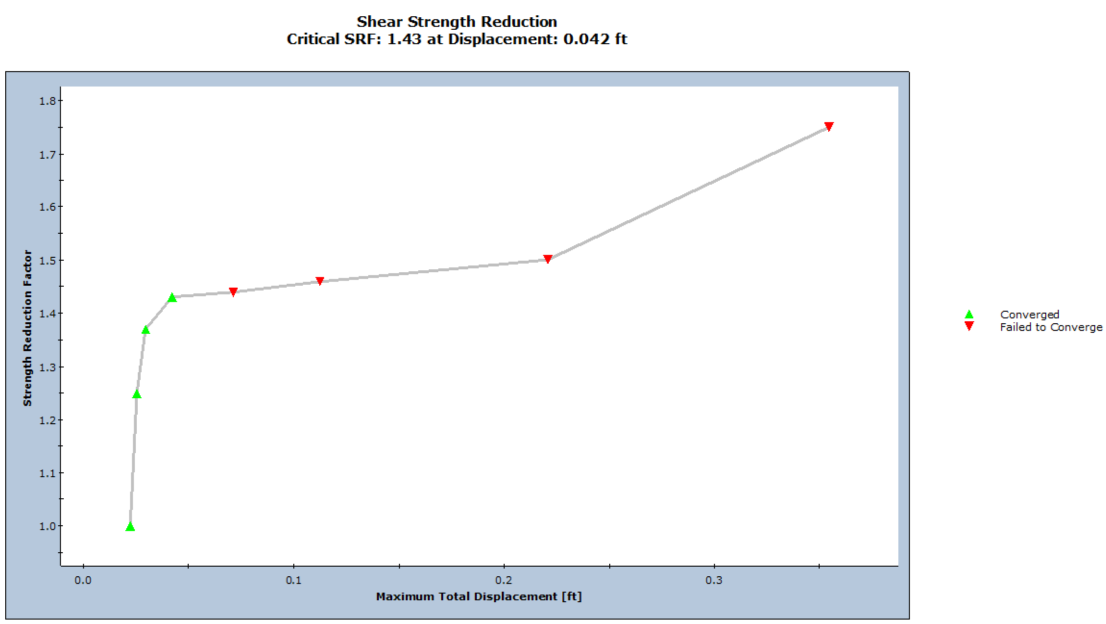


Figure 5 – SSR Convergence Graph (Deep Slip Surface)

42 Planned Cross Section of James Dike

Introduction

This problem is taken from Figure 7.16 on page 124 of Duncan and Wright (2005).

Description

Verification problem #75 for Slide2 – the planned cross section of James Dike – is shown in Figure 1. The material properties are given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Material	c (kN/m^2)	ϕ (^{0})	γ (kN/m^3)
Fill	0	30	20
Clay “crust”	41	0	20
Marine Clay	34.5	0	18.8
Lacustrine Clay	31.2	0	20.3

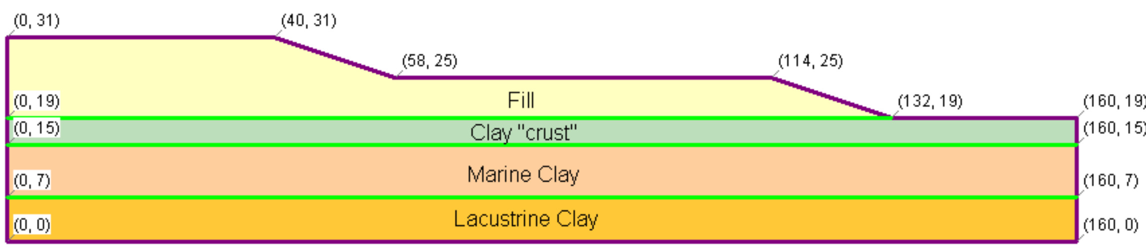


Figure 1 - Geometry

Results

Method	Factor of Safety (non-circular)
SSR	1.26
Bishop	1.11
Spencer	1.16
GLE	1.15

Note: Referee Factor of Safety = 1.17 [Duncan and Wright]

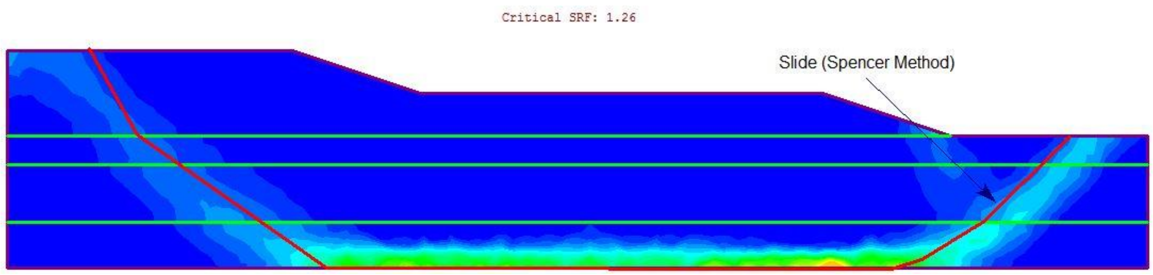


Figure 2 – Maximum Shear Strain Plot

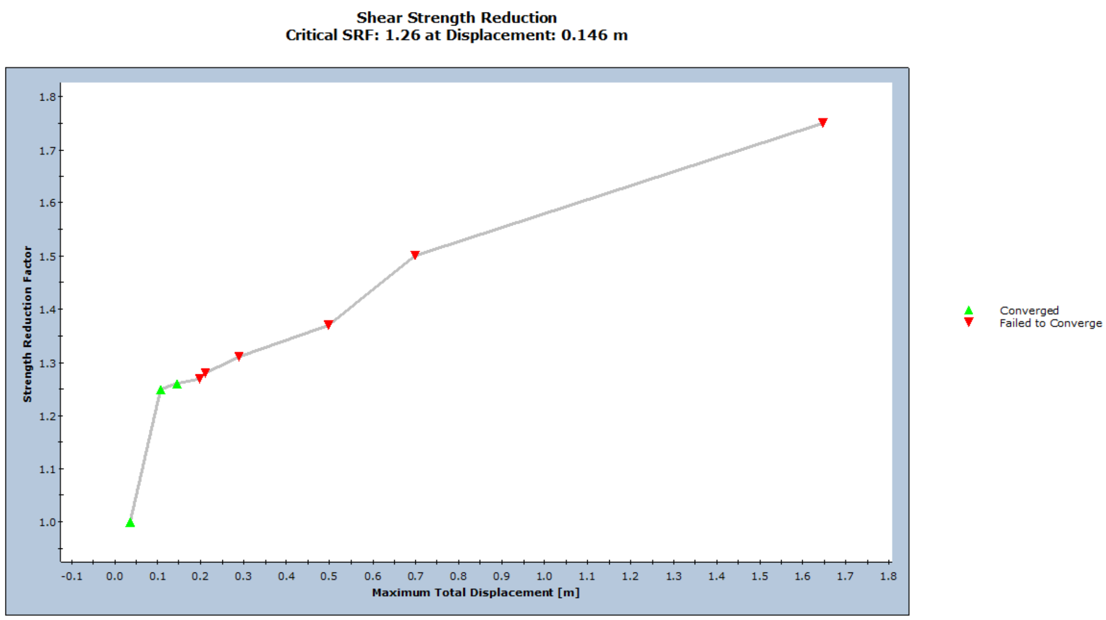


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from Figure 14.7 on page 220 of Duncan and Wright (2005).

Description

Verification problem #81 for Slide2 – an earth embankment – is shown in Figure 1. Two slip surfaces are of interest in this verification problem. The first is slip surface that is very shallow (infinite slope mechanism) and the second is deep slip surface. In order to get the first slip surface, it was assumed that the slip surface would not go through the boundary between the embankment and its foundation. To prevent the slip surface from crossing that boundary, the foundation was considered as elastic material in the analysis. The material properties are given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Zone	c' (psf)	ϕ' (^{0})	γ (pcf)
Embankment	0	30	124
Foundation	500	0	98

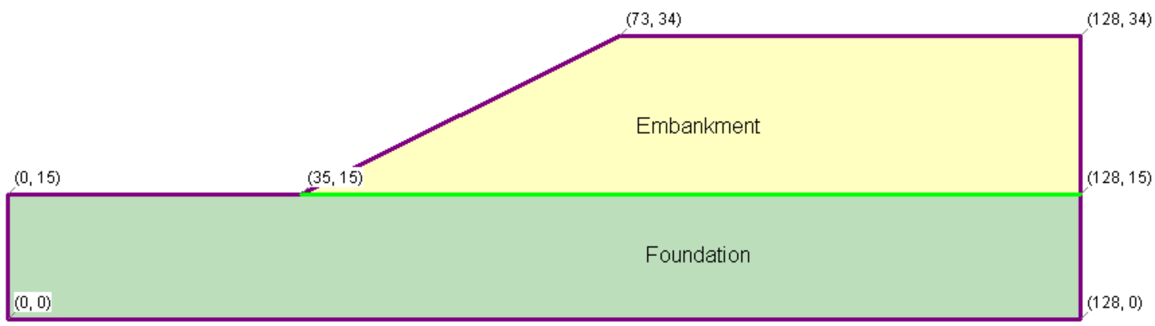


Figure 1 - Geometry

Results – Very Shallow Slip Surface (Infinite Slope Mechanism)

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.19	
Bishop	1.15	1.15
Spencer	1.15	1.15
GLE	1.15	1.15

Note: Referee Factor of Safety = 1.15 [Duncan and Wright]

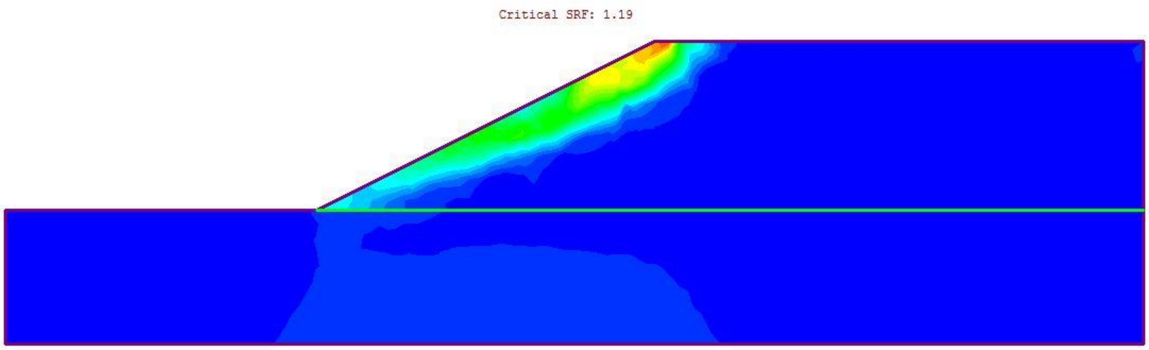


Figure 2 – Maximum Shear Strain Plot (Very Shallow Slip Surface)

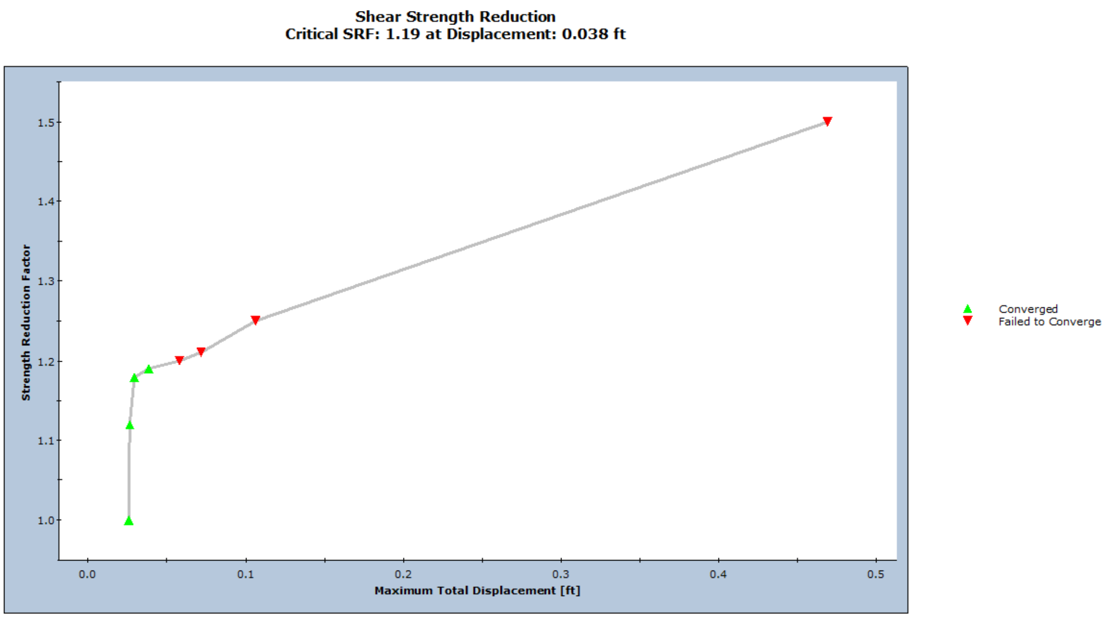


Figure 3 – SSR Convergence Graph (Very Shallow Slip Surface)

Results – Deep Slip Surface

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.23	
Bishop	1.23	1.08
Spencer	1.21	1.19
GLE	1.22	1.20

Note: Referee Factor of Safety = 1.21 [Duncan and Wright]

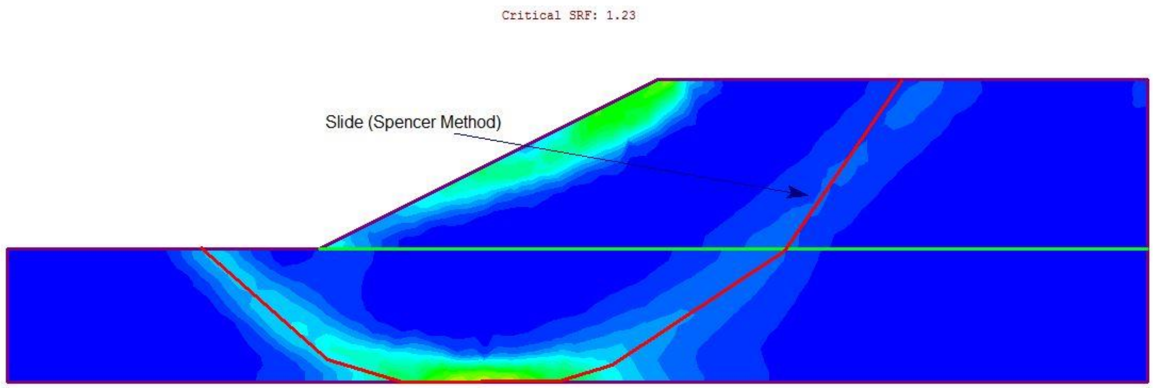


Figure 4 – Maximum Shear Strain Plot (Deep Slip Surface)

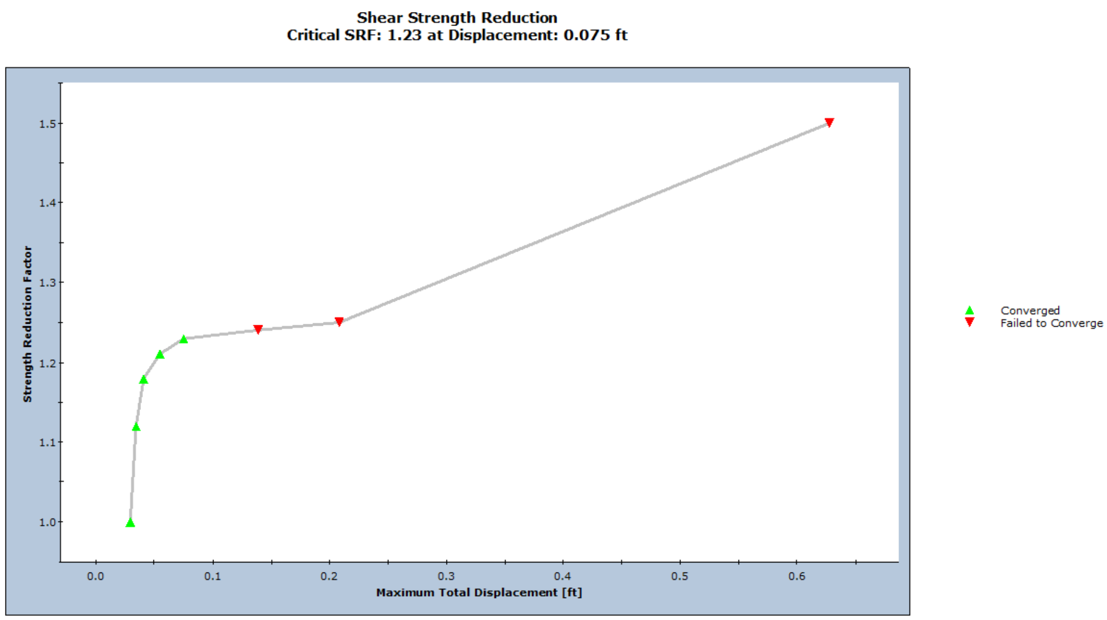


Figure 5 – SSR Convergence Graph (Deep Slip Surface)

Introduction

This problem is taken from Figure 14.20-a on page 230 of Duncan and Wright (2005).

Description

Verification problem #82 for Slide2 – an earth embankment – is shown in Figure 1. The seepage analysis was carried out using piezometric line approximation technique. The material properties are given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Zone	c' (psf)	ϕ' (^{0})	γ (pcf)
Embankment	600	25	125
Foundation	0	30	132

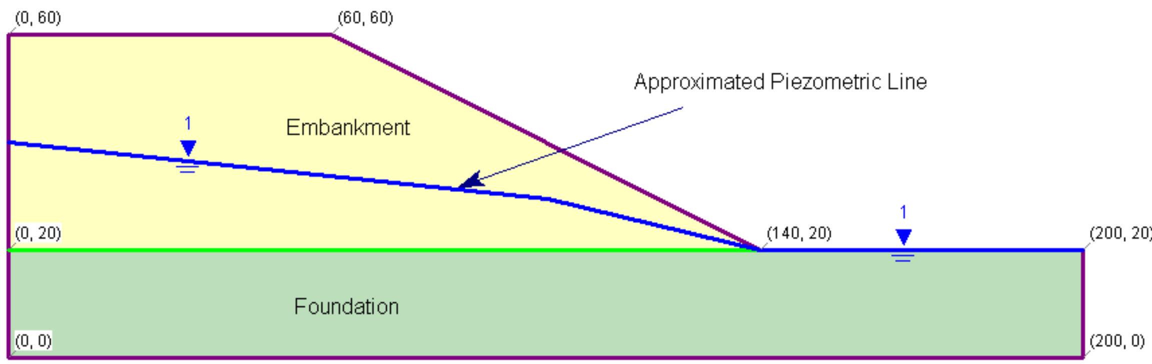


Figure 1 - Geometry

Results

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.51	
Bishop	1.532	1.444
Spencer	1.541	1.535
GLE	1.539	1.526

Note: Referee Factor of Safety = 1.528 – 1.542 [Duncan and Wright]

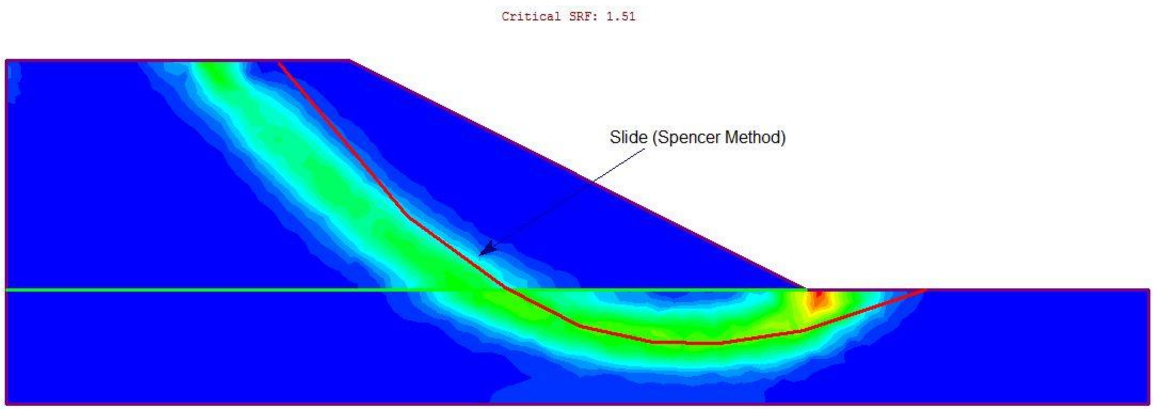


Figure 2 – Maximum Shear Strain Plot

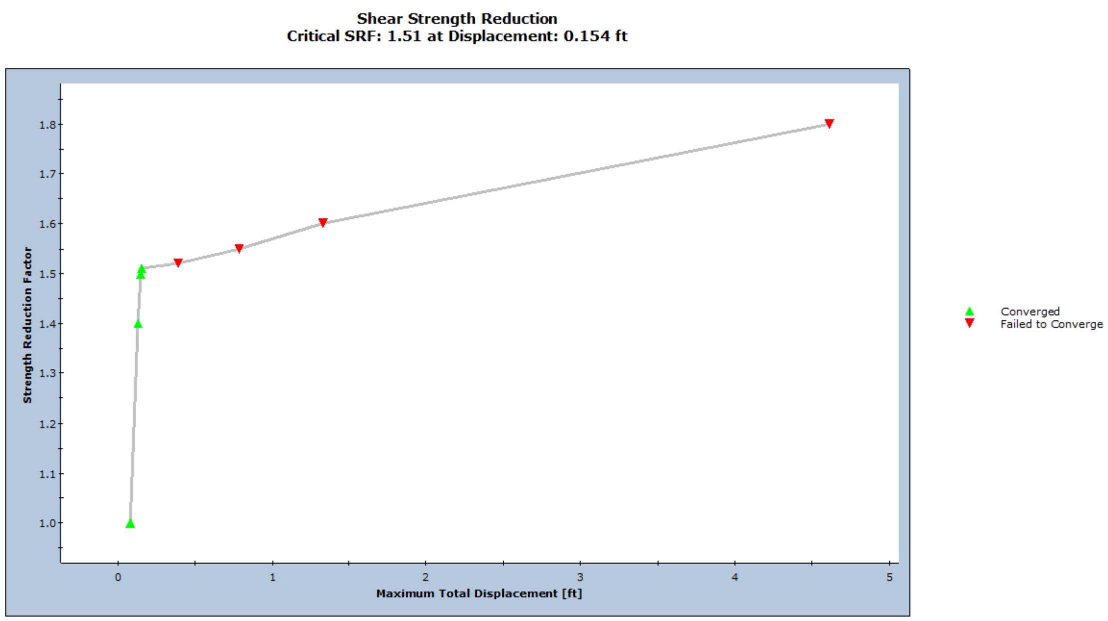


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from Figure 14.20-b on page 230 of Duncan and Wright (2005).

Description

Verification problem #83 for Slide2 – an earth embankment – is shown in Figure 2. Two undrained shear strength profiles for its foundation are tested. The material properties are given in Table 1 and the foundation's undrained shear strength profiles are presented in Figure 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Zone	c' (psf)	φ' (^{0})	γ (pcf)
Embankment	0	36	123
Foundation	see Fig. 1	0	97

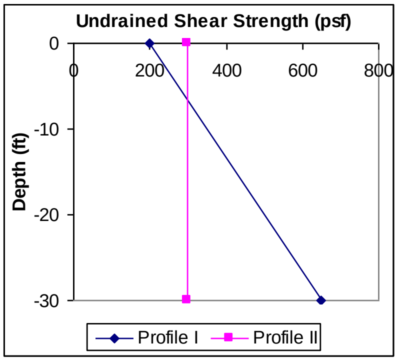


Figure 1 – Undrained Shear Strength Profiles

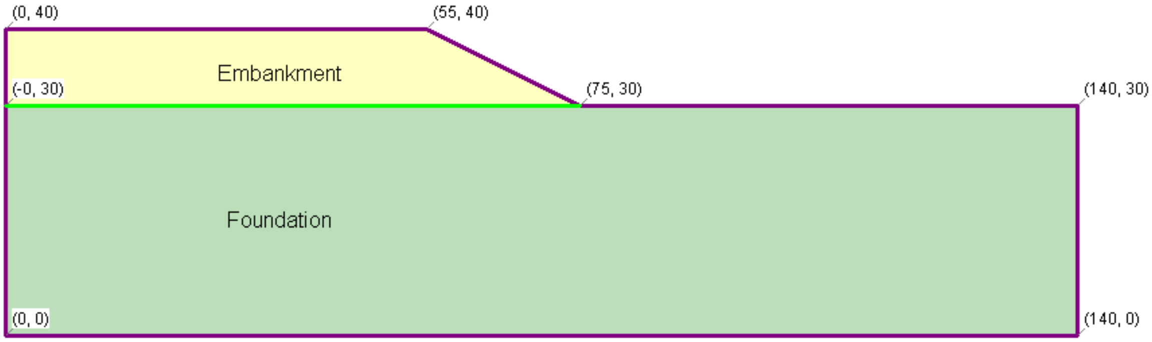


Figure 2 - Geometry

Results – Undrained Shear Strength Profile I

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.32	
Bishop	1.312	1.157
Spencer	1.285	1.263
GLE	1.293	1.269

Note: Referee Factor of Safety = 1.276 – 1.323 [Duncan and Wright]

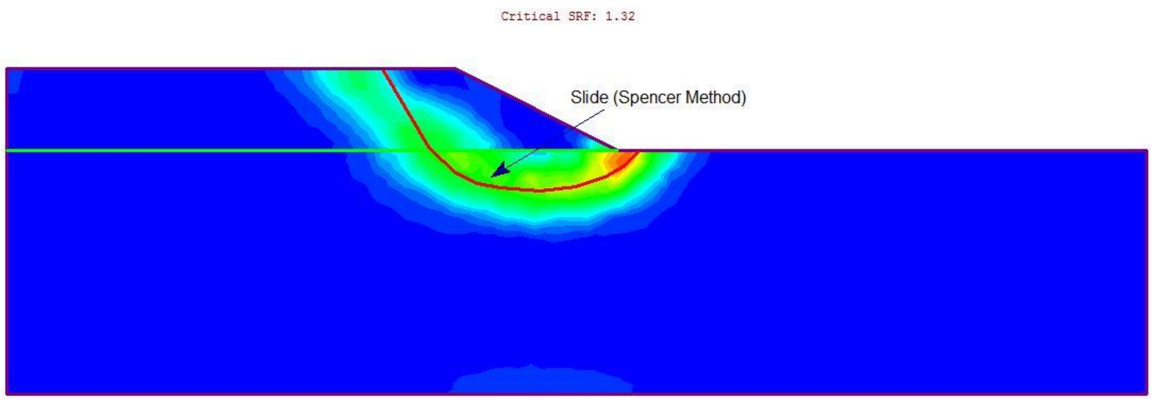


Figure 3 – Maximum Shear Strain Plot (Undrained Shear Strength Profile I)

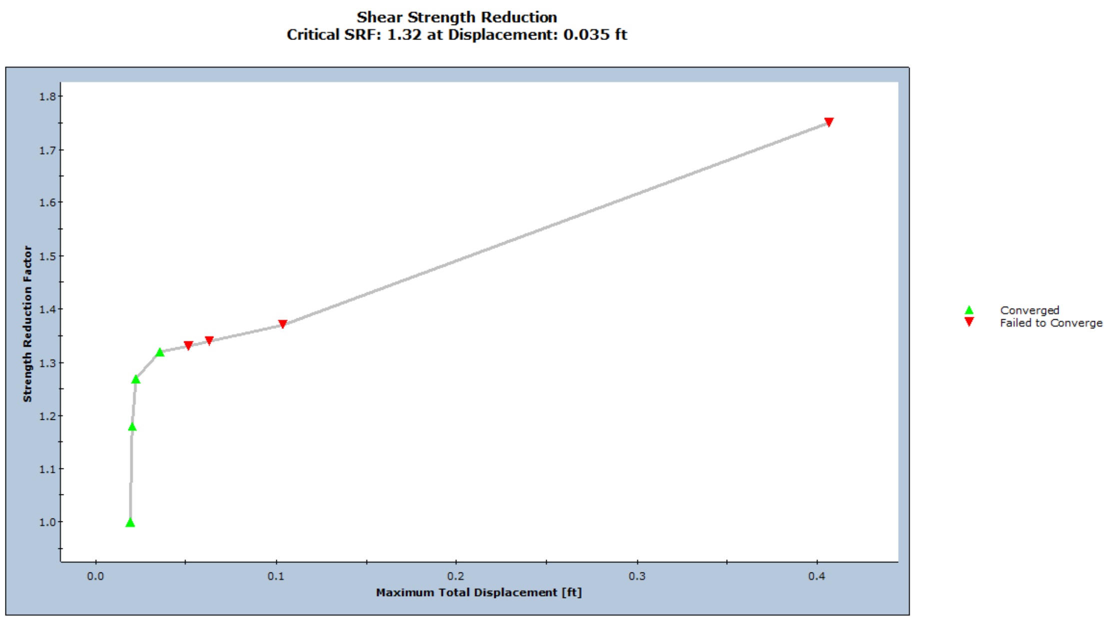


Figure 4 – SSR Convergence Graph (Undrained Shear Strength Profile I)

Results – Undrained Shear Strength Profile II

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.32	
Bishop	1.335	1.068
Spencer	1.329	1.175
GLE	1.331	1.204

Note: Referee Factor of Safety = 1.295 – 1.328 [Duncan and Wright]

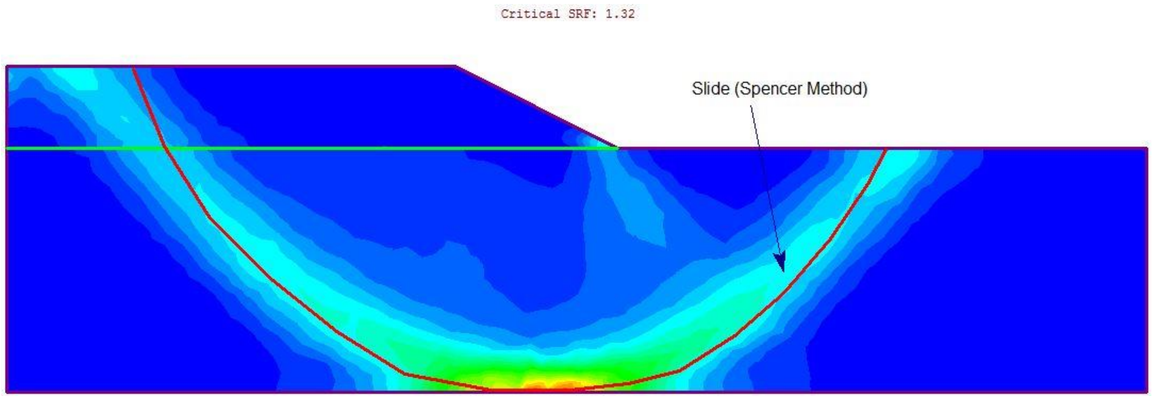


Figure 5 – Maximum Shear Strain Plot (Undrained Shear Strength Profile II)

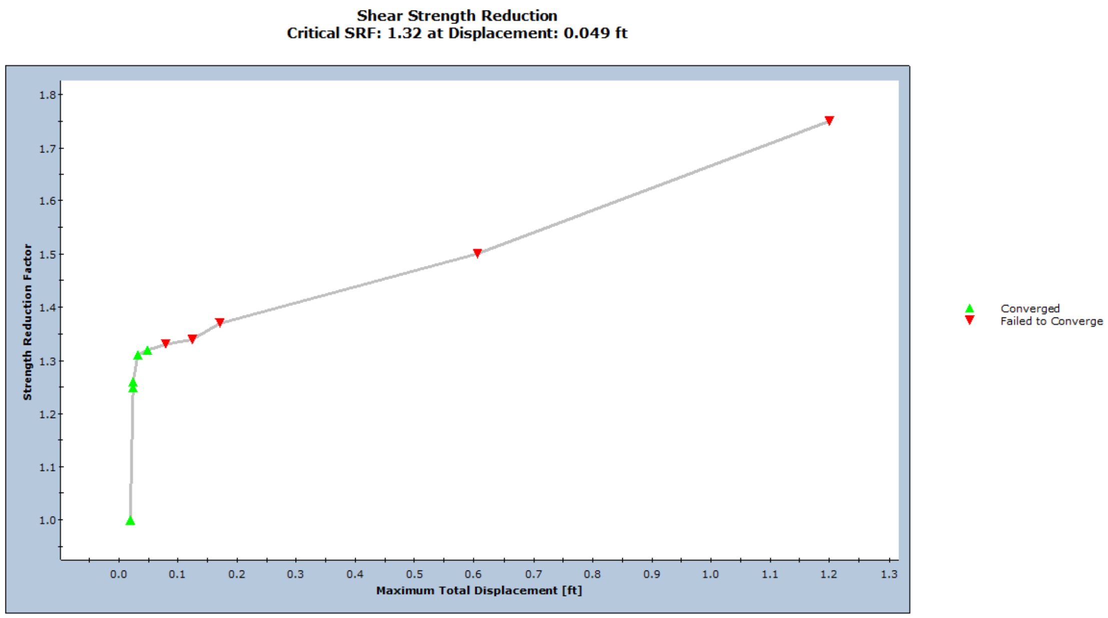


Figure 6 – SSR Convergence Graph (Undrained Shear Strength Profile II)

46 Earth Embankment with Varying Undrained Shear Strength Profiles II

Introduction

This problem is taken from Figure 15.9 on page 244 of Duncan and Wright (2005).

