APPENDIX – Design Examples and Parameter Study

A1. CONVENTIONAL RETAINING WALL

A2. NON-GRAVITY CANTILEVER RETAINING WALL

A3. GROUND ANCHORED WALL

A4. MECHANICALLY STABILIZED EMBANKMENT (MSE)

A5. SOIL NAIL WALL

A1. CONVENTIONAL RETAINING WALL

Design Example

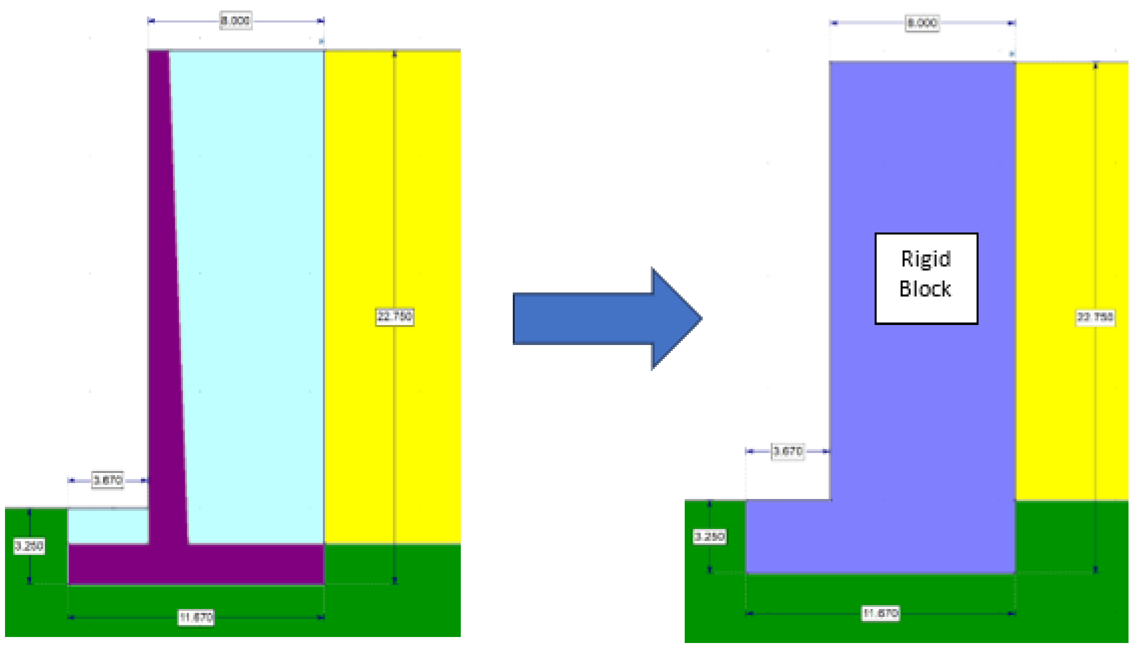
For the design examples and parameter study, a standard plan retaining wall (e.g., Type 1-Case 1) with various design heights is considered to retain a vertical cut slope of granular soil (a friction angle of 30 degrees and unit weight of 120 pcf) and its footing is founded on top of a slope with varying descending angles. The edge of the wall footing is located at 4 feet from the top of the slope. The rigid block is assumed to be composed of very high shear strength soil (a cohesion of 10,000 psf, a friction angle of 34 degrees, and a unit weight of 120 pcf). For overall stability analysis for the seismic condition, a horizontal seismic coefficient of 0.2 is assumed.

Below are the analysis steps used for the design examples and a summary of example analysis results is presented in Tables 1 through 6.

