Slope stability verification manual

DeepXcav software program (Version 2011)

(ParatiePlus within Italy)

Version 1.0

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Deep Excavation LLC

www.deepexcavation.com

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A. INTRODUCTION

This document contains a series of verification slope stability problems that have been analyzed using DeepXCav 2010. 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 DeepXCav 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 DeepXCav can be better veriffied.

B. Slope verification 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/m²)	ϕ′ (deg.)	γ (kN/m³)
3.0	19.6	20.0

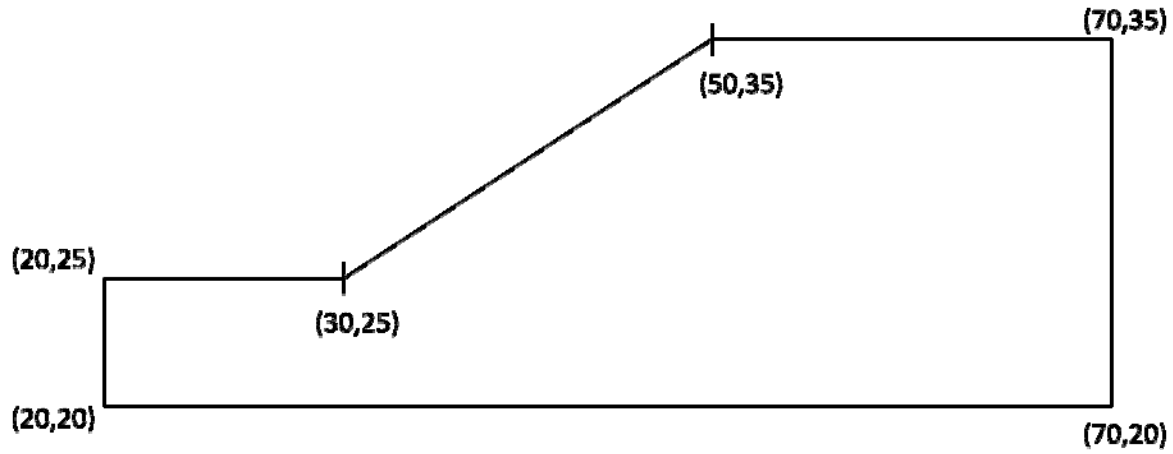


Figure B.1- Model of the problem

B.2 Results

Method: Bishop	Factor of Safety
Normal model	0.978
Reversed model	0.994

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

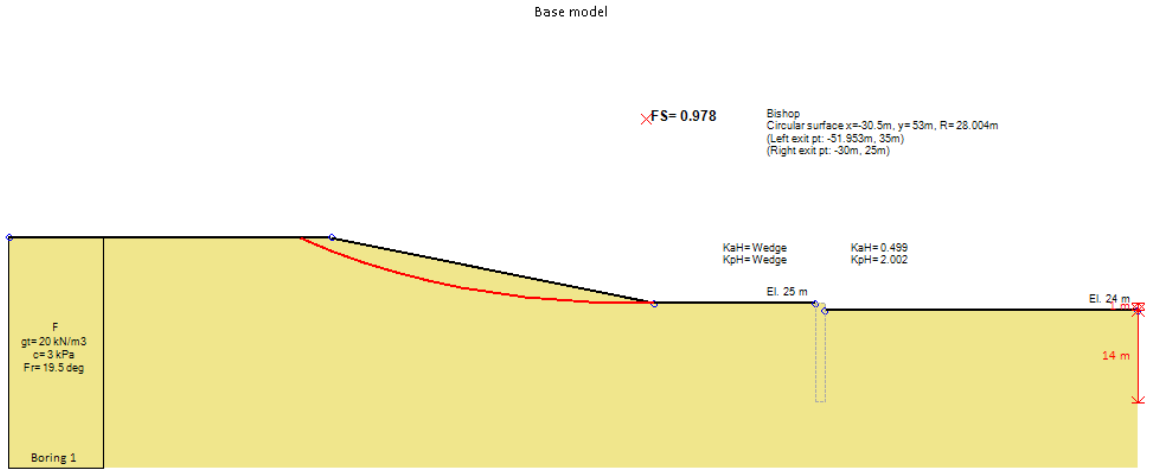


Figure B.2 – Normal model solution

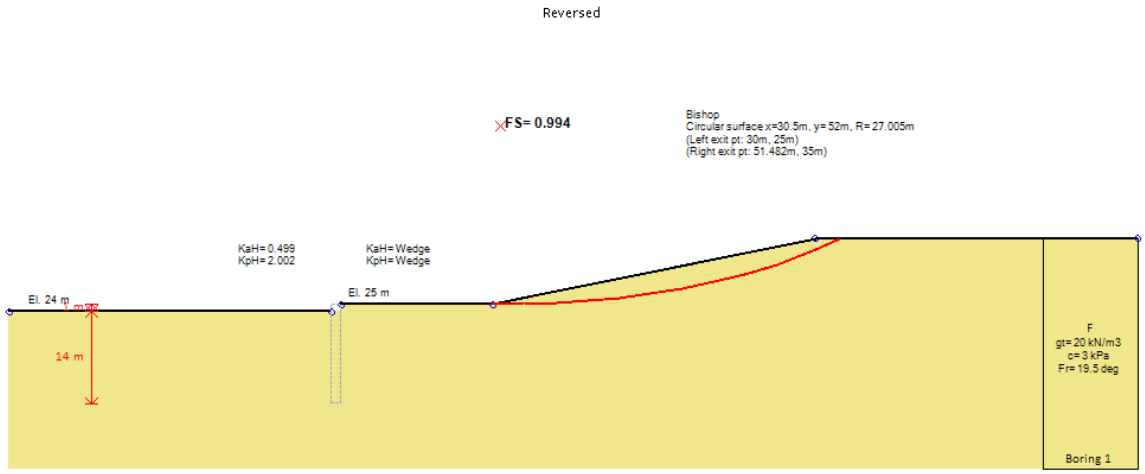


Figure B.3 – Reversed model solution

C. Slope verification 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)]:

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

Table C.1: Material Properties

c′ (kN/m²)	ϕ′ (deg.)	γ (kN/m³)
3.0	10.0	20.0

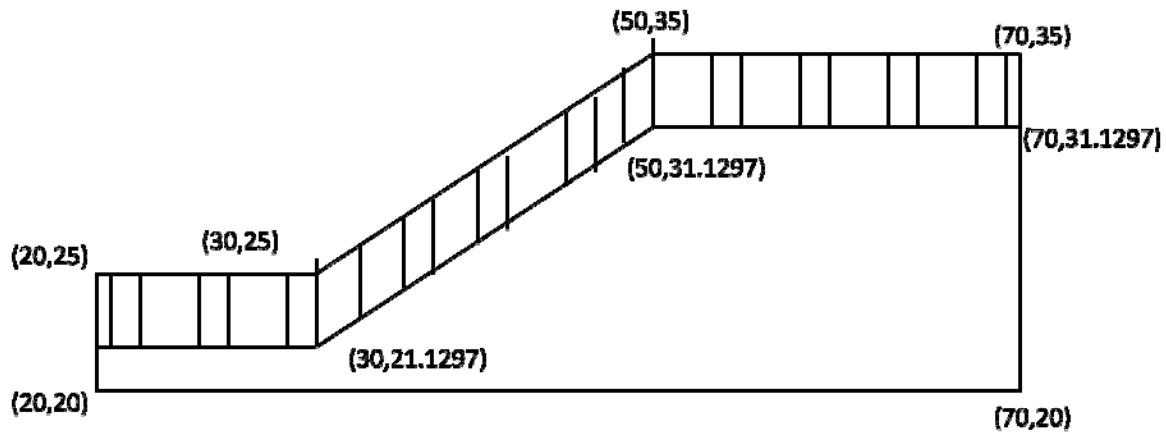


Figure C.1- Model of the problem

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	1.536

Note : Referee Factor of Safety = 1.65 [Giam]