Description

Verification problem #84 for Slide2 – an earth embankment – is shown in Figure 1. Four undrained shear strength profiles for its foundation are investigated. The undrained shear strength profiles can be generalized as:

$$c_u = 300 + c_z z$$

where z is depth (in feet) and c_z is the rate of increase in undrained shear strength. c_z value varies among profiles. The material properties are given in Table 1 and the c_z values are presented in Table 2. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

Zone	c' (psf)	ϕ' (^{0})	γ (pcf)
Embankment	0	35	125
Foundation	$c_u = 300 + c_z z$	0	100

Table 2 - c_z Values

Profile	c_z (psf/ft)
I	0
II	5
III	10
IV	15

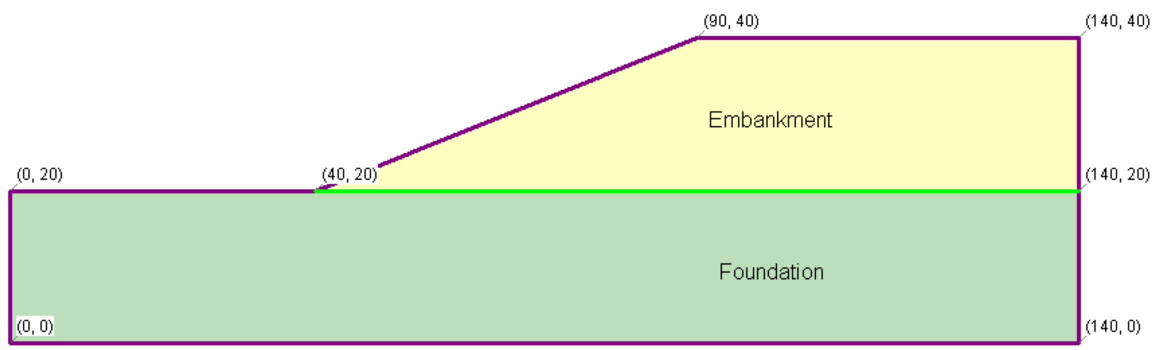


Figure 1 - Geometry

Results – Undrained Shear Strength Profile I

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	0.78	
Bishop	0.76	0.68
Spencer	0.76	0.74
GLE	0.76	0.75

Note: Referee Factor of Safety = 0.75 [Duncan and Wright]

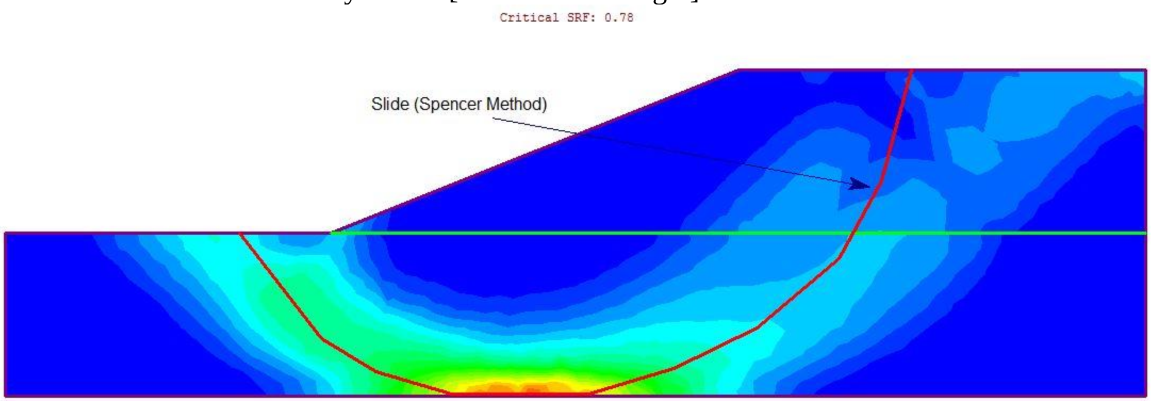


Figure 2 – Maximum Shear Strain Plot (Undrained Shear Strength Profile I)

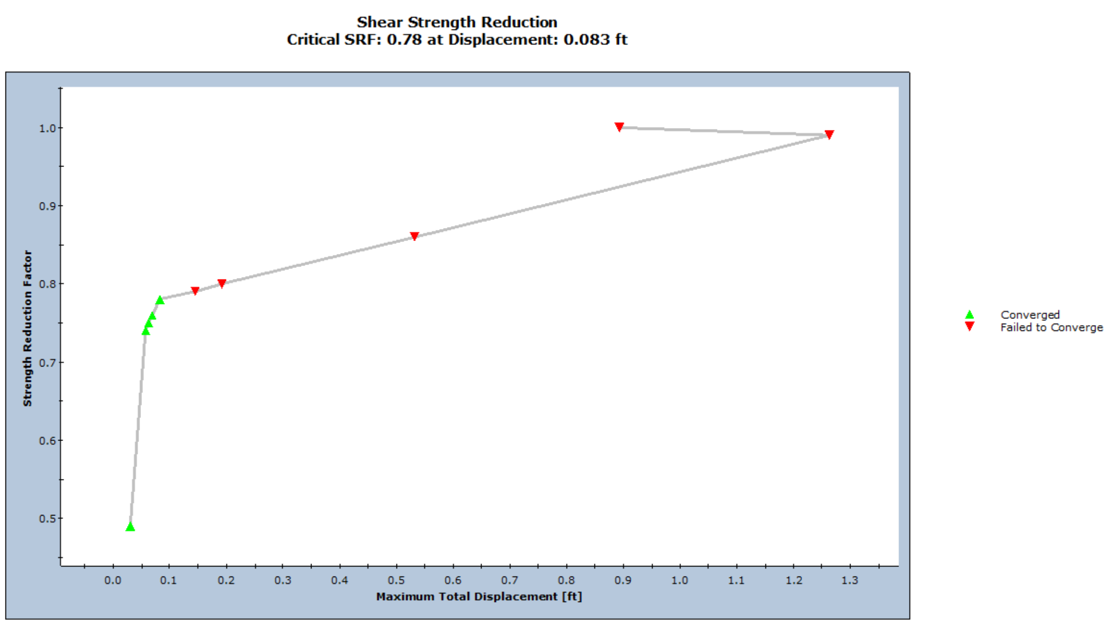


Figure 3 – SSR Convergence Graph (Undrained Shear Strength Profile I)

Results – Undrained Shear Strength Profile II

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	0.93	
Bishop	0.91	0.81
Spencer	0.90	0.91
GLE	0.91	0.92

Note: Referee Factor of Safety = 0.90 [Duncan and Wright]

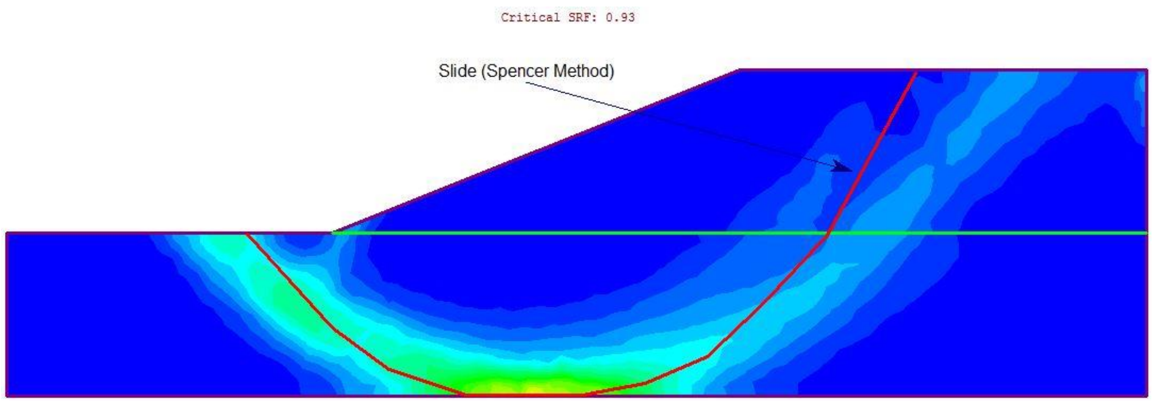


Figure 4 – Maximum Shear Strain Plot (Undrained Shear Strength Profile II)

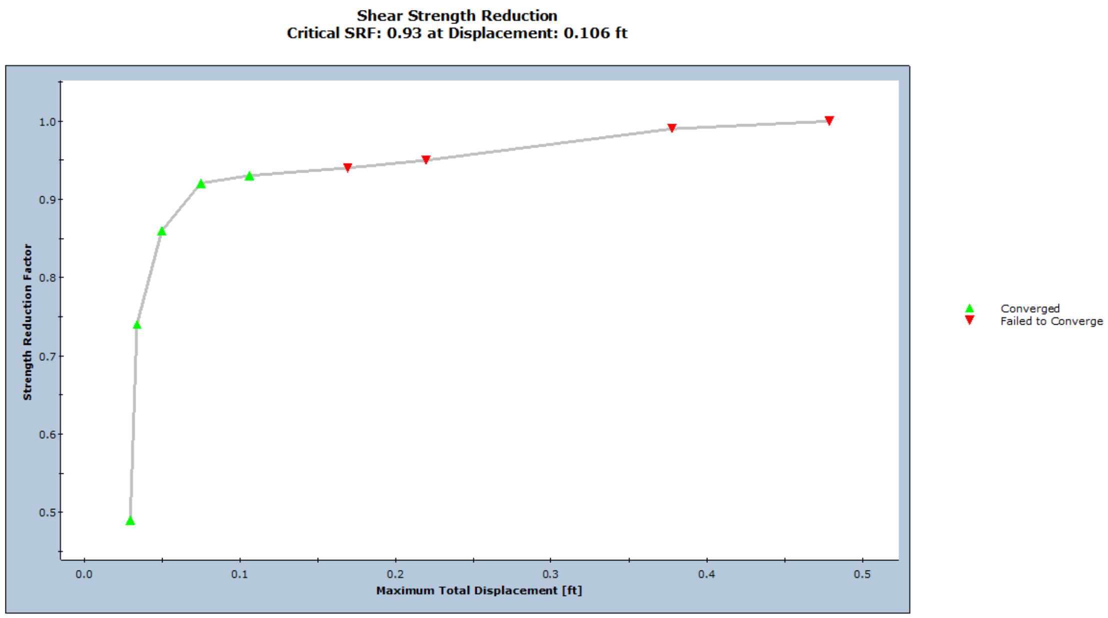


Figure 5 – SSR Convergence Graph (Undrained Shear Strength Profile II)

Results – Undrained Shear Strength Profile III

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.05	
Bishop	1.04	0.93
Spencer	1.03	1.02
GLE	1.03	1.02

Note: Referee Factor of Safety = 1.03 [Duncan and Wright]

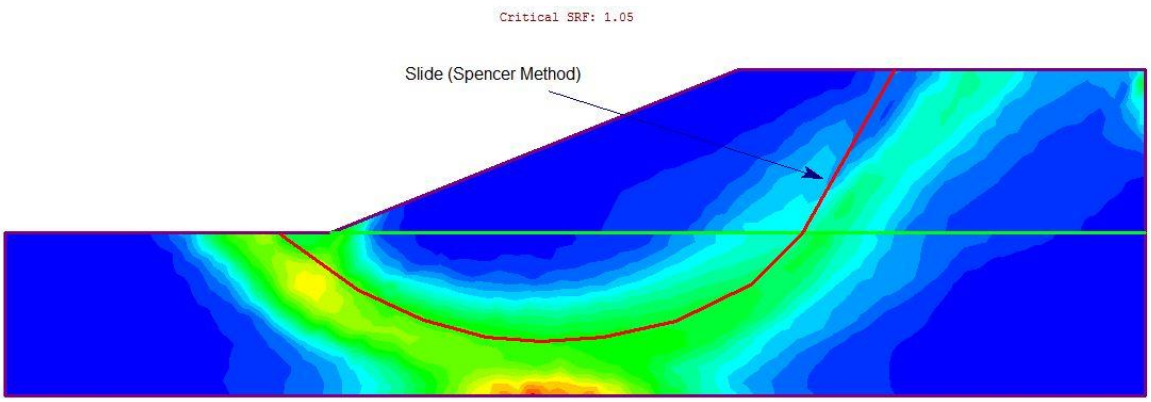


Figure 6 – Maximum Shear Strain Plot (Undrained Shear Strength Profile III)

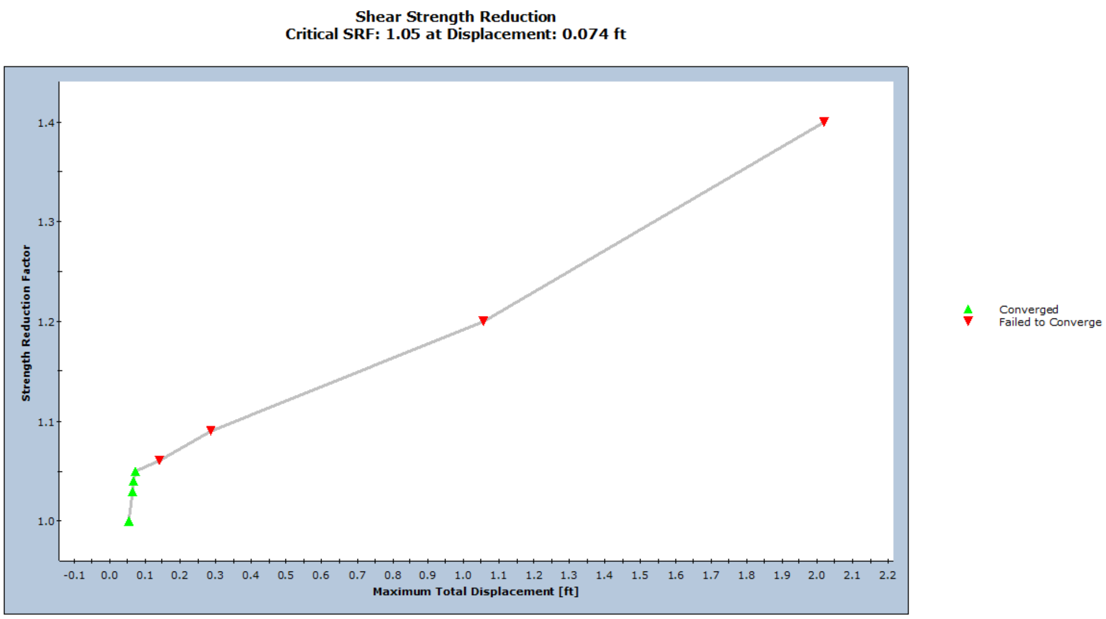


Figure 7 – SSR Convergence Graph (Undrained Shear Strength Profile III)

Results – Undrained Shear Strength Profile IV

Method	Factor of Safety (circular)	Factor of Safety (non-circular)
SSR	1.15	
Bishop	1.15	1.04
Spencer	1.13	1.12
GLE	1.14	1.12

Note: Referee Factor of Safety = 1.13 [Duncan and Wright]

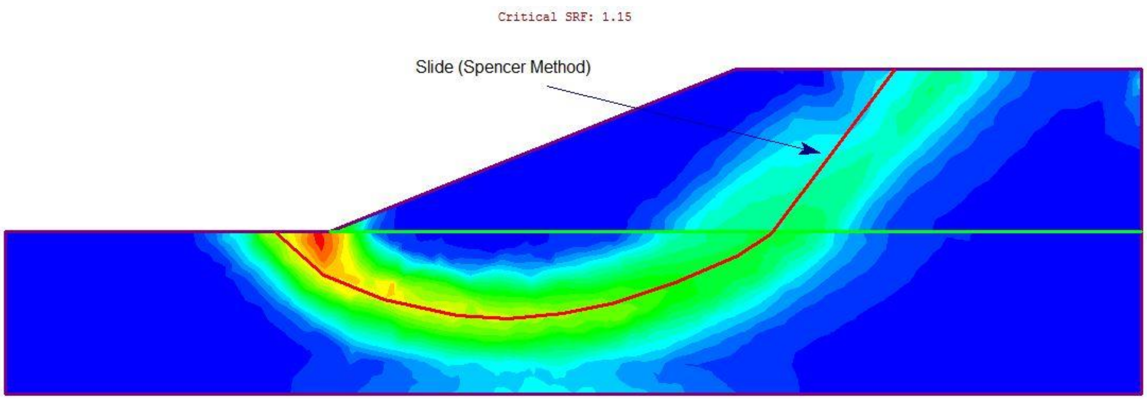


Figure 8 – Maximum Shear Strain Plot (Undrained Shear Strength Profile IV)

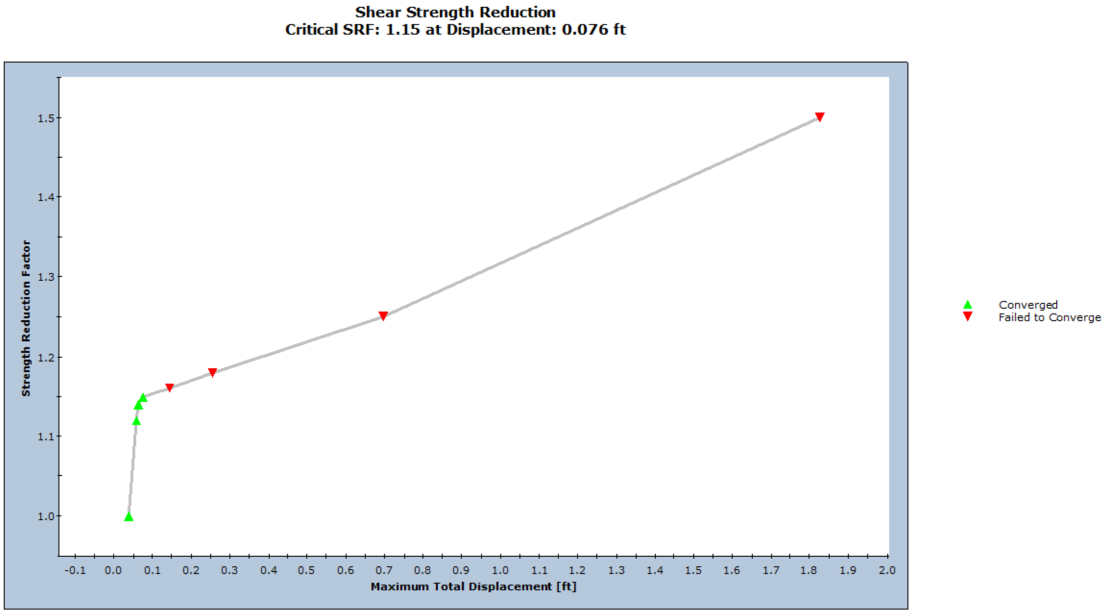


Figure 9 – SSR Convergence Graph (Undrained Shear Strength Profile IV)

47 Simple Purely Cohesive Slope with Varying Thickness

Introduction

This problem is taken from Figure 14.3 on page 216 of Duncan and Wright (2005).

Description

Verification problem #78 for Slide2 – a simple, pure cohesive slope – is shown in Figure 1. Three different foundation thicknesses (30 feet-thick, 46.5 feet-thick and 60 feet-thick) are tested. The material properties are given in Table 1. The factor of safety and its corresponding slip surface are required.

Geometry and Properties

Table 1 Material Properties

c (psf)	ϕ (^{0})	γ (pcf)
1000	0	100

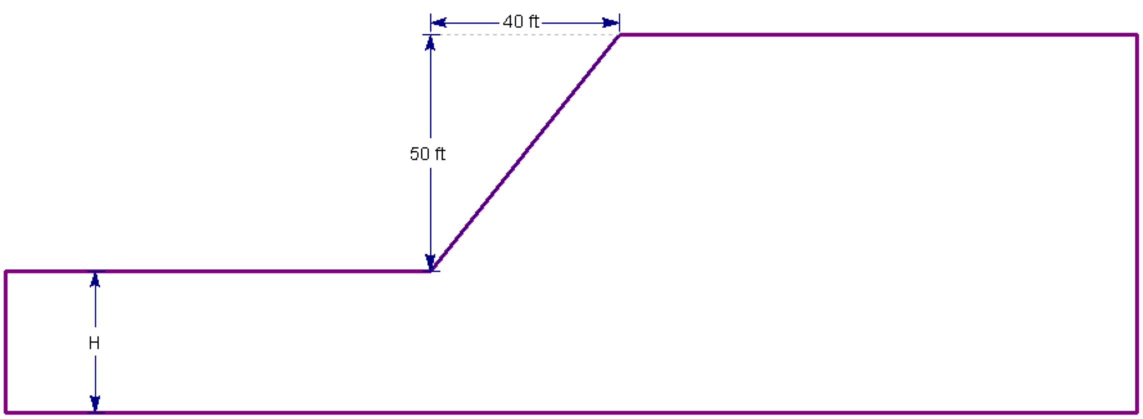


Figure 1 - Geometry

Results – 30 feet-thick Foundation

Method	Factor of Safety (circular)		Factor of Safety (non-circular)
	Passes Trough the Toe	Touches the Bottom of the Foundation	
SSR	1.03		
Bishop	1.126	1.141	0.904
Spencer	1.200	1.139	1.037
GLE	1.185	1.137	1.082

Note: Referee Factor of Safety = 1.124 (passes through the toe) & 1.135 (touches the bottom of the foundation) [Duncan and Wright]

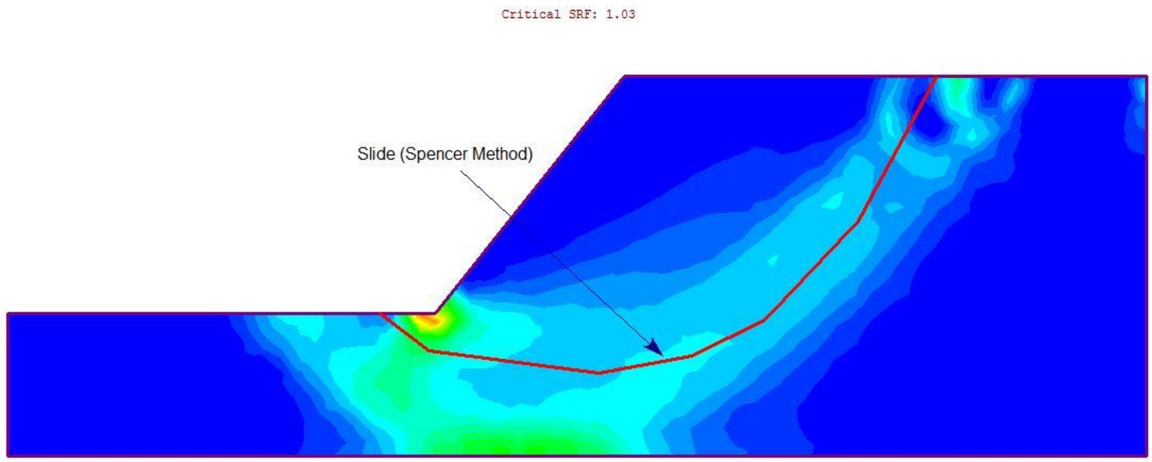


Figure 2 – Maximum Shear Strain Plot (30 feet-thick Foundation)

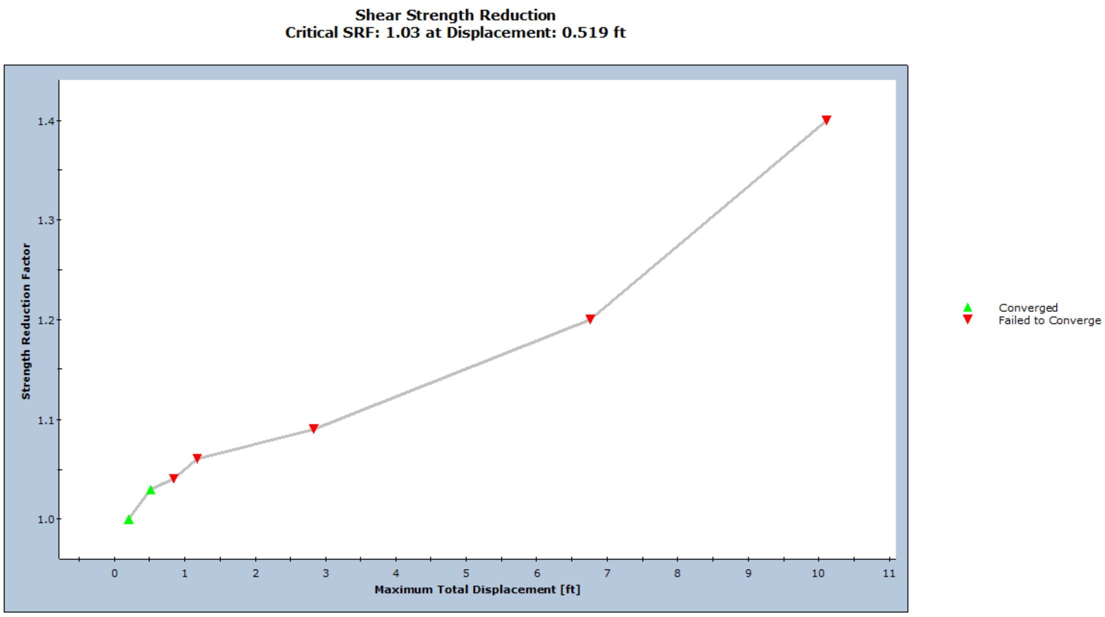


Figure 3 – SSR Convergence Graph (30 feet-thick Foundation)

Results – 46.5 feet-thick Foundation

Method	Factor of Safety (circular)		Factor of Safety (non-circular)
	Passes Trough the Toe	Touches the Bottom of the Foundation	
SSR	1.02		
Bishop	1.126	1.130	0.882
Spencer	1.201	1.128	1.037
GLE	1.186	1.127	1.082

Note: Referee Factor of Safety = 1.124 (passes through the toe & touches the bottom of the foundation) [Duncan and Wright]

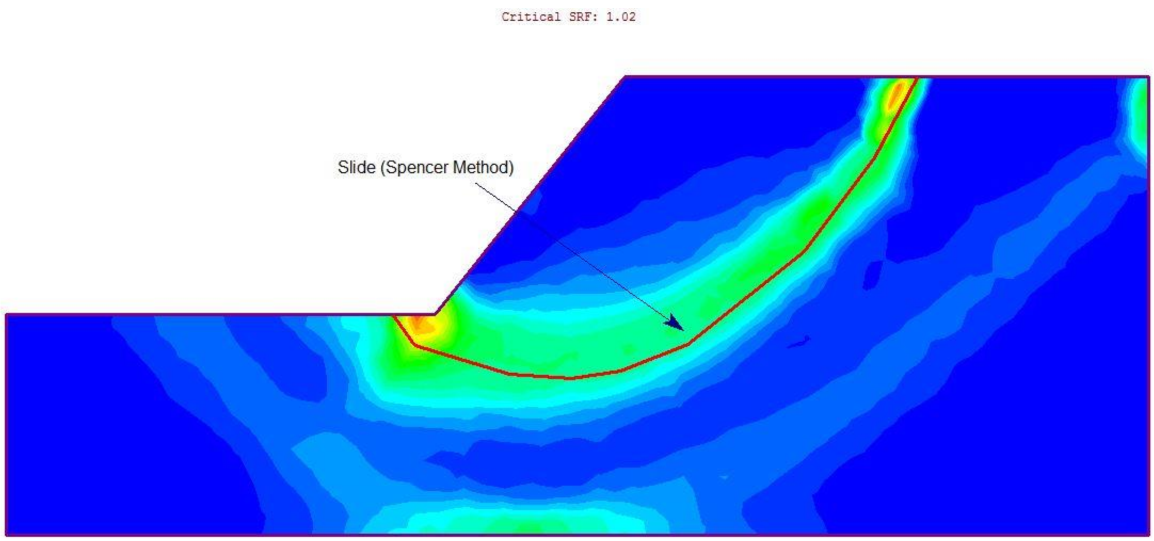


Figure 4 – Maximum Shear Strain Plot (46.5 feet-thick Foundation)

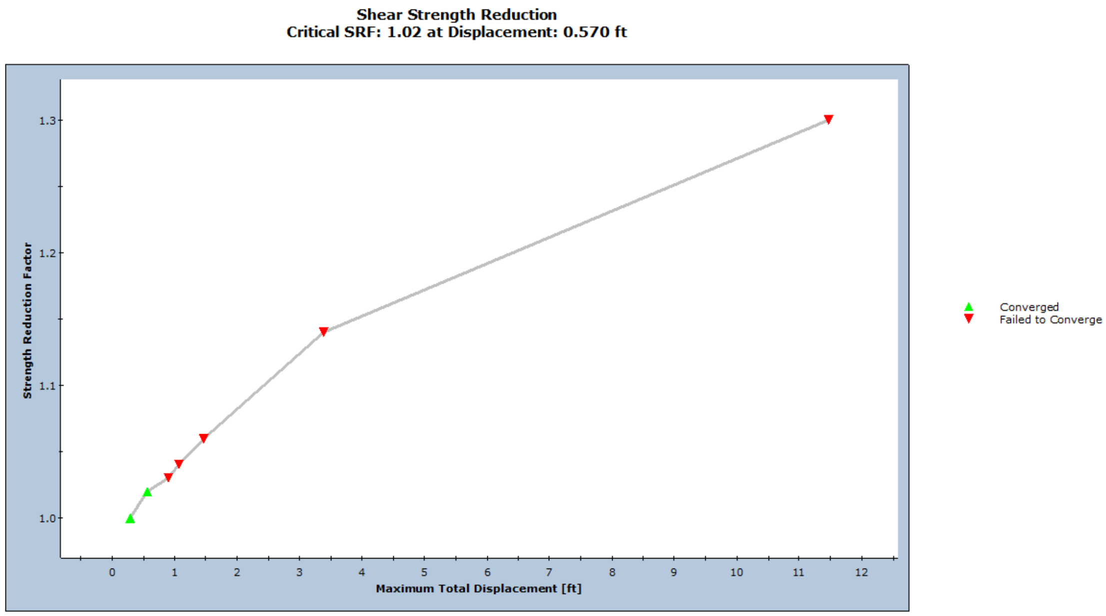


Figure 5 – SSR Convergence Graph (46.5 feet-thick Foundation)

Results – 60 feet-thick Foundation

Method	Factor of Safety (circular)		Factor of Safety (non-circular)
	Passes Trough the Toe	Touches the Bottom of the Foundation	
SSR	1.02		
Bishop	1.125	1.125	0.873
Spencer	1.201	1.124	1.062
GLE	1.185	1.122	1.062

Note: Referee Factor of Safety = 1.124 (passes through the toe) & 1.119 (touches the bottom of the foundation) [Duncan and Wright]

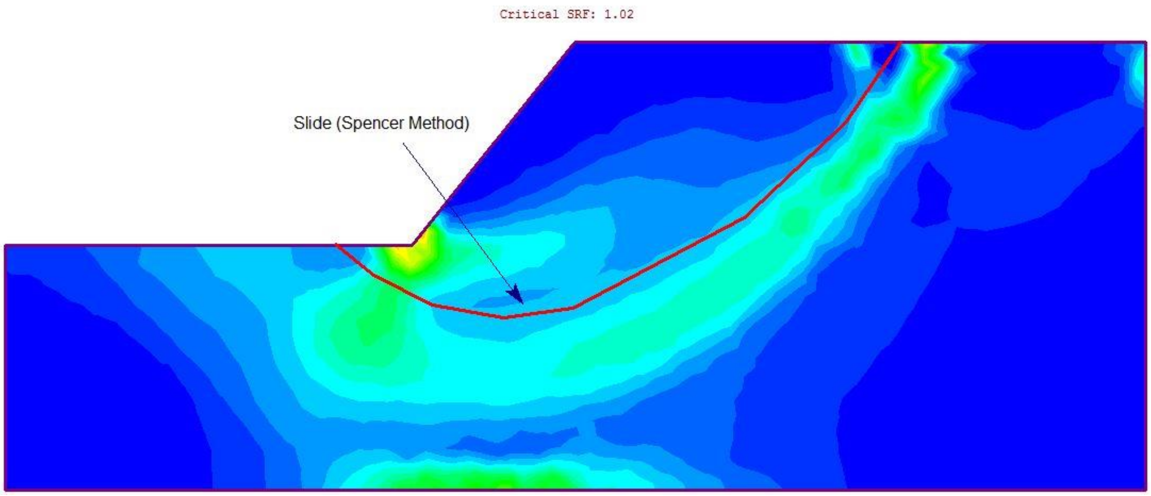


Figure 6 – Maximum Shear Strain Plot (60 feet-thick Foundation)

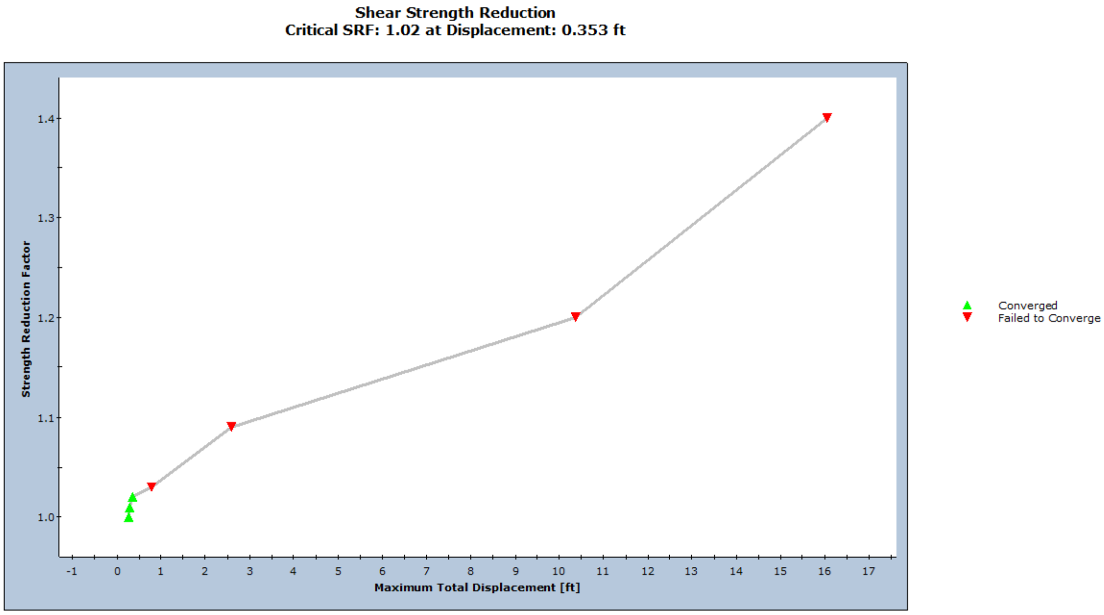


Figure 7 – SSR Convergence Graph (60 feet-thick Foundation)

Introduction

This problem is taken from the Baseline case studied in the "Geosynthetic Reinforced Multitiered Walls", a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #87 for Slide2 – A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the support is assumed to equal to 80% of the fill strength.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	34	18
Foundation soil	10	34	18
Blocks	2.5	34	18

Table 2 Support Properties

Length (m)	Tensile Strength (kN/m)
6.3	10.0

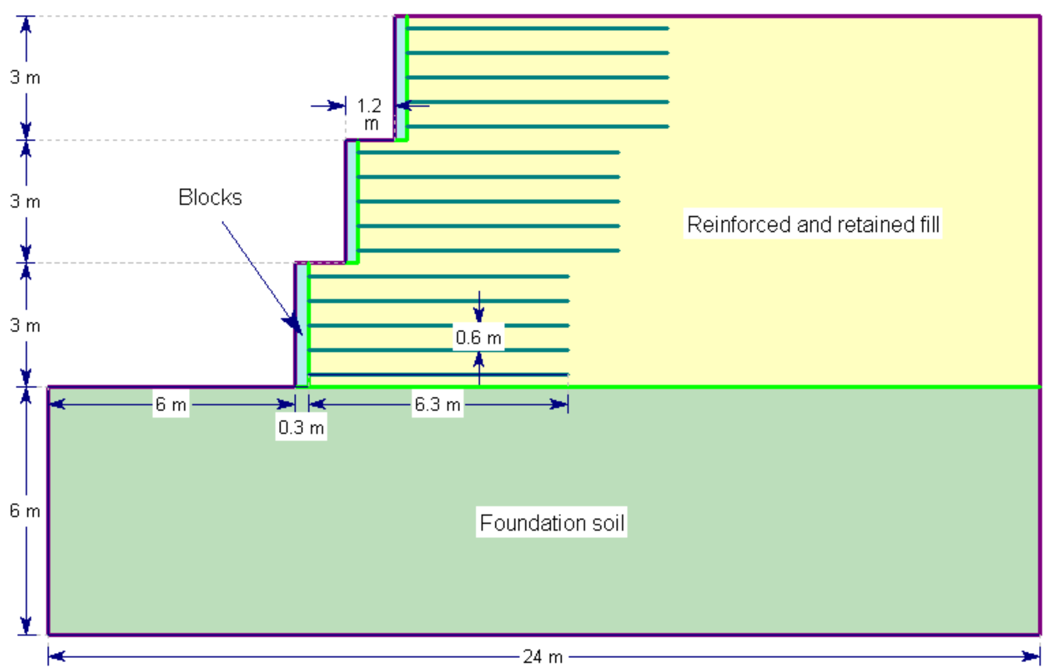


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	1.05
Bishop	1.02
Spencer	1.03
GLE	1.03

Note: Referee Factor of Safety = 0.99 [Leshchinsky and Han]

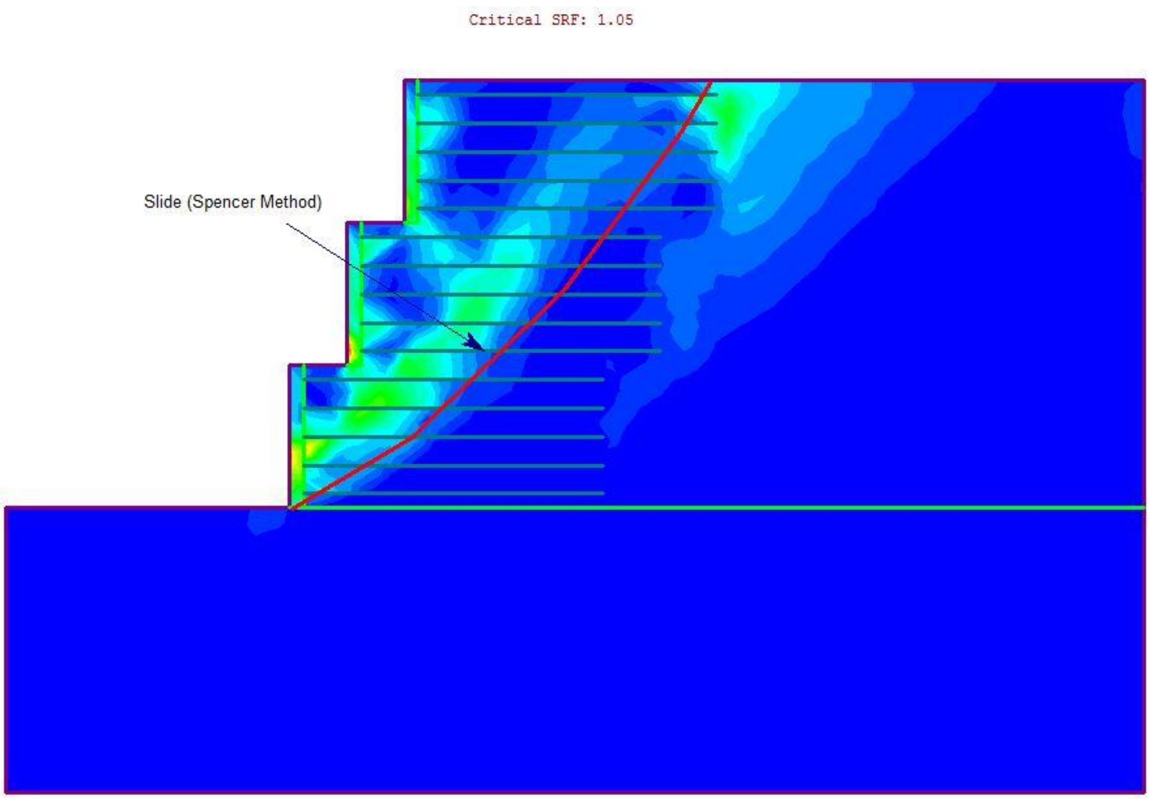


Figure 2 – Maximum Shear Strain Plot

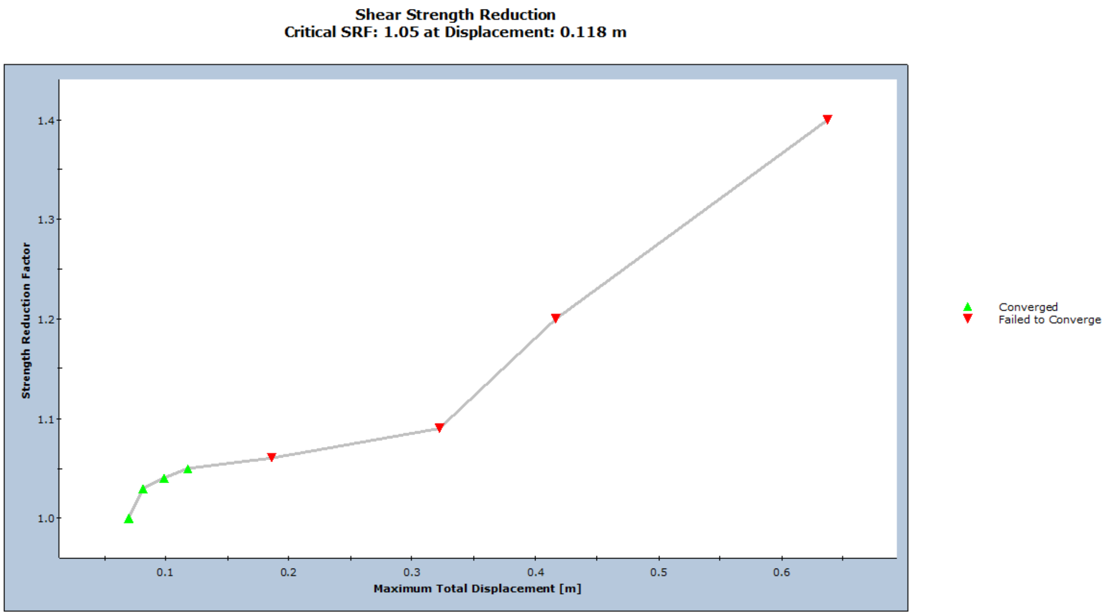


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from the Fill Quality case studied in the "Geosynthetic Reinforced Multitiered Walls", a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #88 for Slide2 – A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the support is assumed to equal to 80% of the fill strength. The purpose of this verification model is to quantify the effect of fill quality on the stability characteristic of a multi-tiered wall.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	25	18
Foundation soil	10	34	18
Blocks	2.5	34	18

