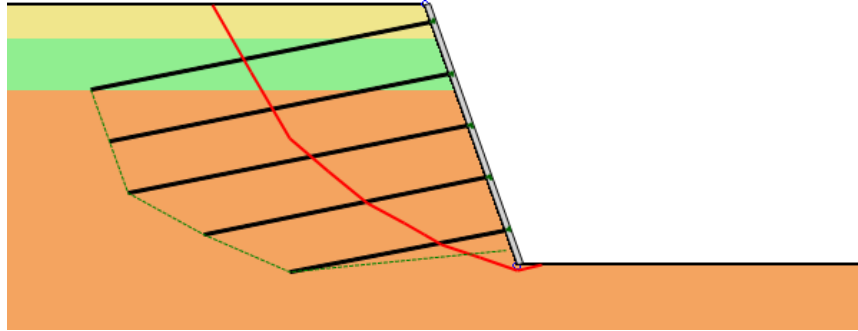


FS= 1.345



## SLOPE STABILITY ANALYSIS MANUAL – EXAMPLES

DeepEX software program (Version 2018)

SnailPlus software program (Version 2018)

Version 18.0.0.1

Issued: 30-May-2018

Deep Excavation LLC



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RELIABLE GEOEXPERTISE

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## A. INTRODUCTION

This document contains a series of verification slope stability problems that have been analyzed using DeepEX. These verification tests come from:

- A set of 5 basic slope stability problems, together with 5 variants, was distributed in the Australian Geomechanics profession and overseas as part of a survey sponsored by ACADS (Association for Computer Aided Design), in 1988. The DeepEX verification problems #1 to #10 are based on these ACADS example problems (Giam & Donald (1989)).
- Published examples found in reference material such as journal and conference proceedings.

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.

All examples are analysed not only in the original, but also in the reversed form, so that the DeepEX can be better verified.

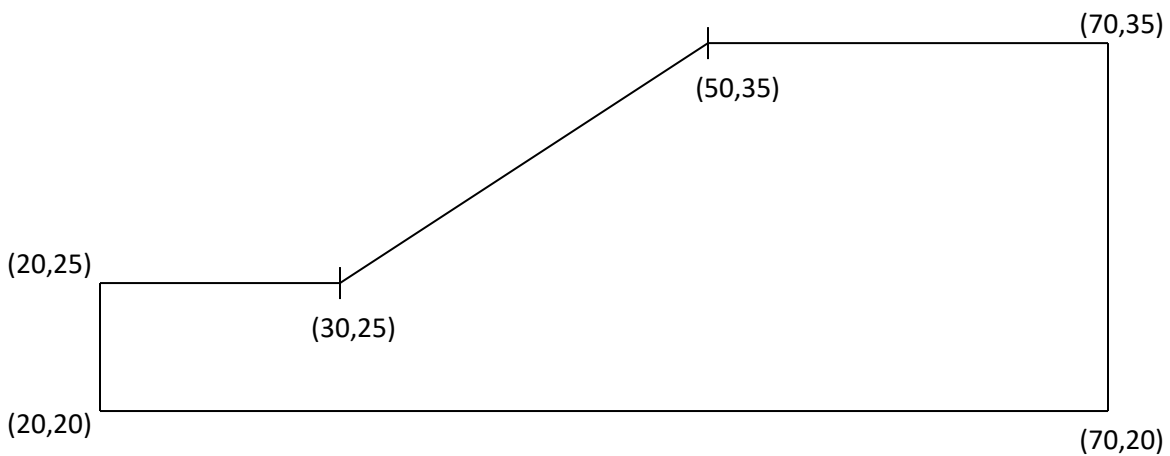
## B. Problem #1: Simple Slope

### B.1 Problem Description

The first problem is the simple case of a total stress analysis without considering pore water pressures. The soil properties are presented in Table 1 and the model of the problem is shown in Figure 1. The factor of safety and its corresponding critical circular failure is required.

**Table B.1: Material Properties**

$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
3.0	19.6	20.0

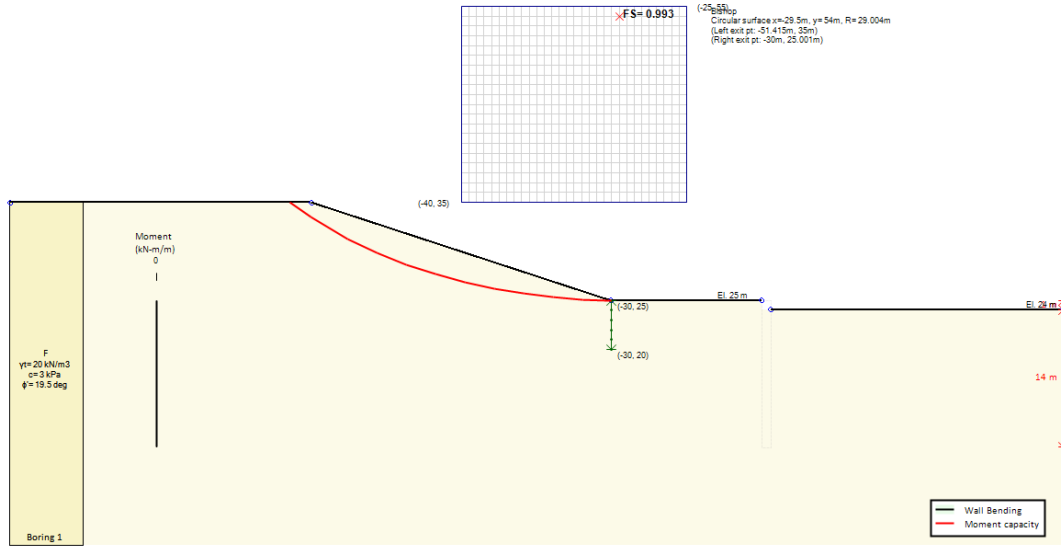


**Figure B.1: Model of the problem**

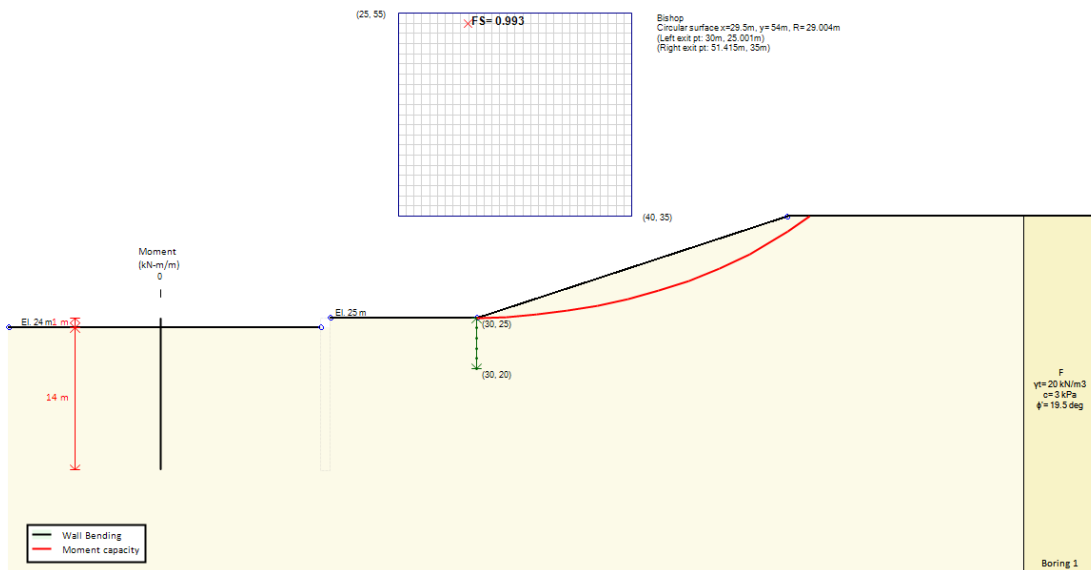
**B.2 Results**

Method: Bishop	Factor of Safety
Normal model	0.993
Reversed model	0.993

Note : Referee Factor of Safety = 1.00 [Giam]  
 Mean Bishop FOS (18 samples) = 0.993  
 Mean FOS (33 samples) = 0.991



**Figure B.2: Normal model solution**



**Figure B.3: Reversed model solution**

**C. Problem #2: Tension crack**

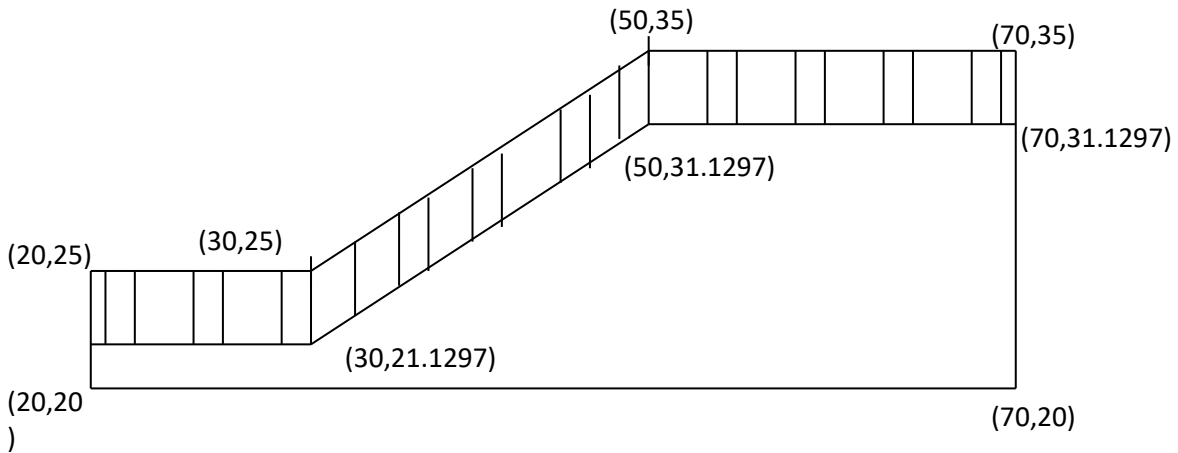
**C.1 Problem Description**

This problem has the exact slope geometry as the Verification problem #2, with the addition of a tension crack zone. A suitable tension crack depth  $D$  is required and it can be estimated from the following equations [Craig (1997)]:

$$D = 2 * c / (\gamma \sqrt{K_a}) , K_a = (1 - \sin\phi) / (1 + \sin\phi)$$

**Table C.1: Material Properties**

$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
3.0	10.0	20.0



**Figure C.1: Model of the problem**

C.2 Results

Method: Bishop	Factor of Safety	Method: MP	Factor of Safety
Normal model	1.618	Normal model	1.555
Reversed model	1.614	Reversed model	1.578