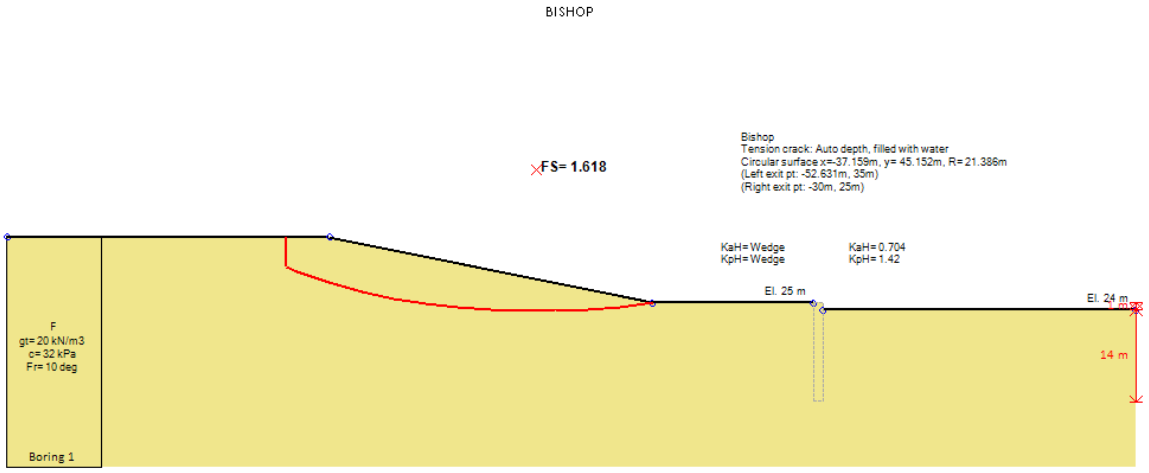


Figure C.2 – BISHOP - Normal model solution

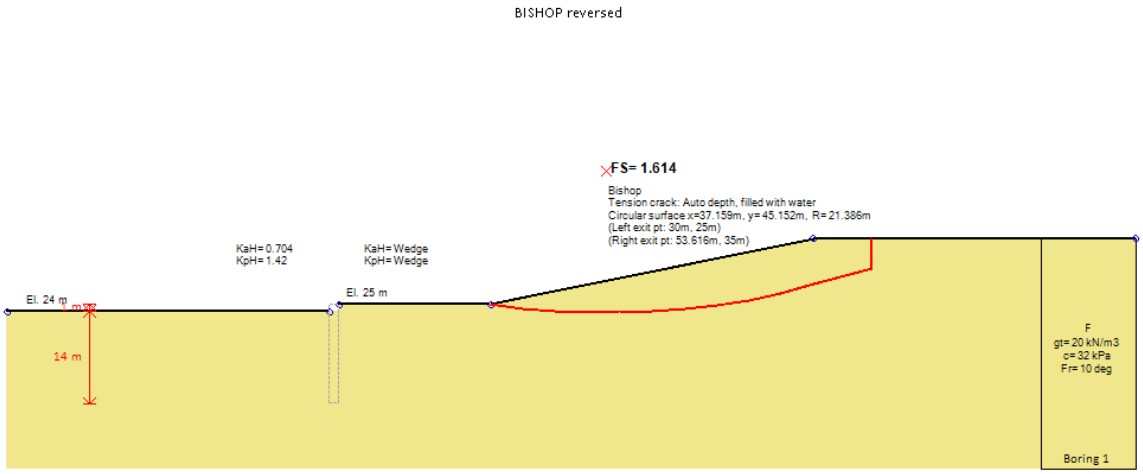


Figure C.3 – BISHOP - Reversed model solution

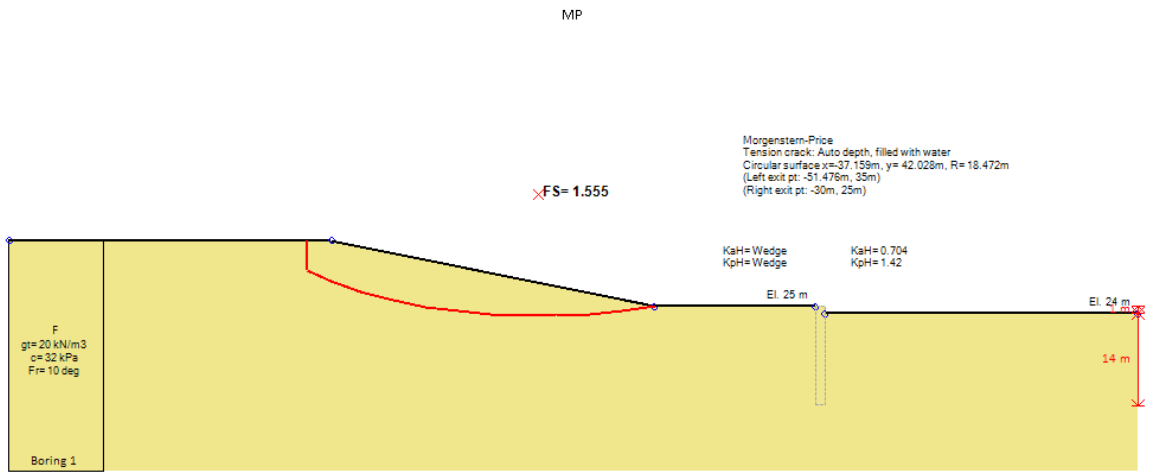


Figure C.4 – MP - Normal model solution

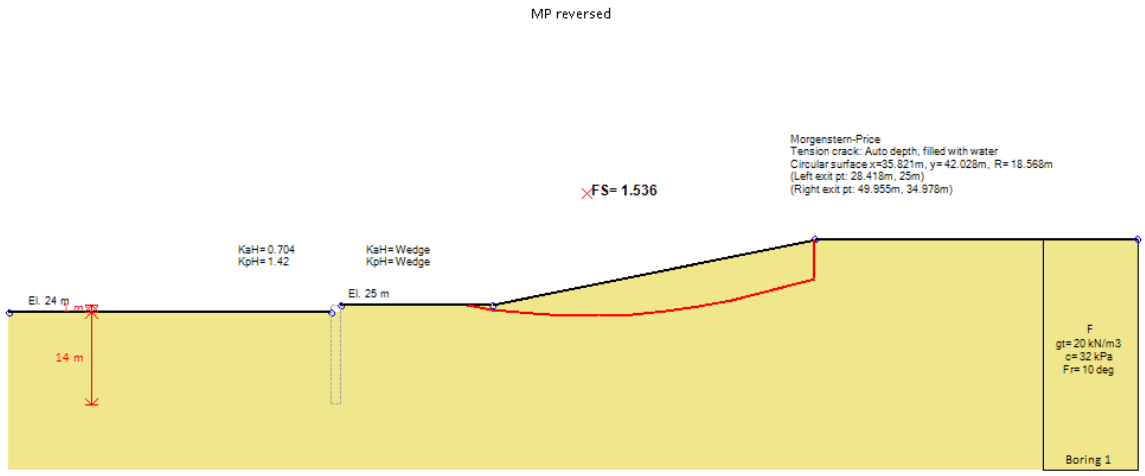


Figure C.5 – MP – Reversed model solution

D. Slope verification 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/m²)	ϕ′ (deg.)	γ (kN/m³)
Soil 1	0.0	38.0	19.5
Soil 2	5.3	23.0	19.5
Soil 3	7.2	20.0	19.5