Table 2 Support Properties

Length (m)	Tensile Strength (kN/m)
6.3	22.0

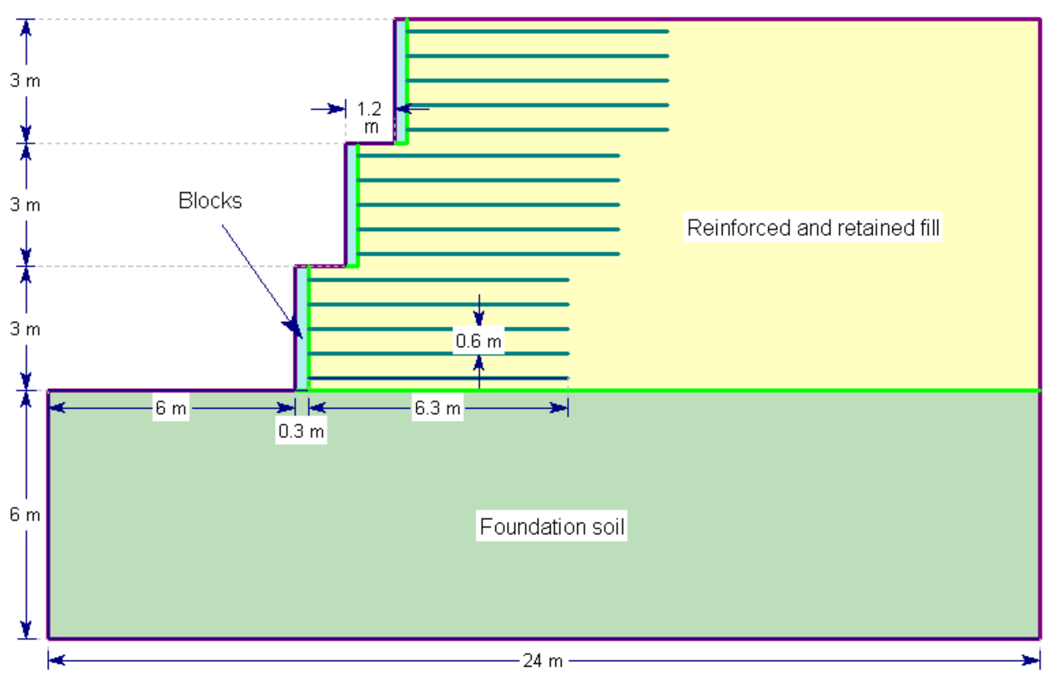


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	1.08
Bishop	0.98
Spencer	0.97
GLE	0.97

Note: Referee Factor of Safety = 0.99 [Leshchinsky and Han]

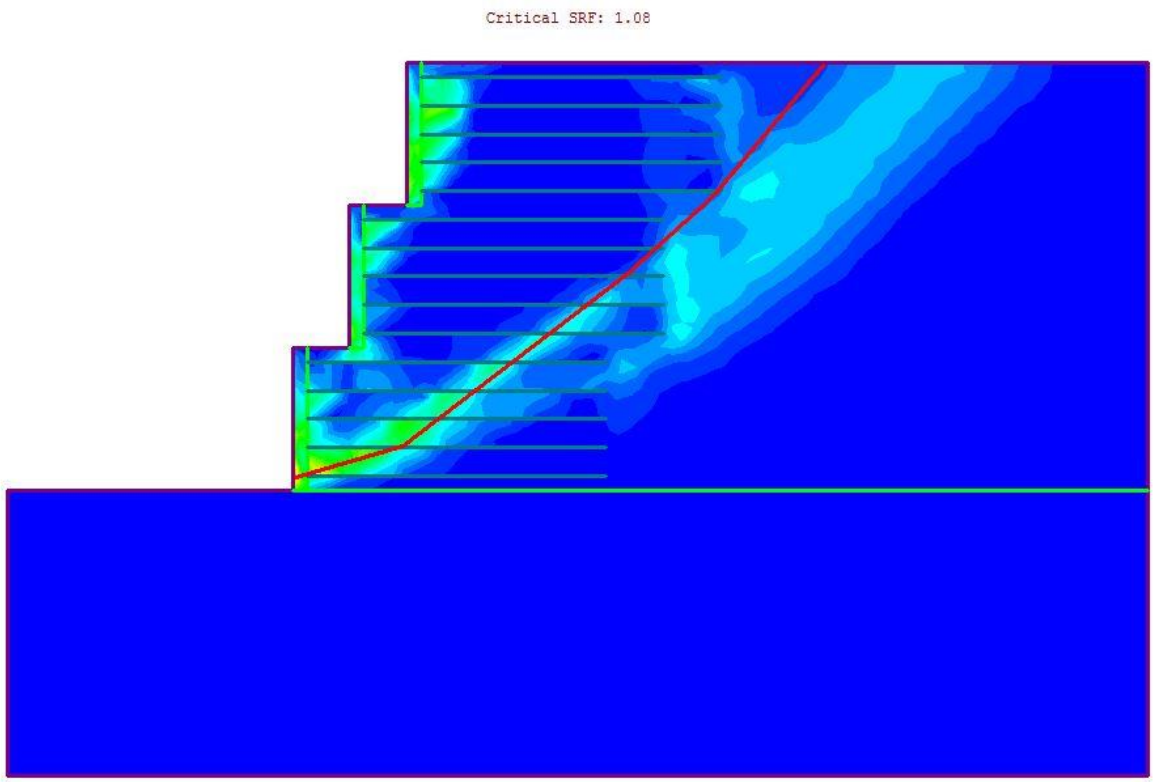


Figure 2 – Maximum Shear Strain Plot

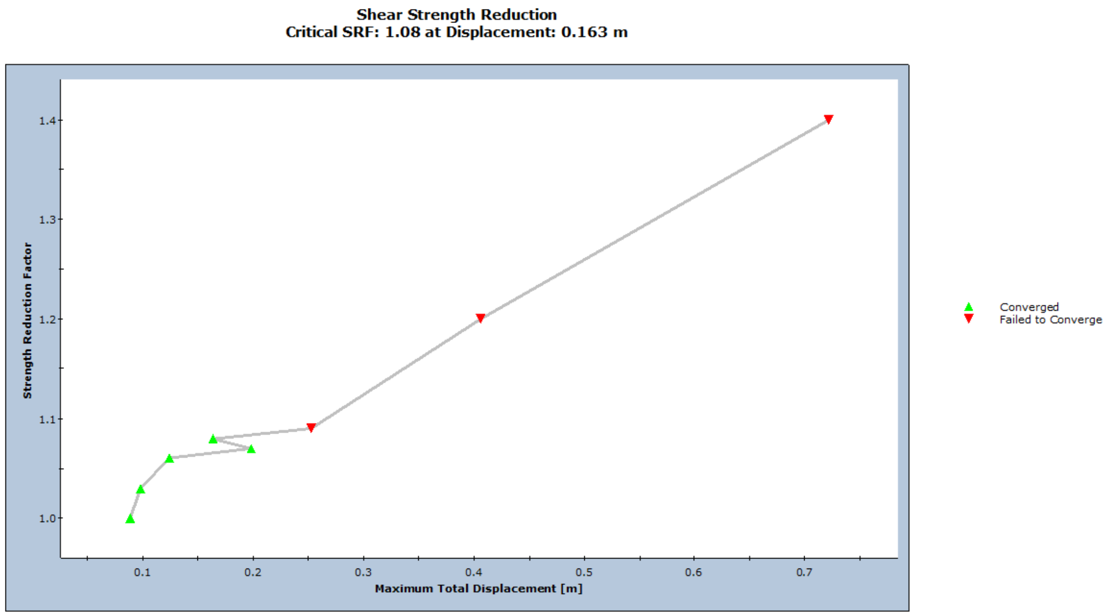


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from the Reinforcement Length case studied in the "Geosynthetic Reinforced Multitiered Walls", a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #89 for Slide2 – A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the support is assumed to equal to 80% of the fill strength. The purpose of this verification model is to quantify the effect of reinforcement length on the stability characteristic of a multi-tiered wall.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	34	18
Foundation soil	10	34	18
Blocks	2.5	34	18

Table 2 Support Properties

Length (m)	Tensile Strength (kN/m)
4.2	11.4

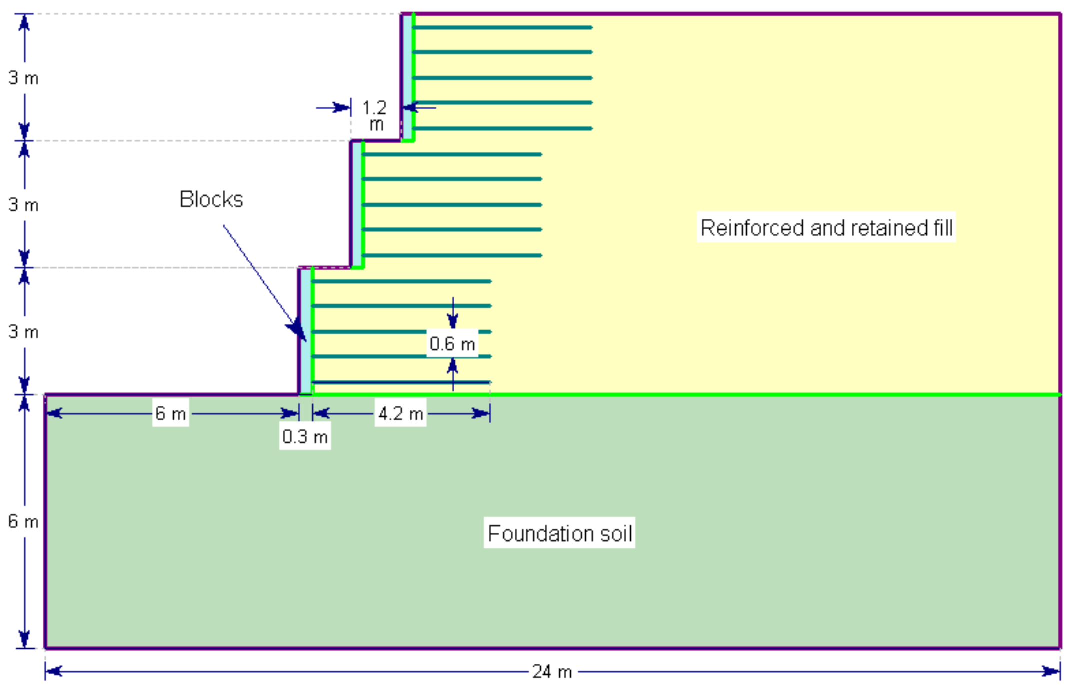


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	0.93
Bishop	0.93
Spencer	0.92
GLE	0.91

Note: Referee Factor of Safety = 0.98 [Leshchinsky and Han]

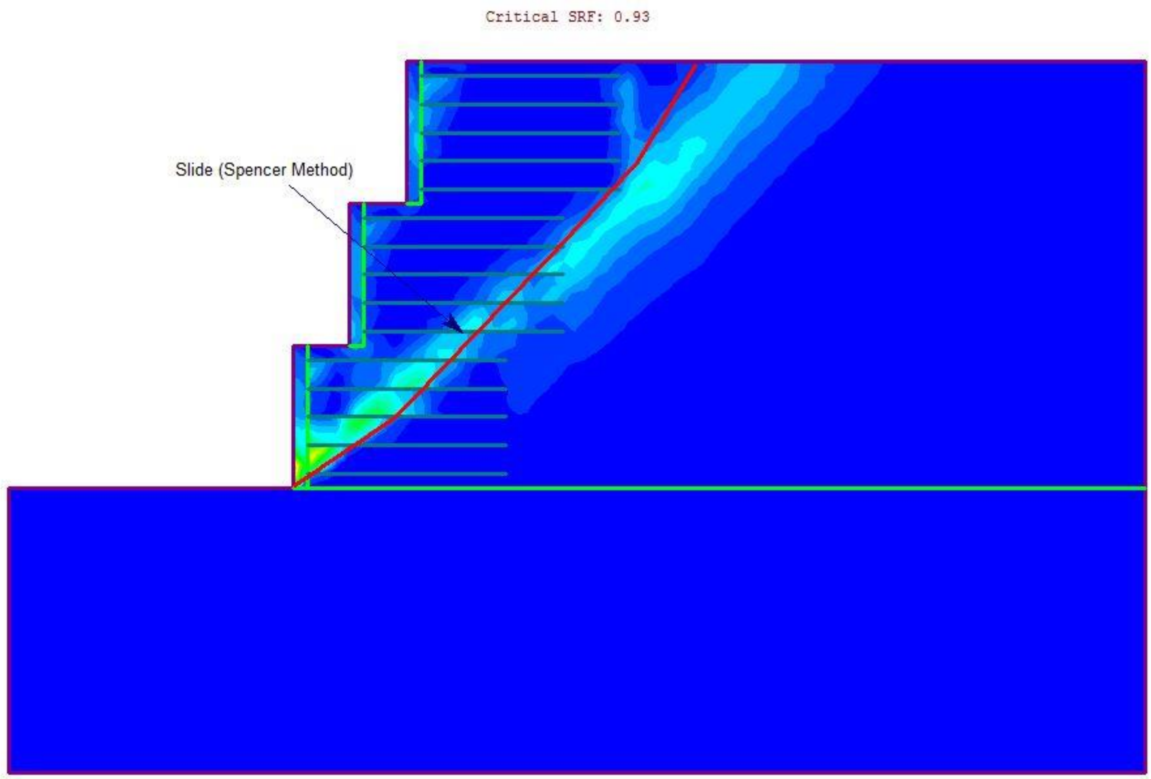


Figure 2 – Maximum Shear Strain Plot

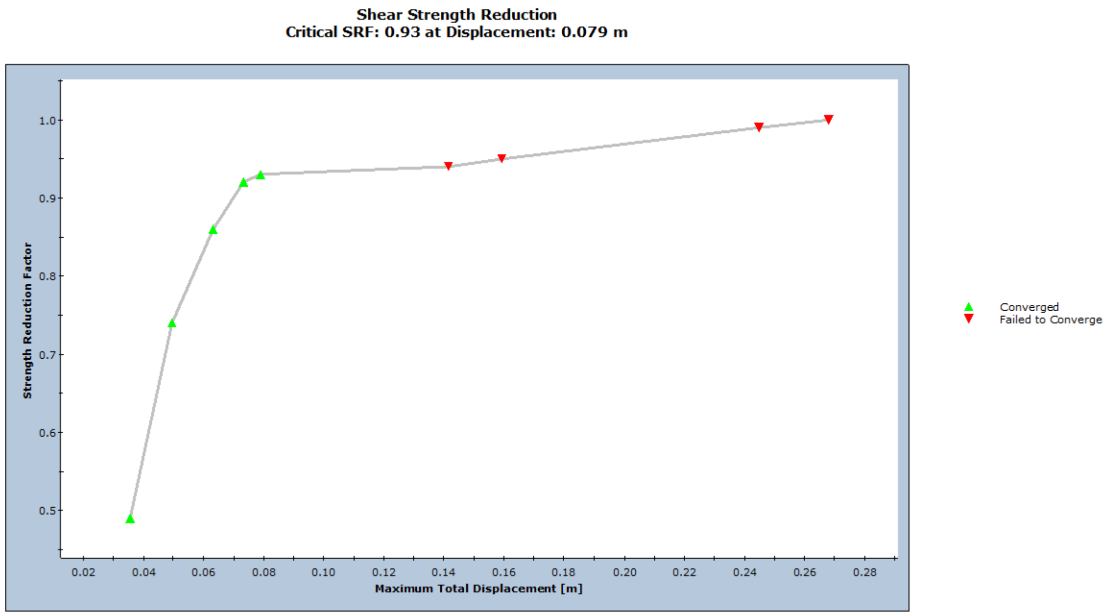


Figure 3 – SSR Convergence Graph

51 Multi-Tiered Wall (Effects of Reinforcement Type)

Introduction

This problem is taken from the Reinforcement Type case studied in the "Geosynthetic Reinforced Multitiered Walls", a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #90 for Slide2 – A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the supports is assumed to equal to 80% of the fill strength. The purpose of this verification model is to quantify the effect of reinforcement type on the stability characteristic of a multi-tiered wall.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	34	18
Foundation soil	10	34	18
Blocks	2.5	34	18

Table 2 Support Properties

Type	Length (m)	Tensile Strength (kN/m)
#1 (upper 8 layers)	6.3	7.5
#2 (lower 7 layers)	6.3	11.0

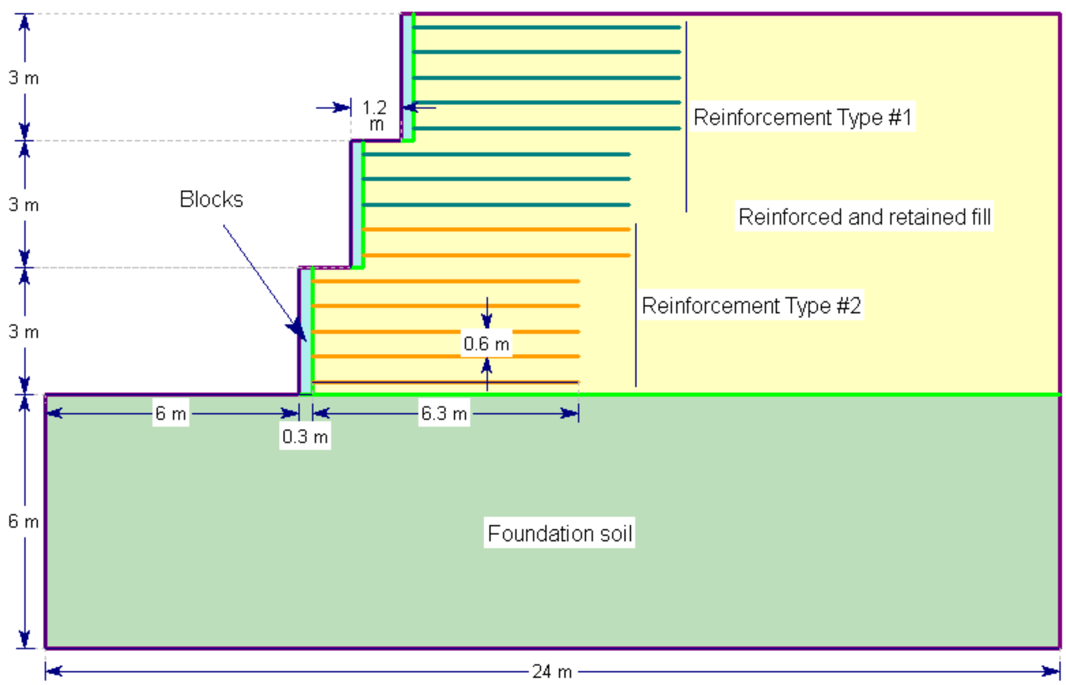


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	1
Bishop	0.92
Spencer	0.91
GLE	0.91

Note: Referee Factor of Safety = 1.01 [Leshchinsky and Han]

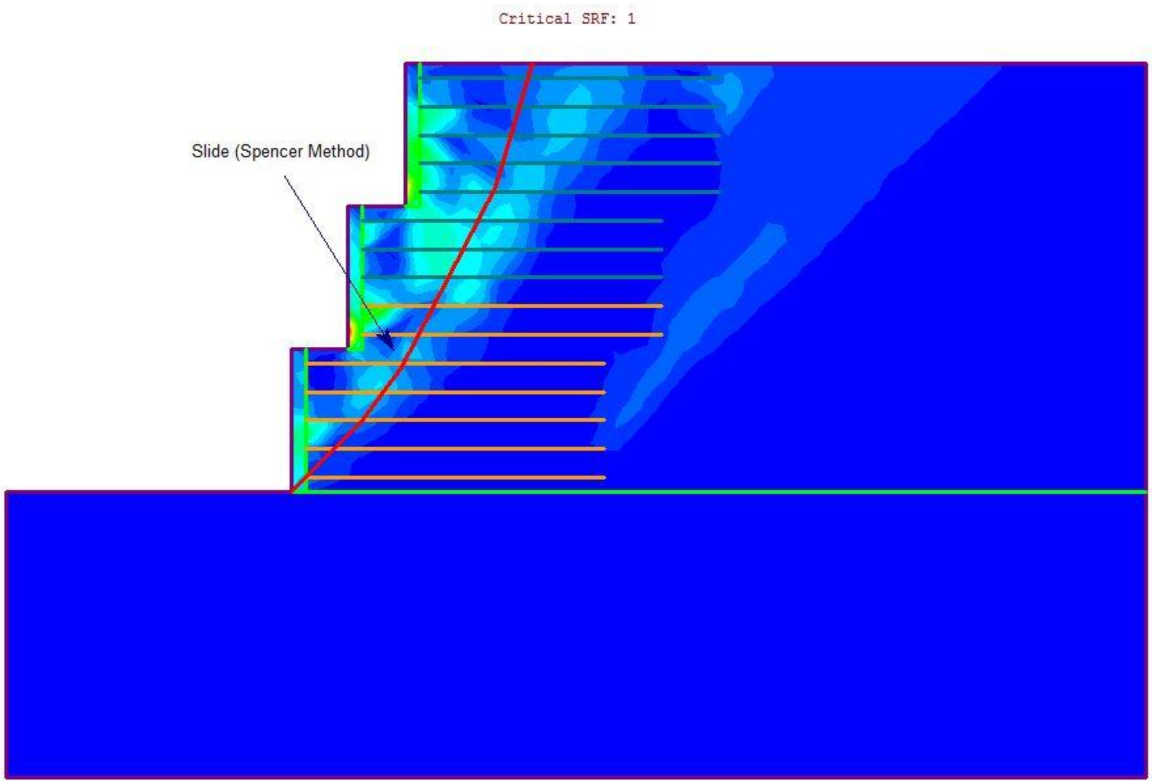


Figure 2 – Maximum Shear Strain Plot

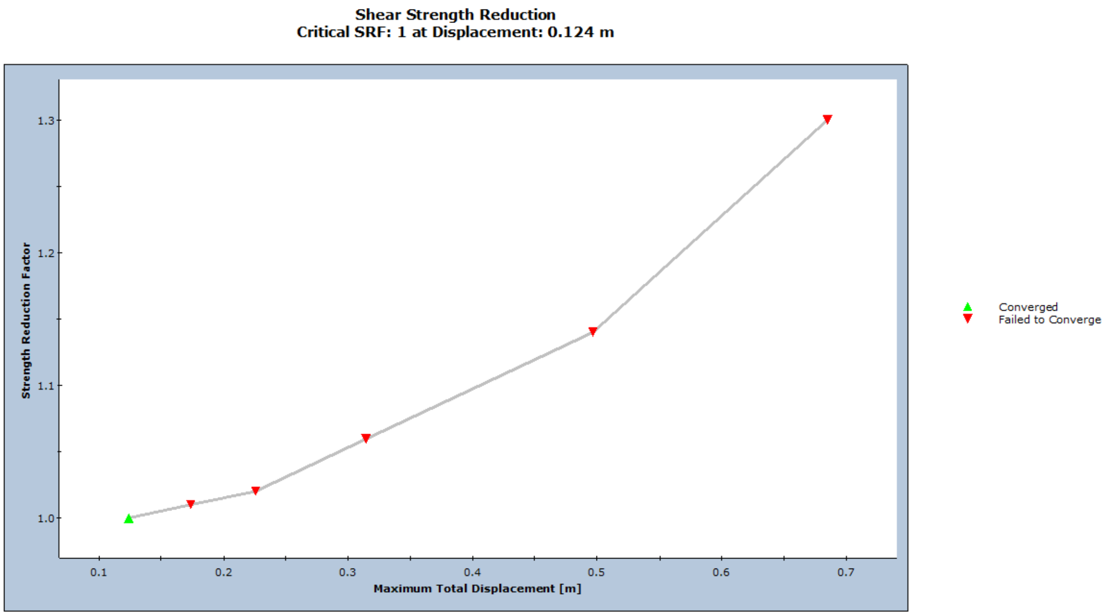


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from the Foundation Soil case studied in the “Geosynthetic Reinforced Multitiered Walls”, a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #91 for Slide2– A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the support is assumed to equal to 80% of the fill strength. The purpose of this verification model is to quantify the effect of foundation soil strength on the stability characteristic of a multi-tiered wall.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	34	18
Foundation soil	0	18	18
Blocks	2.5	34	18

Table 2 Support Properties

Length (m)	Tensile Strength (kN/m)
6.3	10.0

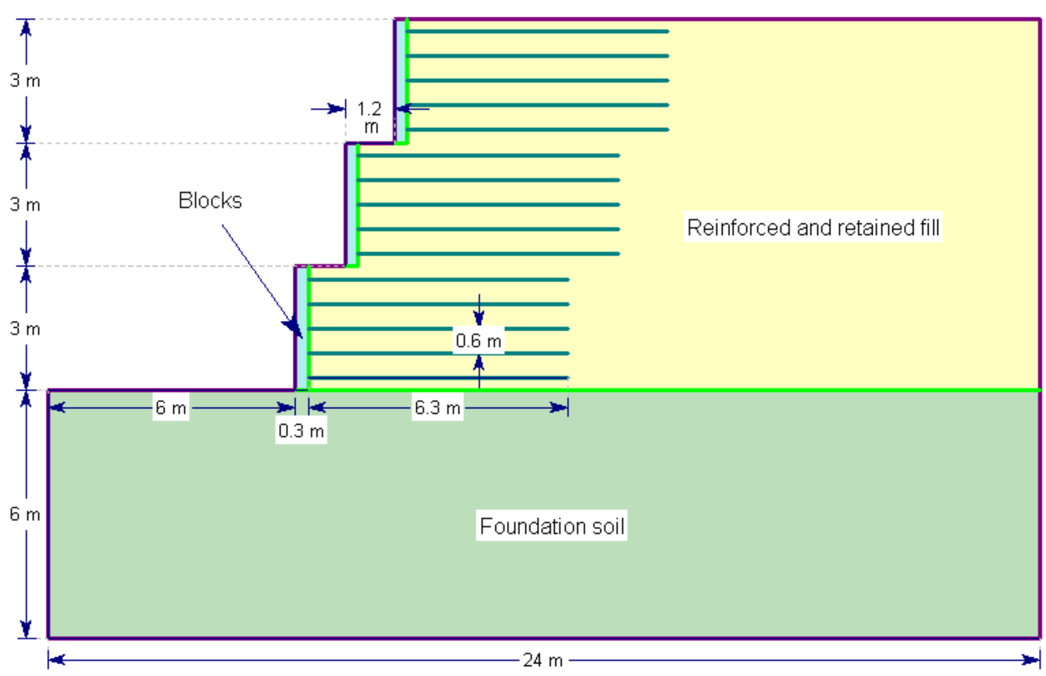


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	0.84
Spencer	0.96
GLE	0.98

Note: Referee Factor of Safety = 0.86 [Leshchinsky and Han]

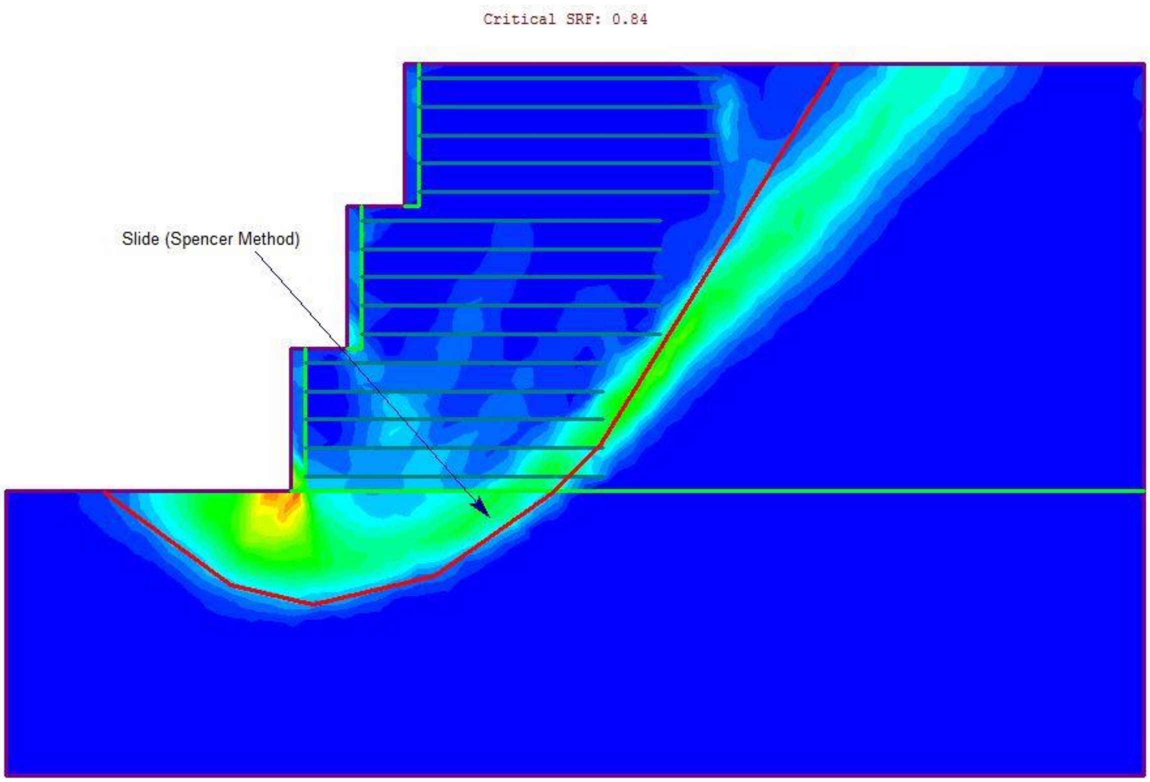


Figure 2 – Maximum Shear Strain Plot

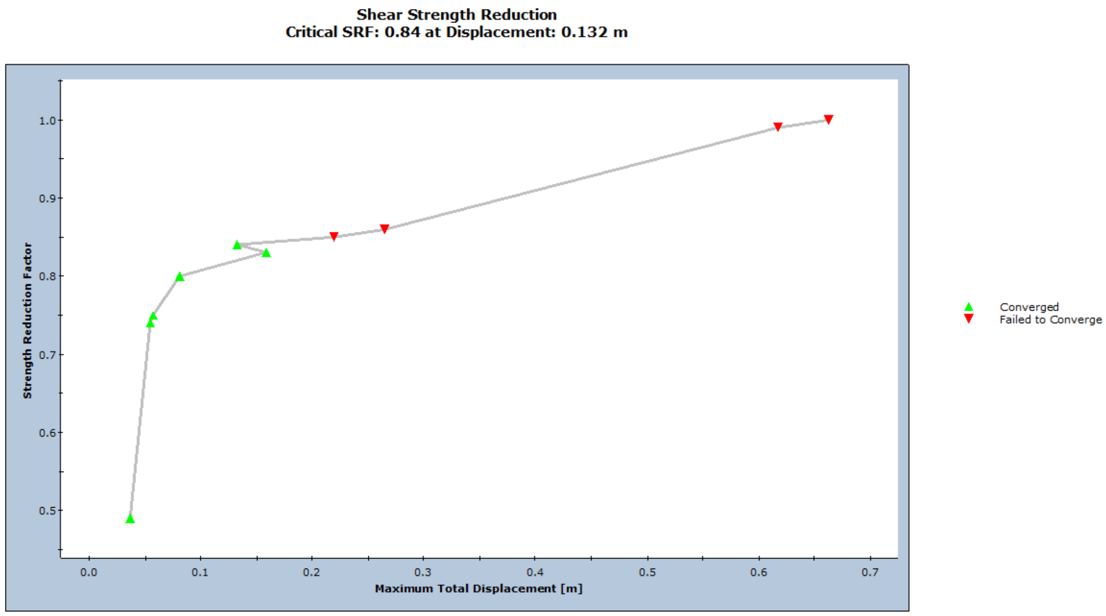


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from the Water case studied in the "Geosynthetic Reinforced Multitiered Walls", a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #92 for Slide2 – A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the support is assumed to equal to 80% of the fill strength. The purpose of this verification model is to quantify the effect of water seepage on the stability characteristic of a multi-tiered wall.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	34	18
Foundation soil	10	34	18
Blocks	2.5	34	18

Table 2 Support Properties

Length (m)	Tensile Strength (kN/m)
6.3	9.25

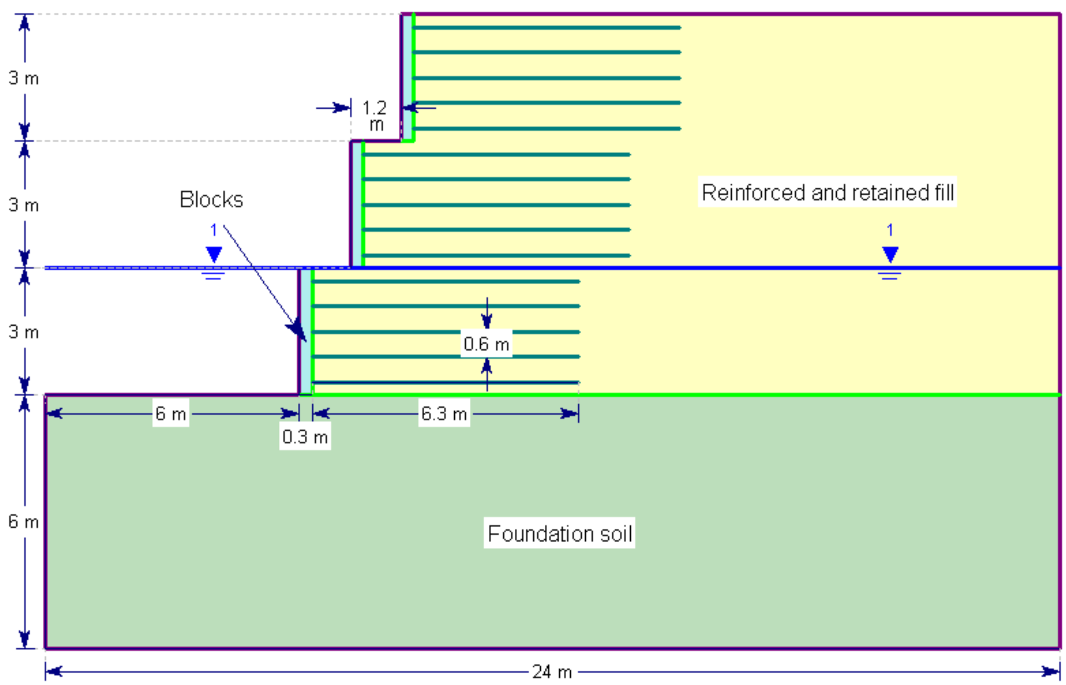


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	1.03
Bishop	0.92
Spencer	1.00
GLE	1.13

Note: Referee Factor of Safety = 1.01 [Leshchinsky and Han]