Note : Referee Factor of Safety = 1.65 [Giam]

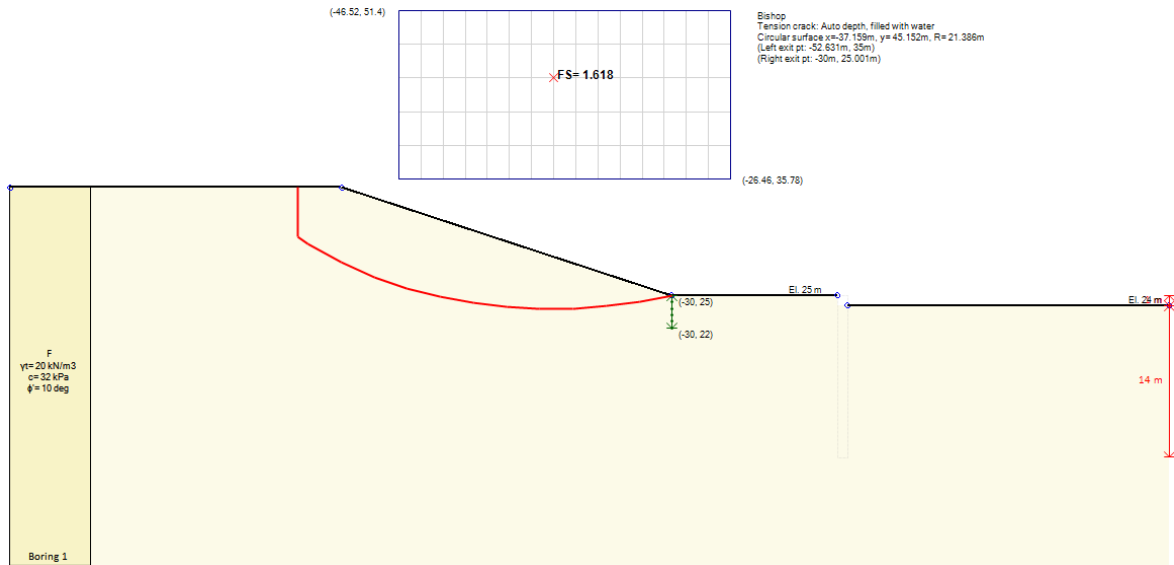


Figure C.2: BISHOP: Normal model solution

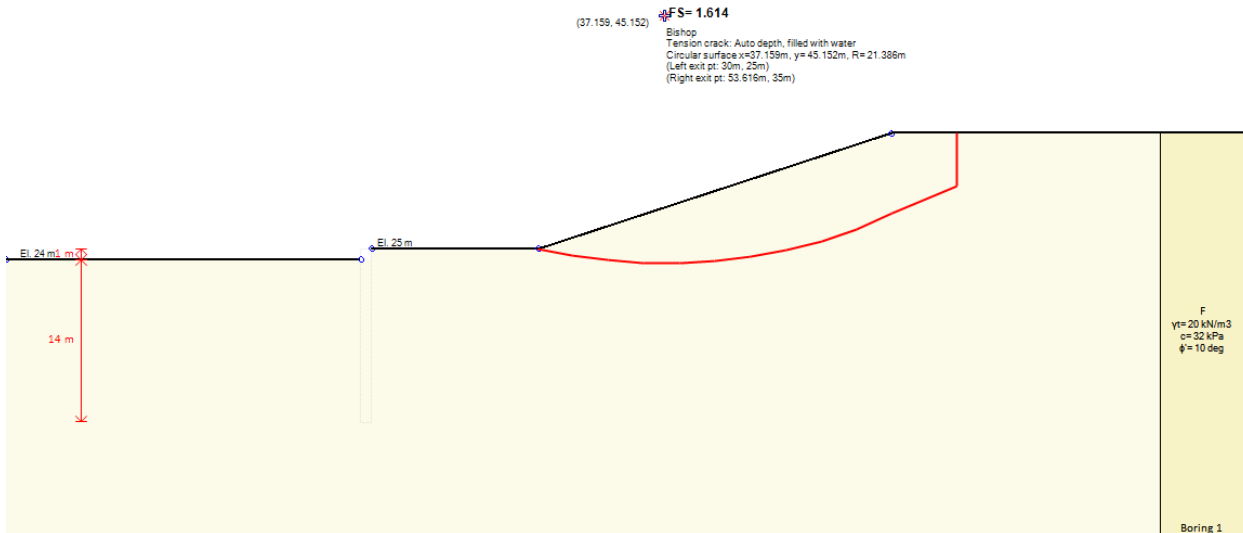


Figure C.3: BISHOP: Reversed model solution

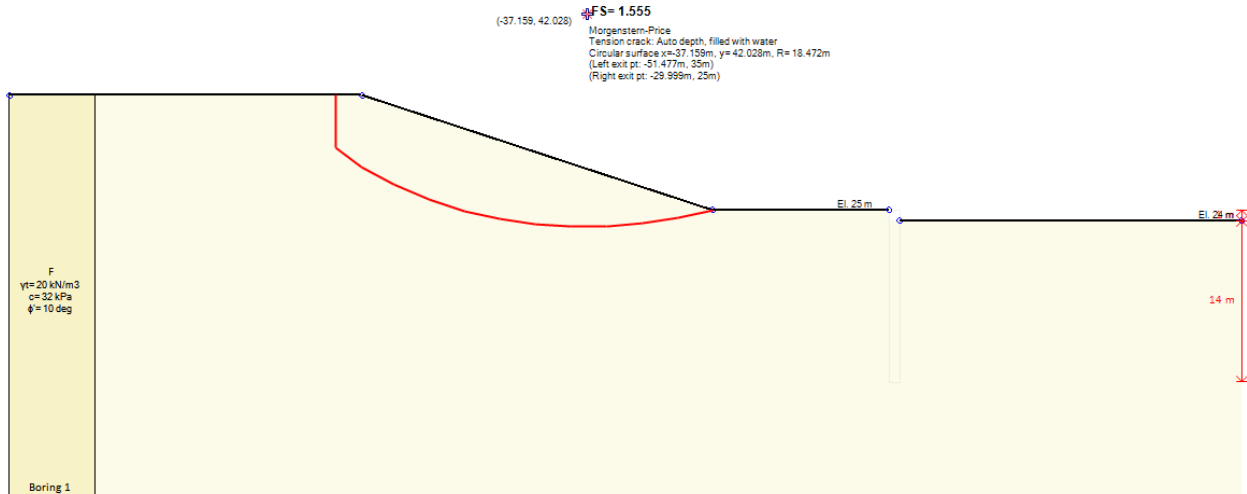


Figure C.4: MP: Normal model solution

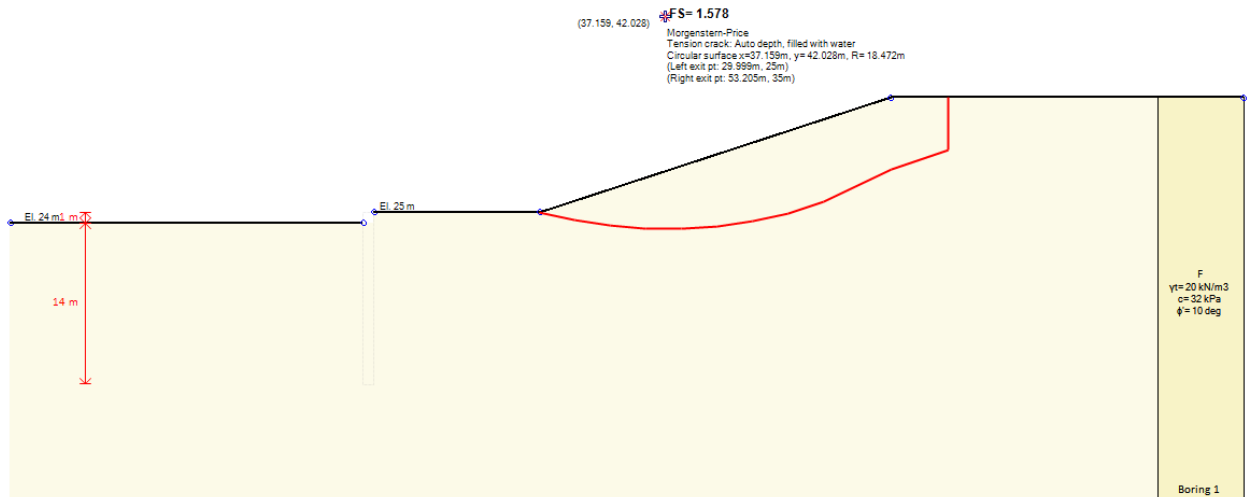


Figure C.5: MP – Reversed model solution



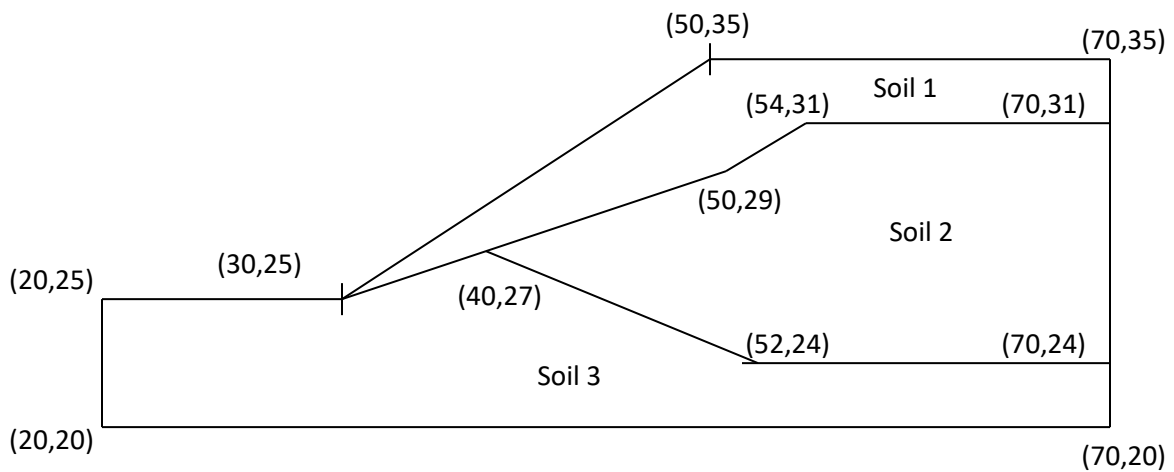
**D. Problem #3: Non-homogeneous**

**D.1 Problem Description**

This problem is a non-homogeneous, three layer slope. The factor of safety and its corresponding critical circular failure surface is required.