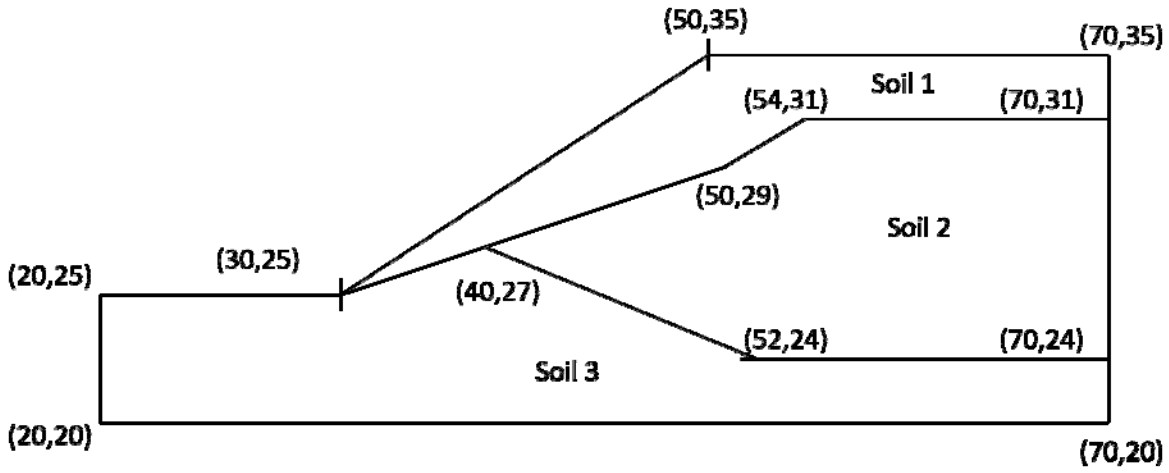


Figure D.1- Model of the problem

D.2 Results

Method: GLE	Factor of Safety
Normal model	1.378
Reversed model	1.384

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

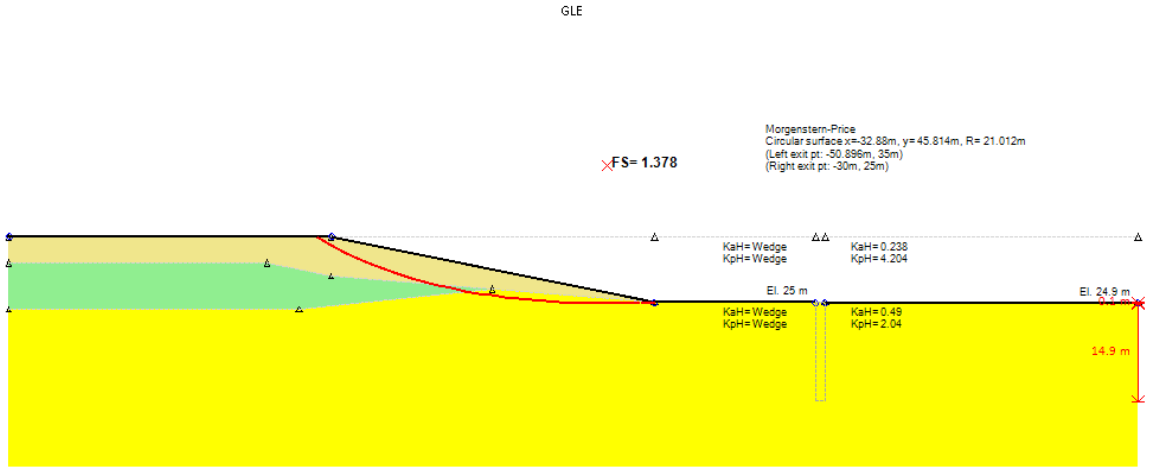


Figure D.2 – GLE - Normal model solution

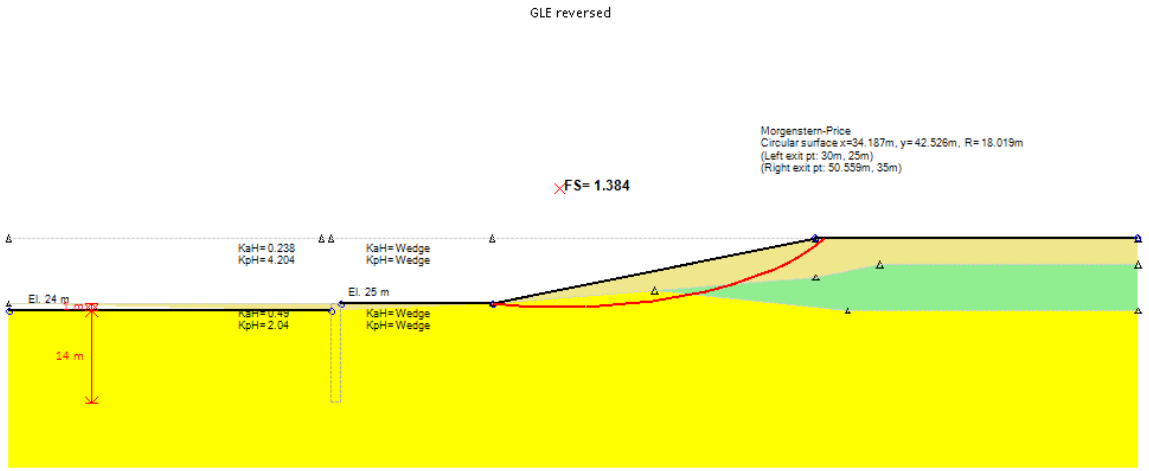


Figure D.3 – GLE – Reversed model solution

E. Slope verification 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/m²)	ϕ′ (deg.)	γ (kN/m³)
Soil 1	0.0	38.0	19.5
Soil 2	5.3	23.0	19.5
Soil 3	7.2	20.0	19.5

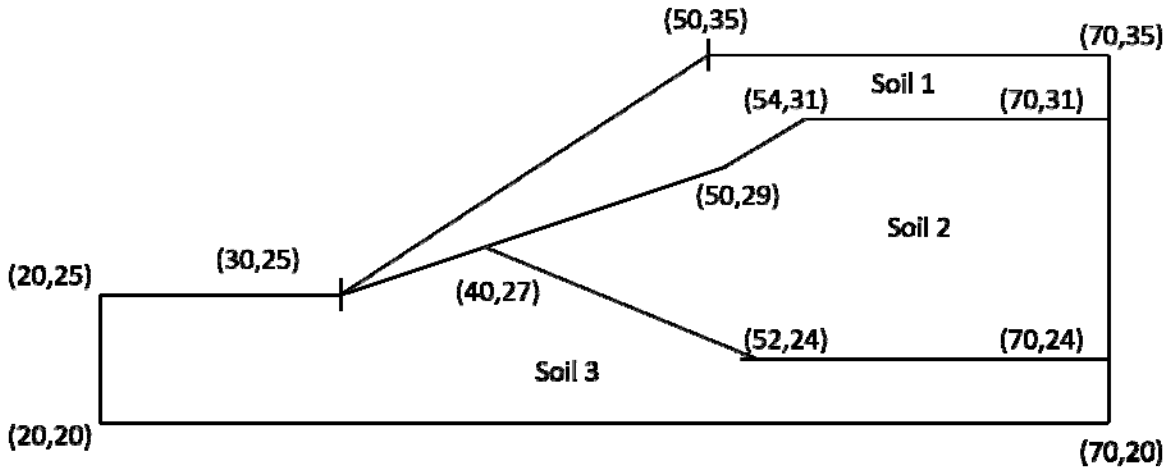


Figure E.1- Model of the problem

E.2 Results

Method: GLE	Factor of Safety	Method: BISHOP	Factor of Safety
Normal model	0.985	Normal model	0.984
Reversed model	0.993	Reversed model	1.015