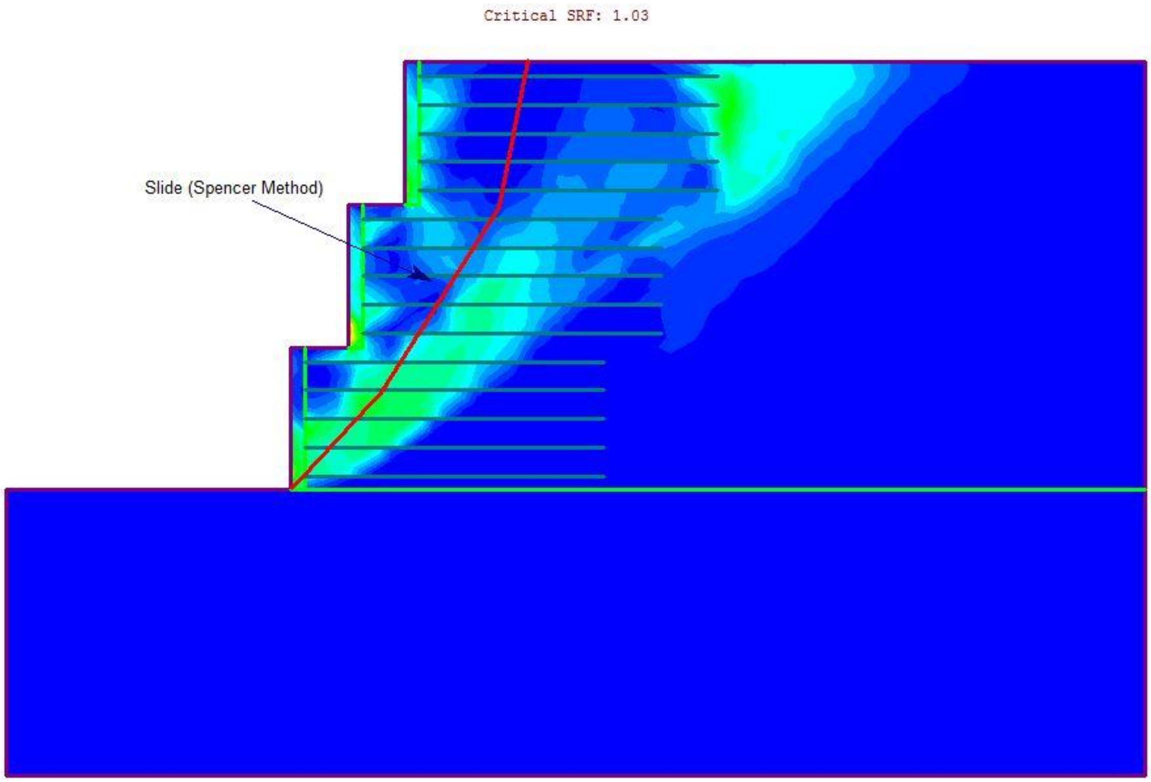


Figure 2 – Maximum Shear Strain Plot

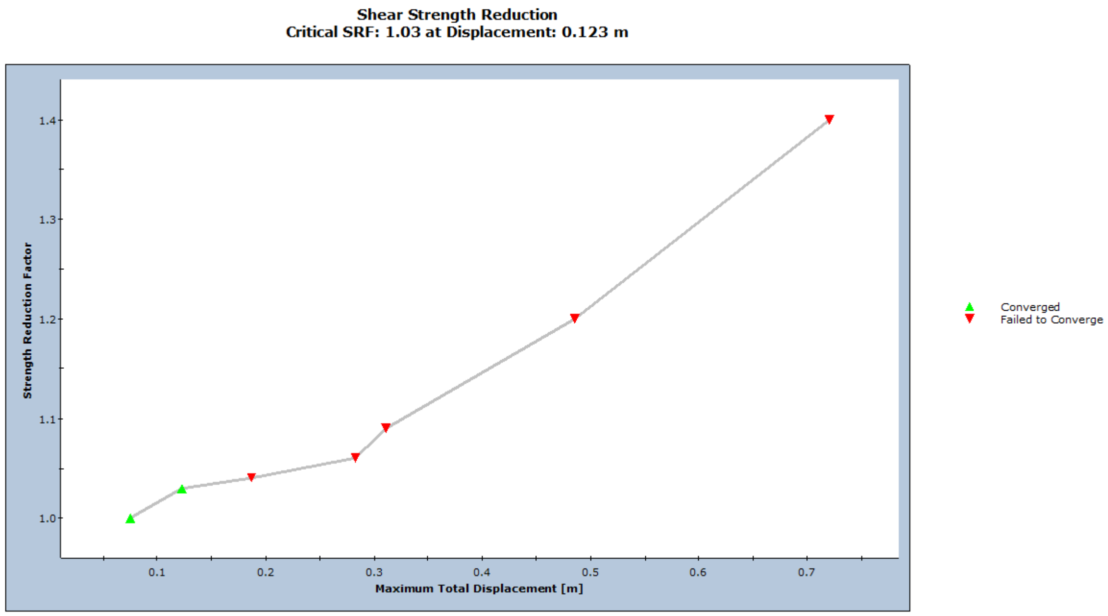


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from the Surcharge case studied in the "Geosynthetic Reinforced Multitiered Walls", a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #93 for Slide2 – A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the support is assumed to equal to 80% of the fill strength. The purpose of this verification model is to quantify the effect of surcharge on the stability characteristic of a multi-tiered wall.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	34	18
Foundation soil	10	34	18
Blocks	2.5	34	18

Table 2 Support Properties

Length (m)	Tensile Strength (kN/m)
6.3	11.6

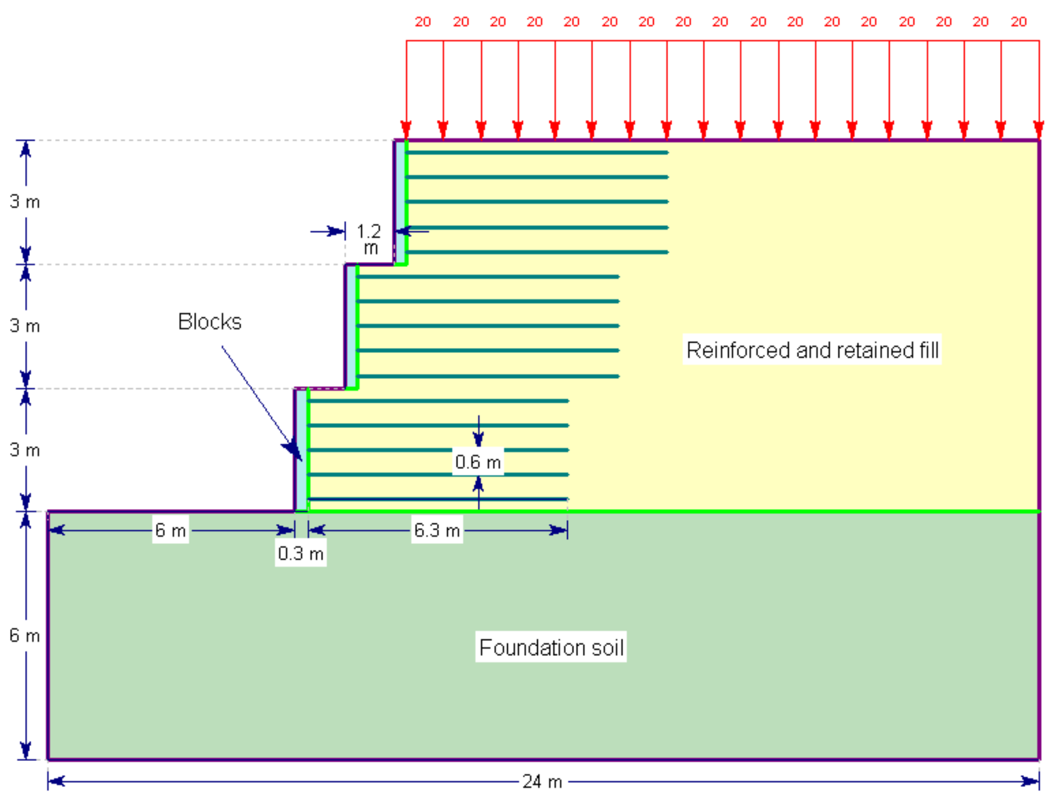


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	0.92
Bishop	0.87
Spencer	0.91
GLE	0.91

Note: Referee Factor of Safety = 1.02 [Leshchinsky and Han]

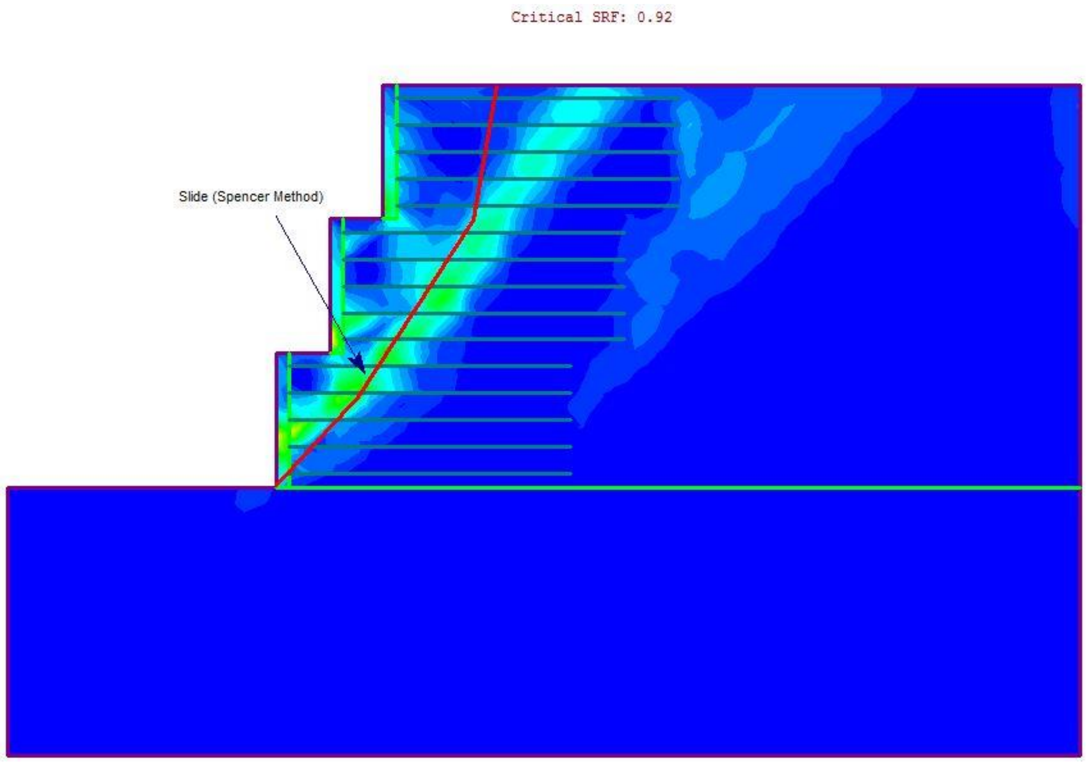


Figure 2 – Maximum Shear Strain Plot

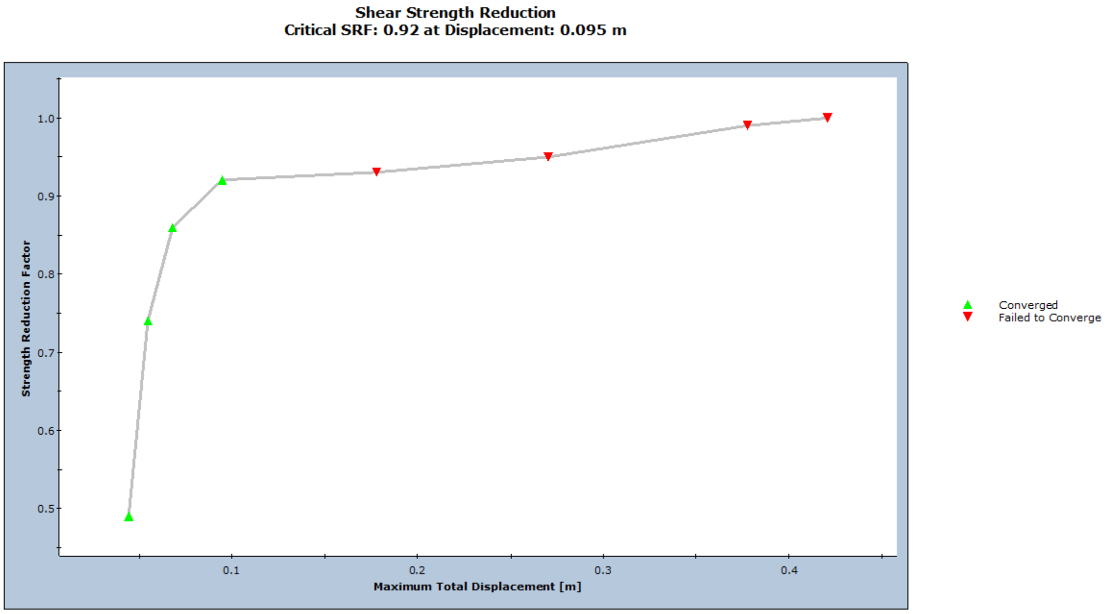


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from the Number of Tiers case studied in the "Geosynthetic Reinforced Multitiered Walls", a paper by Leshchinsky, D. and Han, J. (2004).

Description

Verification problem #94 for Slide2 – A three-tiered wall – is shown in Figure 1. The material properties are presented in Table 1 and the support properties are shown in Table 2. The shear strength of the support is assumed to equal to 80% of the fill strength. The purpose of this verification model is to quantify the effect of number of tiers on the stability characteristic of a multi-tiered wall.

Geometry and Properties

Table 1 Material Properties

Zone	c (kPa)	ϕ (^{0})	γ (kN/m^3)
Reinforced and retained fill	0	34	18
Foundation soil	10	34	18
Blocks	2.5	34	18

Table 2 Support Properties

Length (m)	Tensile Strength (kN/m)
6.3	11.6

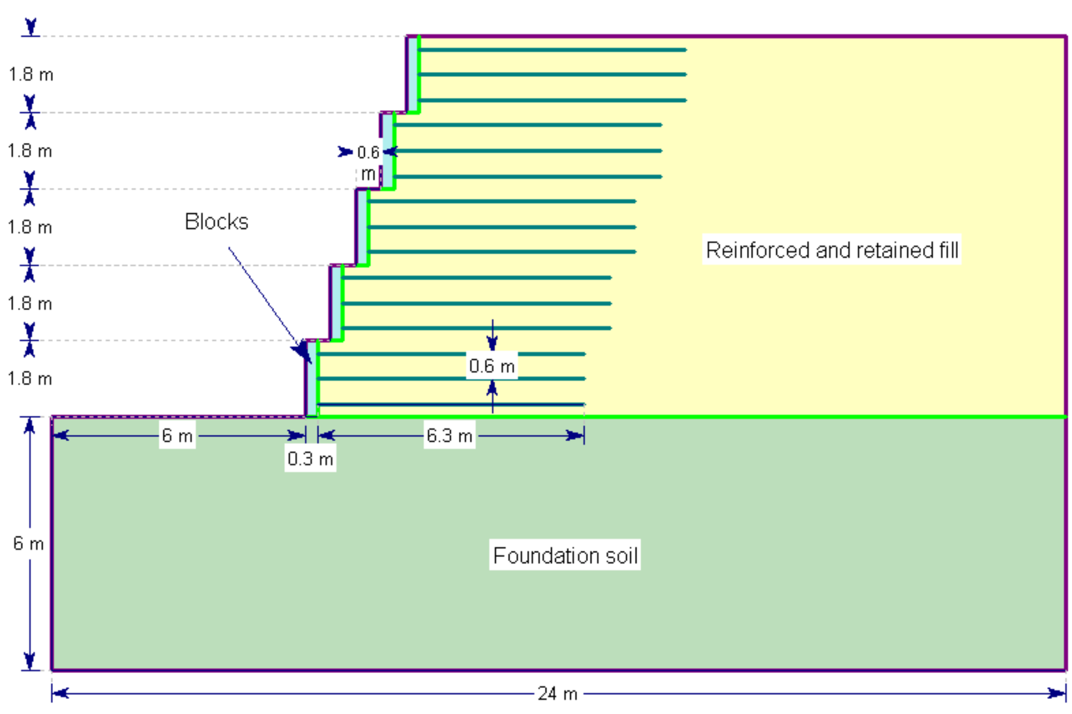


Figure 1 - Geometry

Results

Method	Factor of Safety
SSR	1.04
Bishop	0.92
Spencer	0.94
GLE	0.94

Note: Referee Factor of Safety = 1.00 [Leshchinsky and Han]

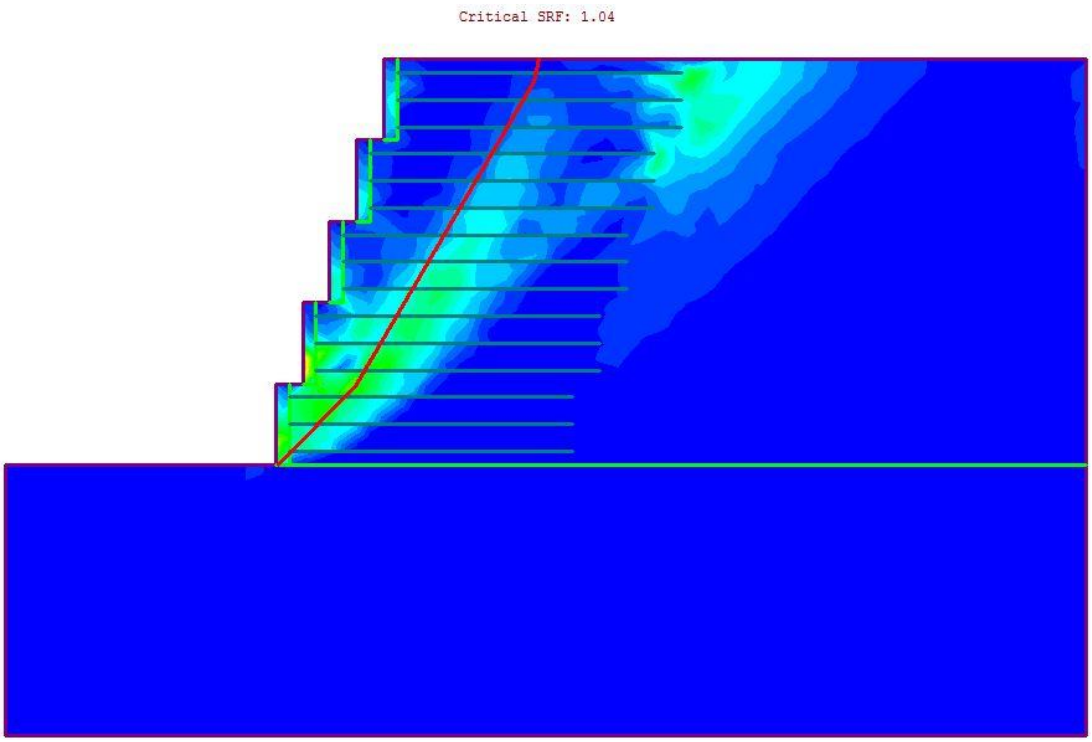


Figure 2 – Maximum Shear Strain Plot

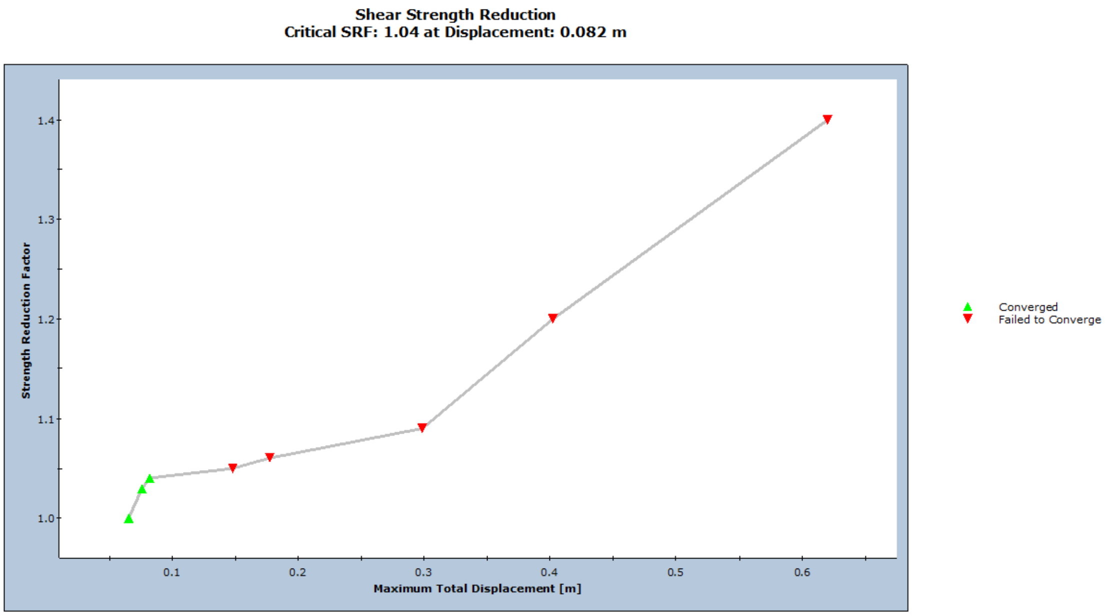


Figure 3 – SSR Convergence Graph

Introduction

This problem is taken from the slope stability problem in the "Comparison of geotechnic softwares", a paper by Pruska, J. (2003).

Description

A homogeneous slope with a slope height of 7 m is shown in Figure 1. Five cases with different soil properties were studied. Mohr-Coulomb (M-C) and Drucker-Prager (D-P) failure criteria were used in the analysis. The material properties of all five cases are given in table 1. The results of all cases are compared to those of Z-Soil, Plaxis and Geo FEM.

Geometry and Properties

Table 1 Material Properties

	Young modulus, E (kPa)	Poisson Ratio, ν	Weight, γ (kN/m^3)	Cohesion, c (kPa)	Friction angle, ϕ (^{0})	Dilatancy angle, ψ (^{0})
Case 1	5,000	0.3	24	20	10	0
Case 2		0.35	18	5	10	
Case 3		0.3	24	20	20	
Case 4		0.35	18	5	20	
Case 5		0.3	24	20	30	

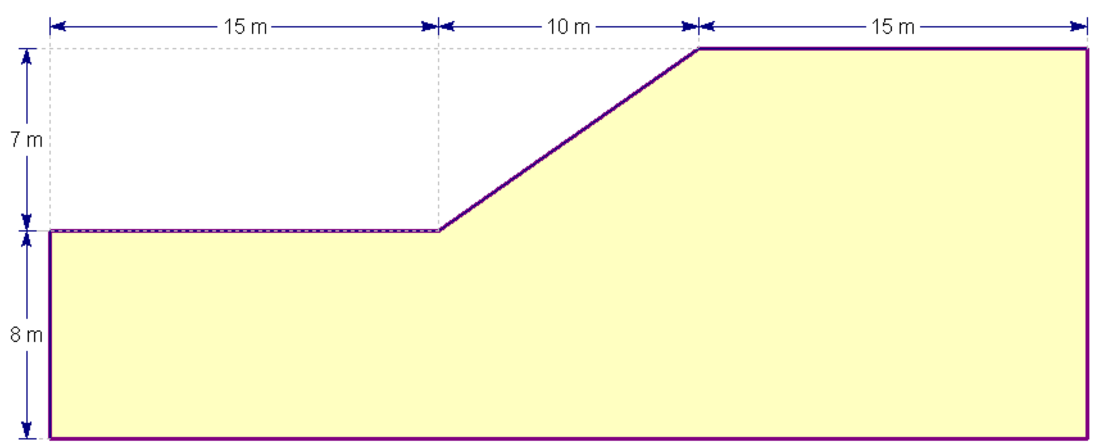
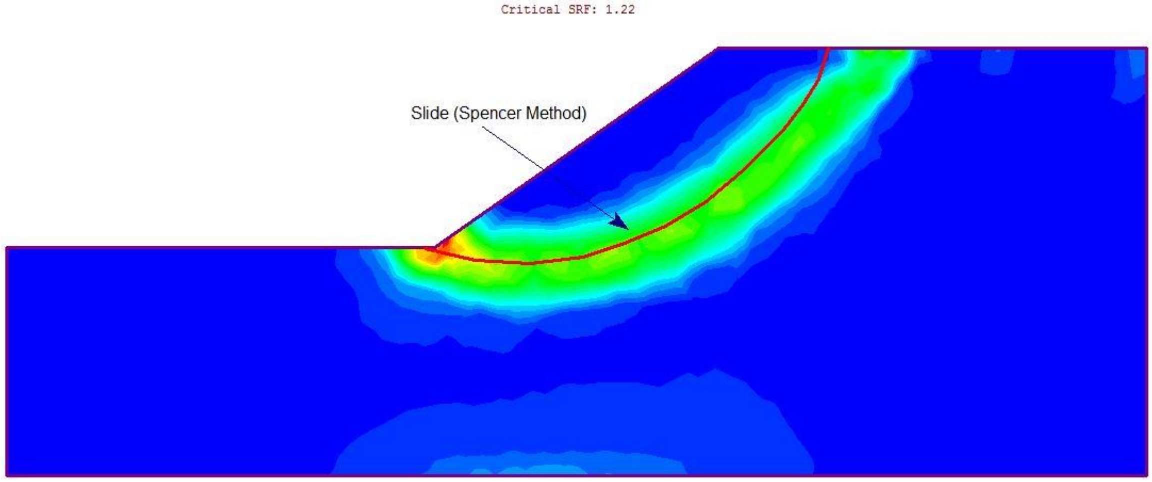


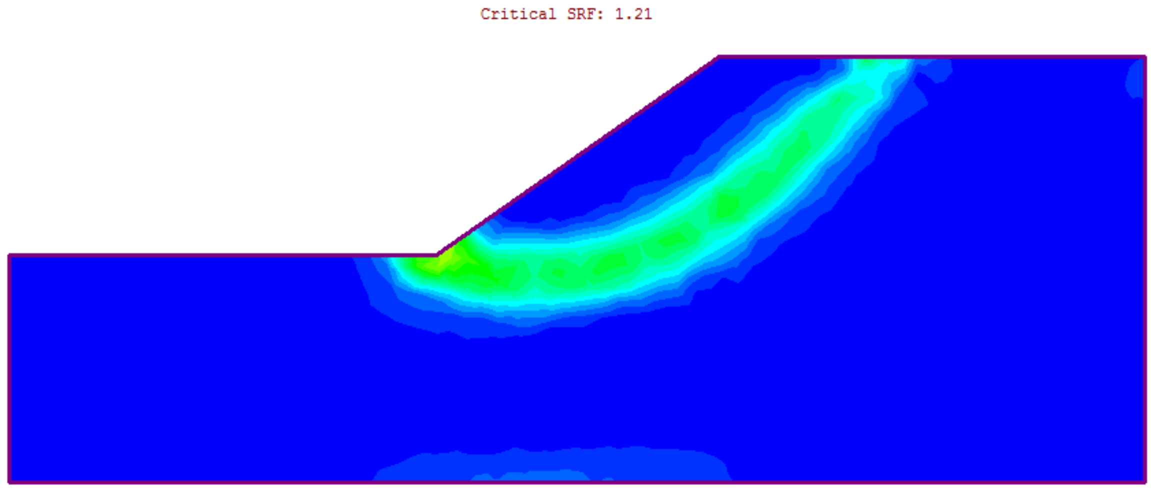
Figure 1 - Geometry

Results: Case 1

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
1.22	1.22	1.21	1.21	1.19	1.22	1.31	1.2

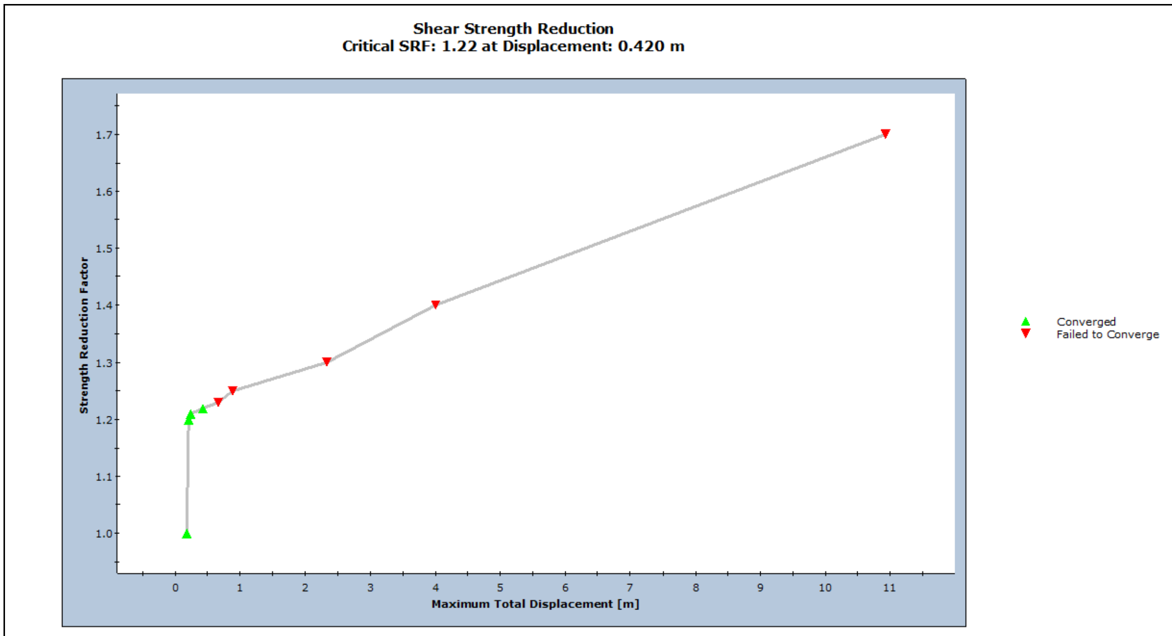


Case 1 – M-C

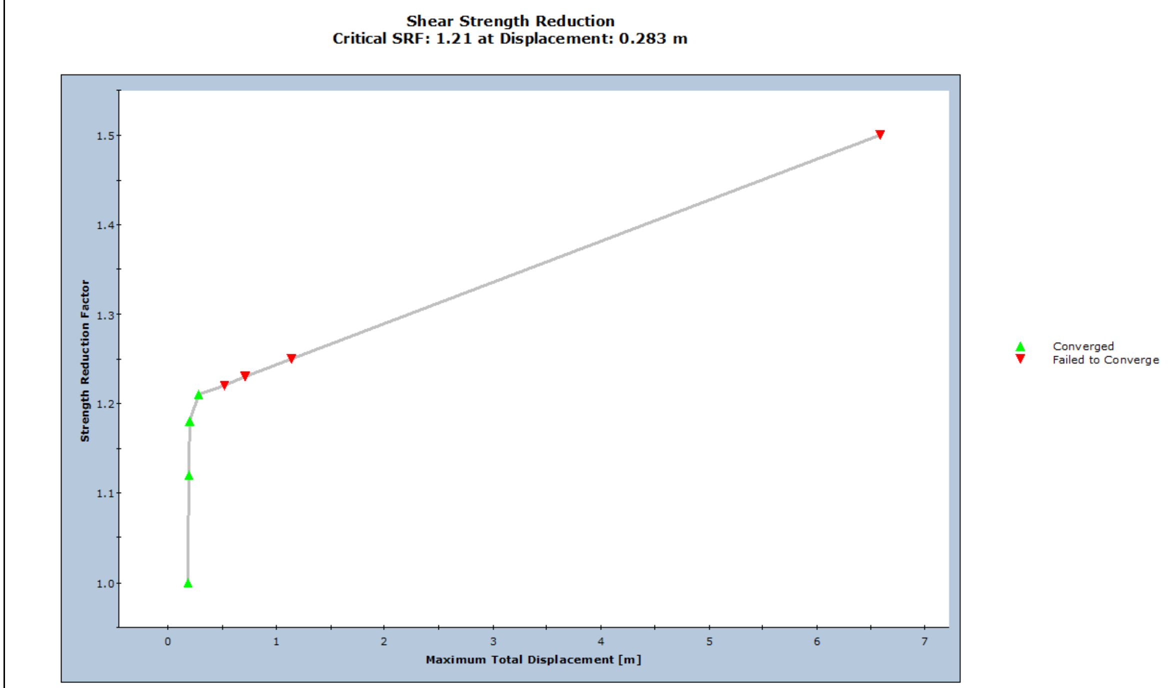


Case 1 – D-P

Figure 2 – Maximum Shear Strain Plot of Case 1



Case 1 – M-C

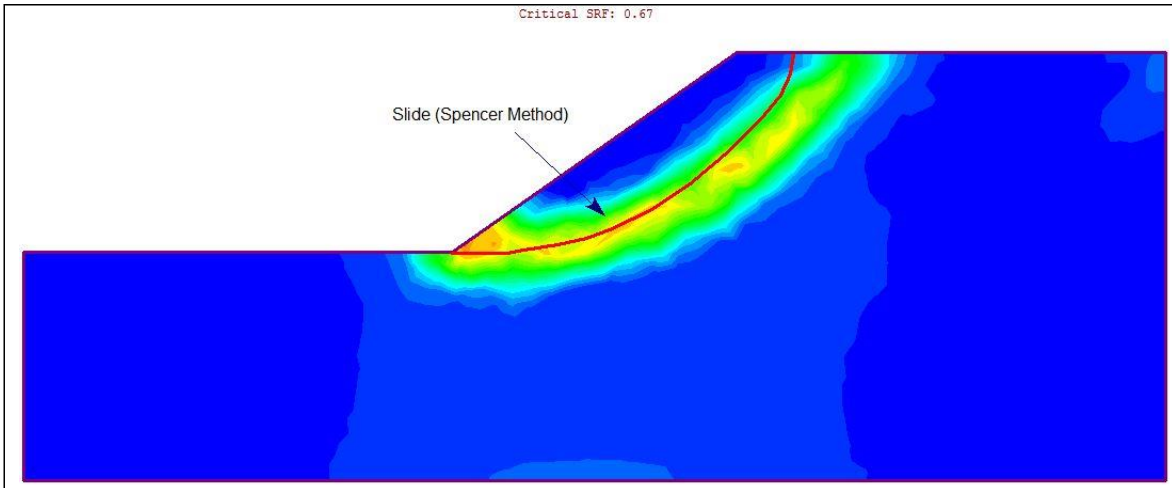


Case 1 – D-P

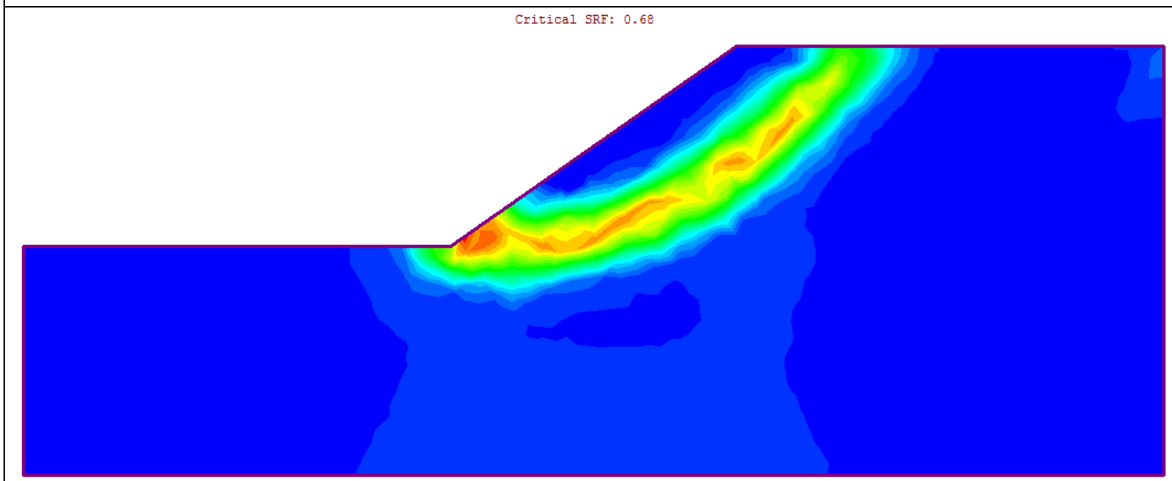
Figure 3 – SSR Convergence Graph of Case 1

Results: Case 2

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.66	0.67	0.68	0.71	0.69	0.68	0.73	0.66