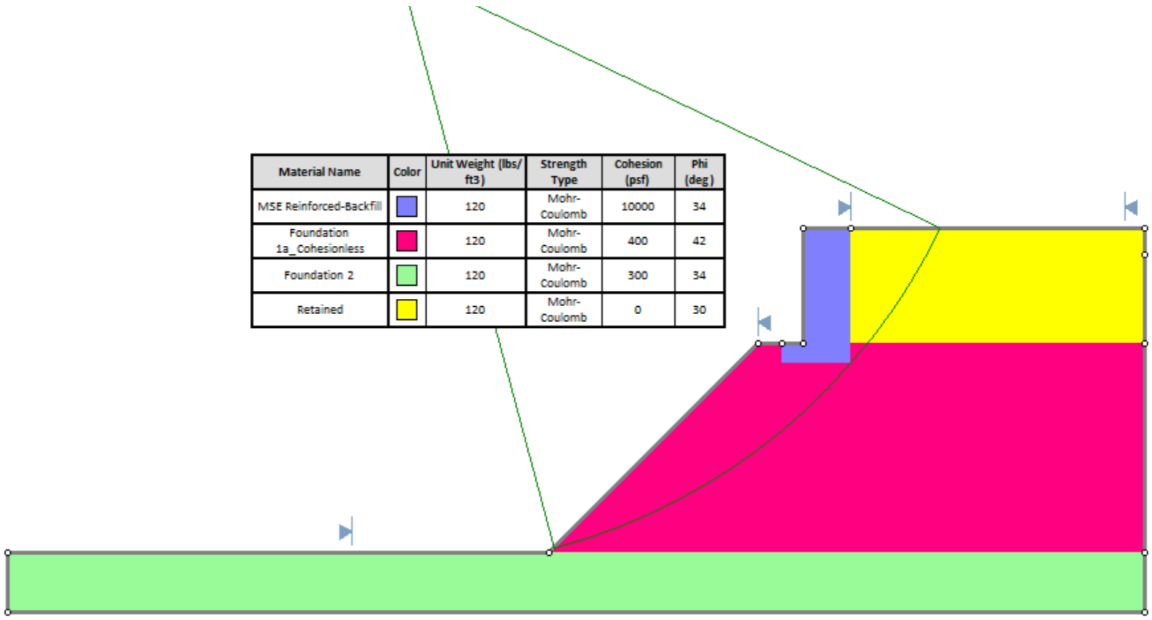
<u>Global Stability Analysis – SGCRW without piles</u>

The global stability modeling and analysis steps for SGCRW are presented below:

1. Model an SGCRW with a soil block with a height equal to the maximum wall design height (H) plus footing thickness (F) and a width equal to footing width.



2. Assign the shear strength of the block as an apparent cohesion of 10,000 psf (a fictitious value to enforce potential failure surfaces outside the block) and an apparent friction angle of 34 degrees.

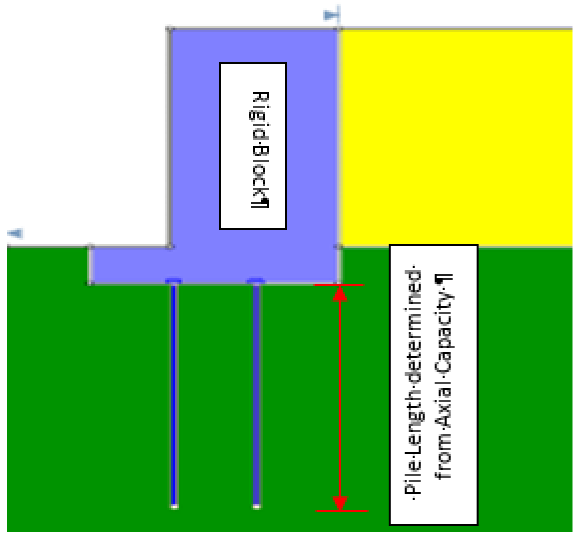


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Reinforced-Backfill		120	Mohr-Coulomb	10000	34
Foundation 1a_Cohesionless		120	Mohr-Coulomb	400	42
Foundation 2		120	Mohr-Coulomb	300	34
Retained		120	Mohr-Coulomb	0	30

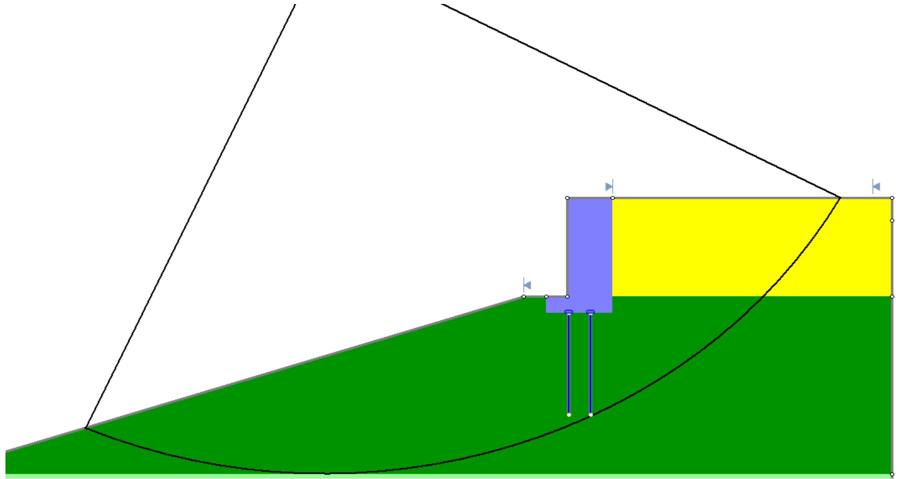
3. Perform stability analysis for both static and seismic cases to calculate a factor of safety (FoS).
4. If the calculated FoS is less than the required minimum FoS, adjust (increase) footing width until achieving the required FoS.