**Table D.1: Material Properties**

	$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
Soil 1	0.0	38.0	19.5
Soil 2	5.3	23.0	19.5
Soil 3	7.2	20.0	19.5

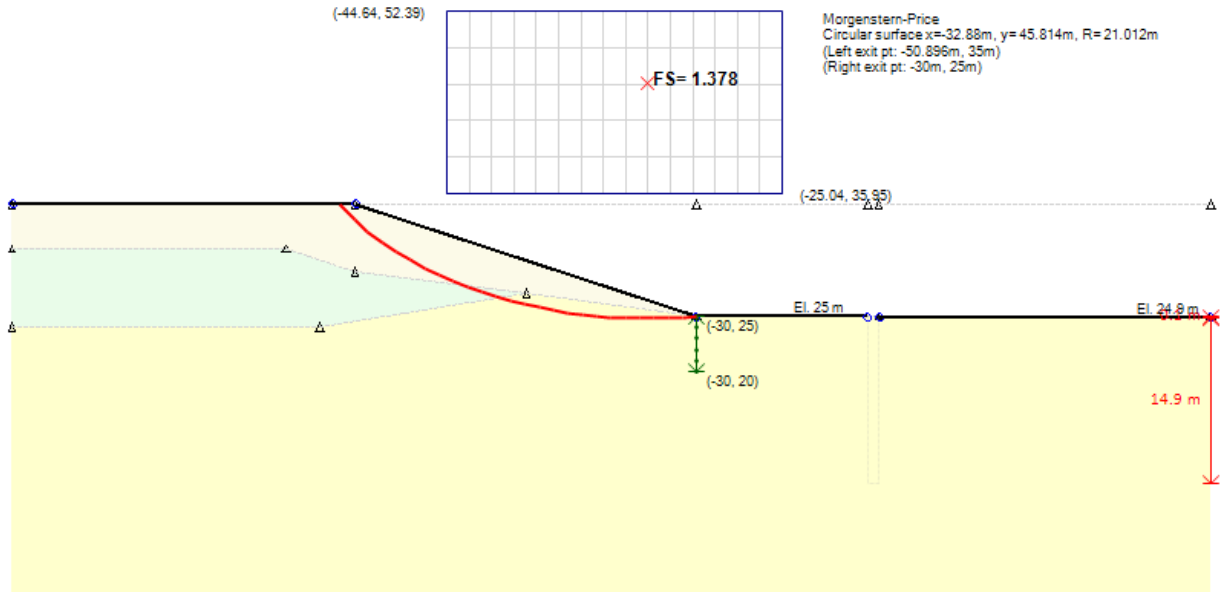


**Figure D.1: Model of the problem**

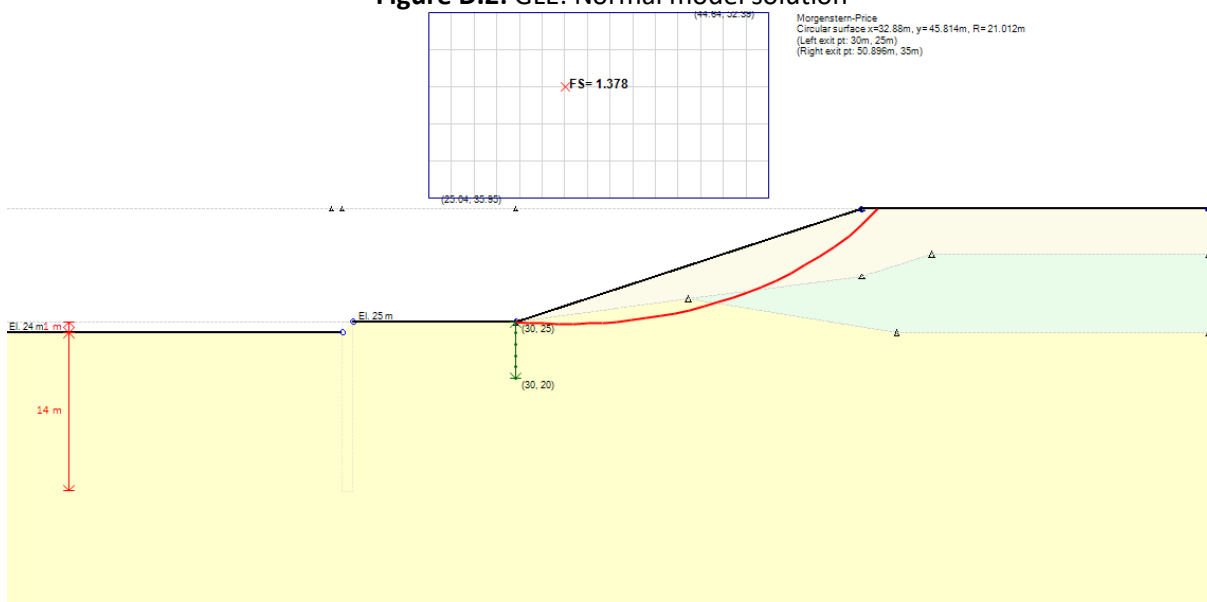
**D.2 Results**

Method: GLE	Factor of Safety
Normal model	1.378
Reversed model	1.378

Note : Referee Factor of Safety = 1.39 [Giam]  
 Mean Bishop FOS (16 samples) = 1.406  
 Mean FOS (31 samples) = 1.381



**Figure D.2: GLE: Normal model solution**



**Figure D.3: GLE – Reversed model solution**

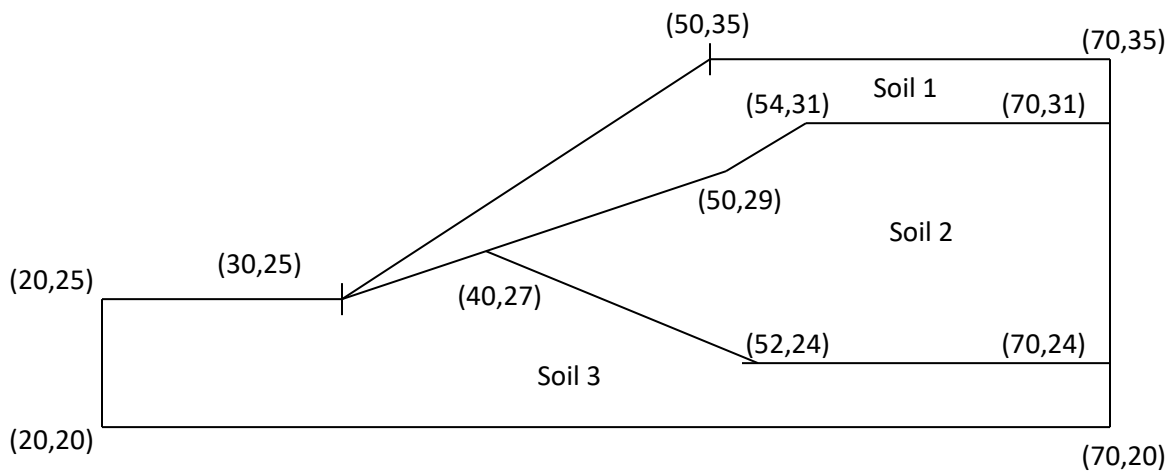
**E. Problem #4: Non-homogeneous with seismic load**

**E.1 Problem Description**

Verification problem #4 is identical to problem #3, but with a horizontal seismically induced acceleration of 0.15g included in the analysis. The factor of safety and its corresponding critical circular failure surface is required.

**Table E.1: Material Properties**

	$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
Soil 1	0.0	38.0	19.5
Soil 2	5.3	23.0	19.5
Soil 3	7.2	20.0	19.5



**Figure E.1: Model of the problem**

E.2 Results

Method: GLE	Factor of Safety	Method: BISHOP	Factor of Safety
Normal model	0.985	Normal model	1.006
Reversed model	0.985	Reversed model	1.006

Note : Referee Factor of Safety = 1.00 [Giam]  
 Mean Bishop FOS (15 samples) = 0.973