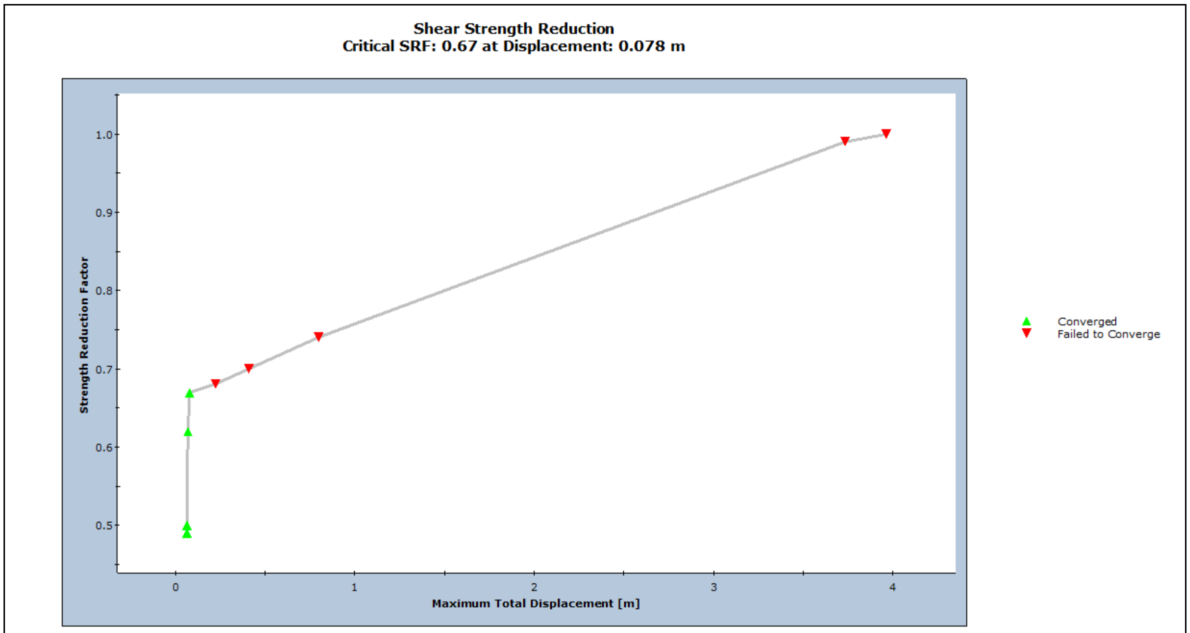


Case 2 – M-C

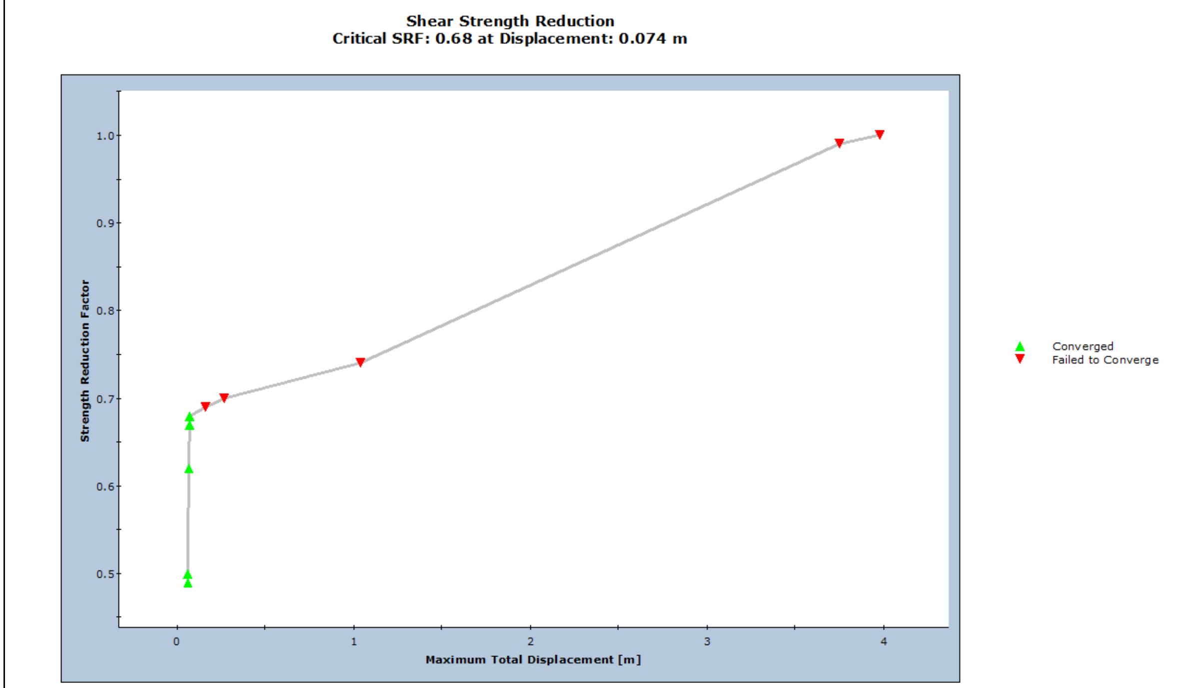


Case 2 – D-P

Figure 4 – Maximum Shear Strain Plot of Case 2



Case 2 – M-C

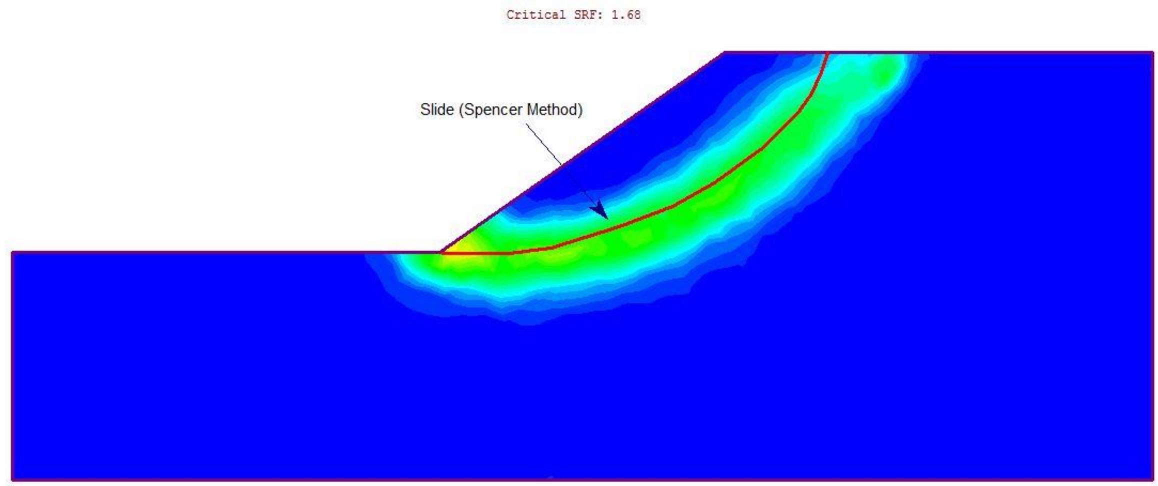


Case 2 – D-P

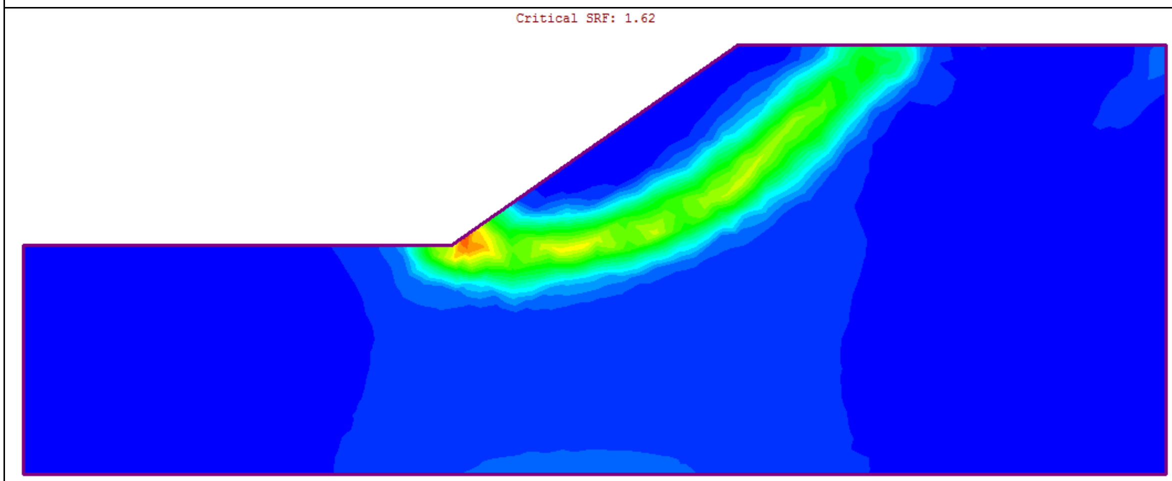
Figure 5 – SSR Convergence Graph of Case 2

Results: Case 3

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
1.64	1.68	1.62	1.64	1.59	1.65	1.71	1.61

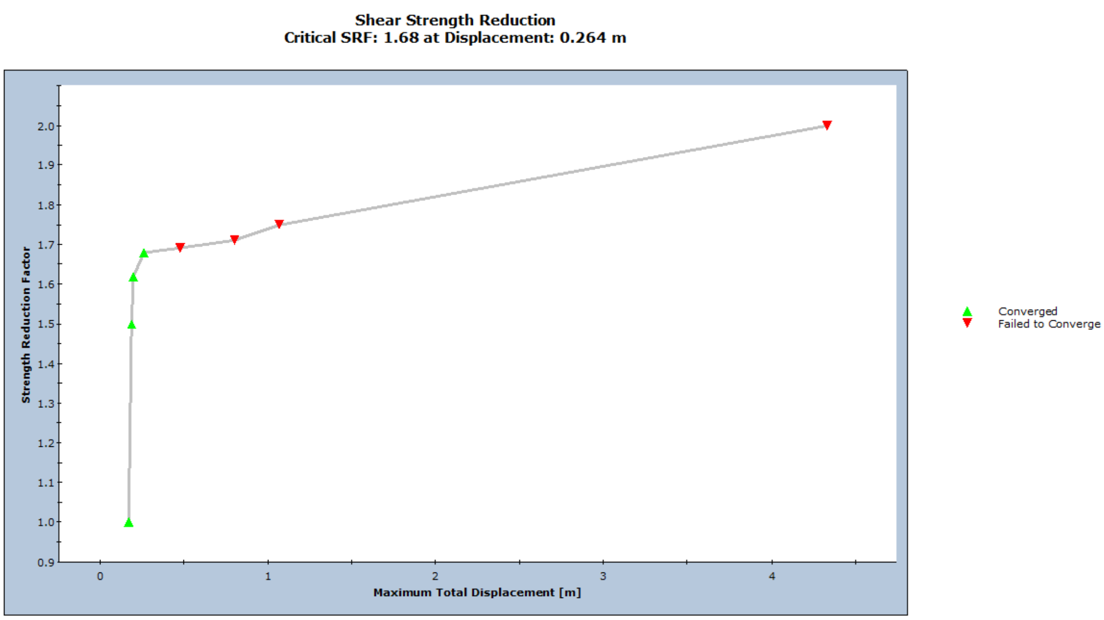


Case 3 – M-C

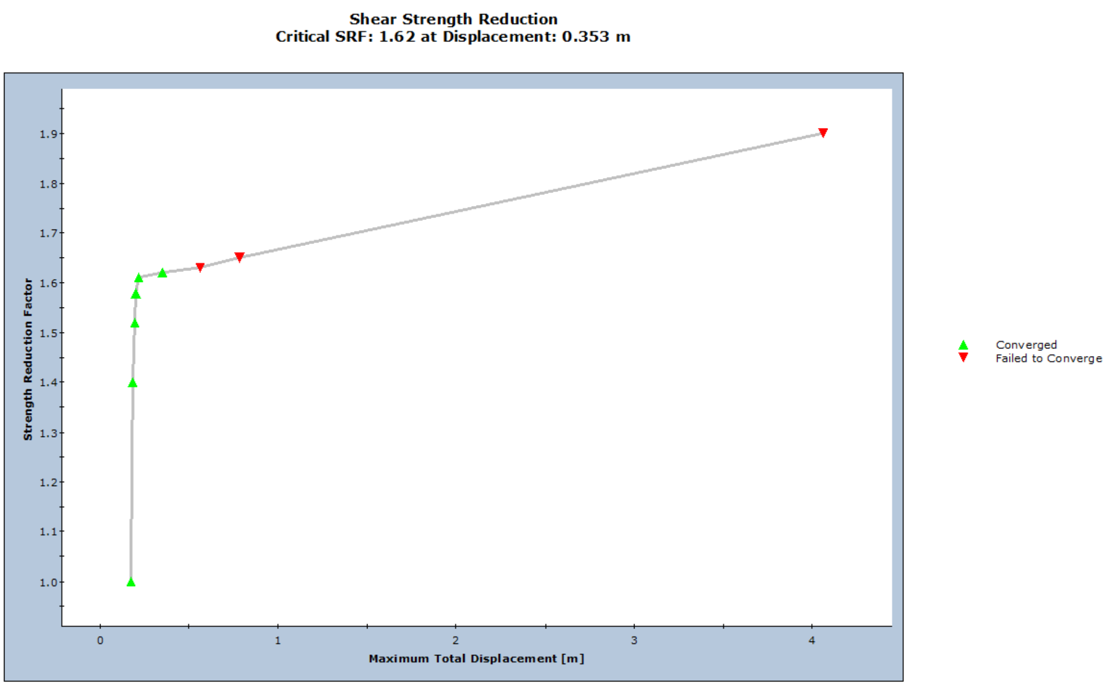


Case 3 – D-P

Figure 6 – Maximum Shear Strain Plot of Case 3



Case 3 – M-C

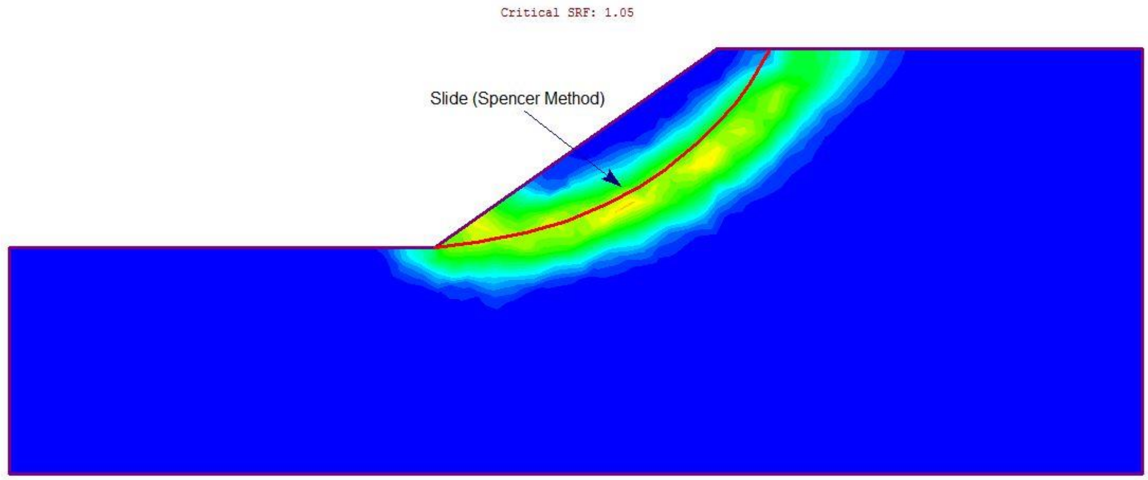


Case 3 – D-P

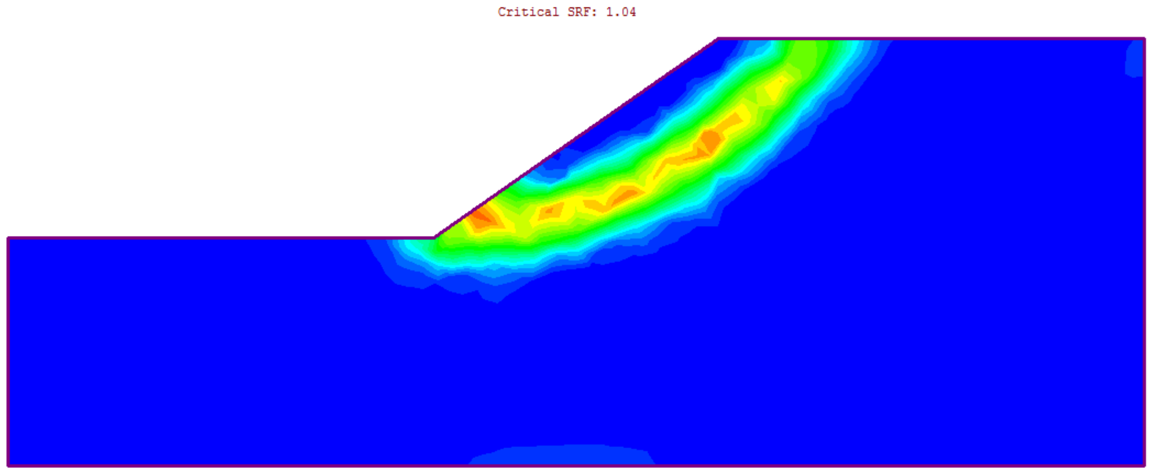
Figure 7 – SSR Convergence Graph of Case 3

Results: Case 4

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
1.02	1.05	1.04	0.95	1.2	0.99	1.17	1.08

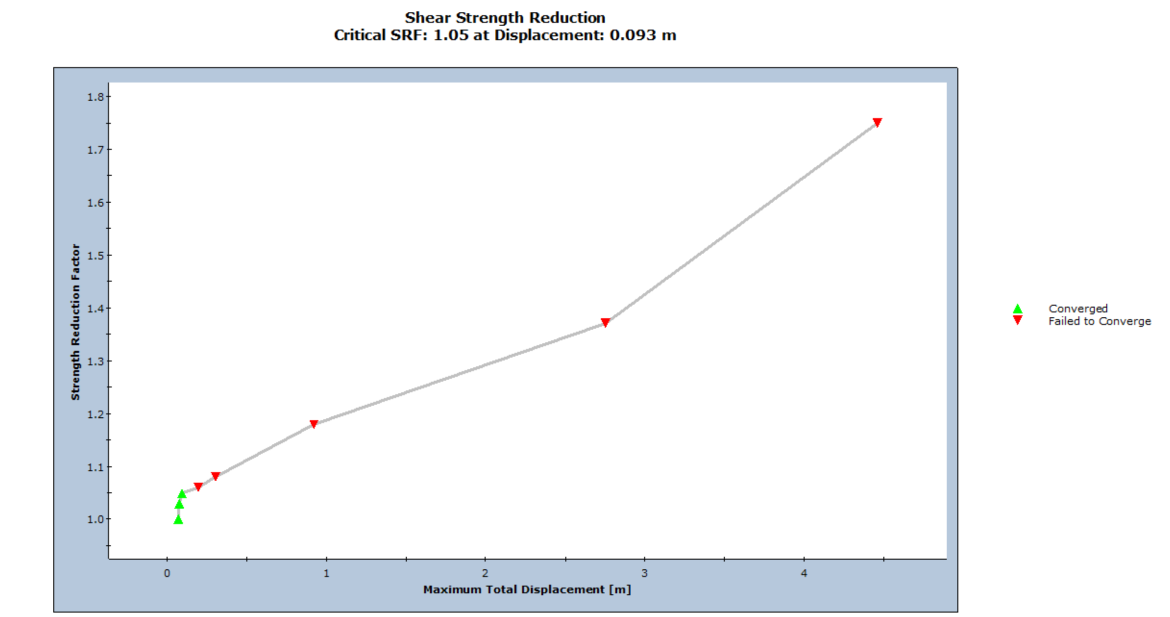


Case 4 – M-C

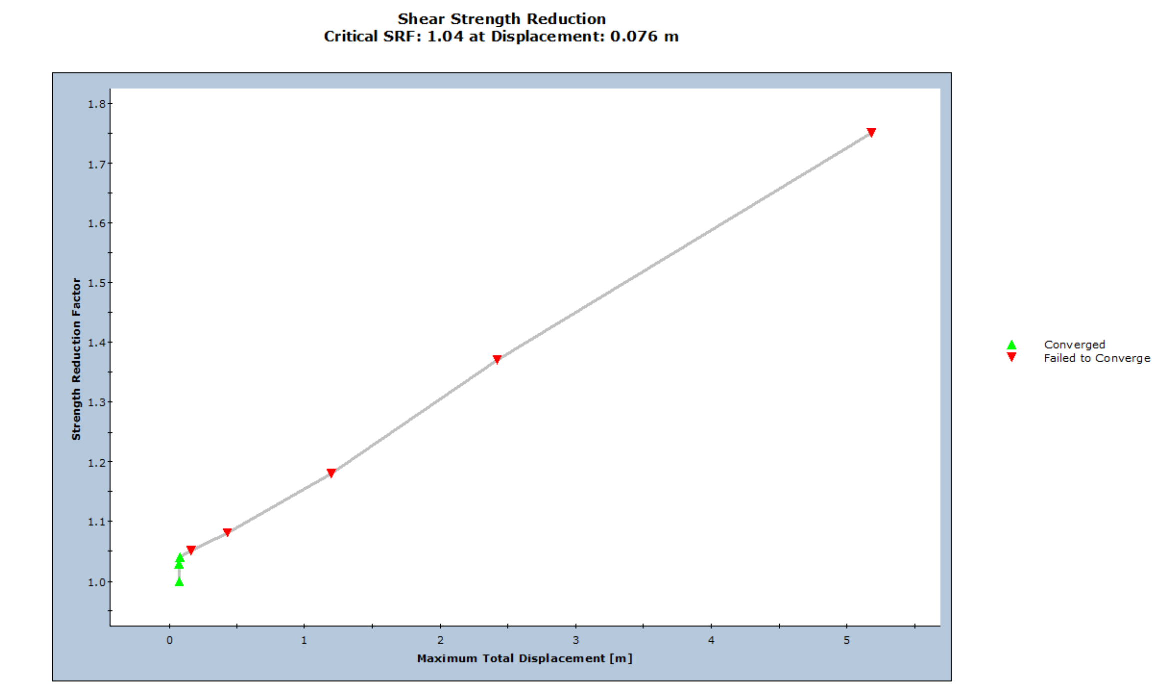


Case 4 – D-P

Figure 8 – Maximum Shear Strain Plot of Case 4



Case 4 – M-C

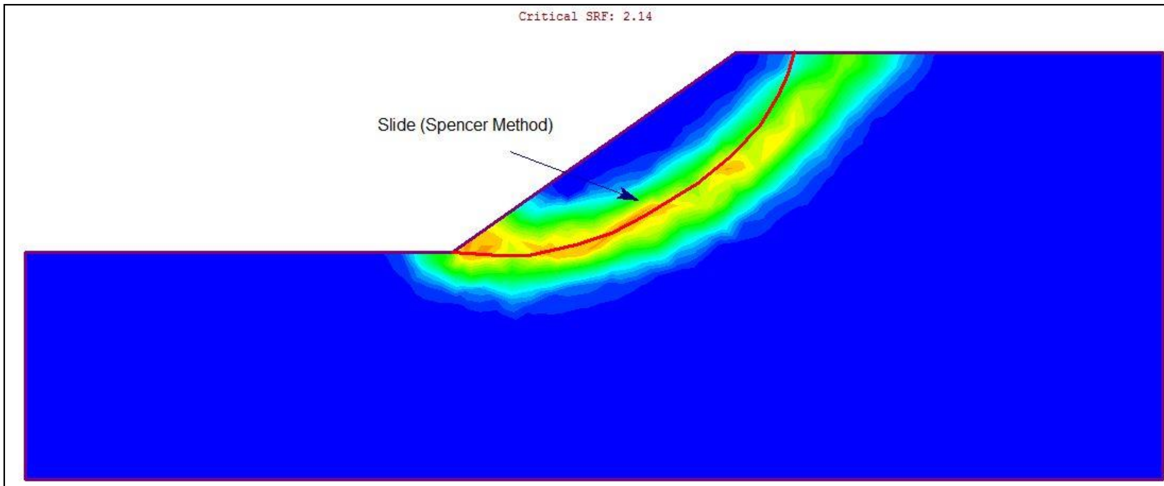


Case 4 – D-P

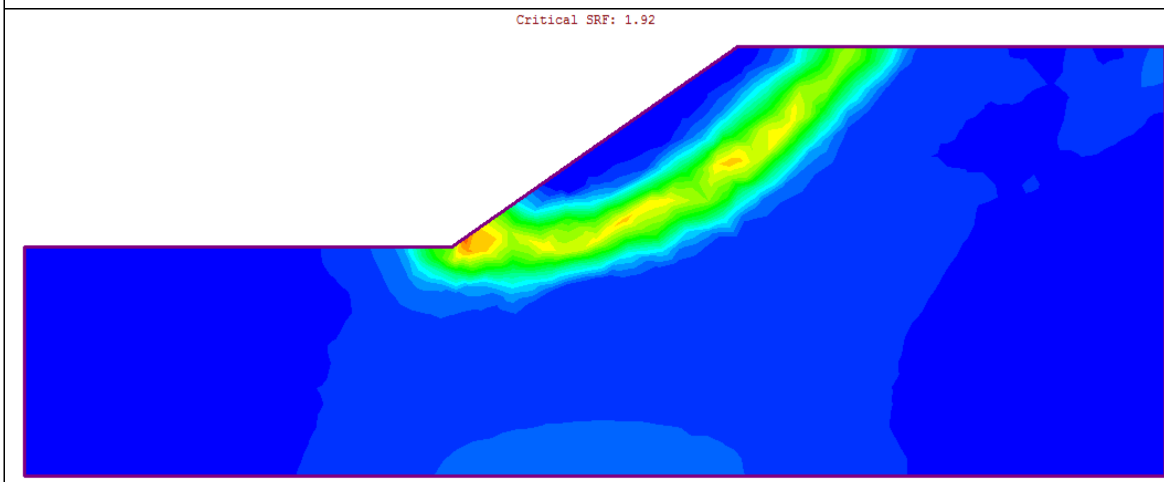
Figure 9 – SSR Convergence Graph of Case 4

Results: Case 5

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
2.08	2.14	1.92	1.98	1.8	2.09	2.19	2

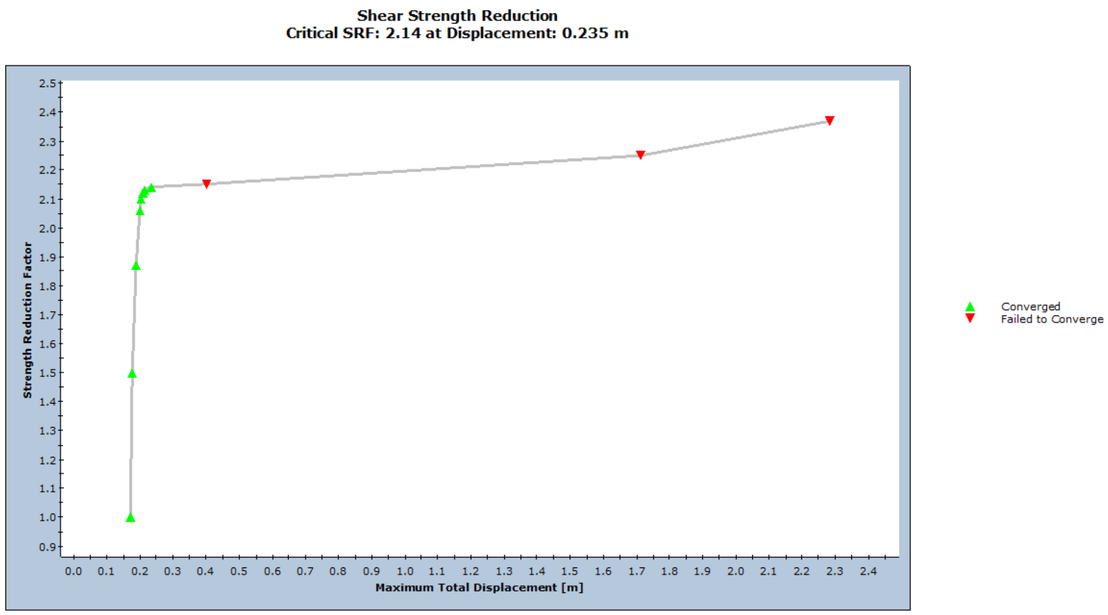


Case 5 – M-C

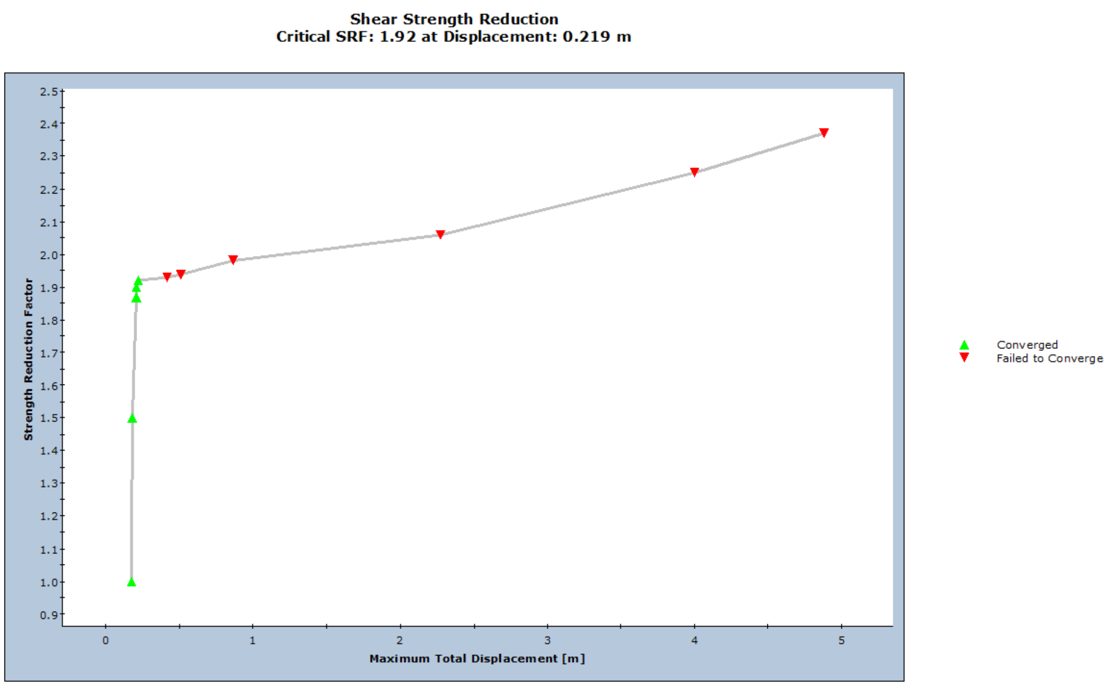


Case 5 – D-P

Figure 10 – Maximum Shear Strain Plot of Case 5



Case 5 – M-C



Case 5 – D-P

Figure 11 – SSR Convergence Graph of Case 5

Introduction

This problem is taken from the slope stability problem in the “Comparison of geotechnic softwares”, a paper by Pruska, J. (2003).

Description

A homogeneous slope with a slope height of 10.5 m is shown in Figure 1. Six cases with different soil properties were studied. Mohr-Coulomb (M-C) and Drucker-Prager (D-P) failure criteria were used in the analysis. The material properties of all six cases are given in table 1. The results of all cases are compared to those of Z-Soil, Plaxis and Geo FEM.

Geometry and Properties

Table 1 Material Properties

	Young modulus, E (kPa)	Poisson Ratio, ν	Weight, γ (kN/m^3)	Cohesion, c (kPa)	Friction angle, ϕ (^{0})	Dilatancy angle, ψ (^{0})
Case 1	5,000	0.35	18	5	10	0
Case 2		0.3	24	20	10	
Case 3		0.35	18	5	20	
Case 4		0.3	24	20	20	
Case 5		0.35	18	5	30	
Case 6		0.3	24	20	30	

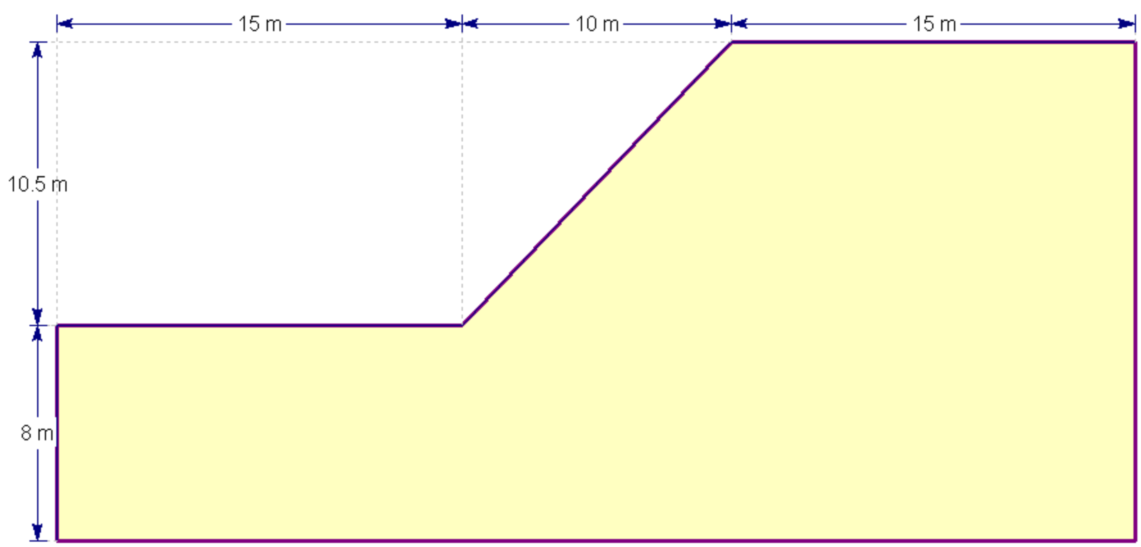
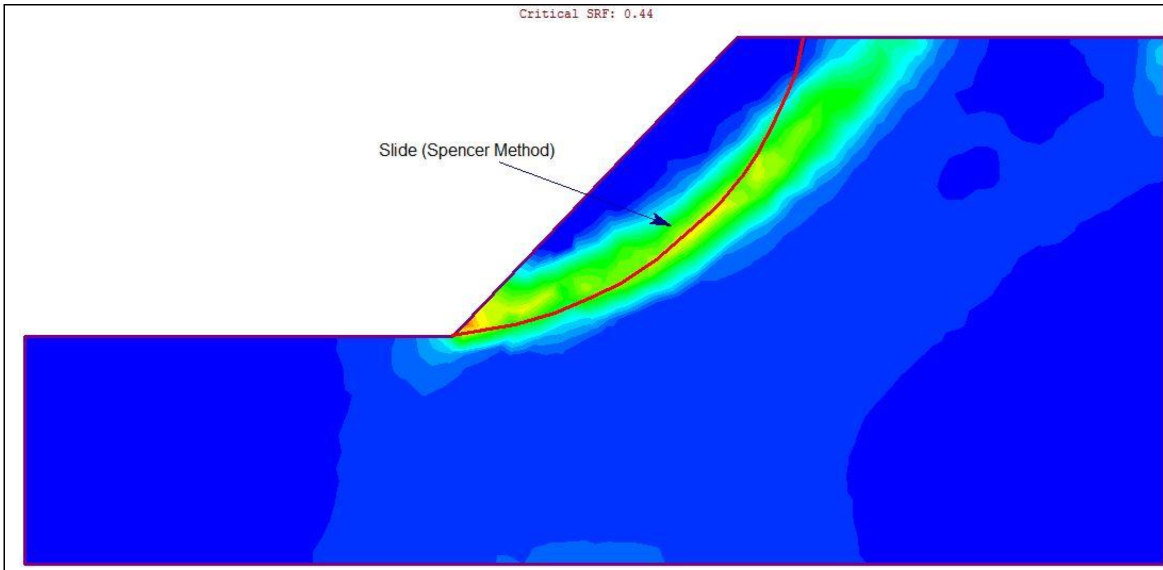


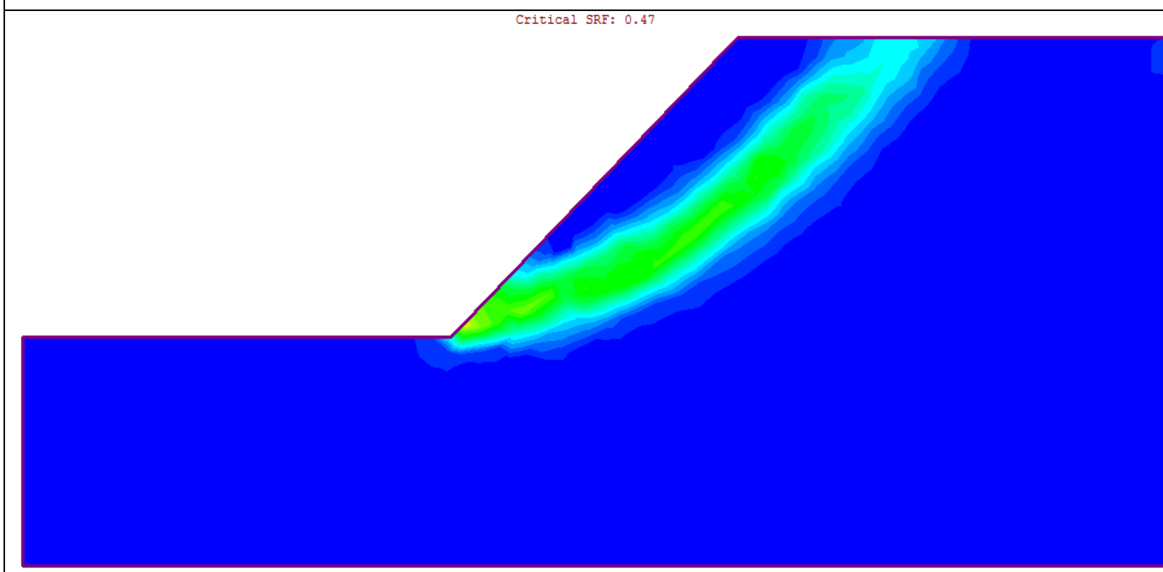
Figure 1 - Geometry

Results: Case 1

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.44	0.44	0.47	0.46	0.43	0.44	0.48	0.43