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

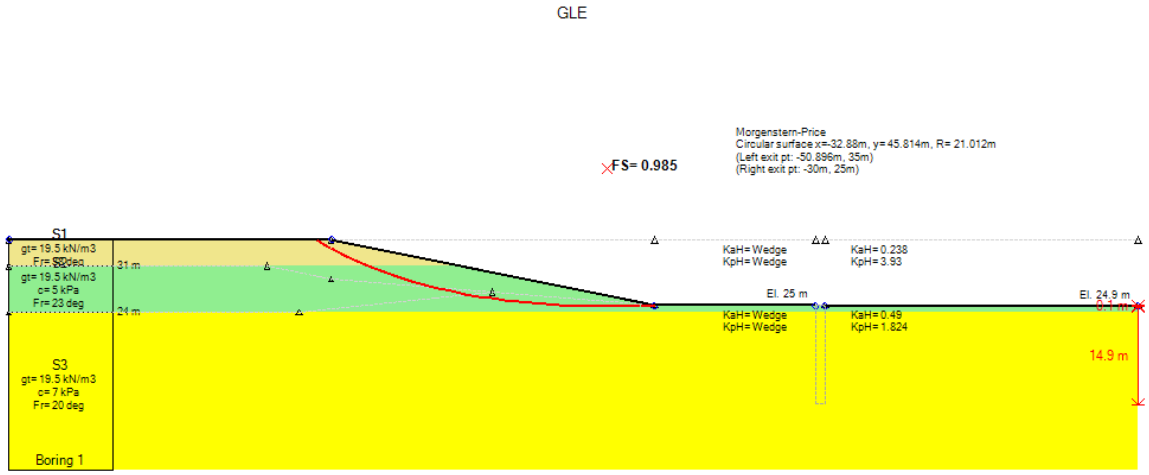


Figure E.2 – GLE - Normal model solution

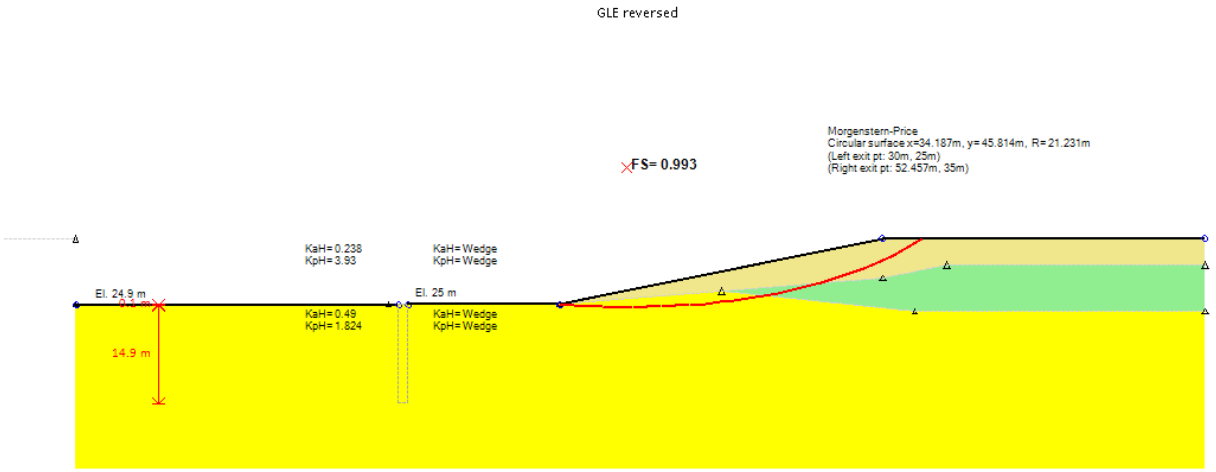


Figure E.3 – GLE – Reversed model solution

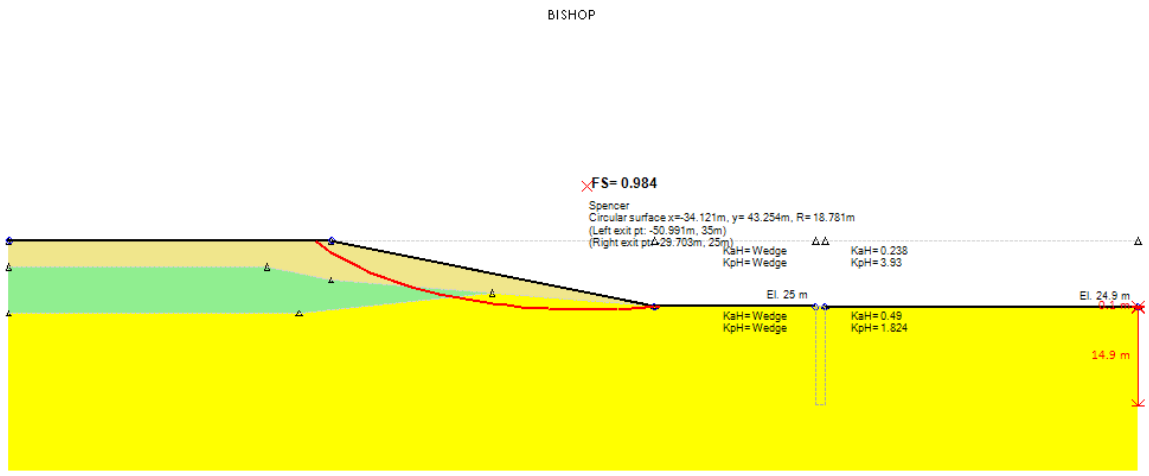


Figure E.4– BISHOP - Normal model solution

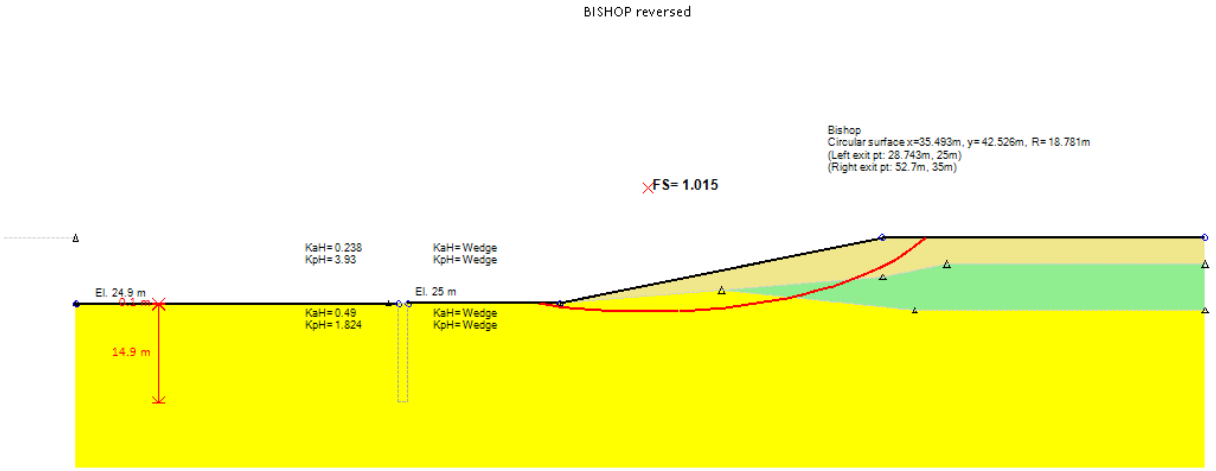


Figure E.5– BISHOP – Reversed model solution

F. Slope verification 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/m²)	ϕ′ (deg.)	γ (kN/m³)
Soil 1	28.5	20.0	18.84
Soil 2	0.0	10.0	18.84