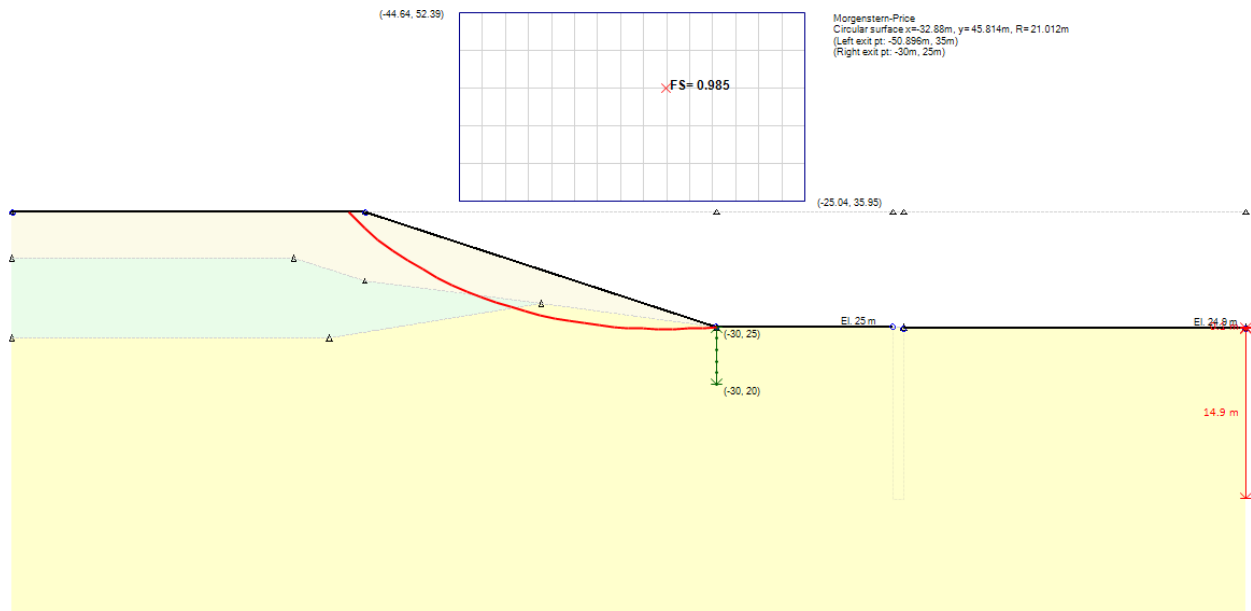


Figure E.2: GLE: Normal model solution

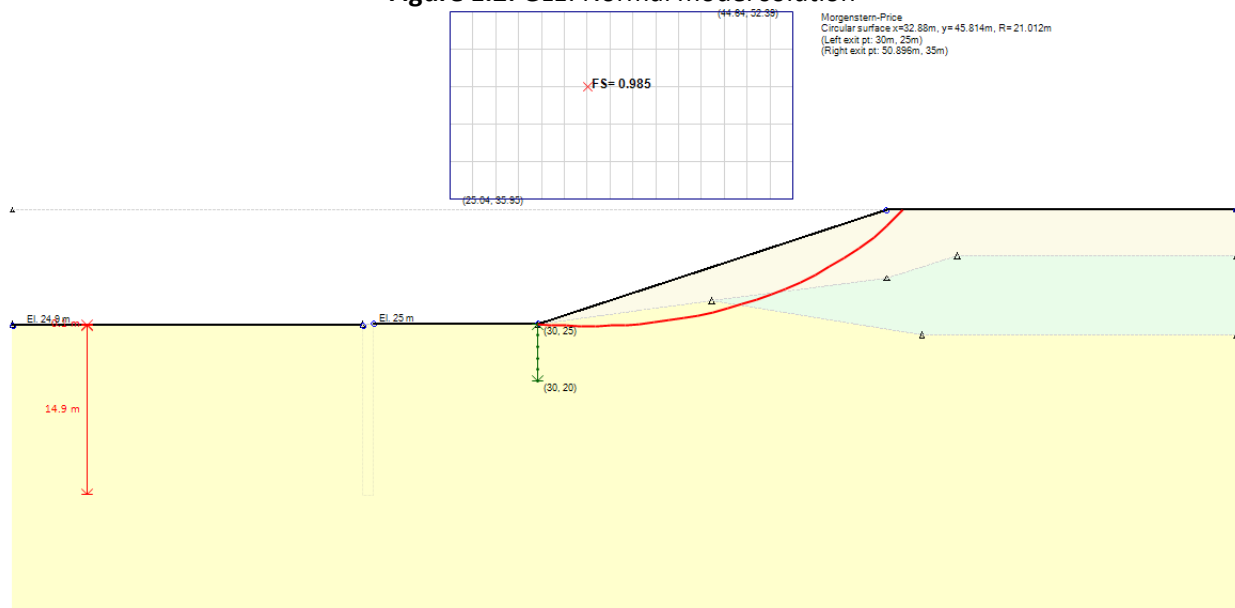


Figure E.3: GLE – Reversed model solution

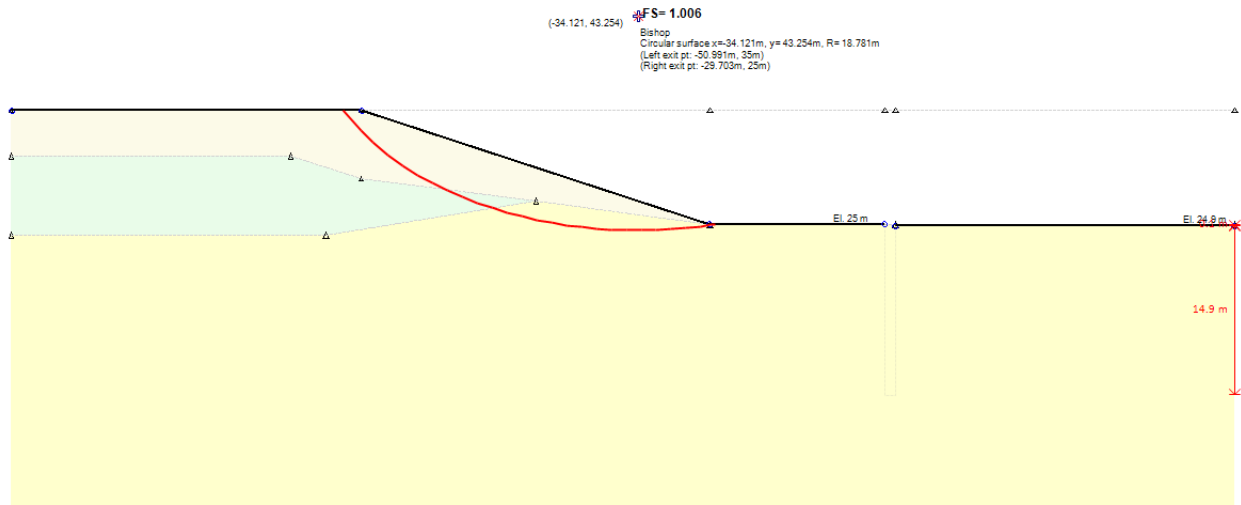


Figure E.4: BISHOP: Normal model solution

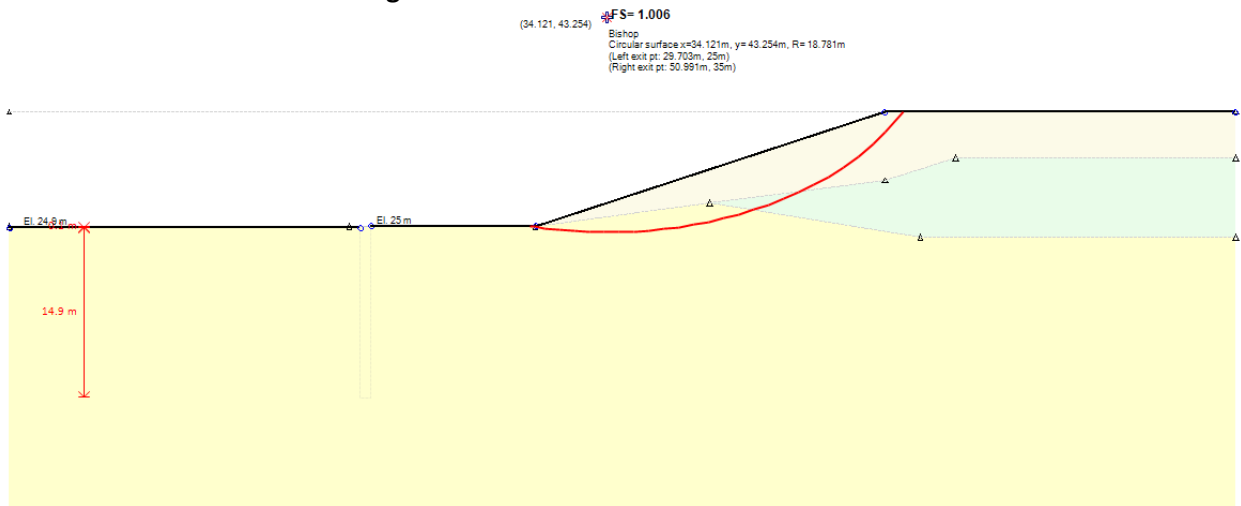


Figure E.5: BISHOP – Reversed model solution

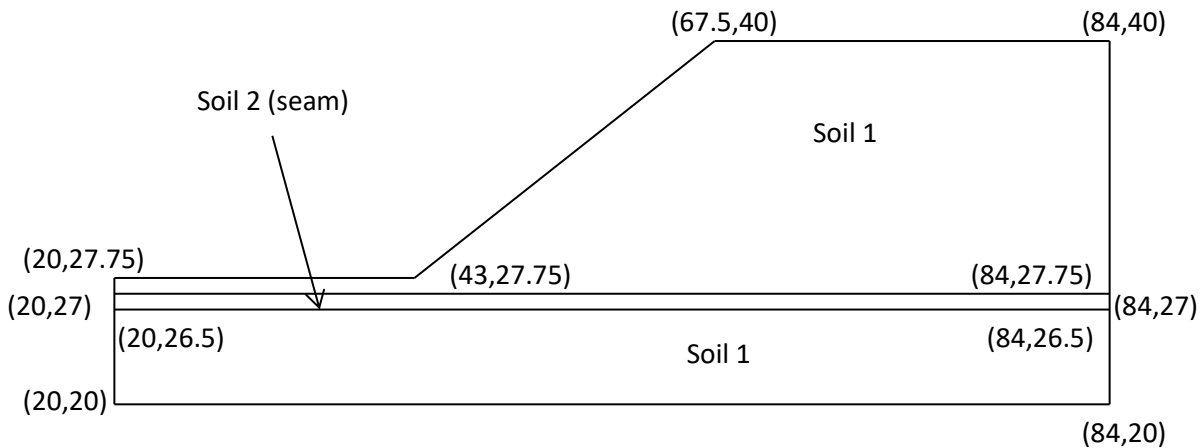
**F. Problem #5: Water table modeled with weak seam**

**F.1 Problem Description**

In this problem, the water table is assumed to coincide with the base of the weak layer. The effect of negative pore water pressure above the water table and the effect of the tension crack is to be ignored. The factor of safety and its corresponding critical non-circular failure surface is required.