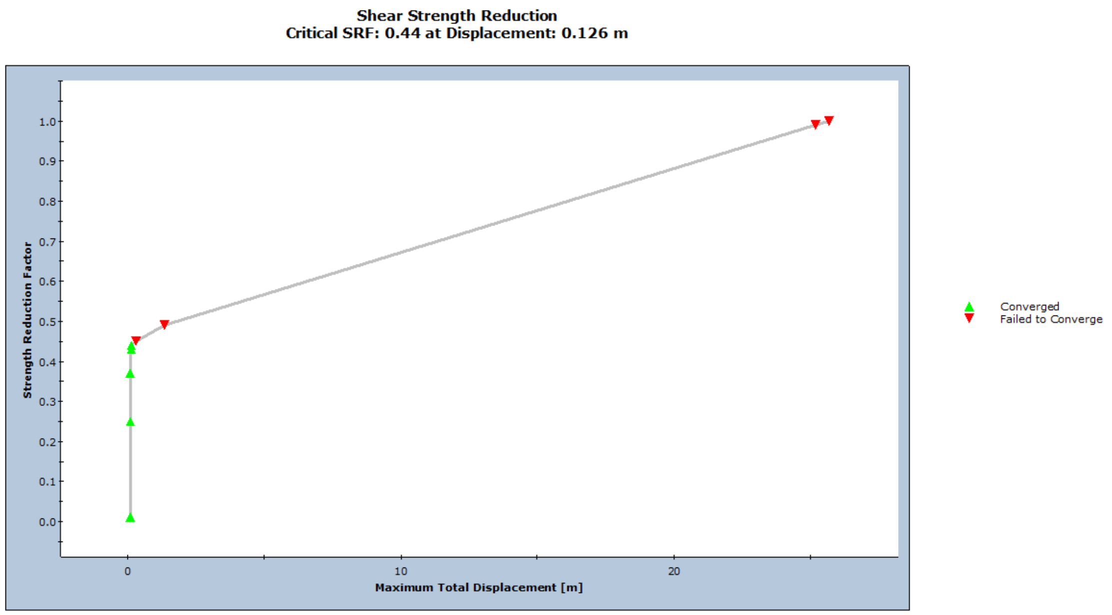


Case 1 – M-C

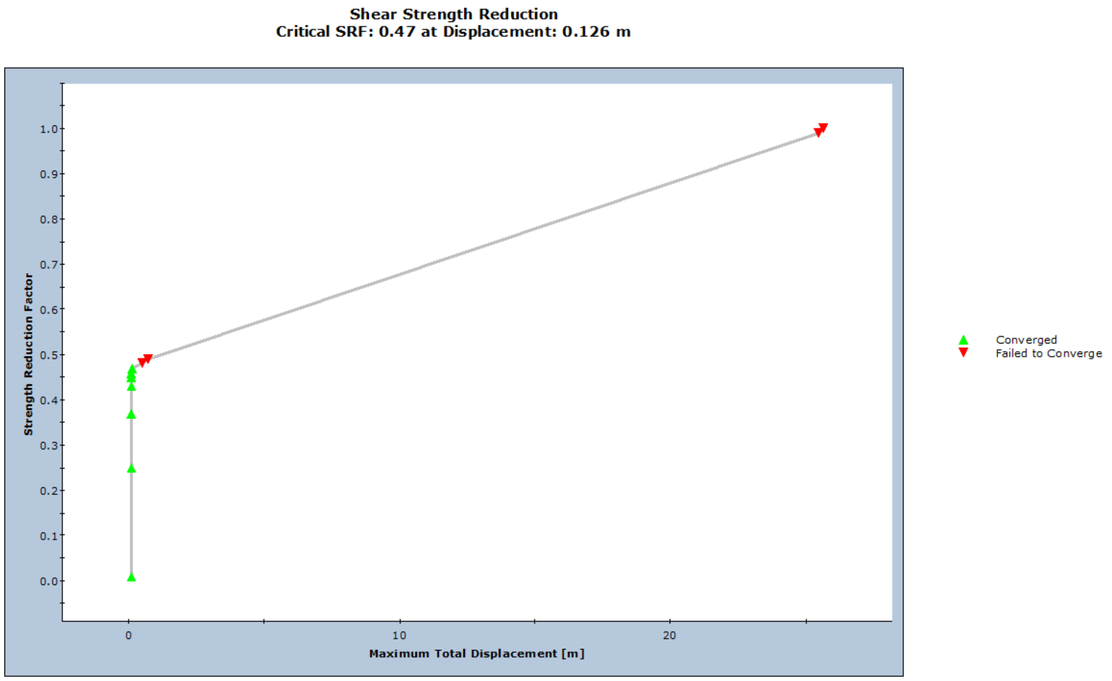


Case 1 – D-P

Figure 2 – Maximum Shear Strain Plot of Case 1



Case 1 – M-C

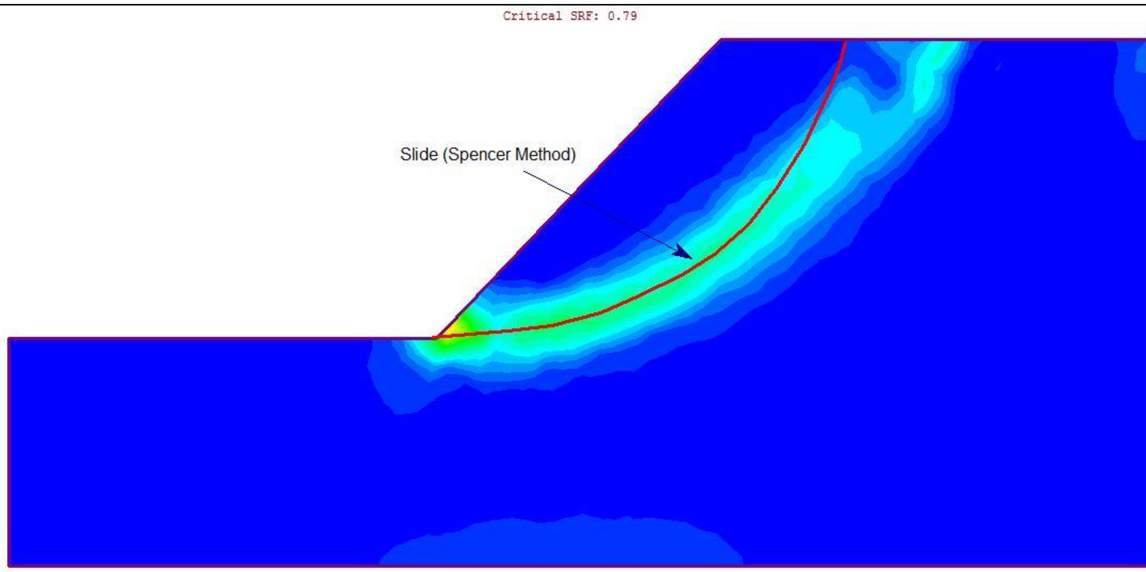


Case 1 – D-P

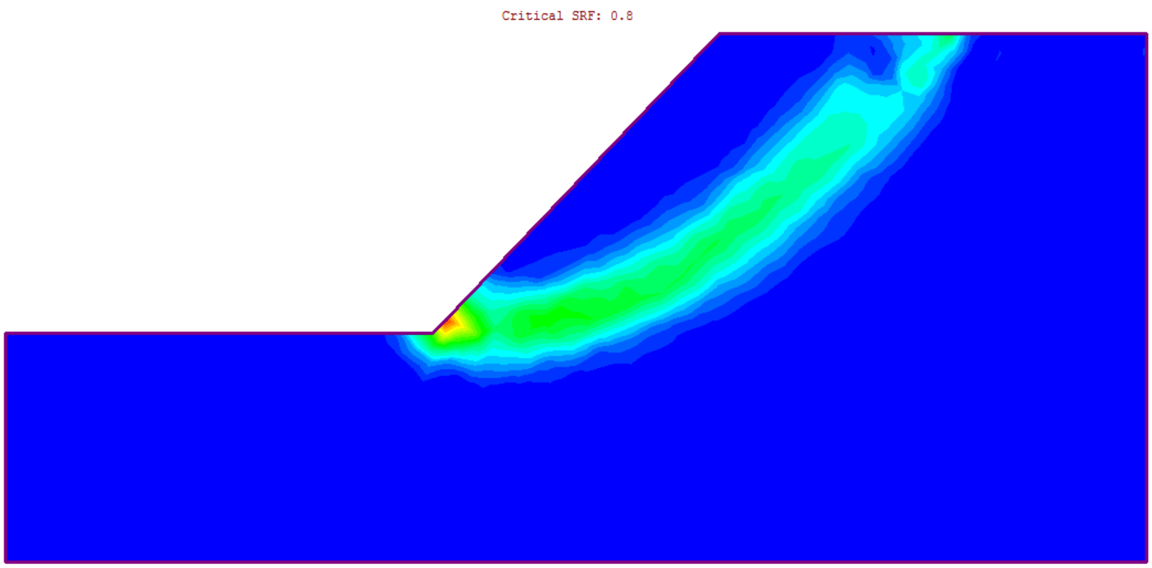
Figure 3 – SSR Convergence Graph of Case 1

Results: Case 2

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.80	0.79	0.80	0.83	0.81	0.85	0.91	0.82

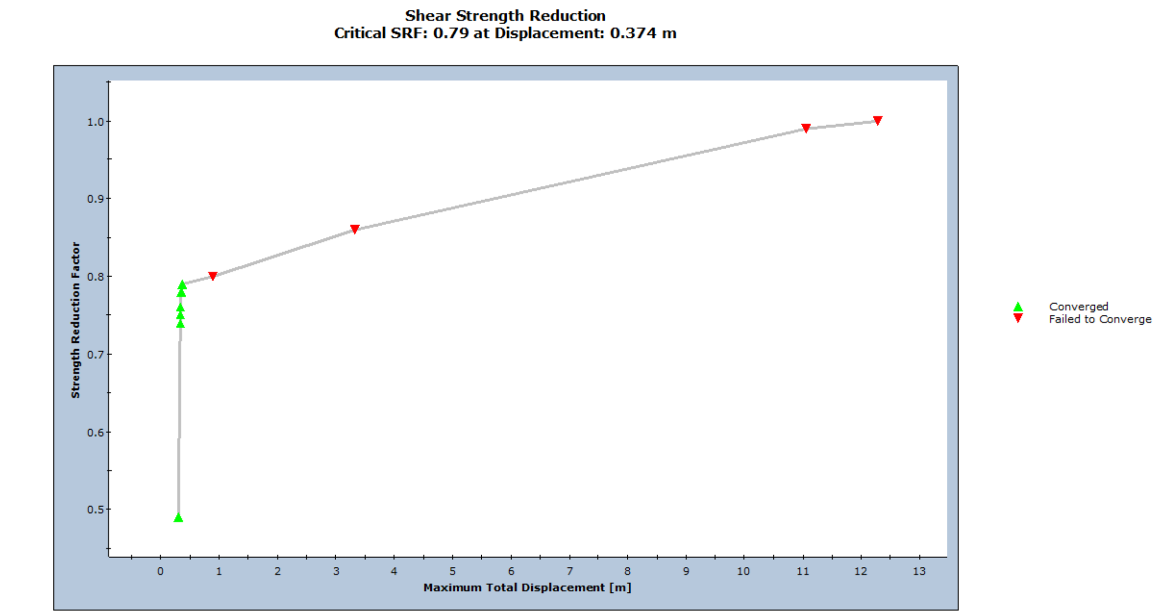


Case 2 – M-C

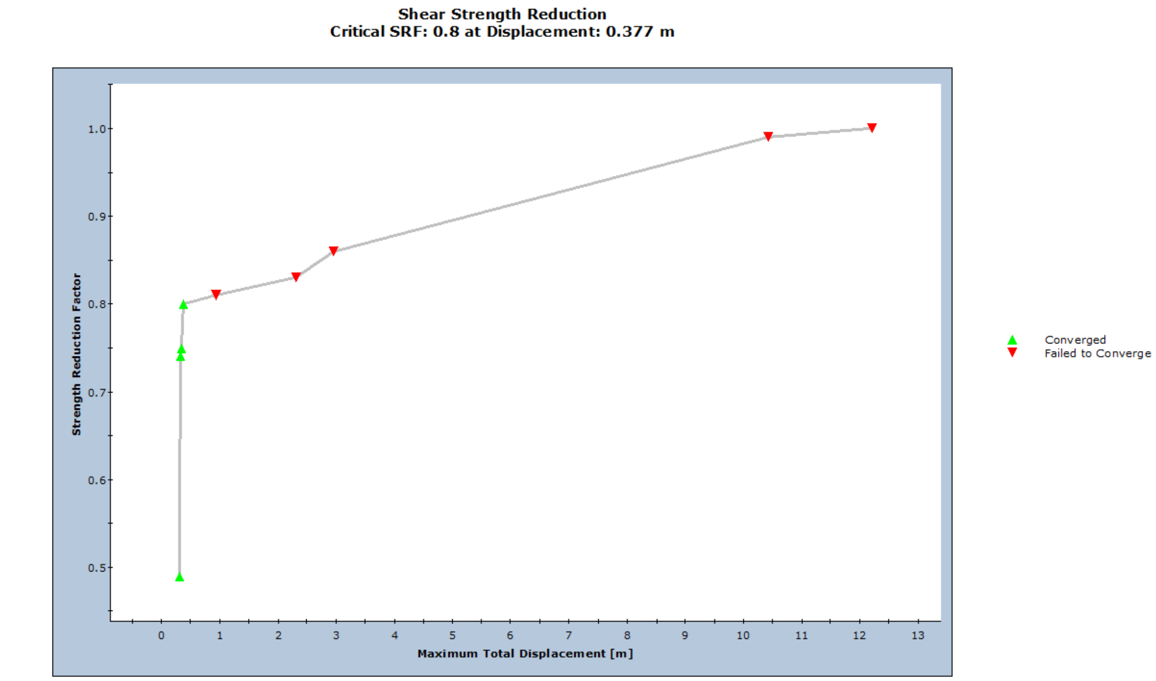


Case 2 – D-P

Figure 4 – Maximum Shear Strain Plot of Case 2



Case 2 – M-C

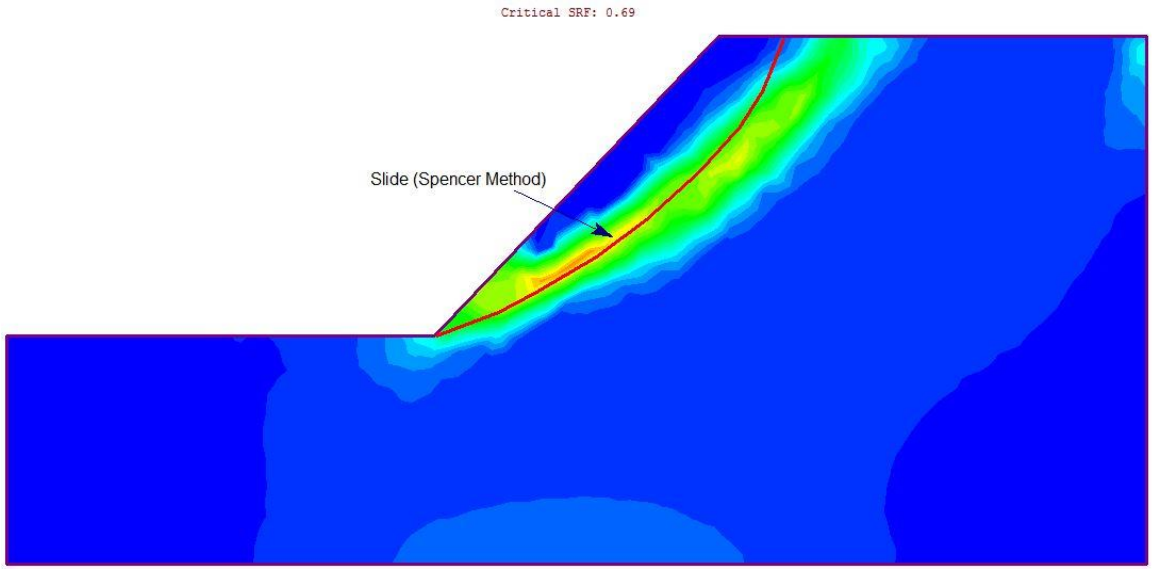


Case 2 – D-P

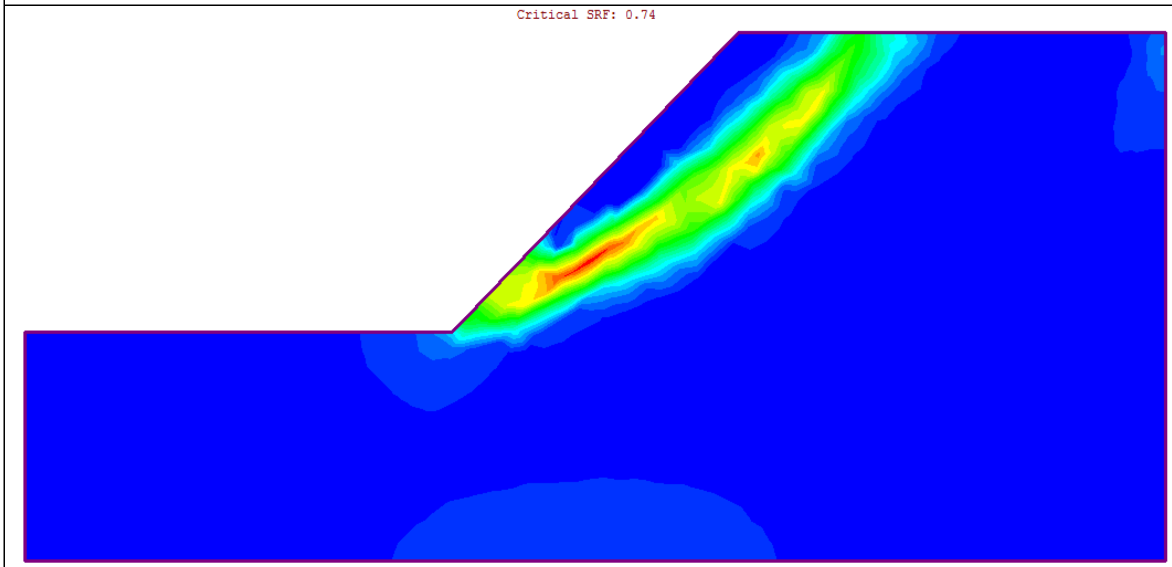
Figure 5 – SSR Convergence Graph of Case 2

Results: Case 3

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.69	0.69	0.74	0.71	0.69	0.71	0.73	0.66

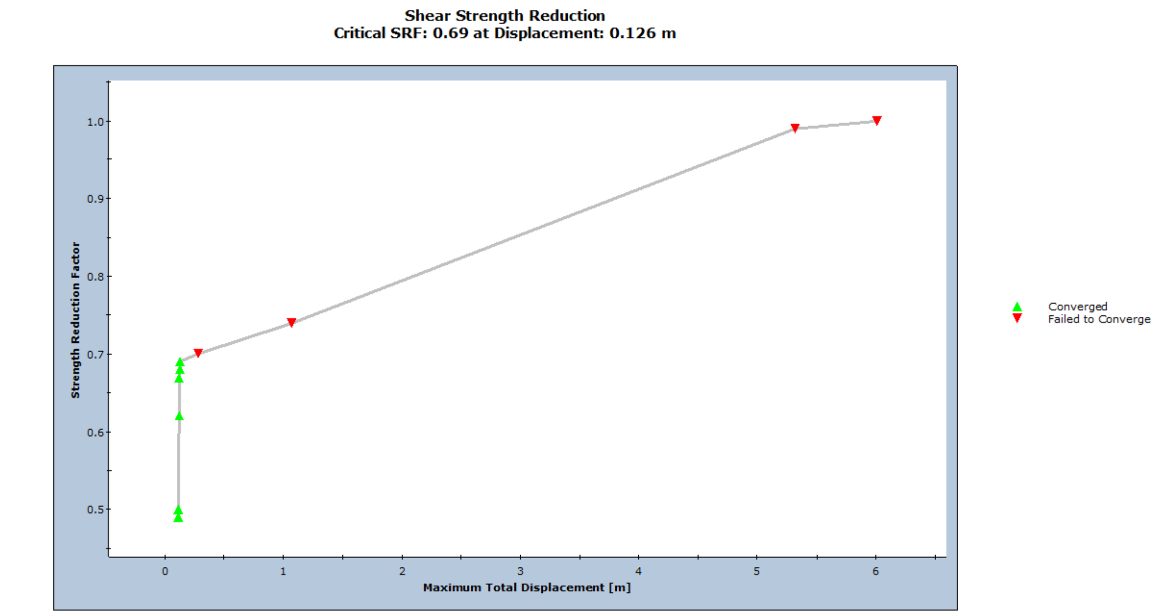


Case 3 – M-C

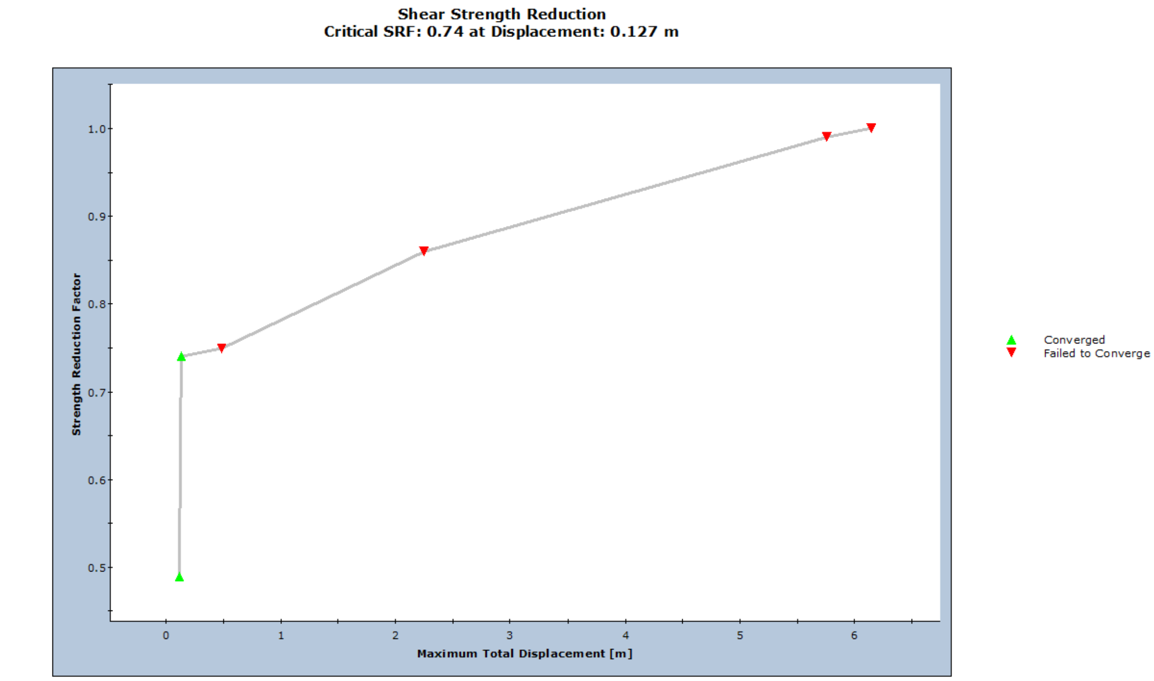


Case 3 – D-P

Figure 6 – Maximum Shear Strain Plot of Case 3



Case 3 – M-C

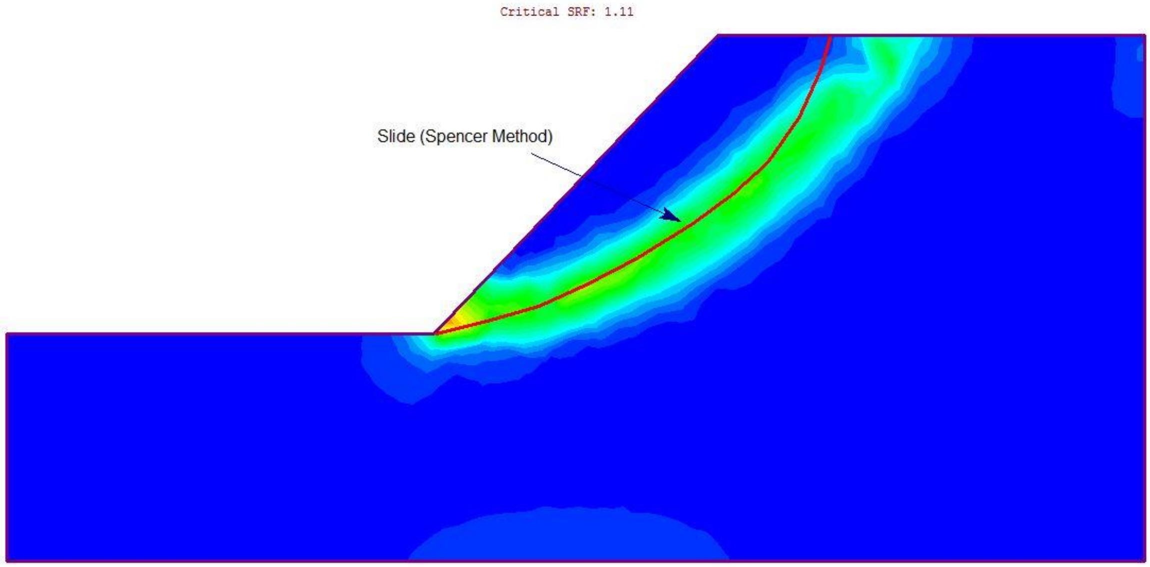


Case 3 – D-P

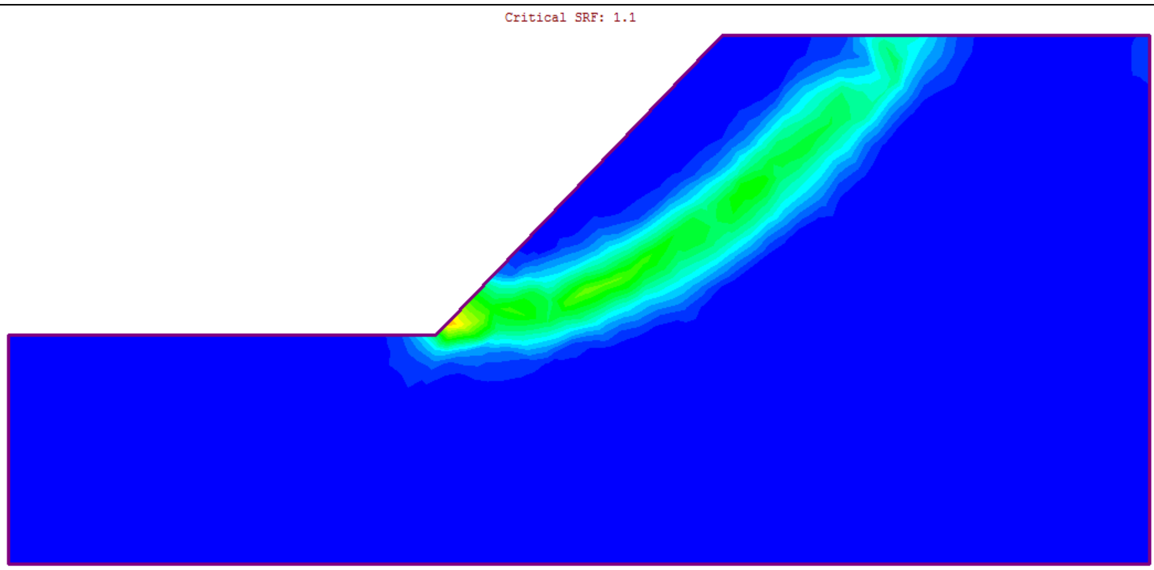
Figure 7 – SSR Convergence Graph of Case 3

Results: Case 4

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
1.10	1.11	1.10	1.14	1.04	1.17	1.18	1.10

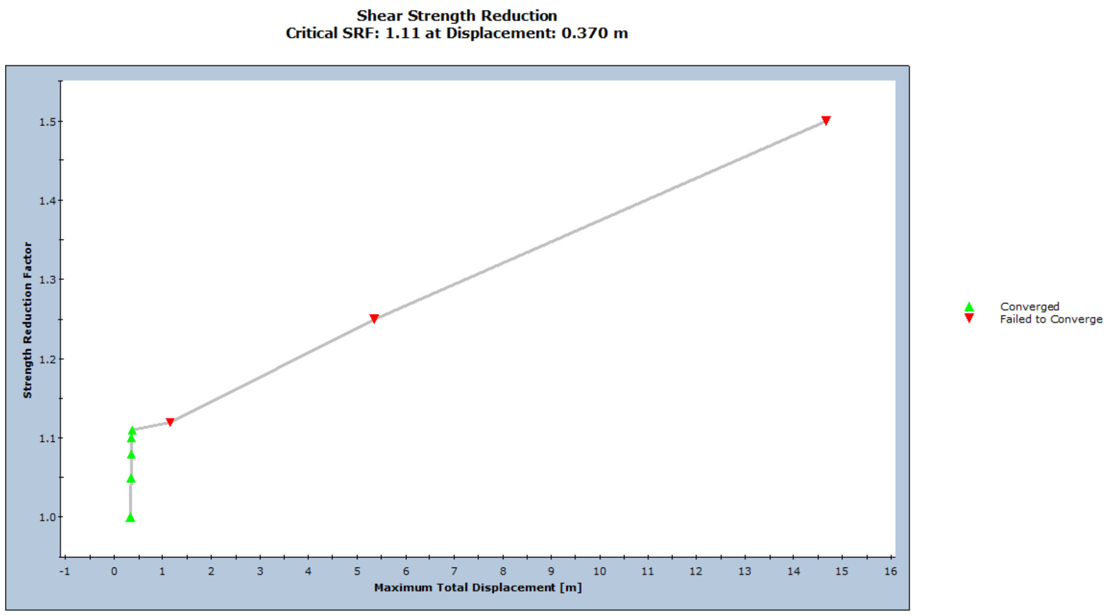


Case 4 – M-C

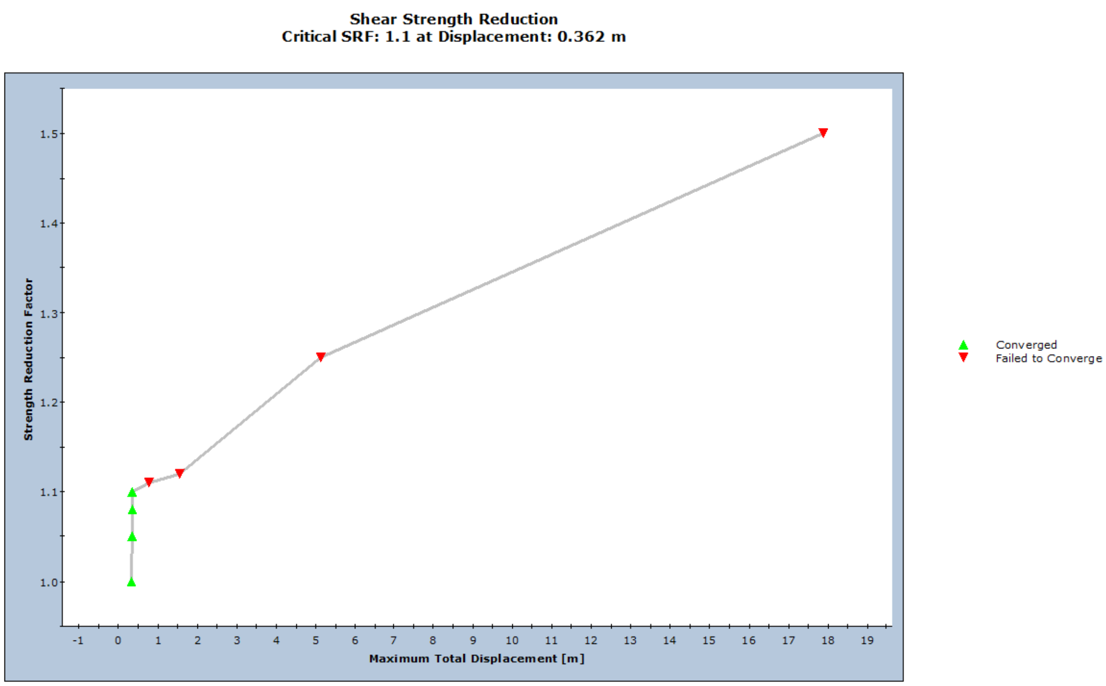


Case 4 – D-P

Figure 8 – Maximum Shear Strain Plot of Case 4



Case 4 – M-C

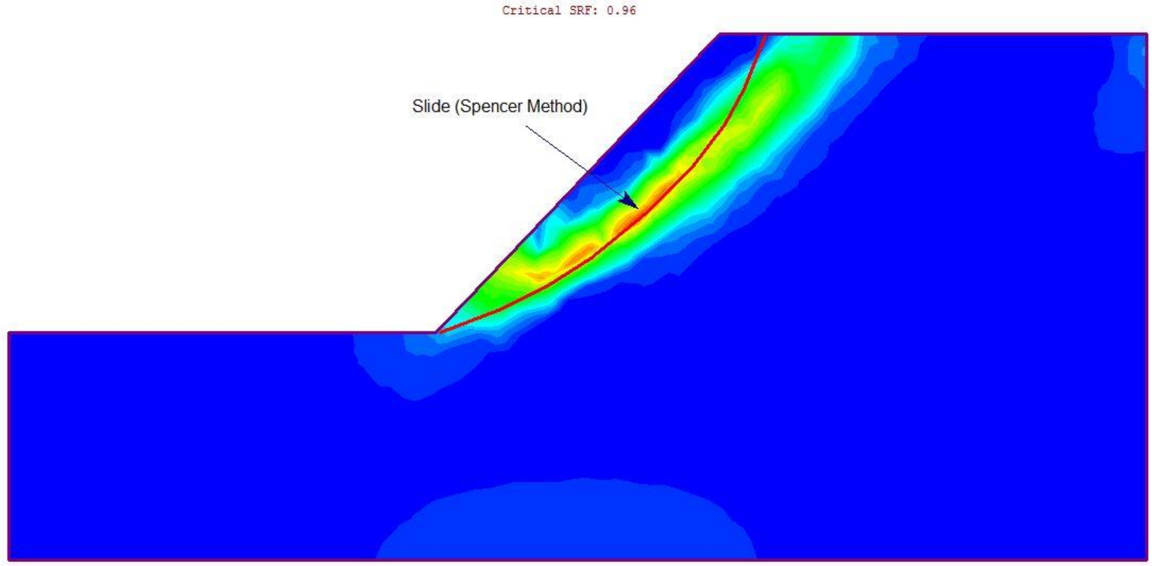


Case 4 – D-P

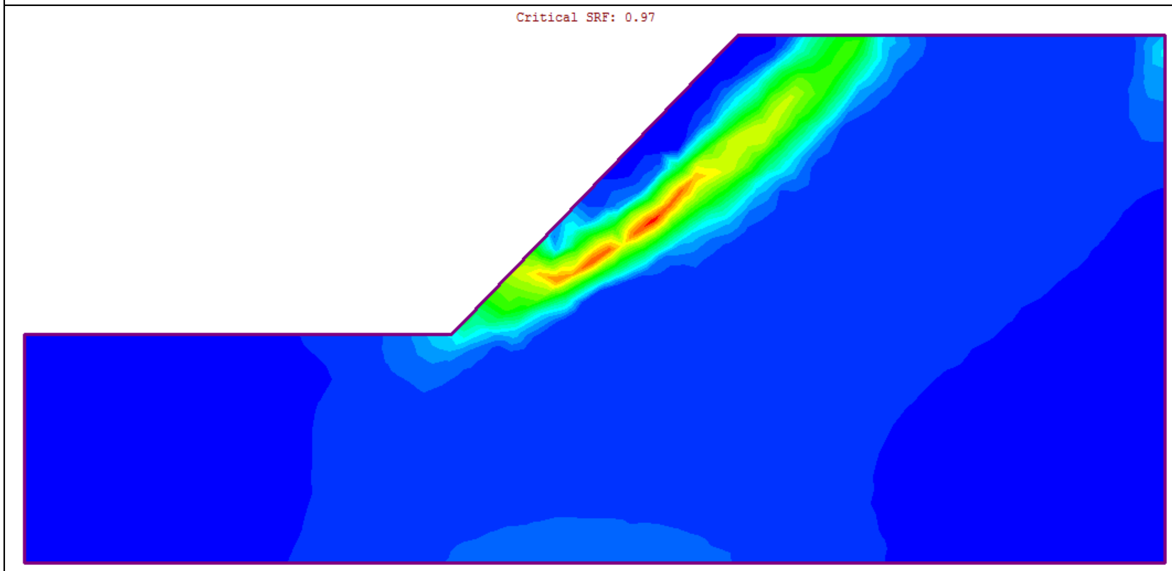
Figure 9 – SSR Convergence Graph of Case 4.