Global Stability Analysis - SGCRW with Piles

1. Model an SGCRW with a soil block defined as the same as the previous section along with piles.



2. Assign the shear strength of the block as the same as the previous section and the shear strength of piles as 20,000 lb (a fictitious value to enforce potential failure surfaces outside the block and the pile tips).
3. Select Support Type as Pile/Micro Pile defined in Software Slide 2 and Force Application and Force Orientation as Active (Method A) and Perpendicular to Pile, respectively. Set "out of plane spacing" to 1 foot: Actual shear strength/force of the pile is equal to the entered pile shear strength times actual pile spacing.
4. Perform stability analysis for both static and seismic cases. If a critical failure surface intersects piles, increase the shear strength of piles to ensure that the critical failure surface does not intersect the piles.

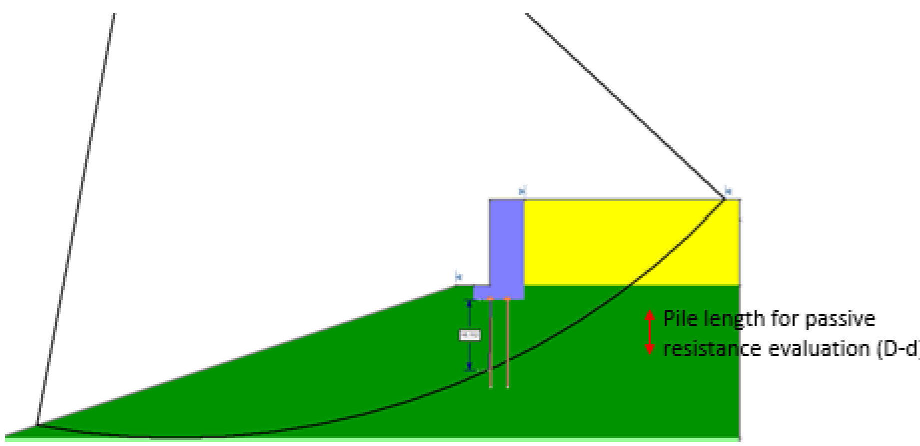


5. If the calculated FoS is less than the required minimum FoS, adjust (increase) pile length until achieving the required FoS

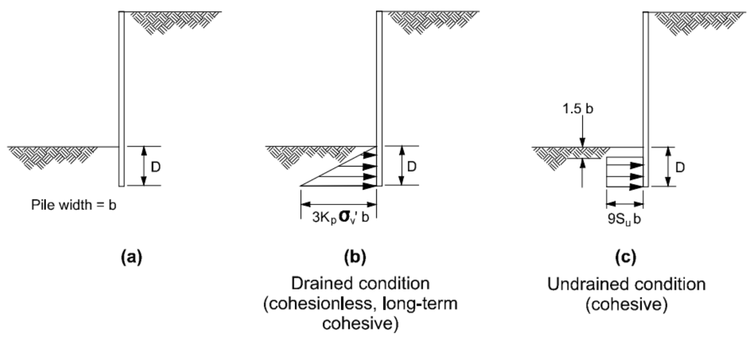
Compound Stability Analysis - SGCRW with Piles

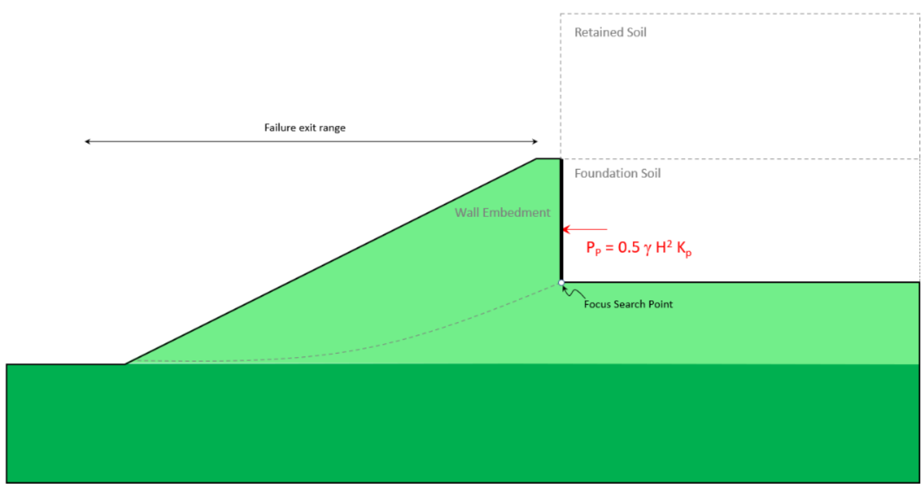
The compound stability modeling and analysis steps for SGCRW with piles are presented below:

1. Repeat the previous steps 1, 2, and 3 except for adjusting (reducing) the shear strength of piles with the pile length calculated from the global stability analysis.
2. Perform stability analysis for both static and seismic cases by reducing the shear strength of piles up to a value to meet the minimum required FOS while the critical failure surface intersects the piles. The adjusted shear strength is the pile shear force demand that will need to be resisted by piles.