**Table F.1: Material Properties**

	$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
Soil 1	28.5	20.0	18.84
Soil 2	0.0	10.0	18.84



**Figure F.1: Model of the problem**

F.2 Results

Method: SPENCER	Factor of Safety
Normal model	1.198
Reversed model	1.195

Note : Referee Factor of Safety = 1.24 – 1.27 [Giam]  
 Mean Non-circular FOS (19 samples) = 1.293

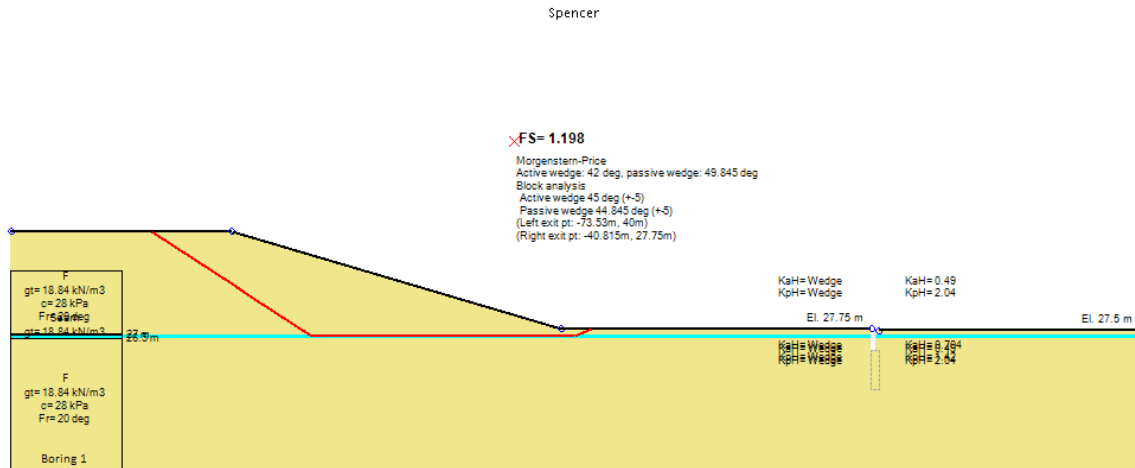


Figure F.2: SPENCER: Normal model solution

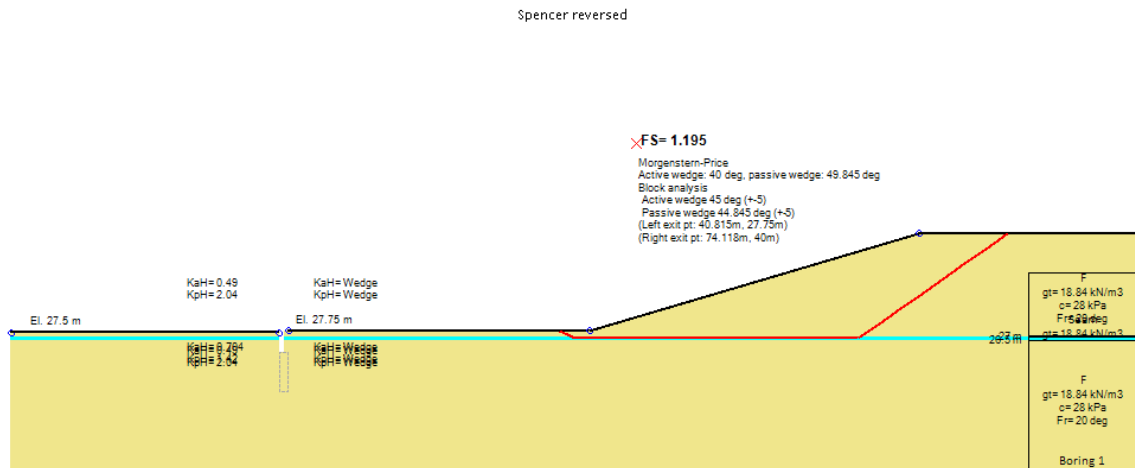


Figure F.3: SPENCER: Reversed model solution

**G. Problem #6: Previous problem with predefined slip surface**

**G.1 Problem Description**

This problem is identical to verification problem #5. The only difference is that a non-circular slip surface of known coordinates is analyzed.

**Table G.1: Material Properties**

	$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
Soil 1	28.5	20.0	18.84
Soil 2	0.0	10.0	18.84

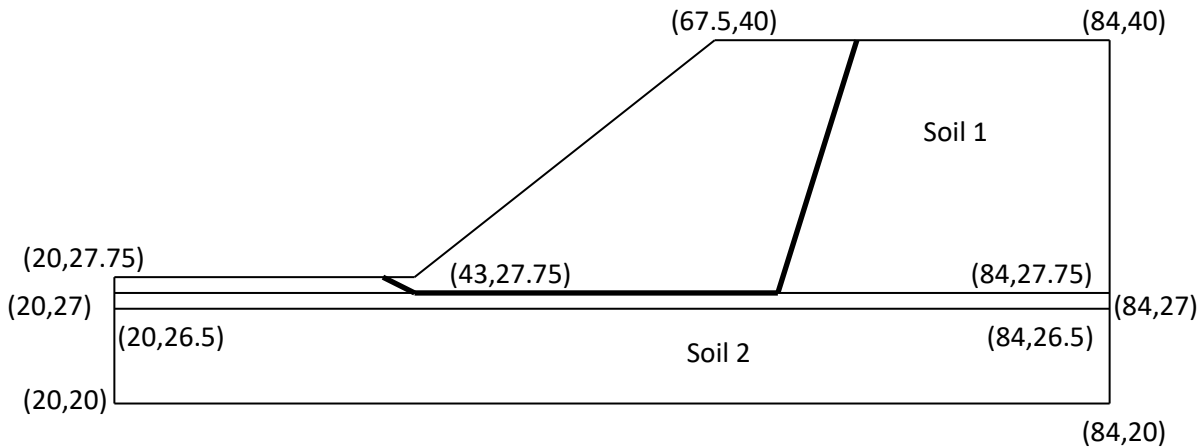


Figure G.1: Model of the problem

**Table G.2: Failure Surface Coordinates**

X (m)	Y (m)
41.85	27.75
44.00	26.50
63.50	27.00
73.31	40.00

Axis of Rotation: (53.3, 45)



G.2 Results

Method: SPENCER	Factor of Safety
Normal model	1.314
Reversed model	1.313

Note : Referee Factor of Safety = 1.34 [Giam]  
 Mean FOS (30 samples) = 1.29

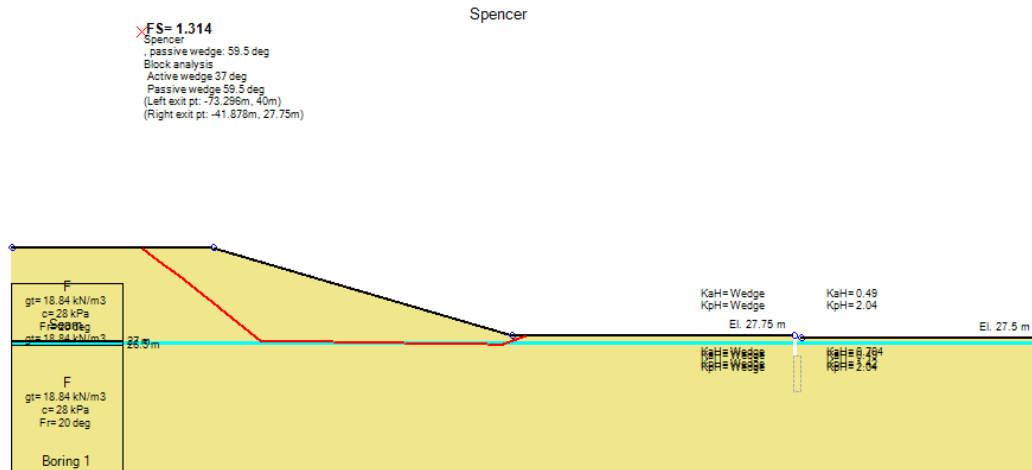


Figure G.2: SPENCER: Normal model solution

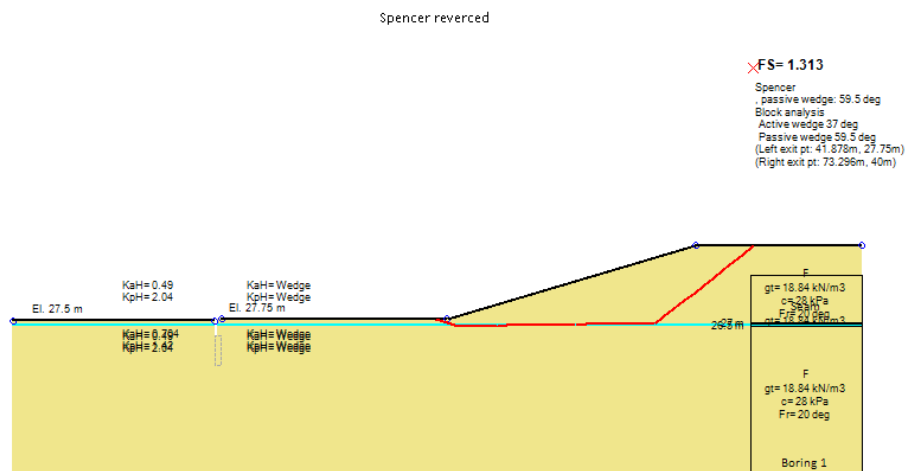


Figure G.3: SPENCER: Reversed model solution

**H. Problem #7: External loading, pore pressure defined by water table****H.1 Problem Description**

The soil parameters of this problem, the external loadings and the piezometric surface are shown in Tables H.1, H.2 and H.3 respectively. The effect of the tension crack is to be ignored. The factor of safety and its corresponding critical non-circular failure surface is required.