Results: Case 5

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.95	0.96	0.97	0.98	0.91	0.97	1.03	0.81

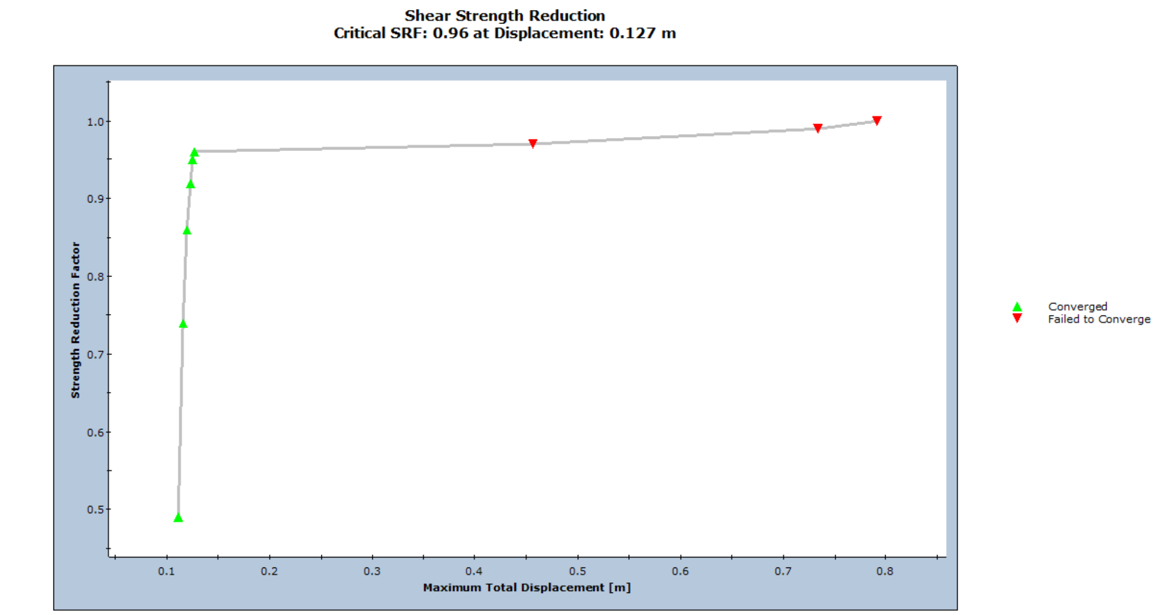


Case 5 – M-C

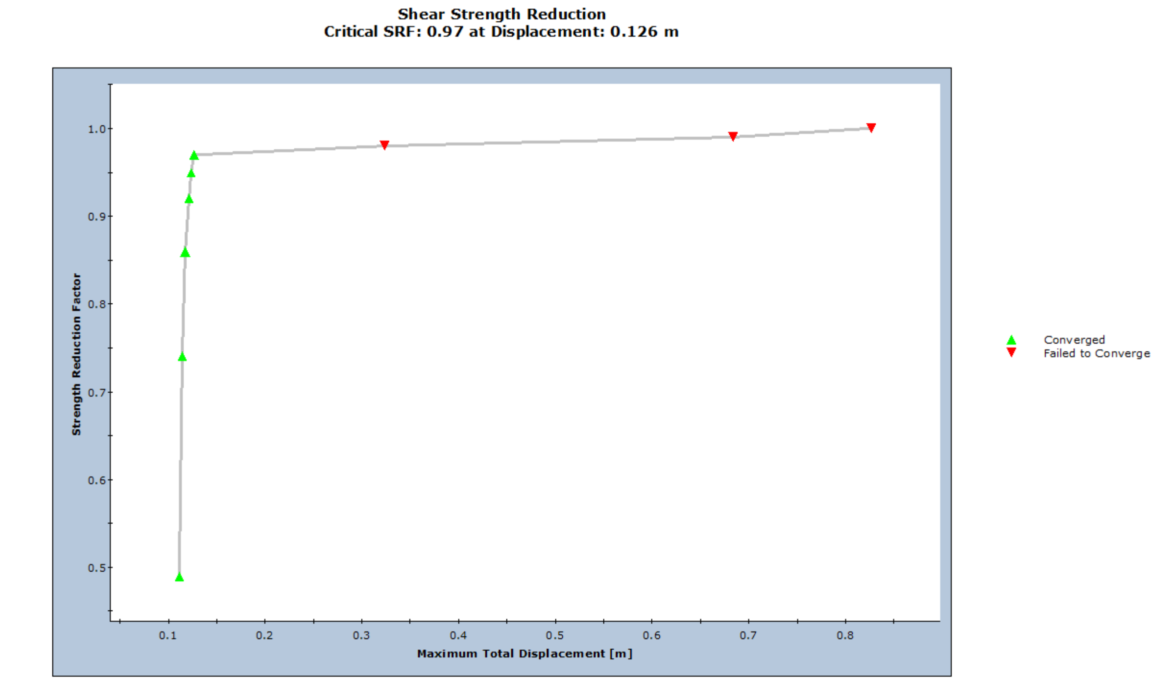


Case 5 – D-P

Figure 10 – Maximum Shear Strain Plot of Case 5



Case 5 – M-C

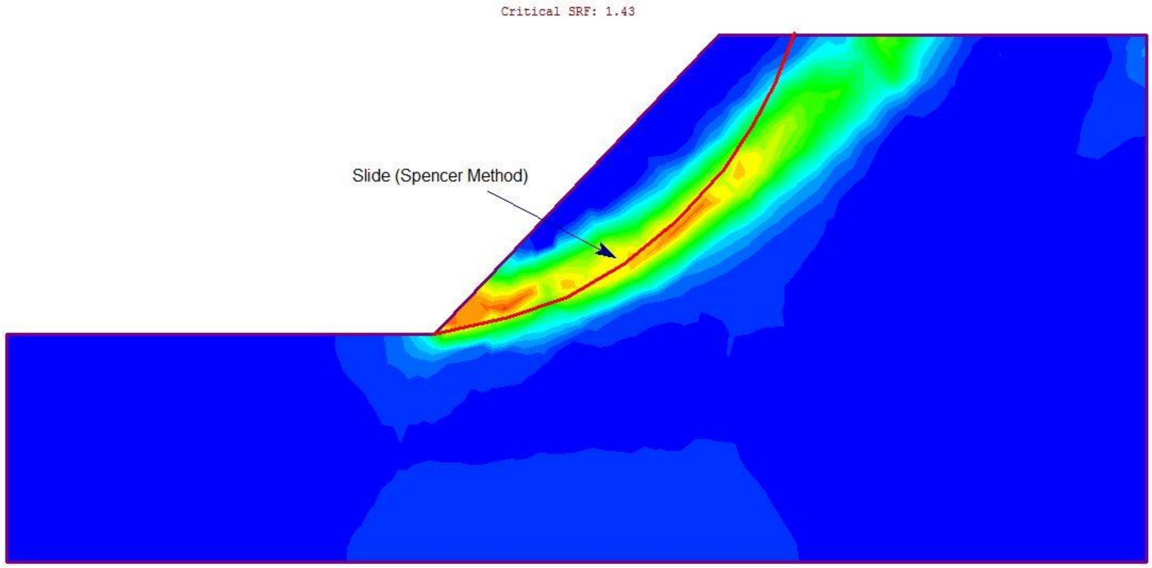


Case 5 – D-P

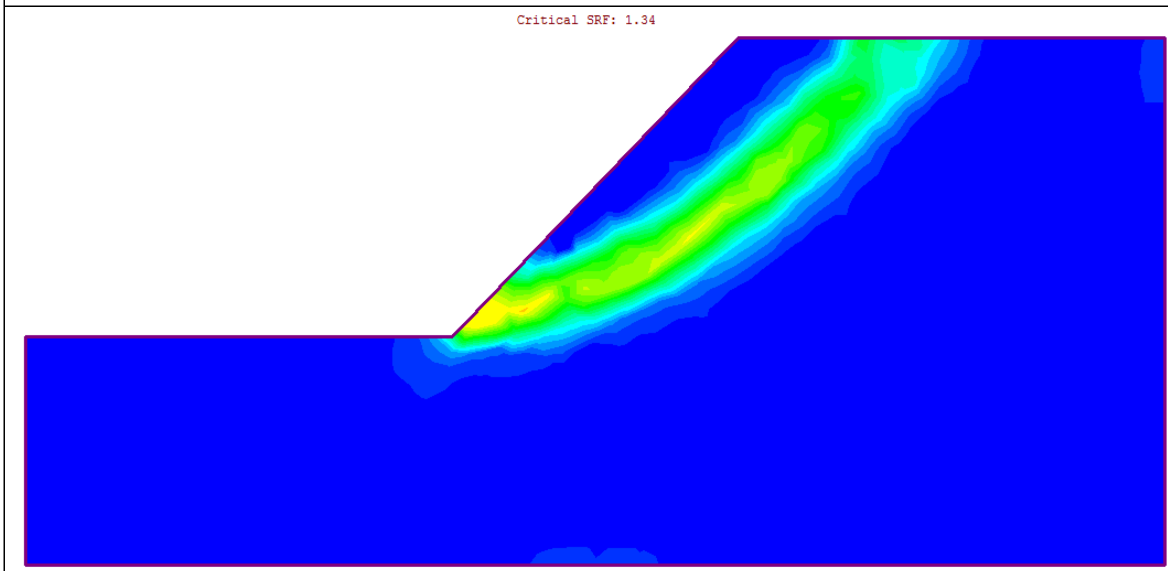
Figure 11 – SSR Convergence Graph of Case 5

Results: Case 6

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
1.40	1.42	1.34	1.52	1.44	1.45	1.54	1.46

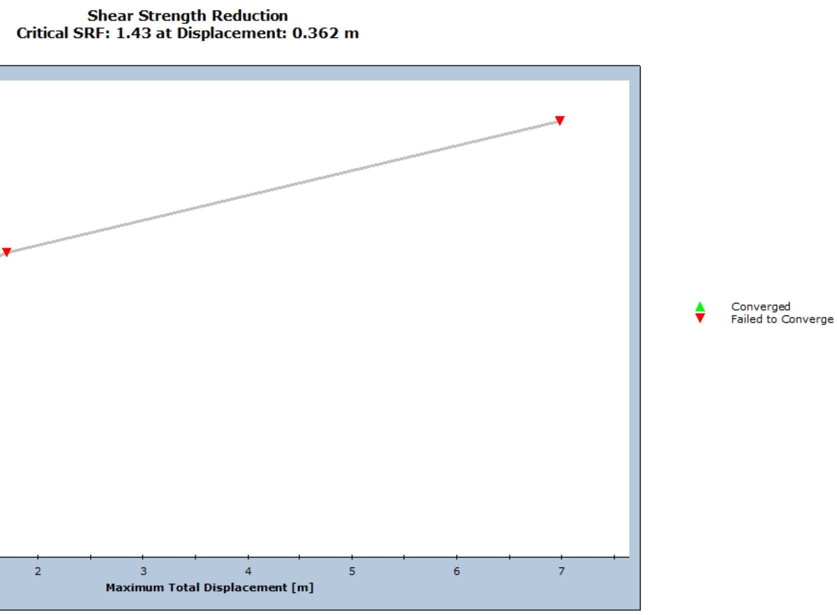


Case 6 – M-C

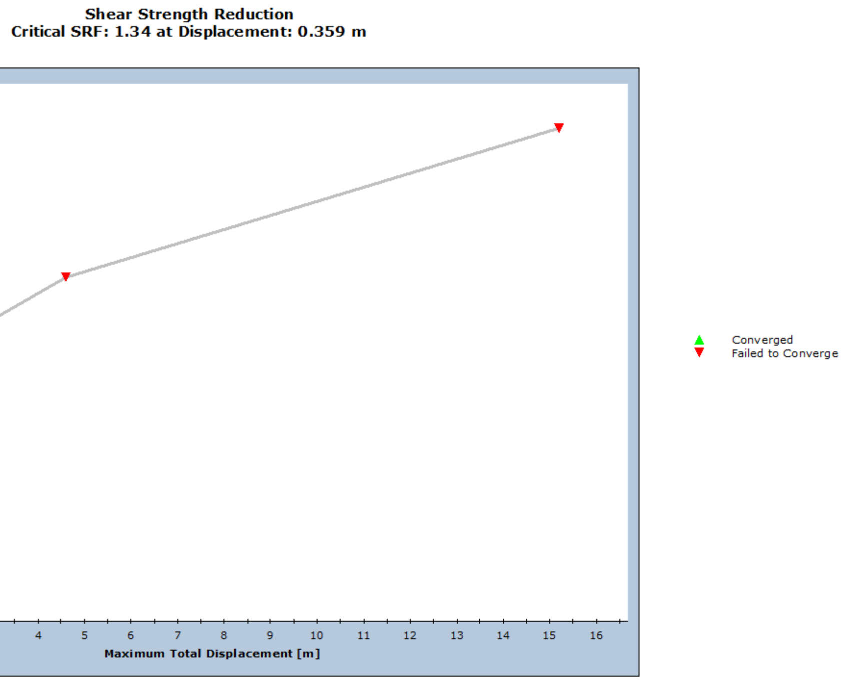


Case 6 – D-P

Figure 12 – Maximum Shear Strain Plot of Case 6



Case 6 – M-C



Case 6 – D-P

Figure 13 – SSR Convergence Graph of Case 6

Introduction

This problem is taken from the slope stability problem in the "Comparison of geotechnic softwares", a paper by Pruska, J. (2003).

Description

A homogeneous slope with a slope height of 14 m is shown in Figure 1. Six cases with different soil properties were studied. Mohr-Coulomb (M-C) and Drucker-Prager (D-P) failure criteria were used in the analysis. The material properties of all six cases are given in table 1. The results of all cases are compared to those of Z-Soil, Plaxis and Geo FEM.

Geometry and Properties

Table 1 Material Properties

	Young modulus, E (kPa)	Poisson Ratio, ν	Weight, γ (kN/m^3)	Cohesion, c (kPa)	Friction angle, ϕ (^{0})	Dilatancy angle, ψ (^{0})
Case 1	5,000	0.35	18	5	10	0
Case 2		0.3	24	20	10	
Case 3		0.35	18	5	20	
Case 4		0.3	24	20	20	
Case 5		0.35	18	5	30	
Case 6		0.3	24	20	30	

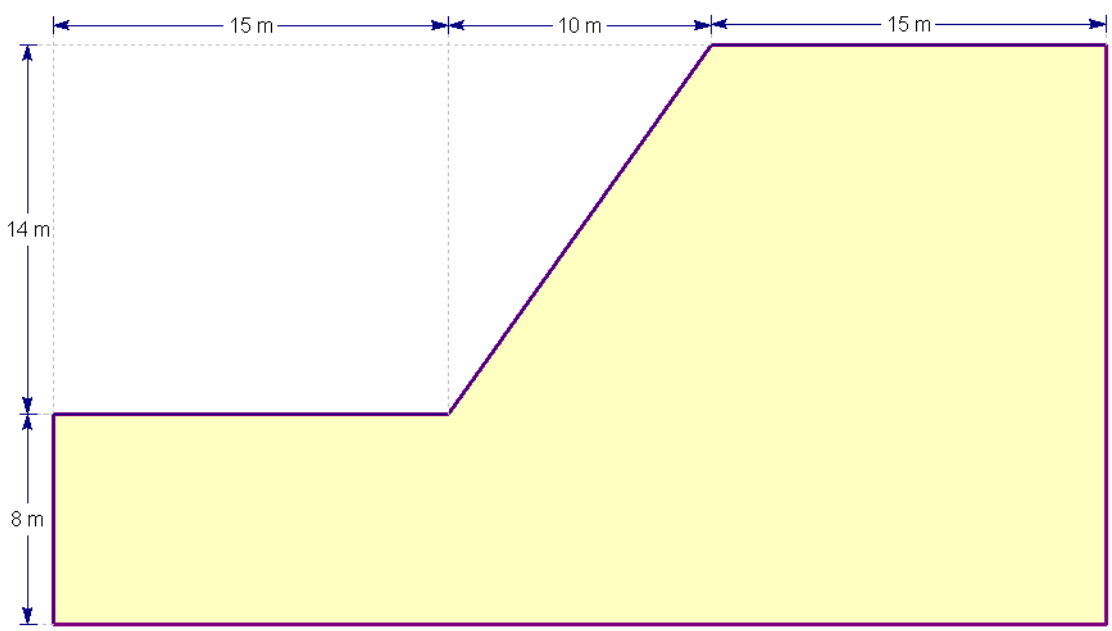
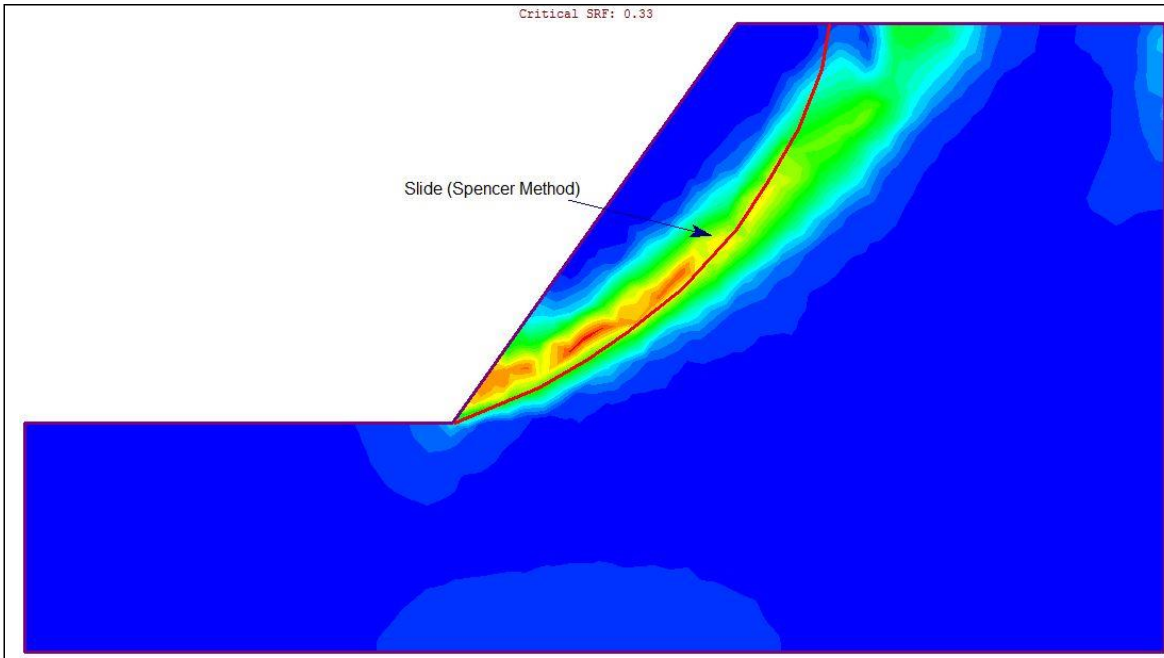


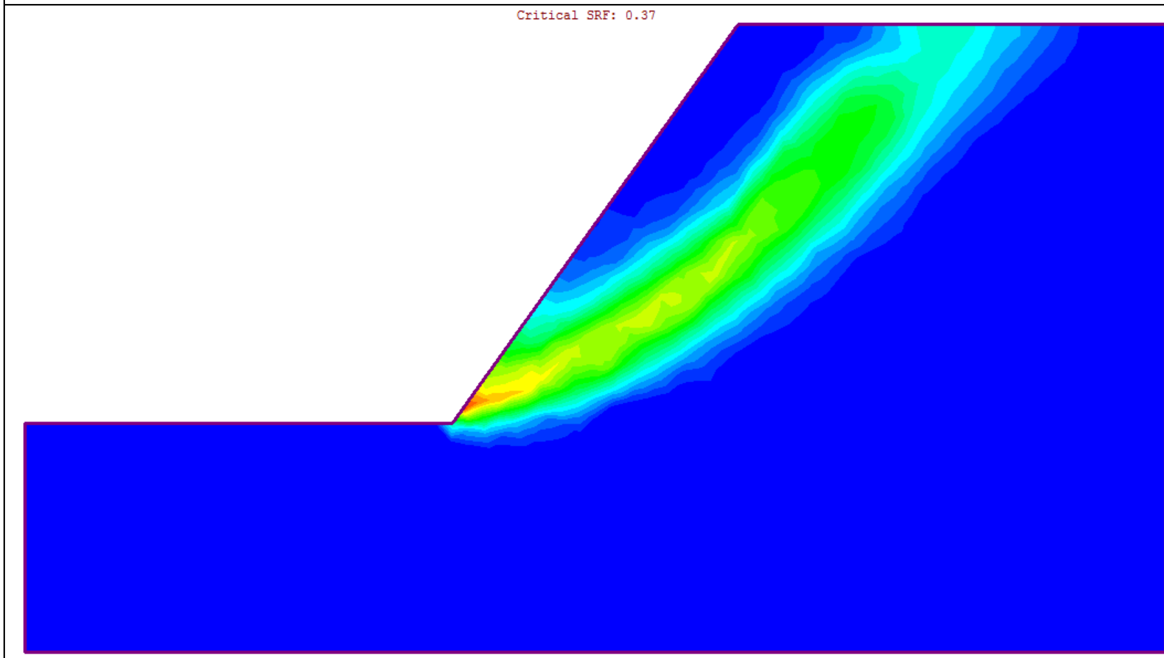
Figure 1 - Geometry

Results: Case 1

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.34	0.33	0.37	0.34	0.32	0.35	0.35	0.31

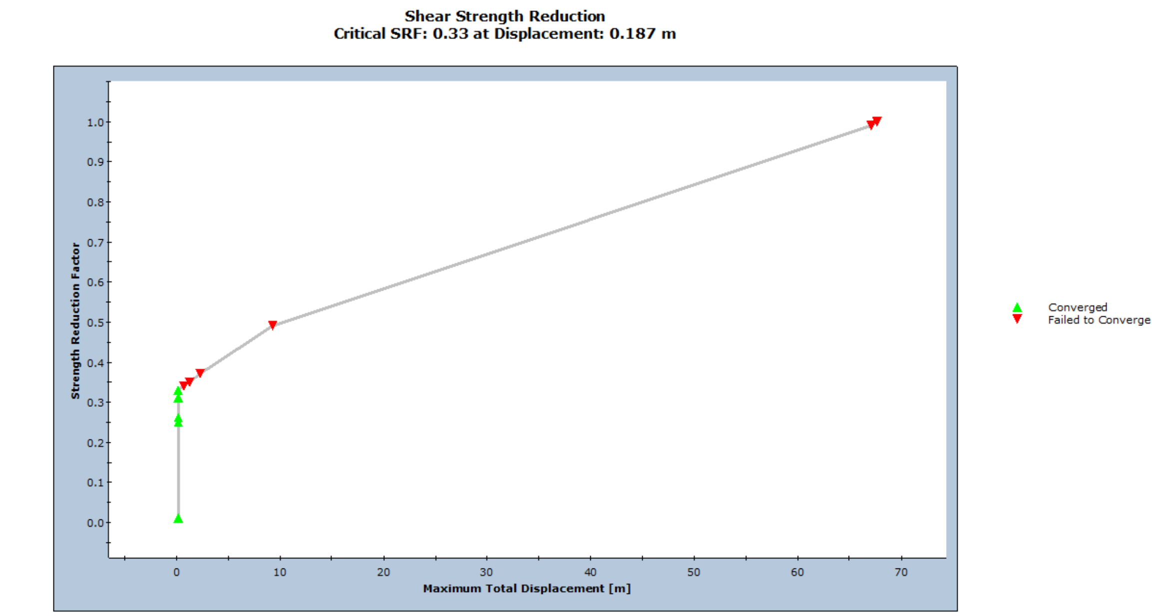


Case 1 – M-C

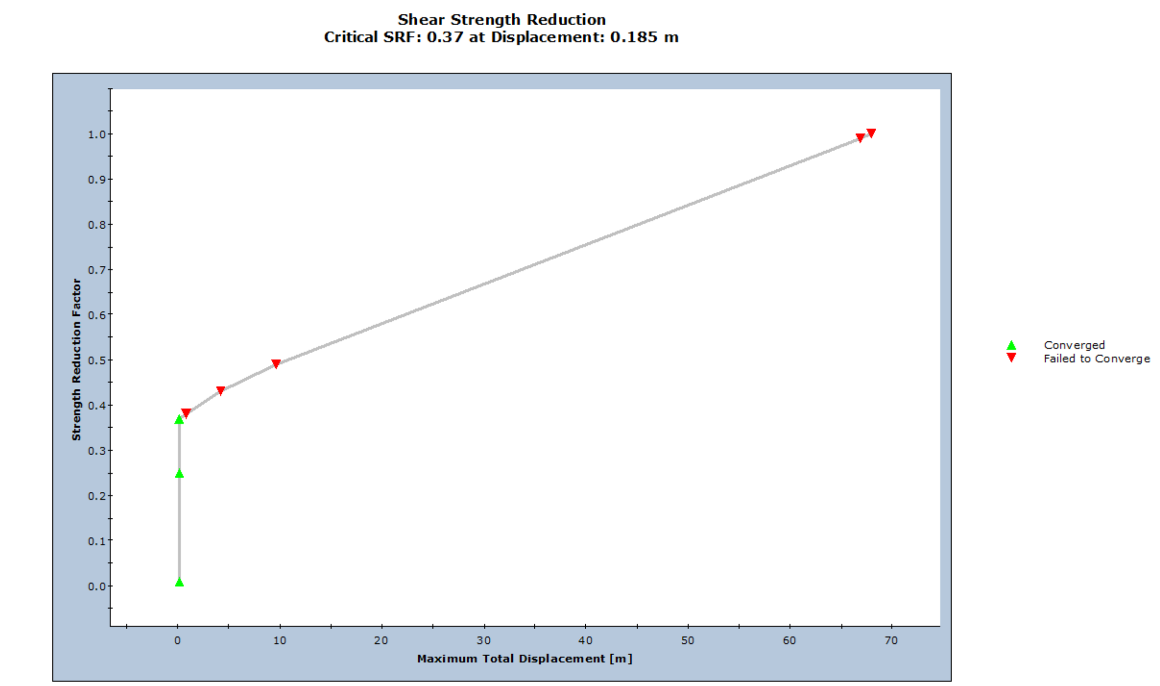


Case 1 – D-P

Figure 2 – Maximum Shear Strain Plot of Case 1



Case 1 – M-C



Case 1 – D-P

Figure 3 – SSR Convergence Graph of Case 1

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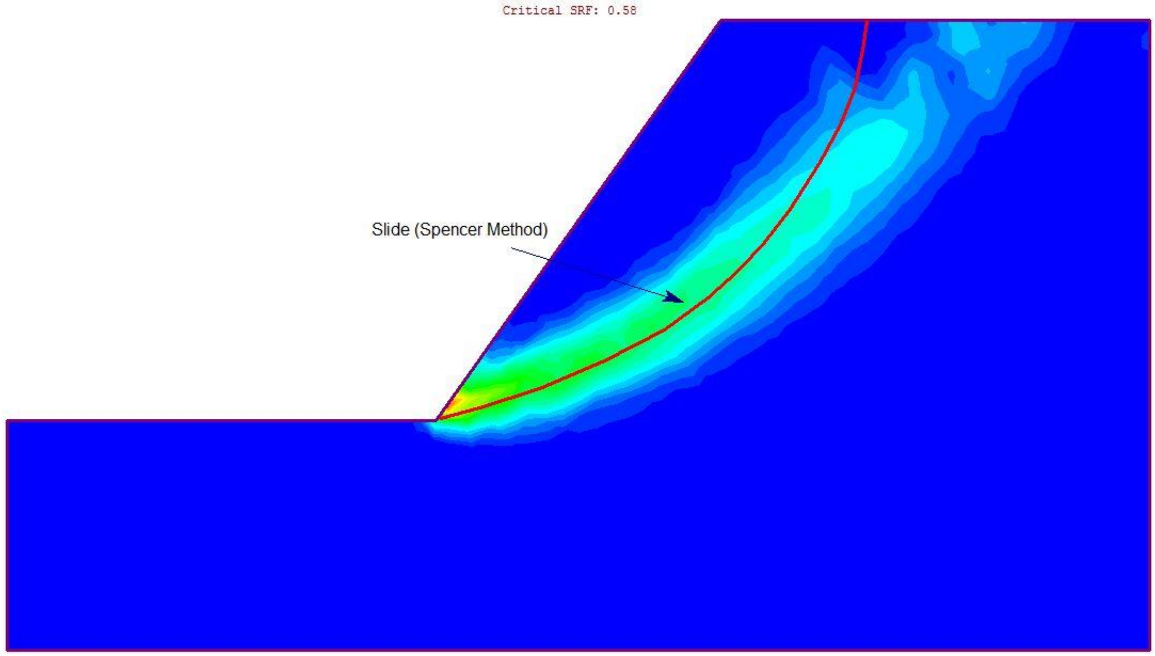
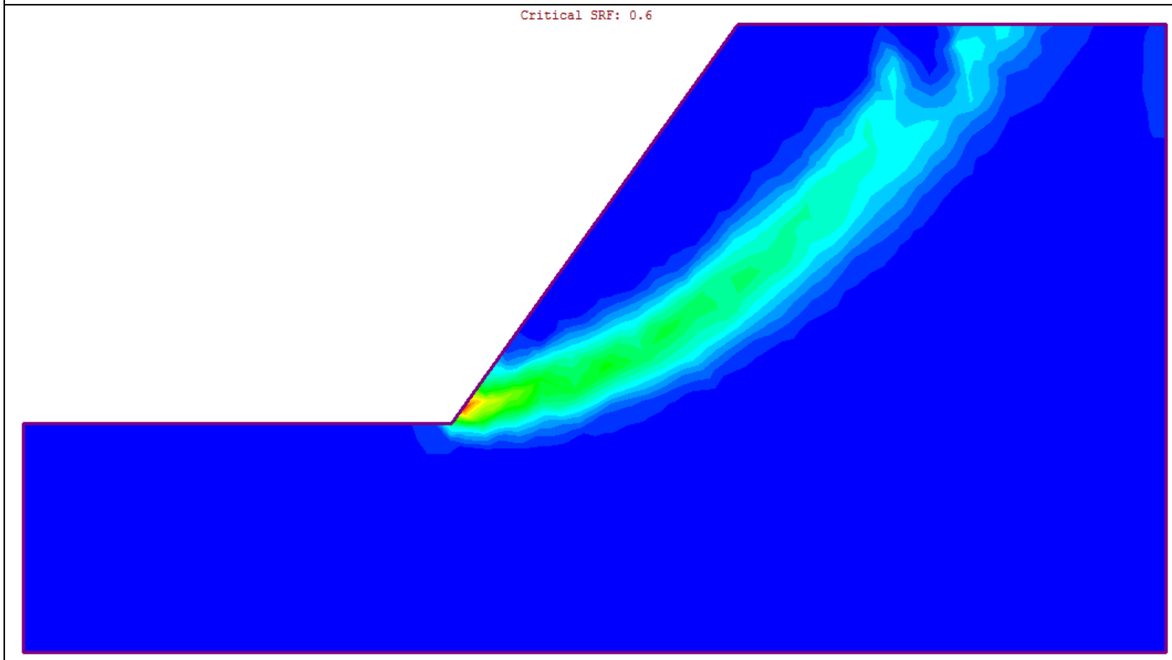
Results: Case 2

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.60	0.59	0.60	0.61	0.59	0.59	0.63	0.60

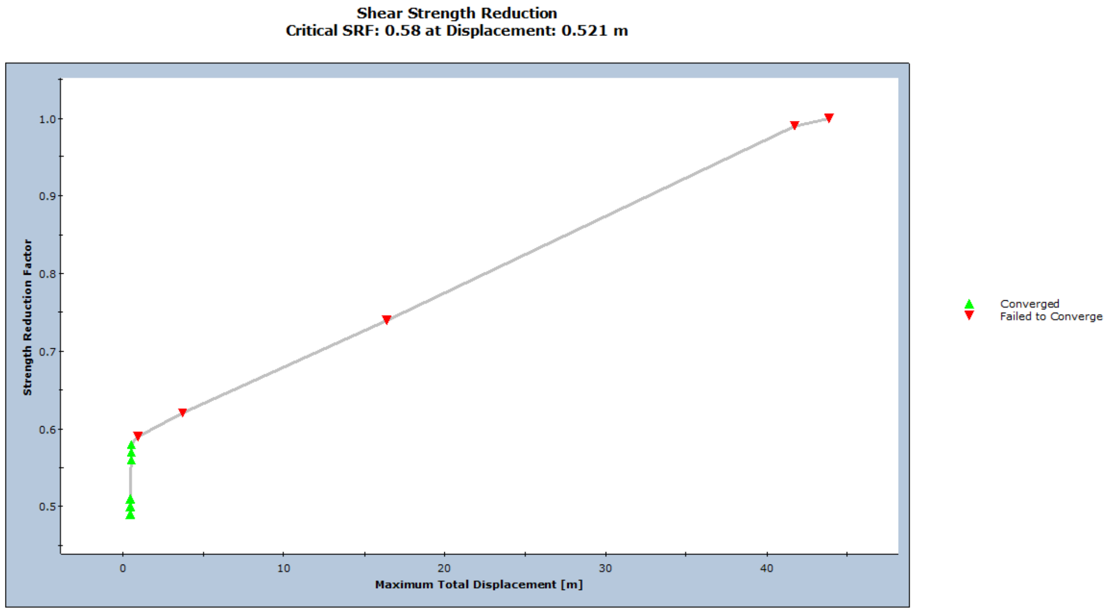


Case 2 – M-C

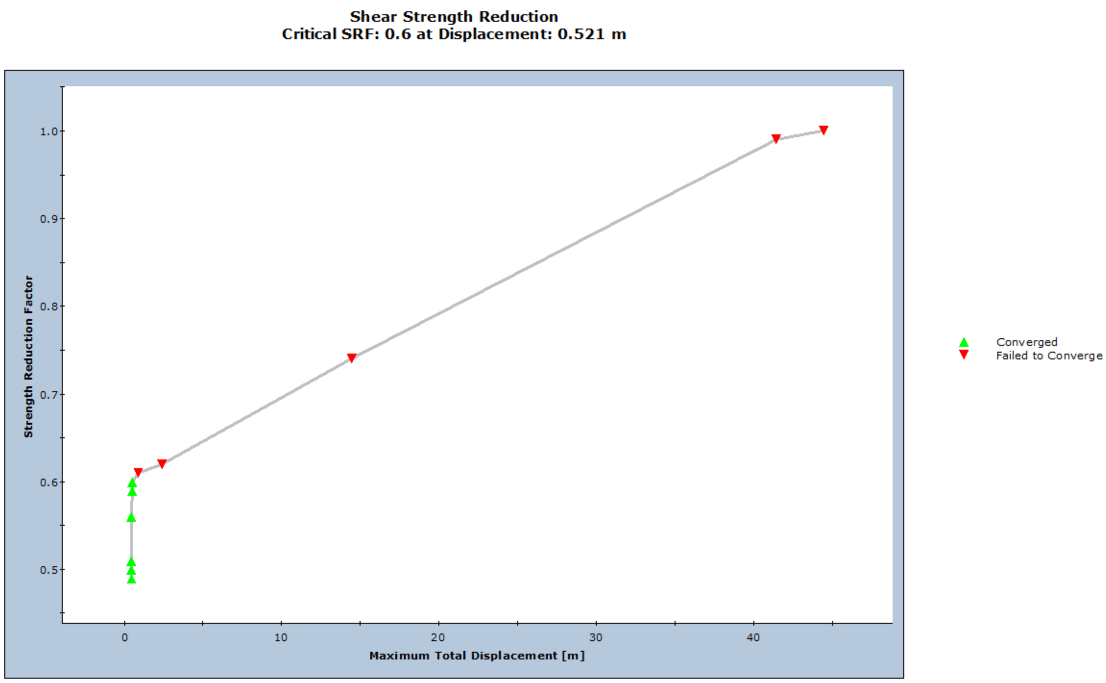


Case 2 – D-P

Figure 4 – Maximum Shear Strain Plot of Case 2



Case 2 – M-C

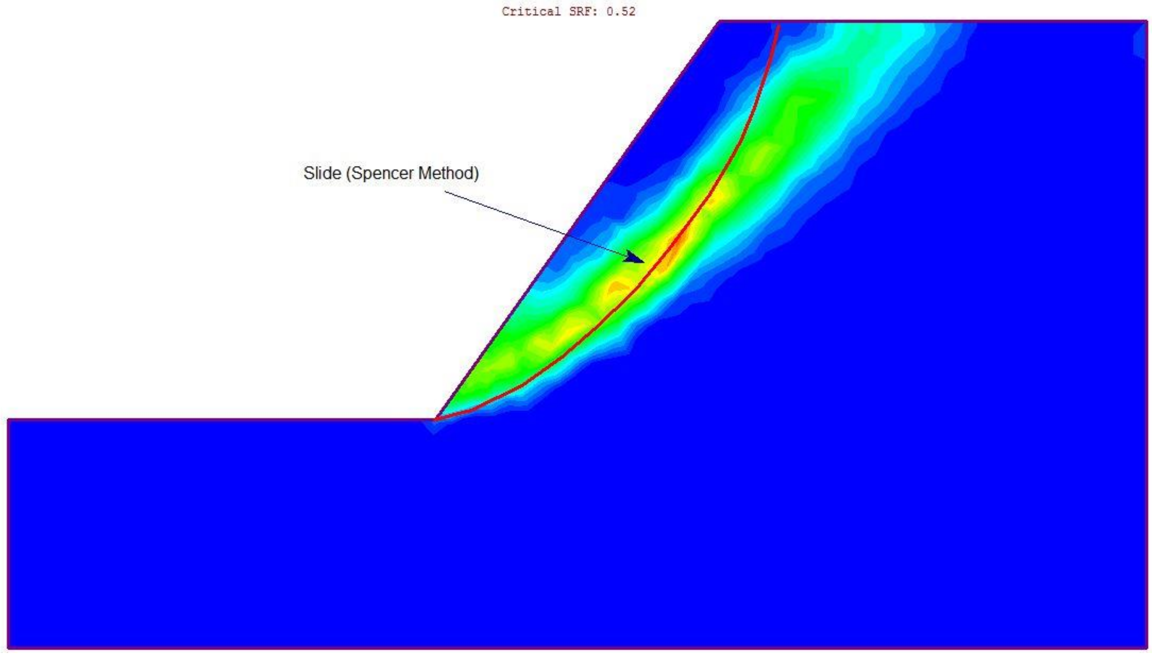


Case 2 – D-P

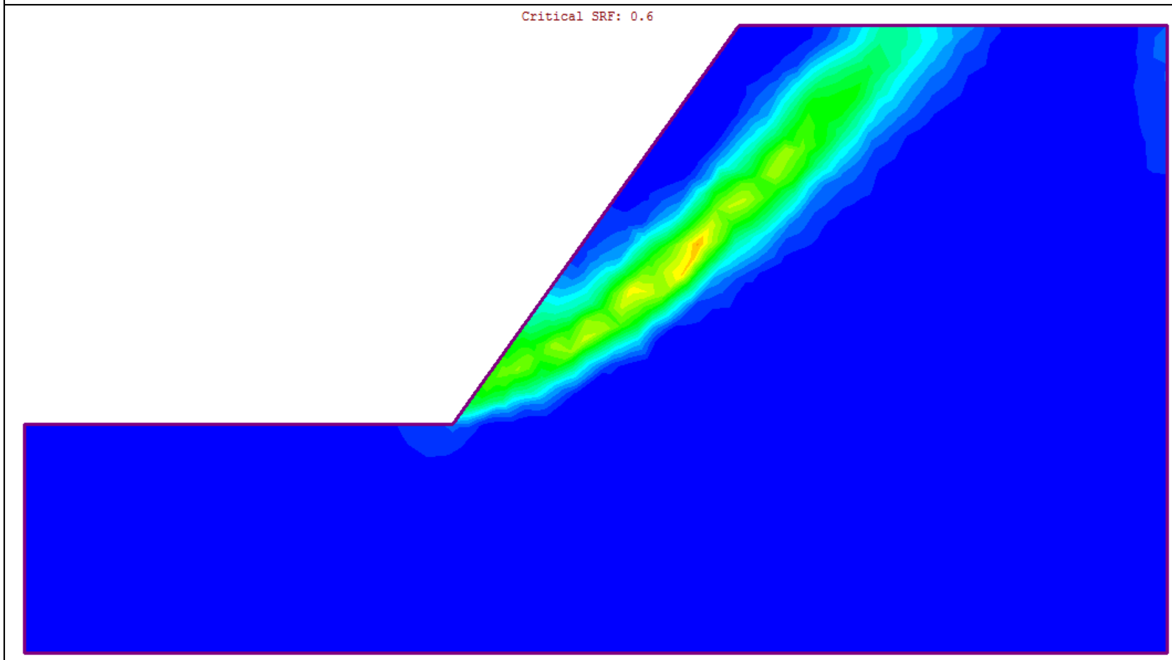
Figure 5 – SSR Convergence Graph of Case 2