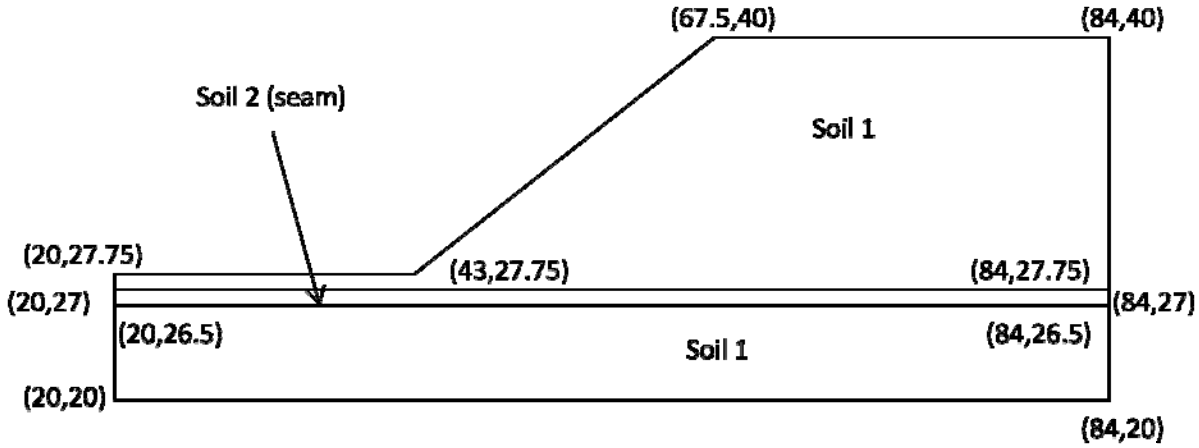


Figure F.1- Model of the problem

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

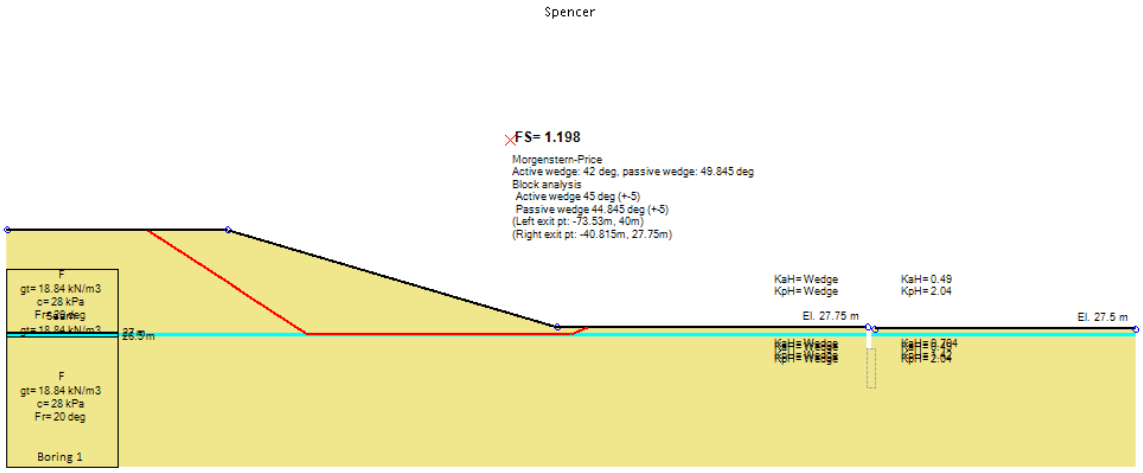


Figure F.2– SPENCER - Normal model solution

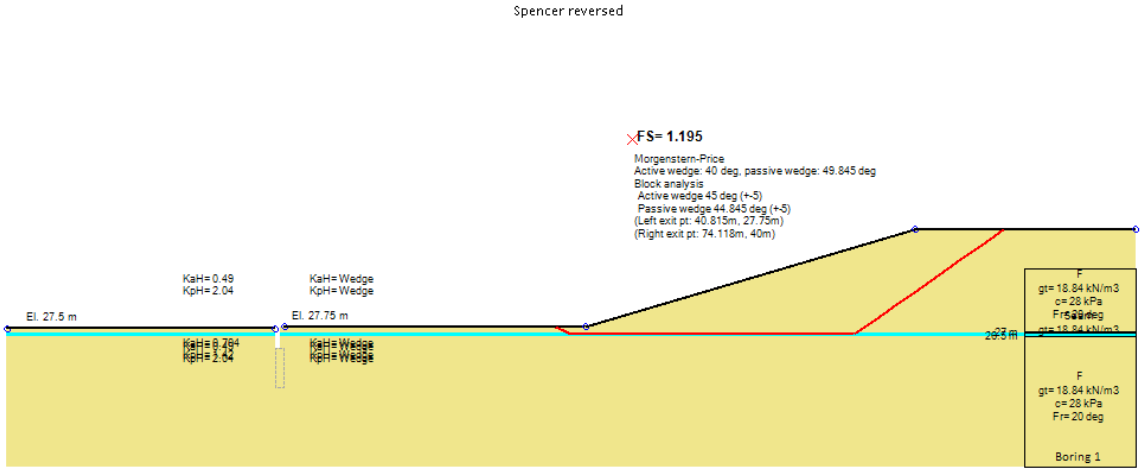


Figure F.3– SPENCER - Reversed model solution

G. Slope verification 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 analysed.

Table G.1: Material Properties

	c′ (kN/m²)	ϕ′ (deg.)	γ (kN/m³)
Soil 1	28.5	20.0	18.84
Soil 2	0.0	10.0	18.84

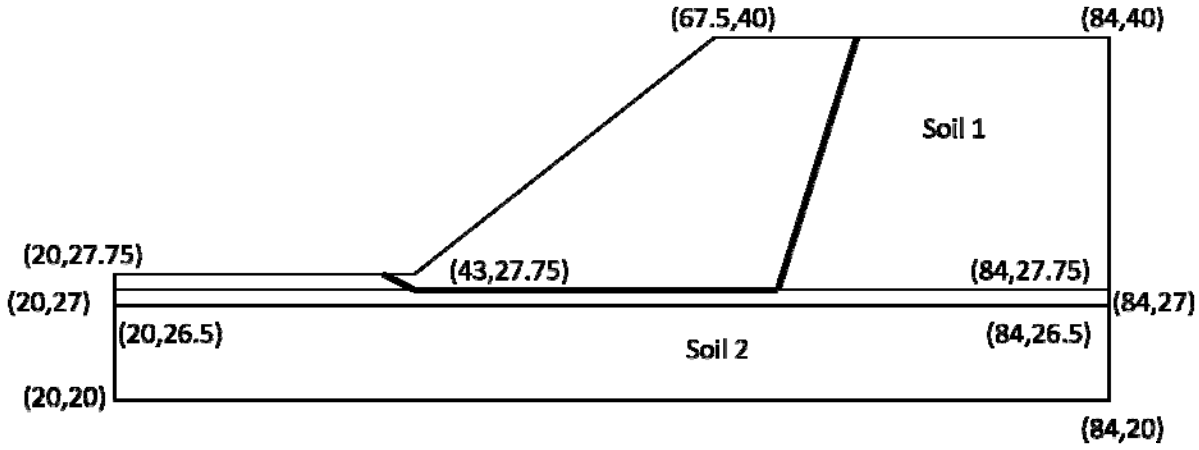


Figure G.1- Model of the problem

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

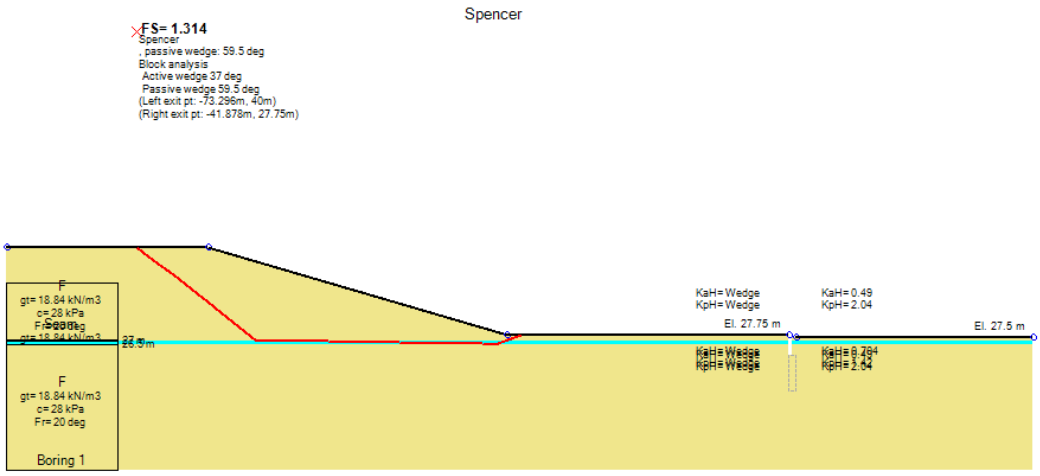


Figure G.2– SPENCER - Normal model solution

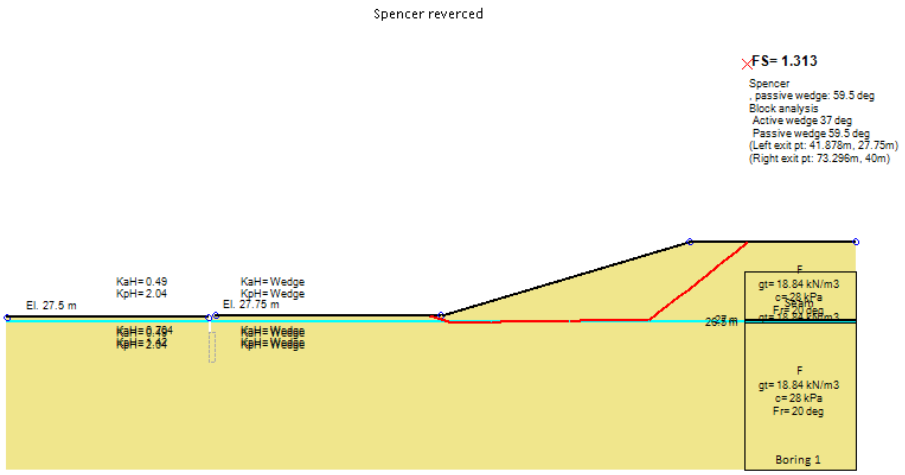


Figure G.3– SPENCER - Reversed model solution

H. Slope verification 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 G.1, G.2 and G.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/m²)	ϕ′ (deg.)	γ (kN/m³)
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/m²)
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

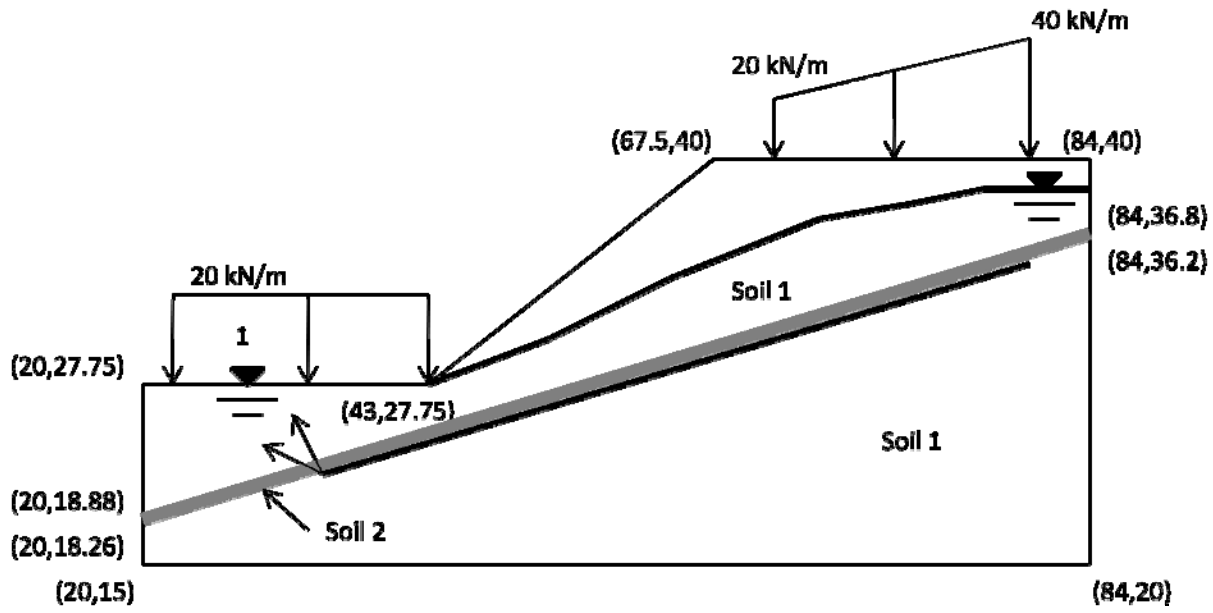


Figure H.1- Model of the problem

H.2 Results

Method: SPENCER	Factor of Safety
Normal model	0.693
Reversed model	0.693

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]