**Table H.1: Material Properties**

	$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
Soil 1	28.5	20.0	18.84
Soil 2	0.0	10.0	18.84

**Table H.2: external Loadings**

X (m)	Y (m)	Normal Stress (kN/m <sup>2</sup> )
23.00	27.75	20.00
43.00	27.75	20.00
70.00	40.00	20.00
80.00	40.00	40.00

**Table H.3: Data for Piezometric surface**

Xc (m)	Yc (m)
20.00	27.75
43.00	27.75
49.00	29.8
60.00	34.00
66.00	35.80
74.00	37.60
80.00	38.40
84.00	38.40

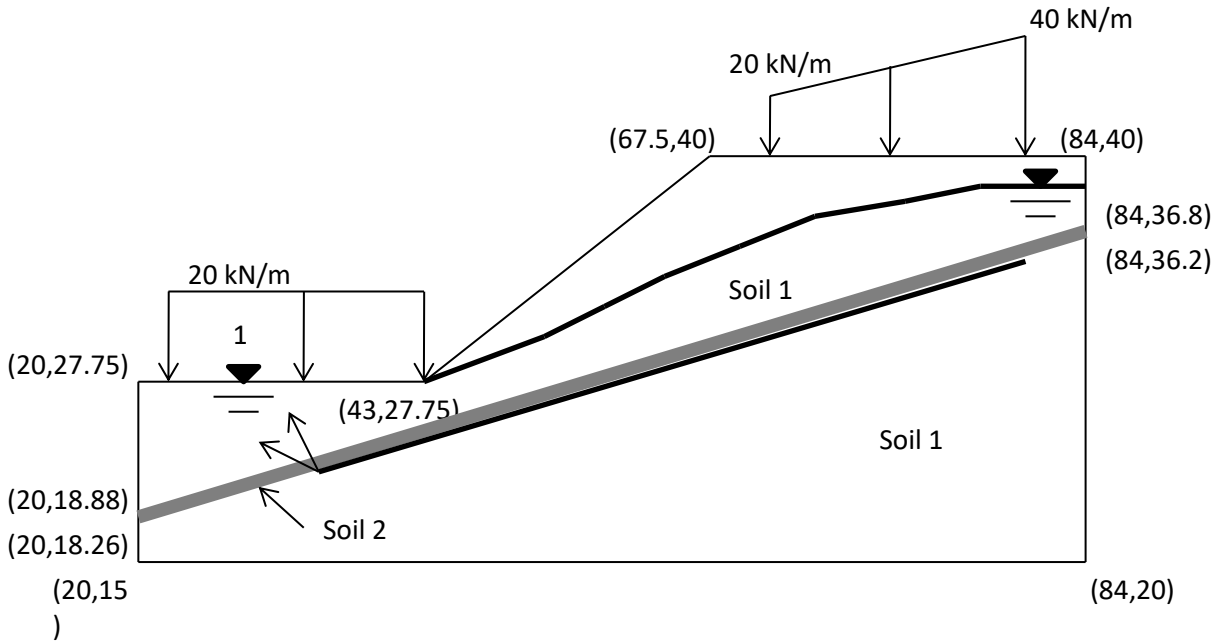


Figure H.1: Model of the problem

## H.2 Results

Method: SPENCER	Factor of Safety
Normal model	0.669
Reversed model	0.663

Note: Referee Factor of Safety = 0.78 [Giam]  
 Mean Non-circular FOS (20 samples) = 0.808  
 Referee GLE Factor of Safety = 0.6878 [Slope 2000]



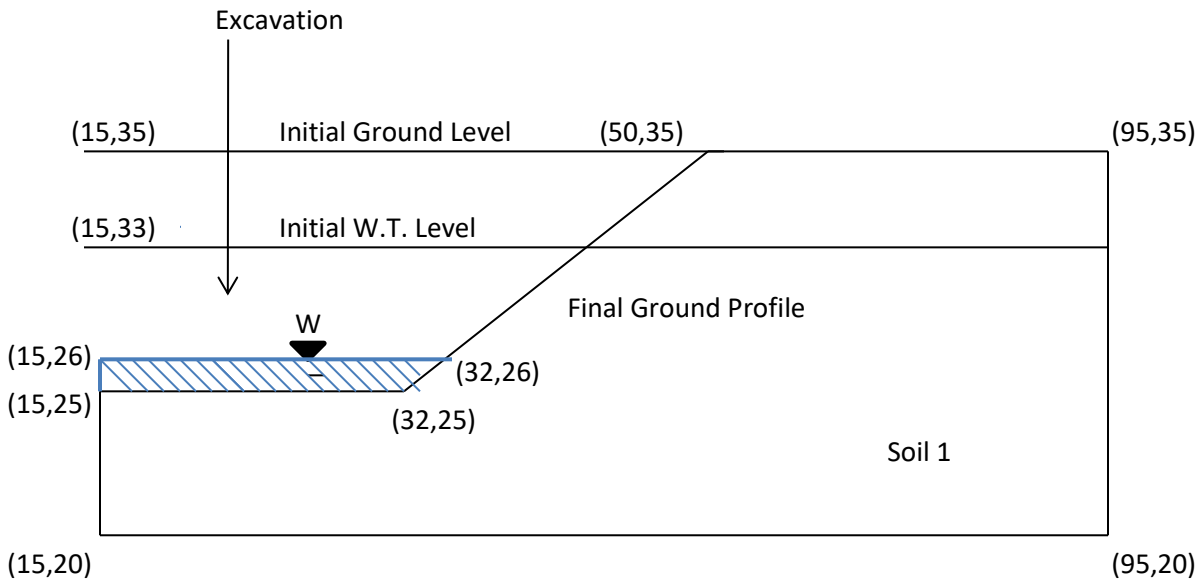
**I. Problem #8: Pore pressure defined by digitized total head grid**

**I.1 Problem Description**

This slope has been excavated at a slope of 1:2 ( $\beta=26.56^\circ$ ) below an initially horizontal ground surface. The position of the critical slip surface and the corresponding factor of safety are required for the long term condition, i.e. after the ground water conditions have stabilized. Grid interpolation is done with TIN triangulation. The critical slip surface (circular) and the corresponding factor of safety are required.

**Table I.1: Material Properties**

$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
11.0	28.0	20.00



**Figure I.1: Model of the problem**

I.2 Results

Method: SPENCER	Factor of Safety	Method: GLE	Factor of Safety	Method: BISHOP	Factor of Safety
Normal model	1.433	Normal model	1.429	Normal model	1.496
Reversed model	1.428	Reversed model	1.427	Reversed model	1.418