Results: Case 3

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.53	0.52	0.60	0.54	0.50	0.53	0.59	0.48

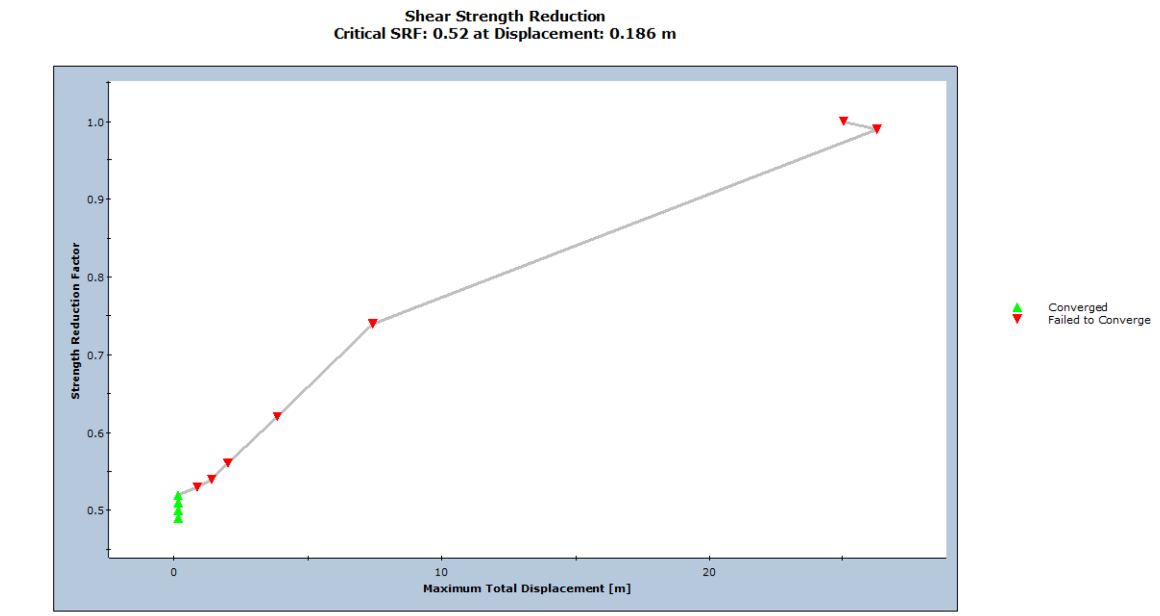


Case 3 – M-C

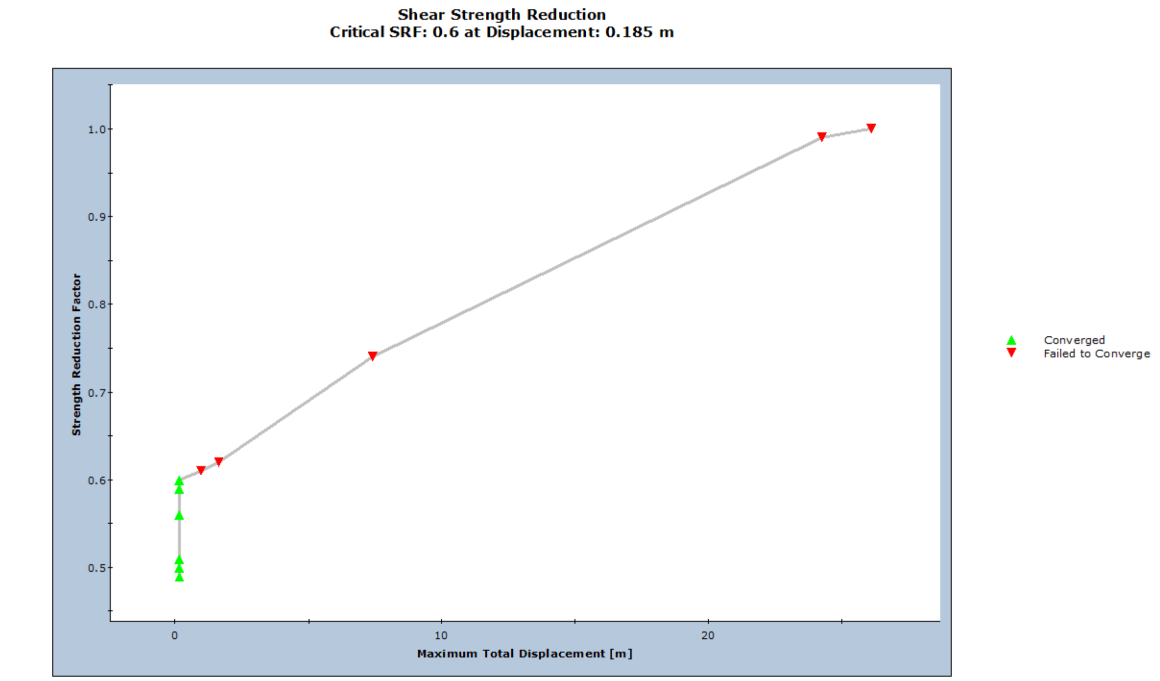


Case 3 – D-P

Figure 6 – Maximum Shear Strain Plot of Case 3



Case 3 – M-C

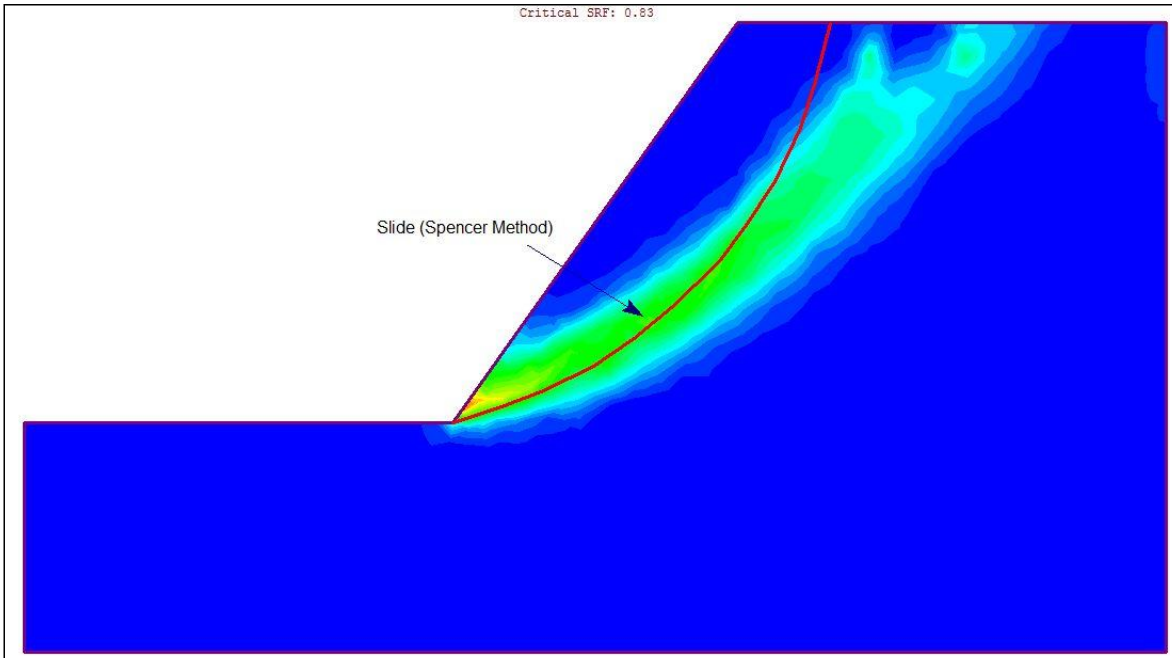


Case 3 – D-P

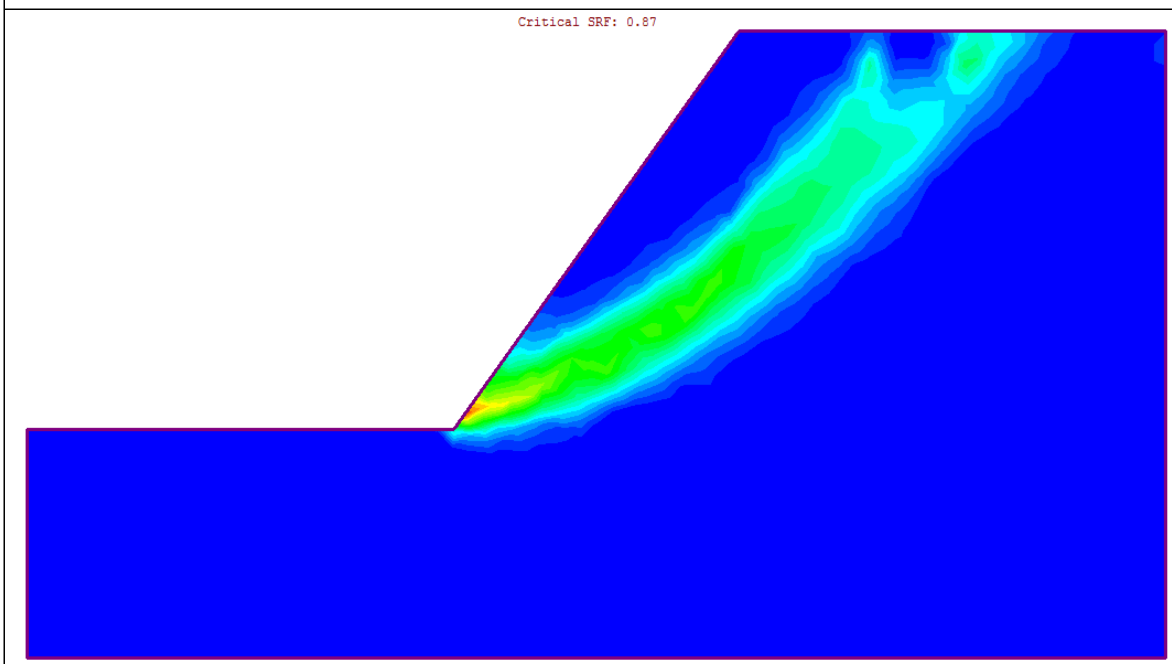
Figure 7 – SSR Convergence Graph of Case 3

Results: Case 4

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.84	0.83	0.87	0.84	0.81	0.82	0.86	0.82

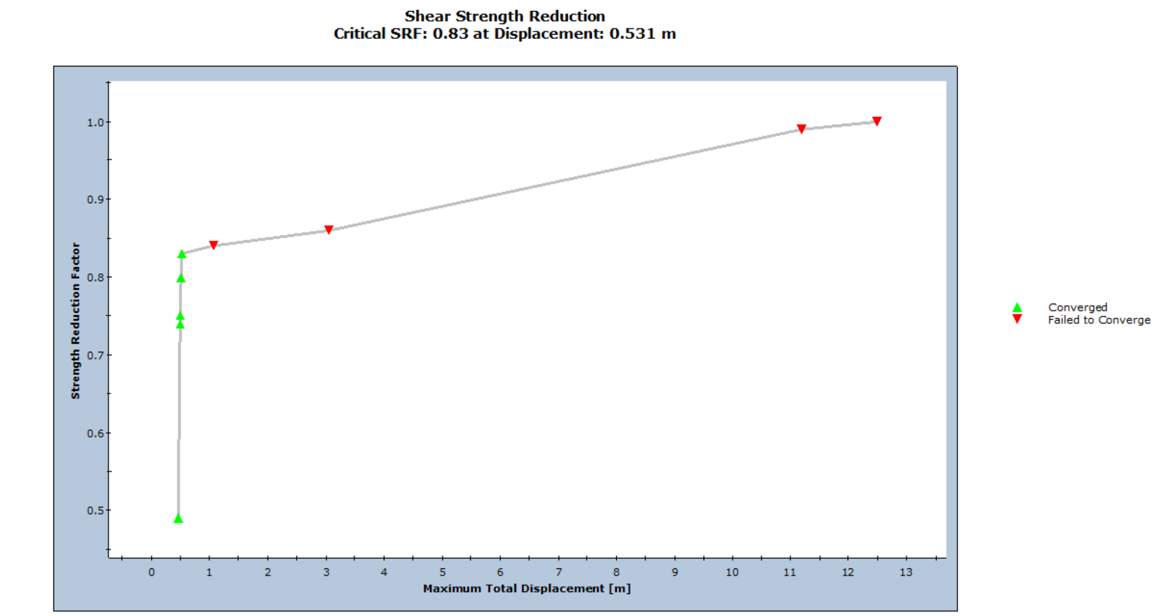


Case 4 – M-C

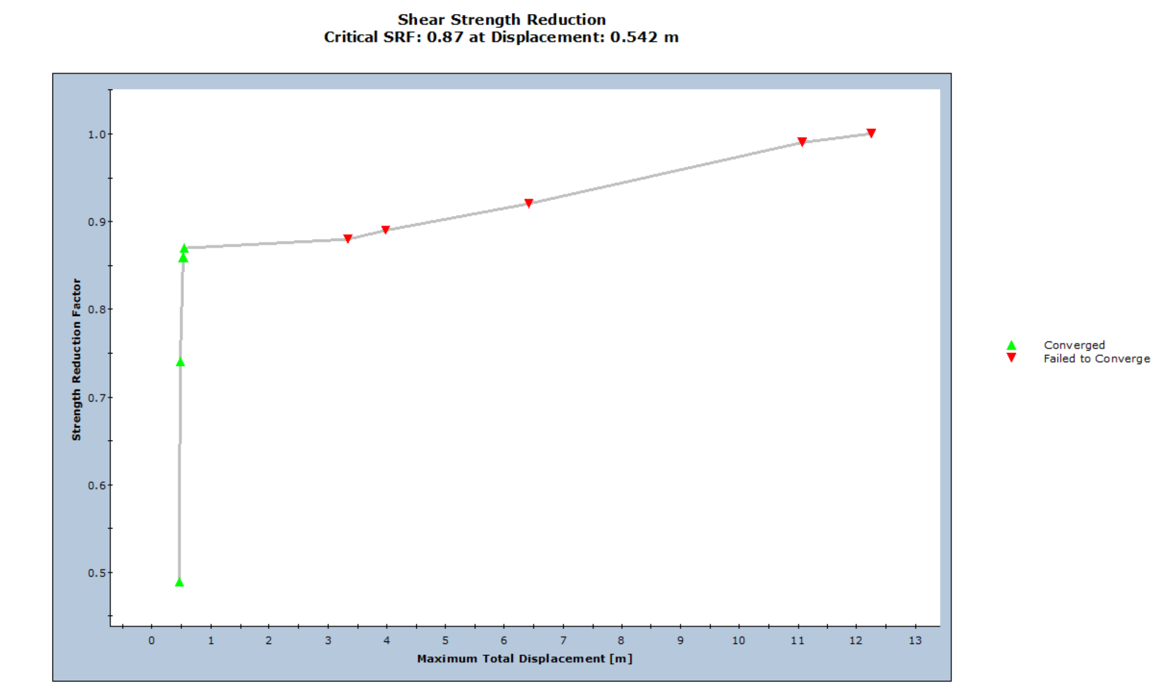


Case 4 – D-P

Figure 8 – Maximum Shear Strain Plot of Case 4



Case 4 – M-C

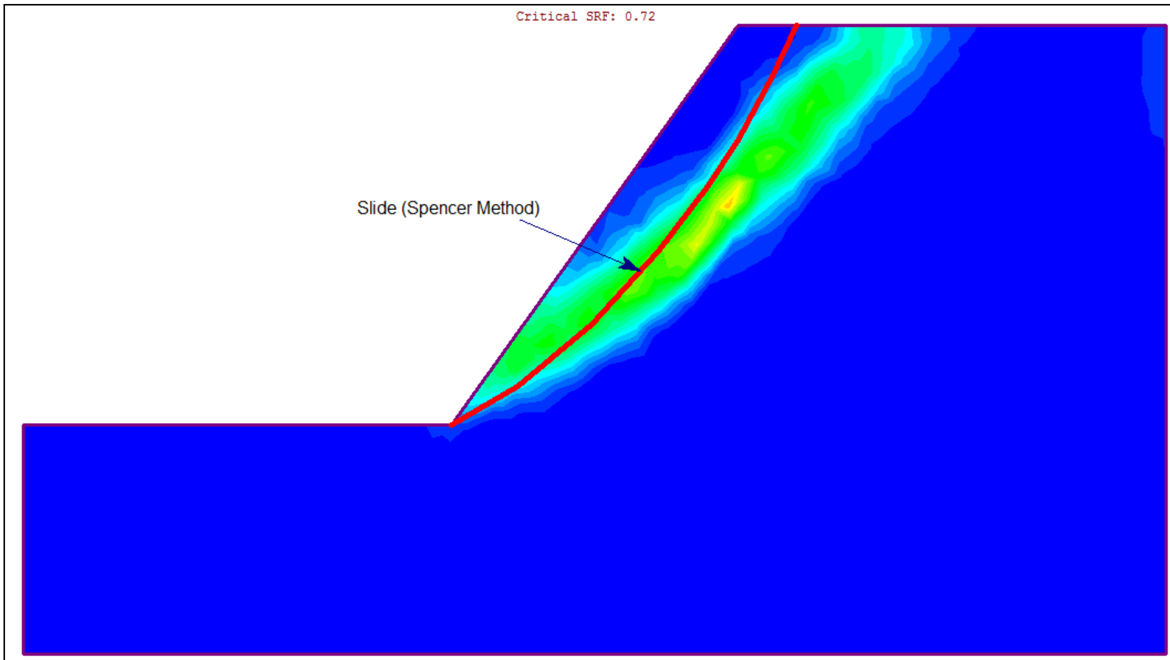


Case 4 – D-P

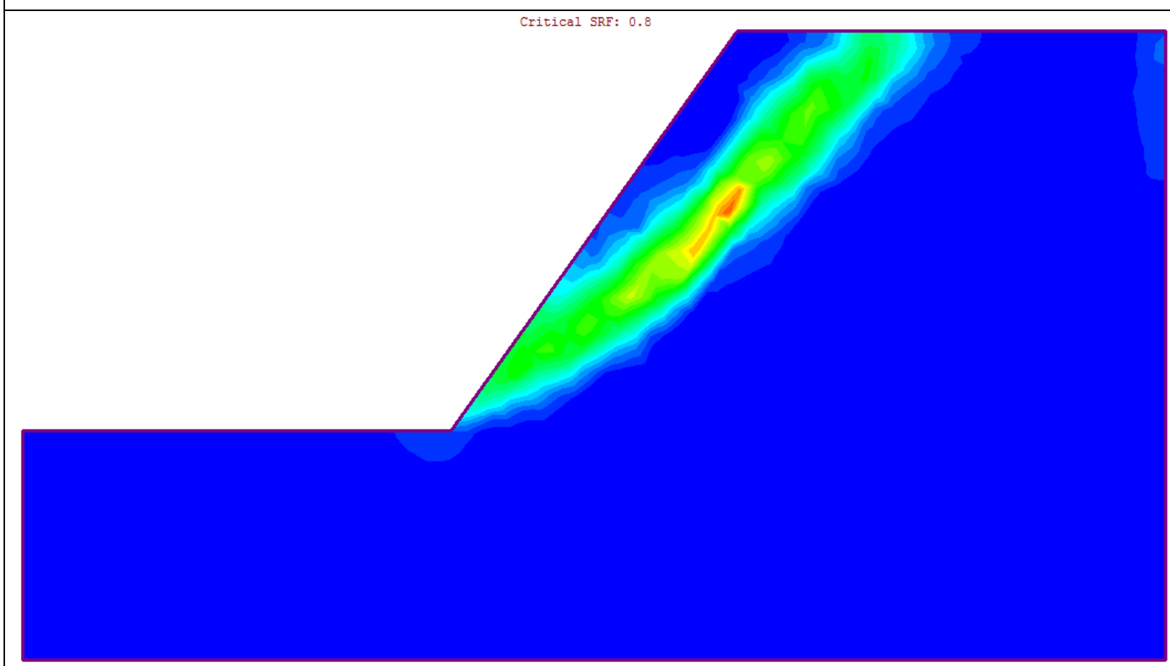
Figure 9 – SSR Convergence Graph of Case 4

Results: Case 5

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
0.73	0.72	0.80	0.75	0.72	0.74	0.73	0.66

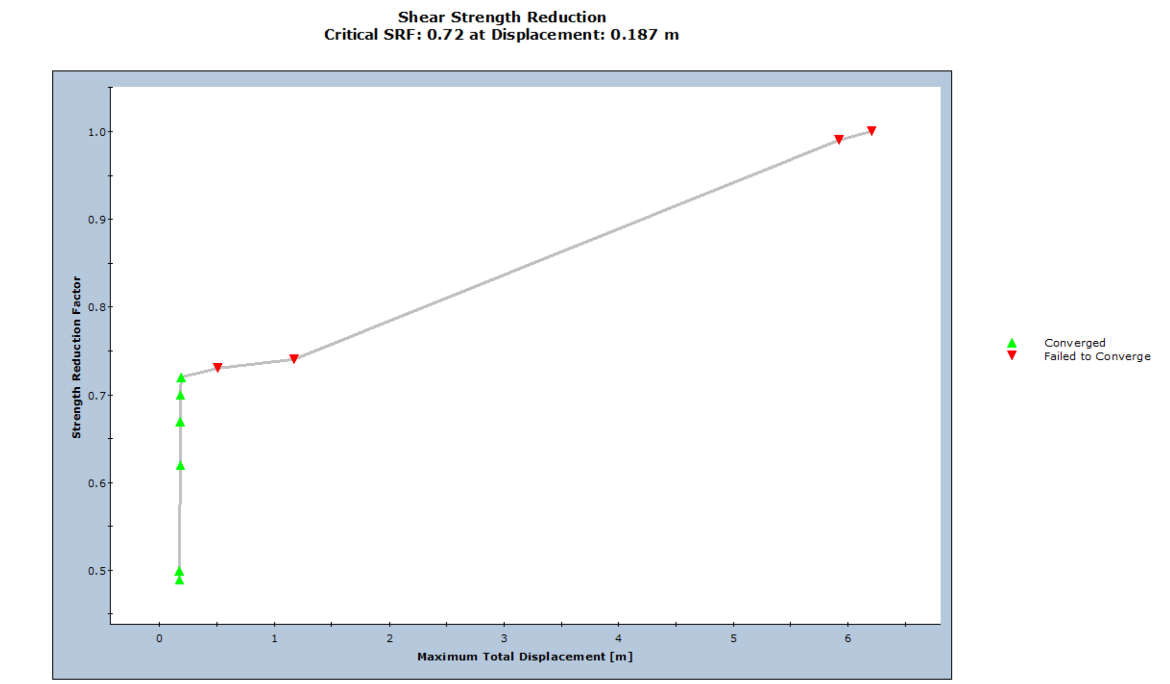


Case 5 – M-C

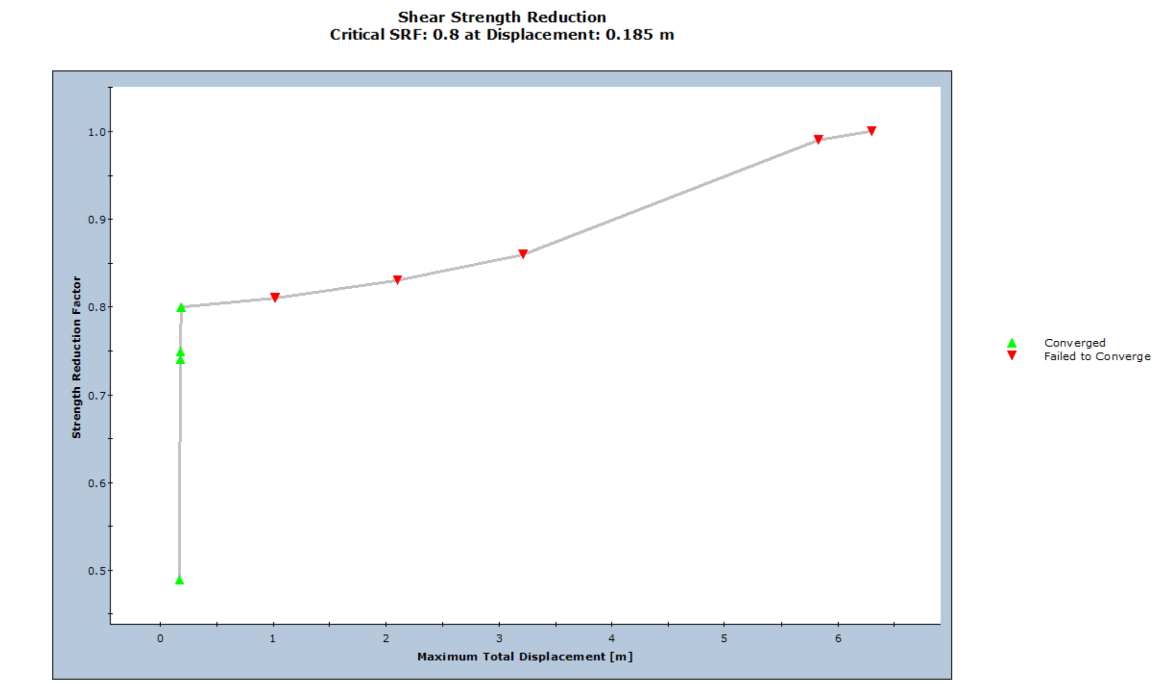


Case 5 – D-P

Figure 10 – Maximum Shear Strain Plot of Case 5



Case 5 – M-C

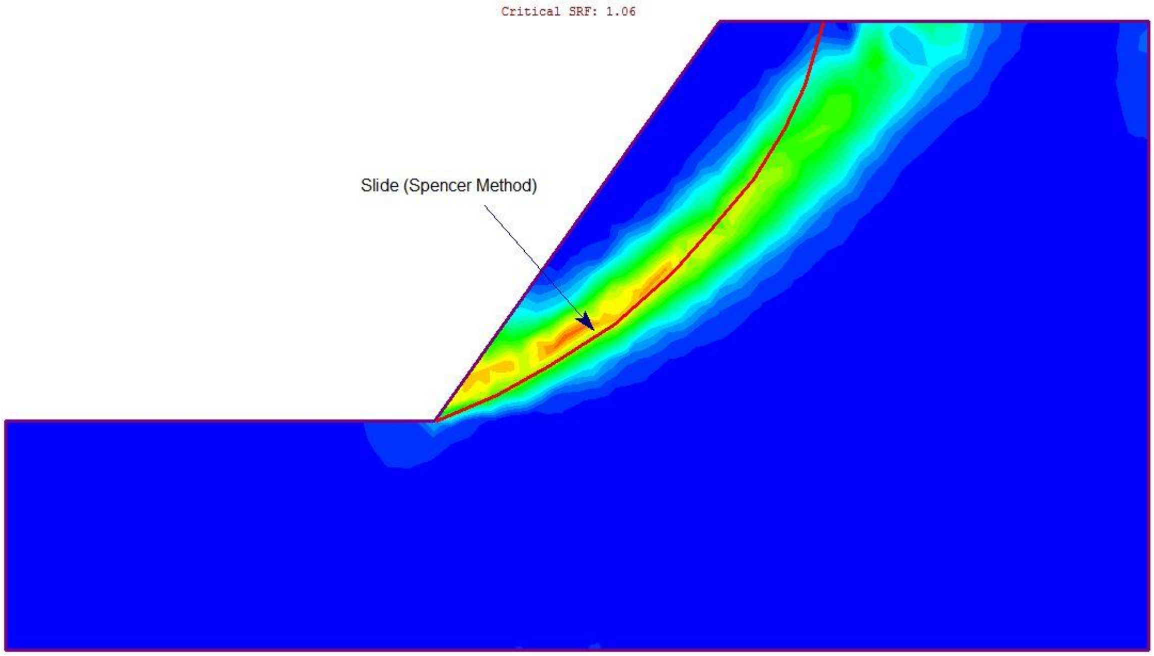


Case 5 – D-P

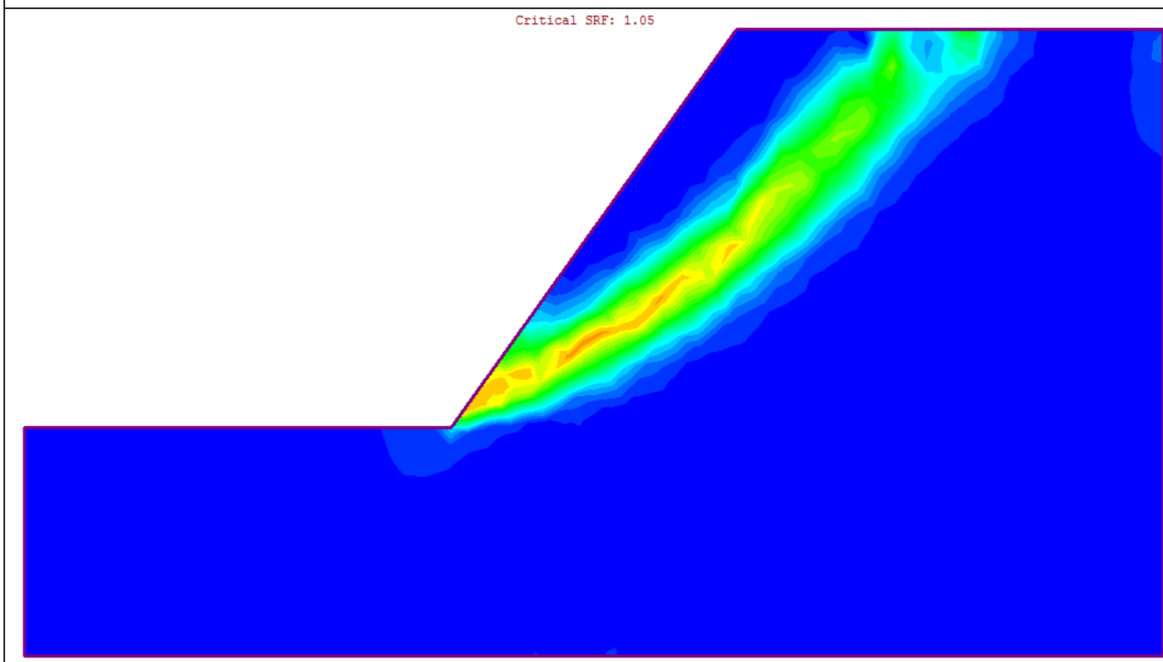
Figure 11 – SSR Convergence Graph of Case 5

Results: Case 6

Slide2	RS2		Z-Soil		Plaxis	GEO FEM	
	M-C	D-P	M-C	D-P	M-C	M-C	D-P
1.08	1.06	1.05	1.07	1.03	1.06	1.10	1.05

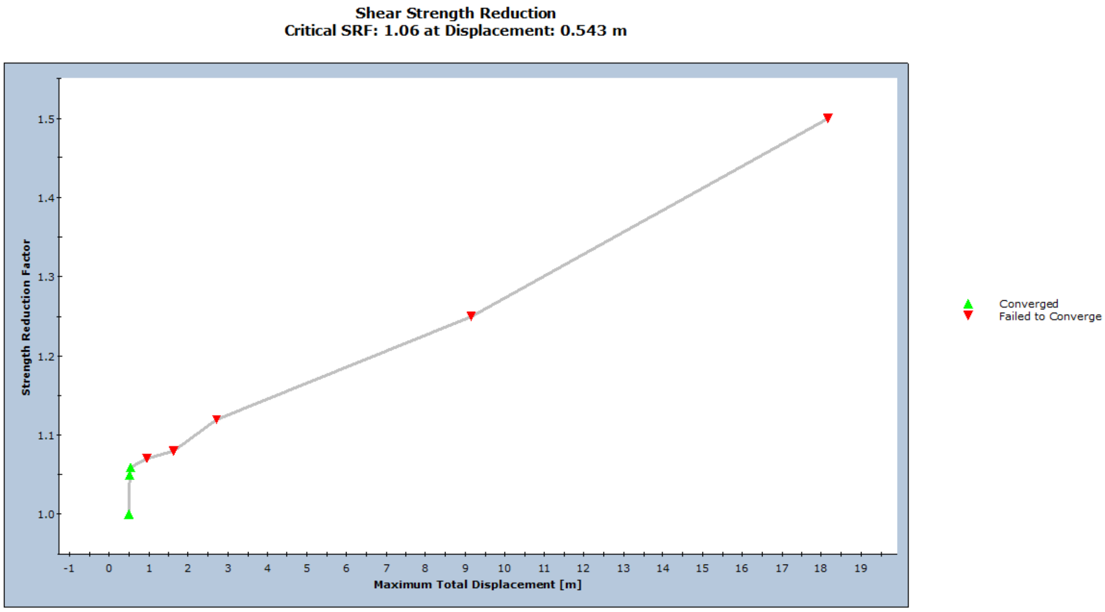


Case 6 – M-C

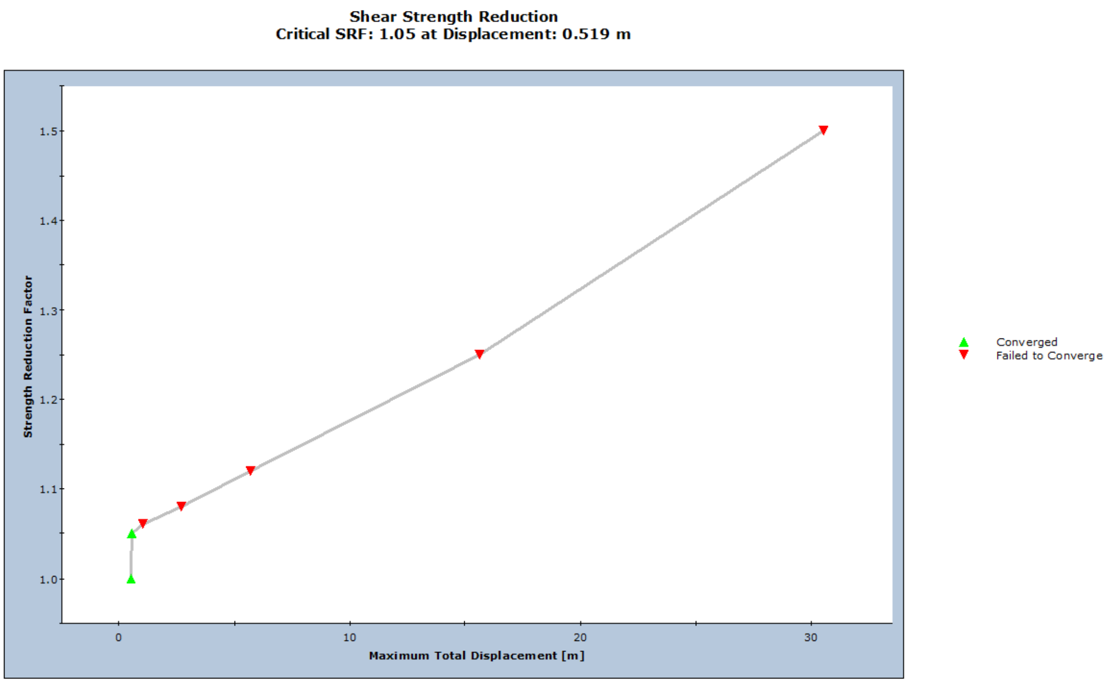


Case 6 – D-P

Figure 12 – Maximum Shear Strain Plot of Case 6



Case 6 – M-C



Case 6 – D-P

Figure 13 – SSR Convergence Graph of Case 6

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1. Duncan, J. M. and Wright, S. G. (2005), "Soil Strength and Slope Stability." John Wiley & Sons, Hoboken, N.J.

2. Leshchinsky, D. and Han, J. (2004), "Geosynthetic Reinforced Multitiered Walls." Journal of Geotechnical and Geoenvironmental Engineering. Vol. 130, No. 12, December, pp. 1225-1235.

3. Pruska, J. (2003), "Comparison of geotechnic softwares – Geo FEM, Plaxis, Z-Soil." Proc. XIII ECSMGE, Vanicek et al. (eds), CGtS, Prague. Vol. 2, August, pp. 819-824.