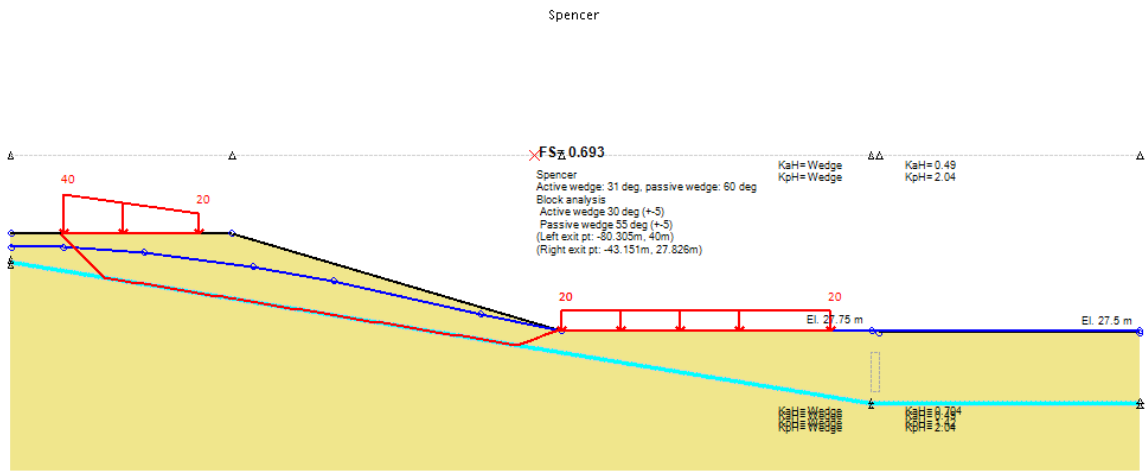


Figure H.2– SPENCER - Normal model solution

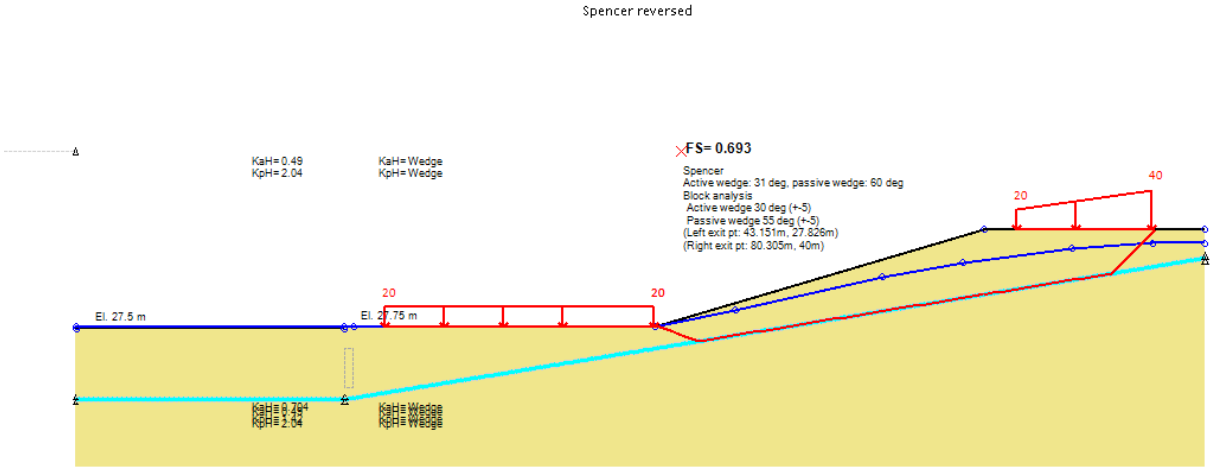


Figure H.3– SPENCER - Reversed model solution

I. Slope verification 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 (β=26.56°) 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/m²)	ϕ′ (deg.)	γ (kN/m³)
11.0	28.0	20.00

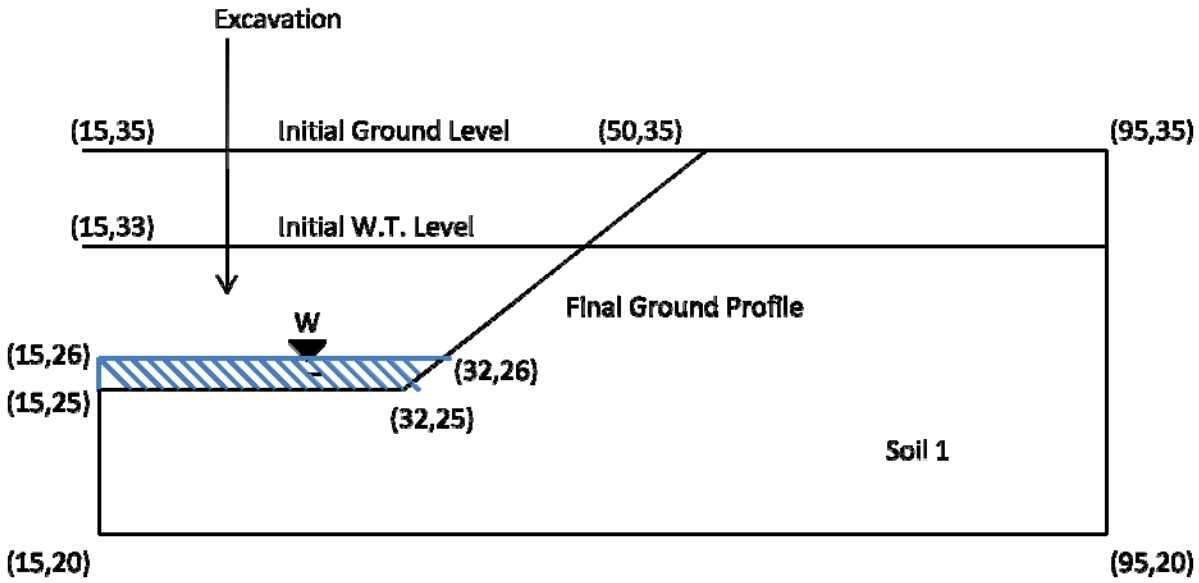


Figure I.1- Model of the problem

I.2 Results

Method: SPENCER	Factor of Safety	Method: GLE	Factor of Safety	Method: BISHOP	Factor of Safety
Normal model	1.468	Normal model	1.441	Normal model	1.495
Reversed model	1.462	Reversed model	1.439	Reversed model	1.417