Note: Referee Factor of Safety = 1.53 [Giam]  
 Mean FOS (23 samples) = 1.464

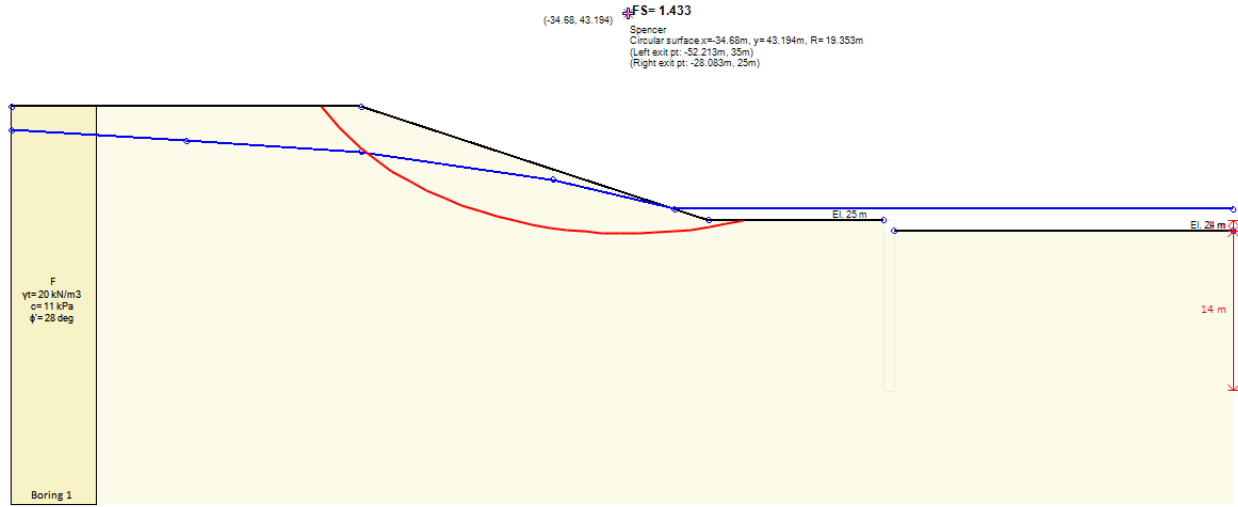


Figure I.2: SPENCER: Normal model solution

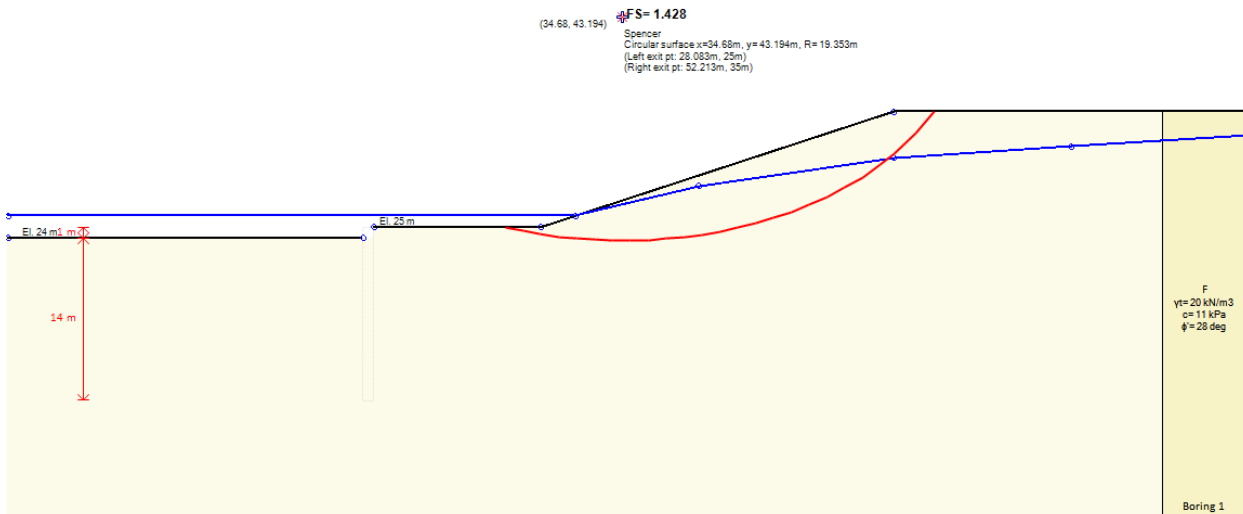


Figure I.3: SPENCER: Reversed model solution

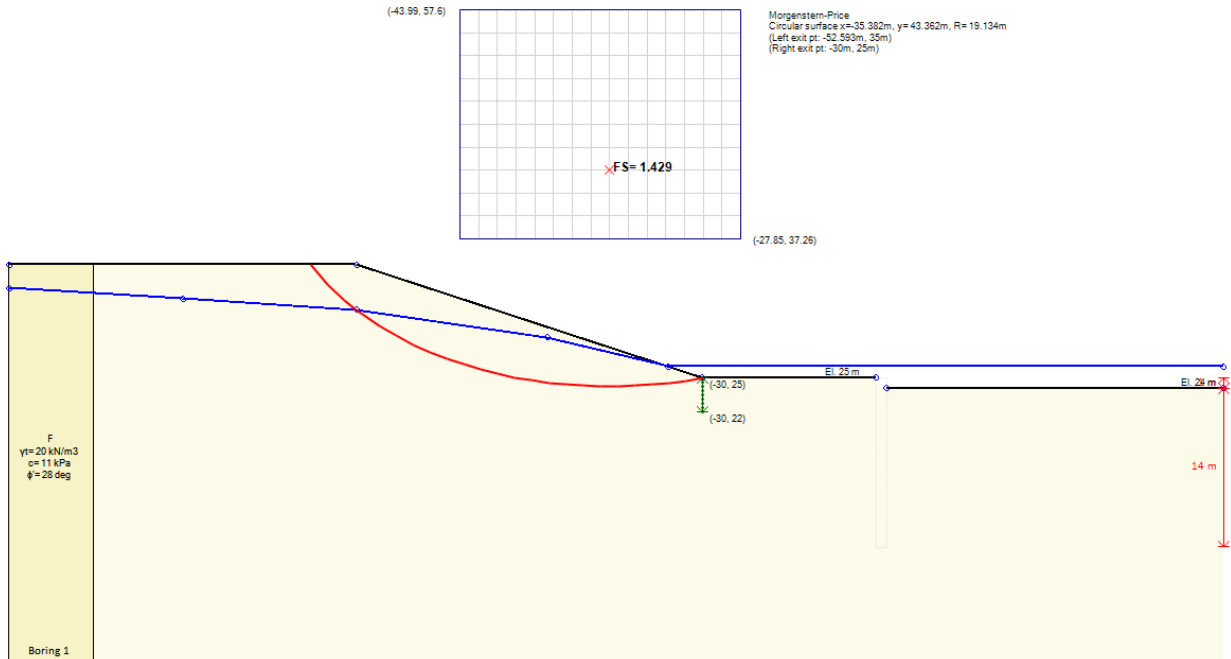


Figure I.4: GLE: Normal model solution

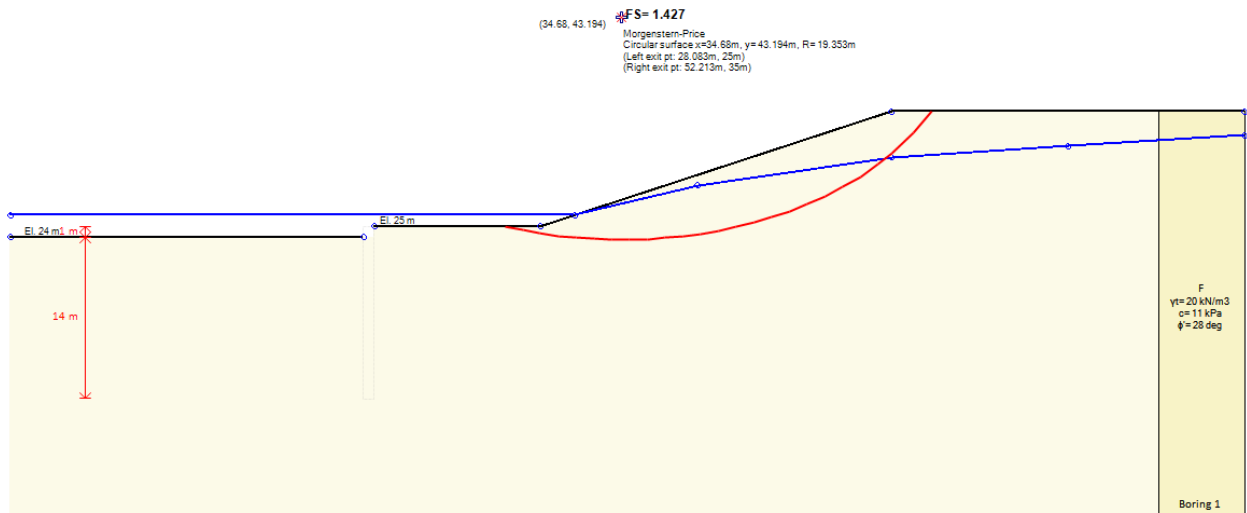


Figure I.5: GLE: Reversed model solution

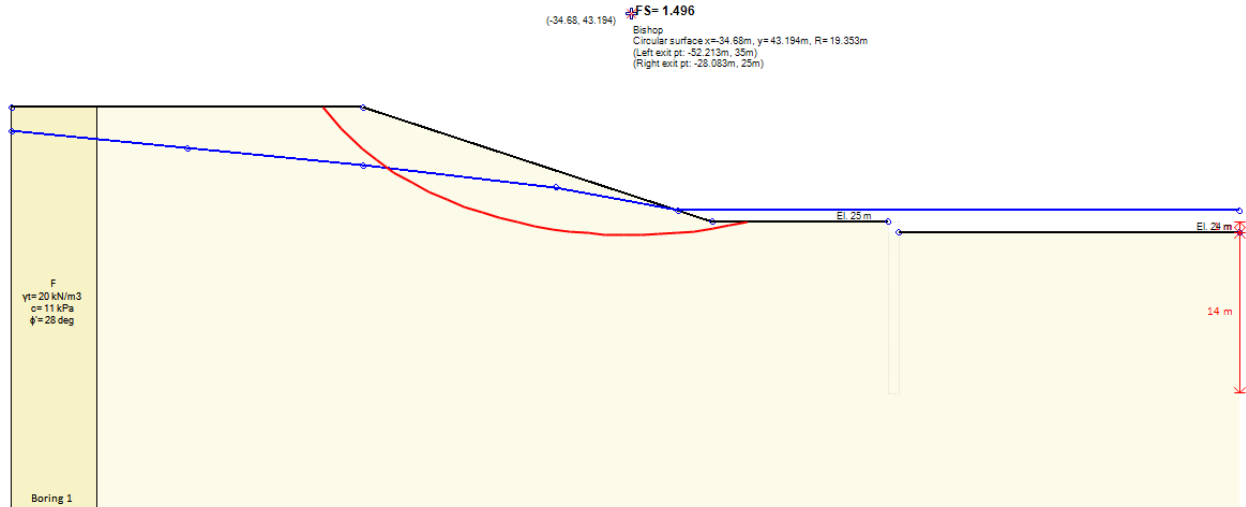


Figure I.6: BISHOP: Normal model solution

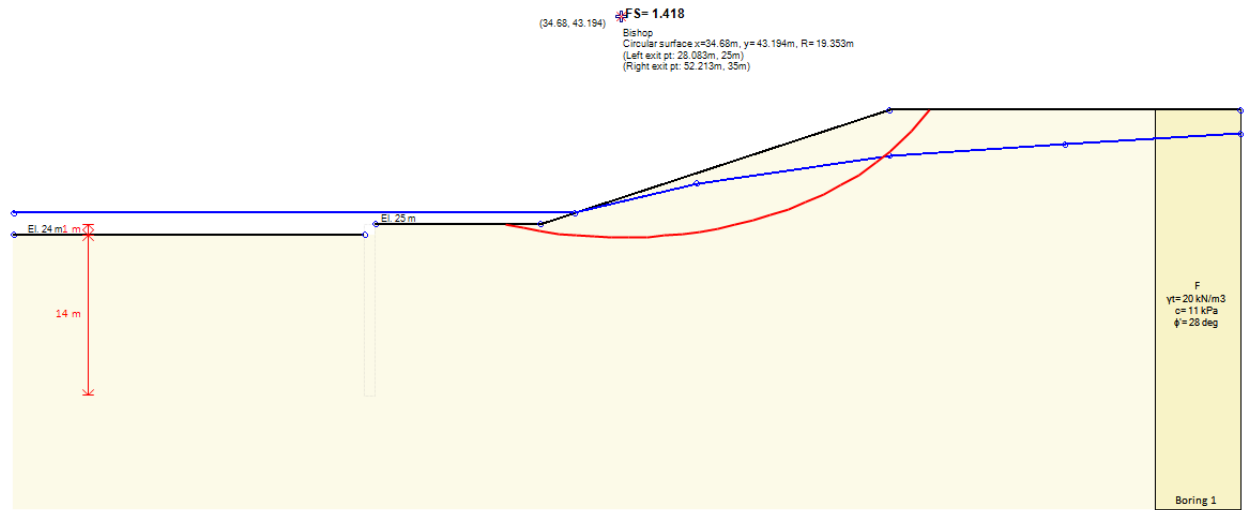


Figure I.7: BISHOP: Reversed model solution



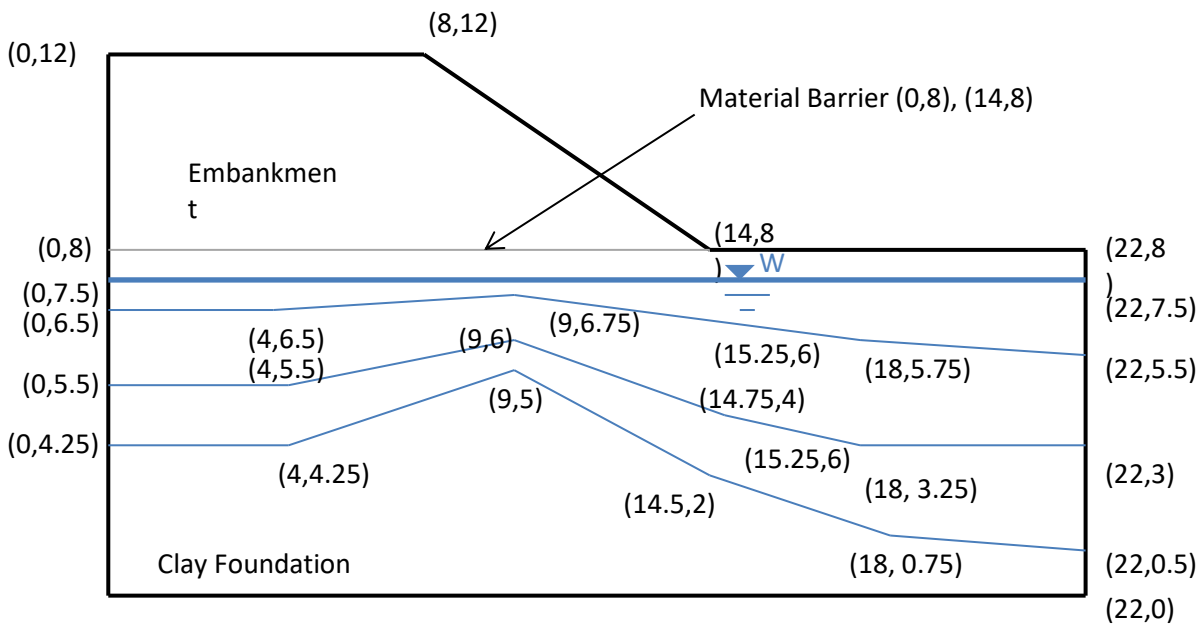
**J. Problem #9: Pore pressure defined by pore pressure grid**

**J.1 Problem Description**

The material properties of this problem are given in Table J.1. The position of the critical slip surface and the corresponding factor of safety are required. Pore water pressures were derived from the given equal pore pressure lines on Figure 11. using the Thin-Plate Spline interpolation method.