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

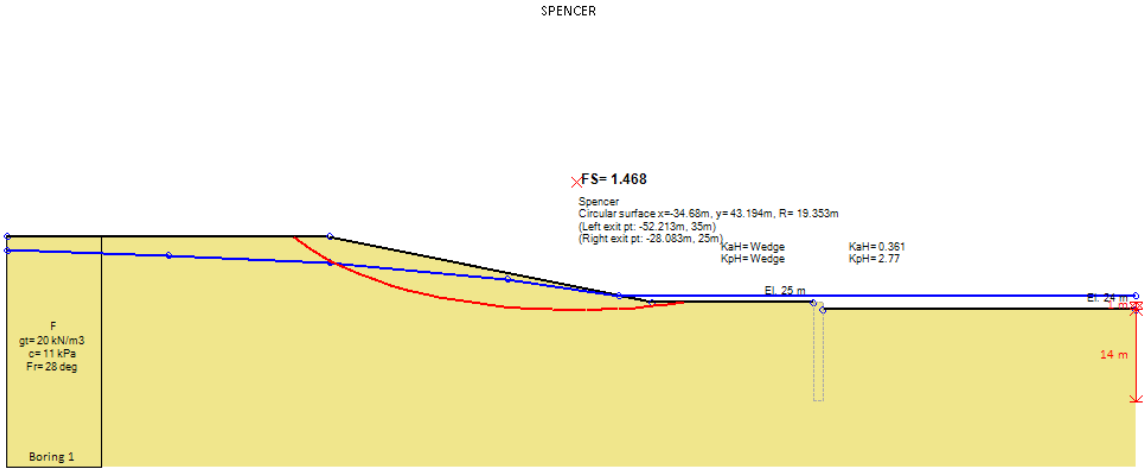


Figure I.2– SPENCER - Normal model solution

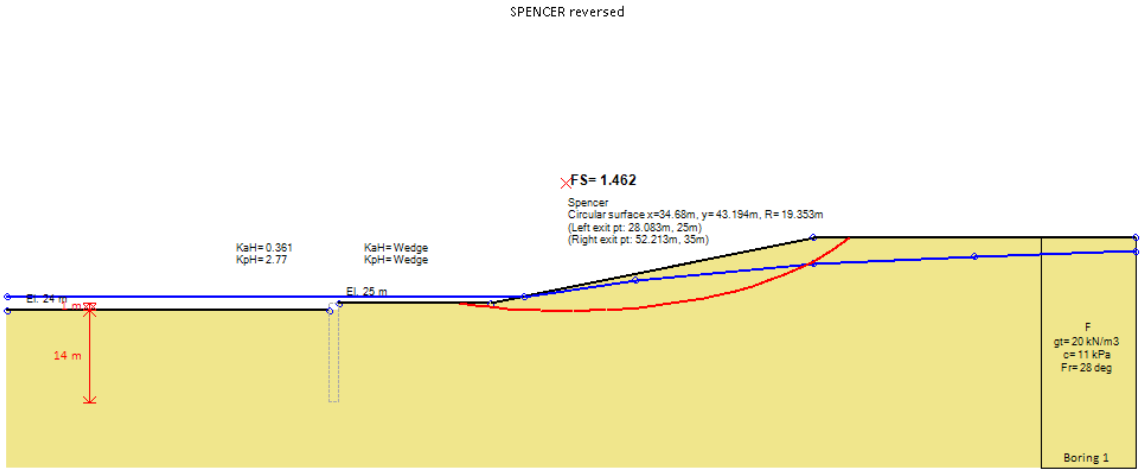


Figure I.3– SPENCER - Reversed model solution

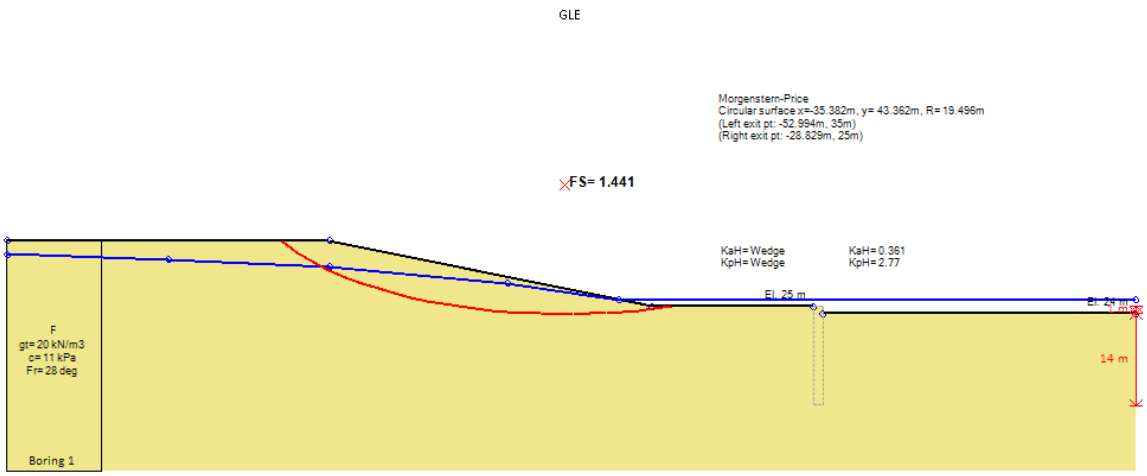


Figure I.4– GLE - Normal model solution

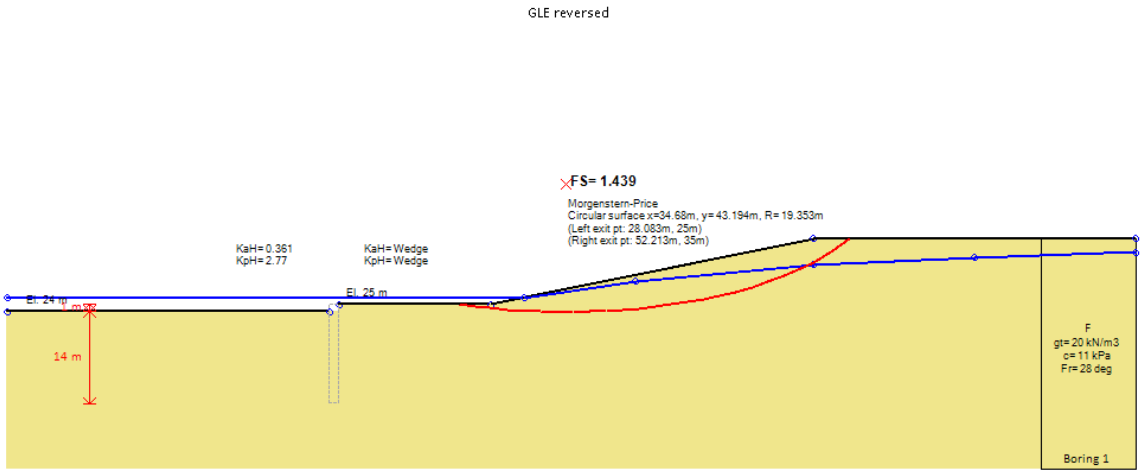


Figure I.5– GLE - Reversed model solution

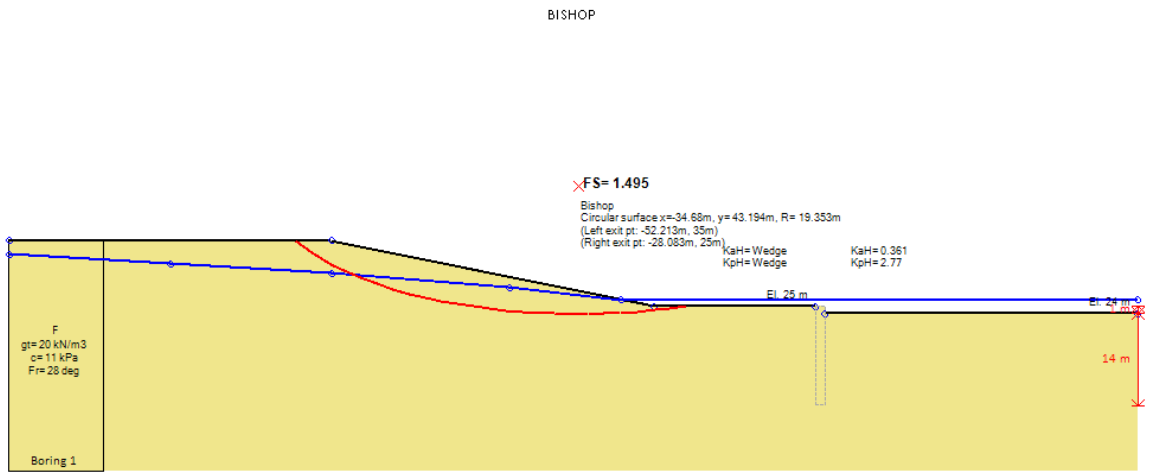


Figure I.6– BISHOP - Normal model solution

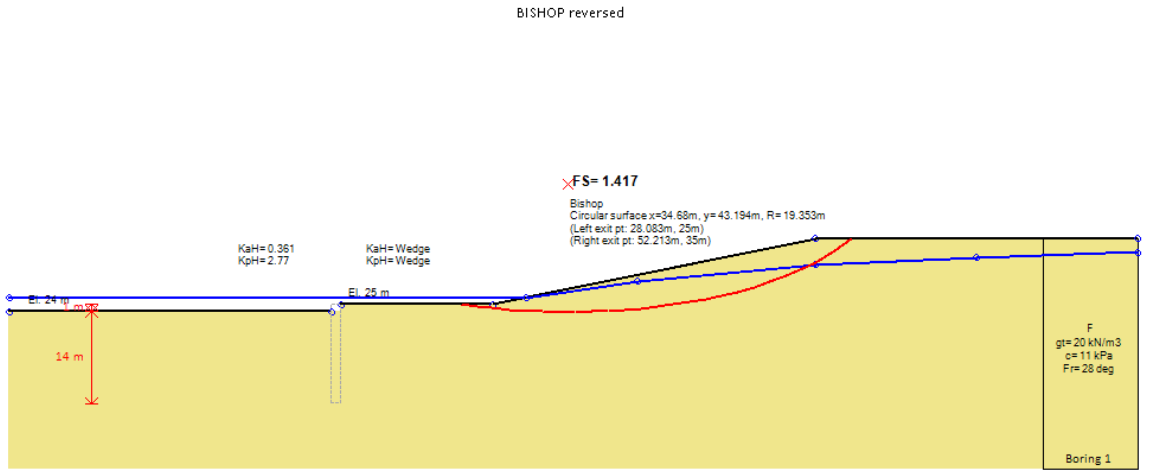


Figure I.7– BISHOP - Reversed model solution

J. Slope verification 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/m²)	ϕ′ (deg.)	γ (kN/m³)
Embankment	0.0	44.0	18.8
Clay foundation	2.0	28.0	16.68