**Table J.1: Material Properties**

	$c'$ (kN/m <sup>2</sup> )	$\phi'$ (deg.)	$\gamma$ (kN/m <sup>3</sup> )
Embankment	0.0	44.0	18.8
Clay foundation	2.0	28.0	16.68

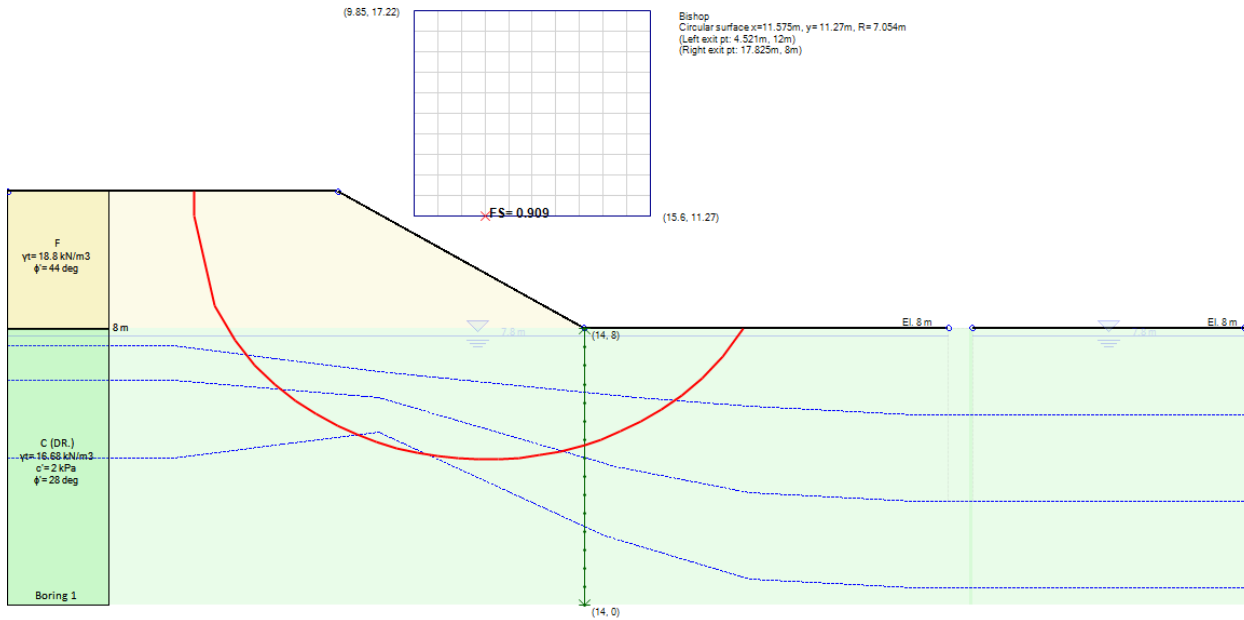


**Figure J.1: Model of the problem**

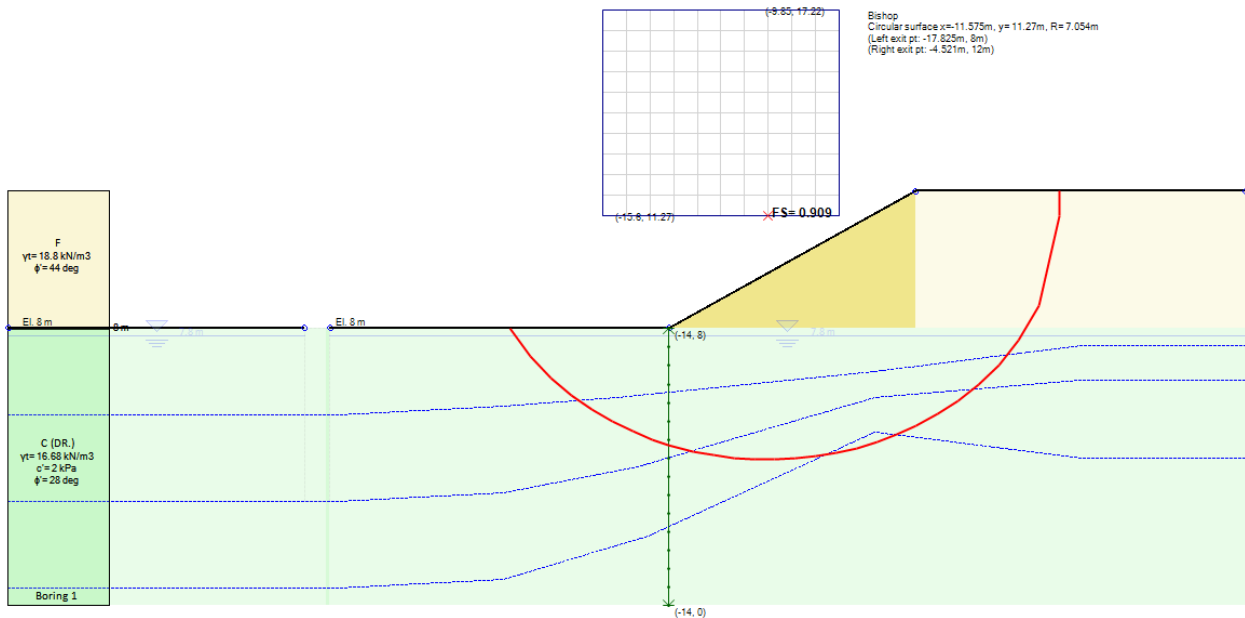
**J.2 Results**

Method: SPENCER	Factor of Safety
Normal model	0.909
Reversed model	0.909

Note: Referee Factor of Safety = 1.04 [Pilot]



**Figure J.2: SPENCER: Normal model solution**



**Figure J.3: SPENCER: Reversed model solution**

**K. Problem #10: Verification example with soil nails from FHWA soil nailing manual**

**K.1 Problem Description**

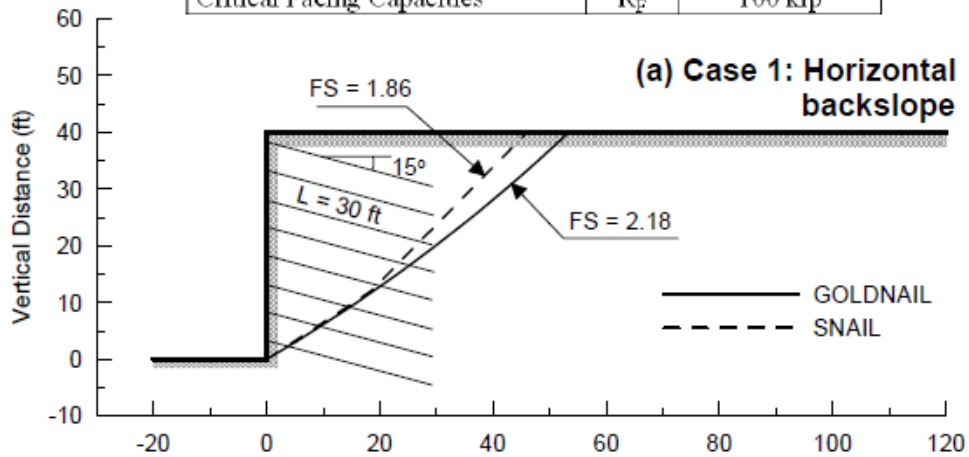
The material properties of this problem are given in Table k.1. The position of the critical slip surface and the corresponding factor of safety are required. A safety factor of 2 is used in the soil nail skin resistance.

**Table K.1: Material Properties**

	$c'$ (ksf)	$\phi'$ (deg.)	$\gamma$ (pcf)	$q_{\text{Skin Ult}}$ (psi)
Sand	0.1	32	120	50

All soil nails have  $F_y = 60$  ksi and an area of  $1 \text{ in}^2$ . The horizontal spacing is assumed at 5 ft.

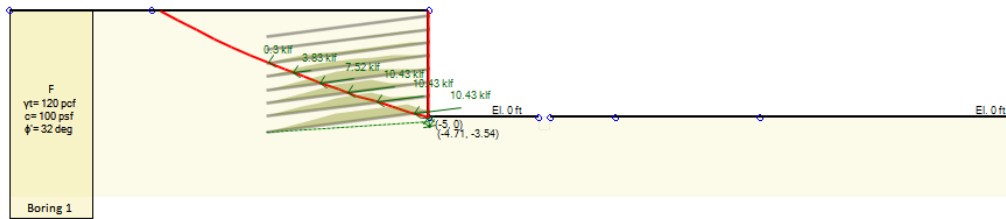
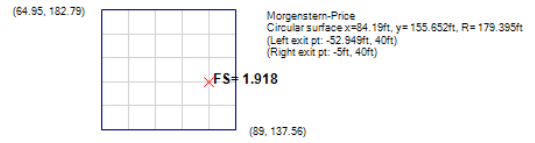
Soil unit weight	$\gamma$	120 pcf
Soil friction angle	$\phi^\circ$	32 degrees
Soil cohesion	$c$	100 psf
Drillhole Diameter	$D_{\text{DH}}$	4 inch
Bond Ultimate Strength	$q_b$	50 psi
Pullout Safety Factor	$FS_p$	2.0
Nail Bar Length	$L$	30 ft
Nail Bar Cross-Sectional Area	$A_t$	$1.0 \text{ in}^2$
Steel yield strength	$f_y$	60 ksi
Critical Facing Capacities	$R_F$	100 kip



**Figure K.1: Model of the problem**

**K.2 Results**

Method: MP	Factor of Safety
Normal model	1.918
Reversed model	-



**Figure K.2:** Results with DeepEX