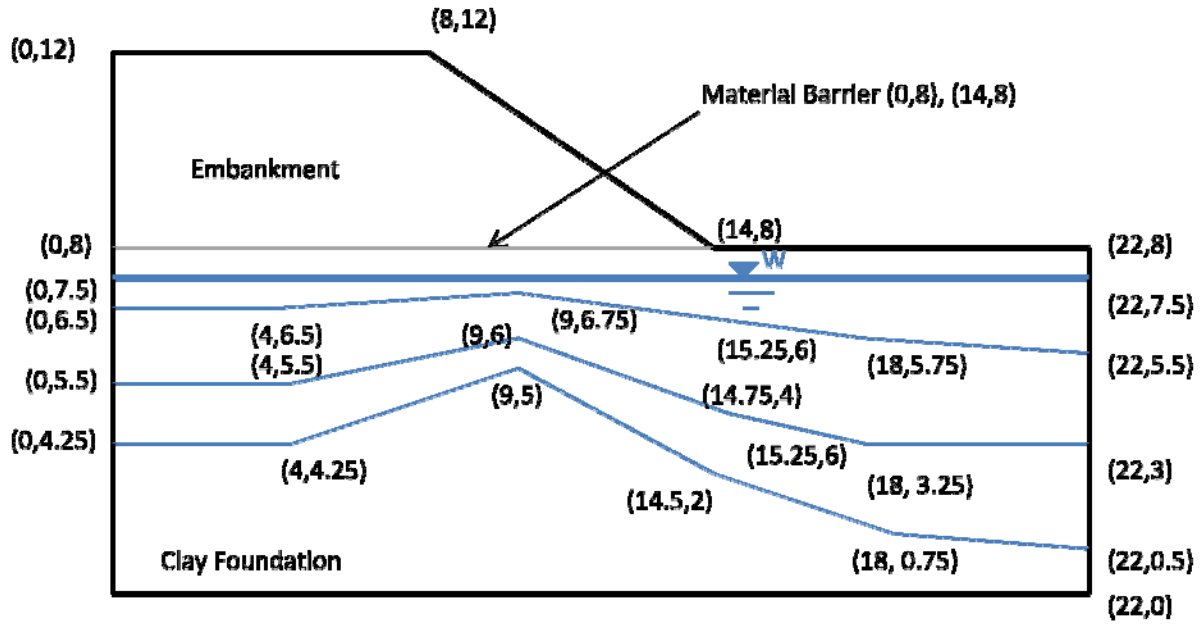


Figure J.1- Model of the problem

J.2 Results

Method: SPENCER	Factor of Safety
Normal model	0.907
Reversed model	-

Note: Referee Factor of Safety = 1.04 [Pilot]

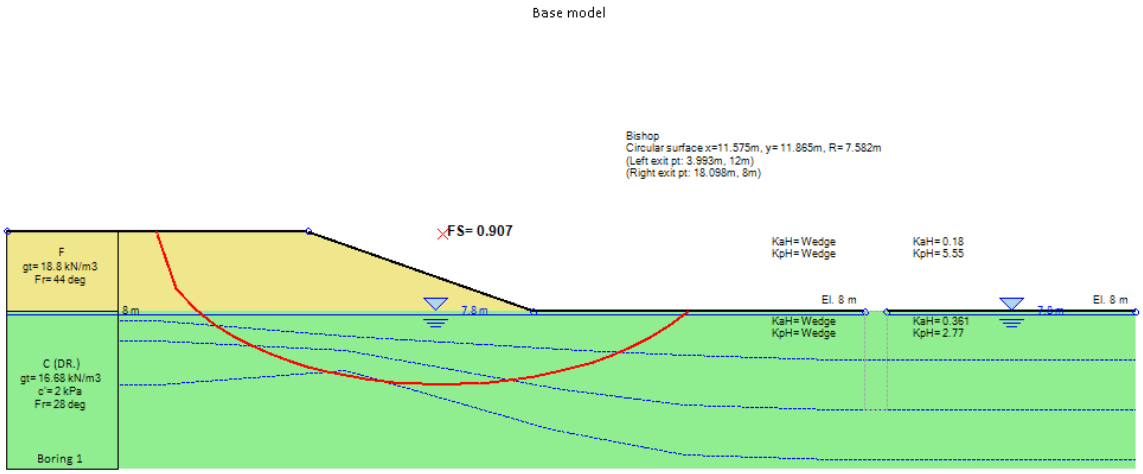


Figure J.2– SPENCER - Normal model solution

k. Slope verification 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)	ϕ′ (deg.)	γ (pcf)	qSkin Ult (psi)
Sand	0.1	32	120	50

All soil nails have Fy= 60 ksi and an area of 1in^2. The horizontal spacing is assumed at 5 ft.

Soil unit weight	γ	120 pcf
Soil friction angle	ϕ'	32 degrees
Soil cohesion	c	100 psf
Drillhole Diameter	D_{DH}	4 inch
Bond Ultimate Strength	q_u	50 psi
Pullout Safety Factor	FS_P	2.0
Nail Bar Length	L	30 ft
Nail Bar Cross-Sectional Area	A_t	1.0 in^2
Steel yield strength	f_Y	60 ksi
Critical Facing Capacities	R_F	100 kip

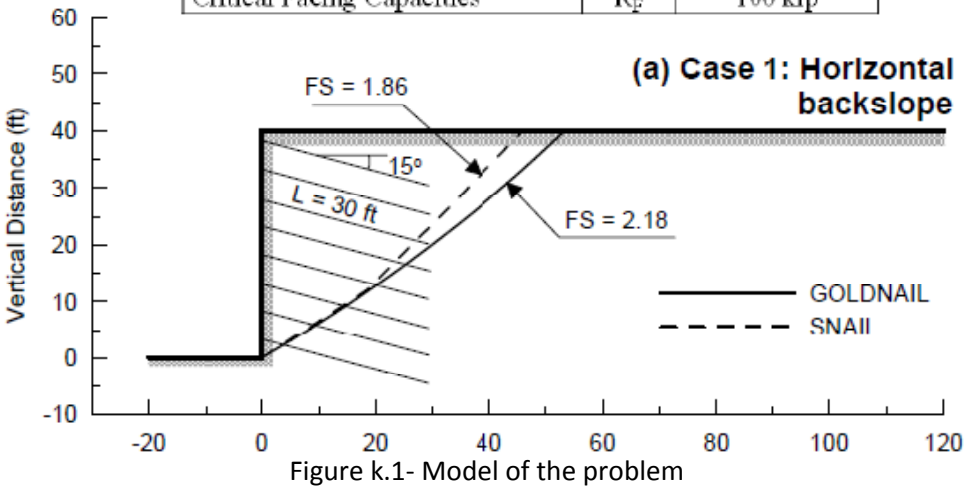
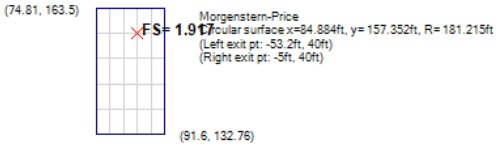


Figure k.1- Model of the problem

k.2 Results

Method: MP	Factor of Safety
Normal model	1.92
Reversed model	-



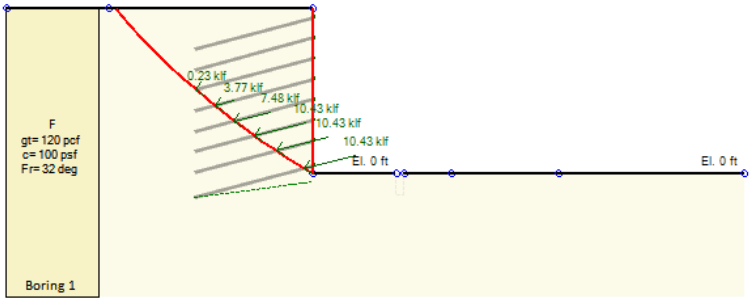


Figure k.2– Results with DeepXcav