3. Measure the pile length below the critical failure surface and verify it is long enough to provide the required pile passive resistance against the pile shear force demand in the previous step. Use Brom's method for the evaluation of the passive resistance of discrete piles.
4. If the passive resistance does not meet the required FoS of 1.5 against the calculated pile shear force demand (passive resistance < 1.5 times demand force), increase pile length until achieving the minimum FoS of 1.5 for the required passive resistance of piles.
5. Calculate Kp using the GLE method as shown below.





Brom's method for evaluating ultimate passive resistance (FHWA-IF-99-015)

6. Report the calculated pile shear force demand to Bridge Design as needed.

Summary of Example Analysis Results - SGCRW without Piles

Table A1.1: Overall Factor of Safety of Wall vs Block (Case 1)

Retaining Wall Type/ Height (feet)	Soil Properties under Footing on 1H:1V Sloping Ground		FOS (Overall)			
	Friction (°)	Cohesion (psf)	Static		Seismic	
			Wall	Block	Wall	Block
Type 1 (Case 1) / 20	42	400	1.48	1.52	1.10	1.12
	20	1100	1.42	1.45	1.10	1.12
Type 1 (Case 1) / 24	43	400	1.48	1.48	1.10	1.10
	20	1250	1.45	1.44	1.13	1.13
Type 1 (Case 1) / 28	44	400	1.48	1.49	1.10	1.11
	20	1400	1.43	1.44	1.13	1.14
Type 1 (Case 1) / 32	44	400	1.47	1.47	1.11	1.11
	20	1550	1.42	1.43	1.12	1.13
Type 1 (Case 1) / 36	44	400	1.48	1.48	1.11	1.11
	20	1750	1.42	1.43	1.12	1.13

Table A1.2: Overall Factor of Safety of Wall vs Block (Case 2)

Retaining Wall Type/ Height (feet)	Soil Properties under Footing on 2H:1V Sloping Ground		FOS (Overall)			
	Friction (°)	Cohesion (psf)	Static		Seismic	
			Wall	Block	Wall	Block
Type 1 (Case 1) / 20	40	100	1.66	1.68	1.15	1.16
	20	750	1.61	1.63	1.13	1.13
Type 1 (Case 1) / 24	40	100	1.62	1.62	1.12	1.13
	20	850	1.58	1.59	1.12	1.12
Type 1 (Case 1) / 28	41	100	1.63	1.63	1.14	1.14
	20	950	1.55	1.55	1.10	1.11
Type 1 (Case 1) / 32	41	100	1.61	1.61	1.13	1.14
	20	1100	1.52	1.54	1.11	1.11
Type 1 (Case 1) / 36	41	100	1.61	1.60	1.16	1.13
	20	1300	1.52	1.54	1.12	1.13

Table A1.3: Overall Factor of Safety of Wall vs Block (3)

Retaining Wall Type/ Height (feet)	Soil Properties under Footing on 3H:1V Sloping Ground		FOS (Overall)			
	Friction (°)	Cohesion (psf)	Static		Seismic	
			Wall	Block	Wall	Block
Type 1 (Case 1) / 20	33	100	1.56	1.57	1.11	1.12
	20	500	1.60	1.62	1.12	1.13
Type 1 (Case 1) / 24	34	100	1.56	1.56	1.11	1.11
	20	550	1.53	1.53	1.11	1.11
Type 1 (Case 1) / 28	35	100	1.57	1.57	1.12	1.12
	20	650	1.52	1.52	1.11	1.12
Type 1 (Case 1) / 32	35	100	1.55	1.55	1.11	1.10
	20	750	1.51	1.52	1.11	1.11
Type 1 (Case 1) / 36	35	100	1.55	1.55	1.12	1.11
	20	850	1.51	1.52	1.11	1.11

Summary of Example Analysis Results - SGCRW Piles

Table A1.4: Overall Factor of Safety and Minimum Embedment Depth of Piles (Case 1)

Retaining Wall Type/ Height (feet)	Length of Piles (feet)	Soil Properties under Footing on 1H:1V Sloping Ground		FOS (Overall)		Minimum Embedment Depth (feet) / Minimum Shear Strength of Piles (lb/ft)
		Friction (°)	Cohesion (psf)	Static	Seismic	
Type 1 (Case 1) / 20	20	34	400	1.52	1.14	11 / 6000
		20	1100	1.46	1.12	20 / 1000

Table A1.5: Overall Factor of Safety and Minimum Embedment Depth of Piles (Case 2)

Retaining Wall Type/ Height (feet)	Length/Spacing of Piles (feet)	Soil Properties under Footing on 2H:1V Sloping Ground		FOS (Overall)		Minimum Embedment Depth (feet) / Minimum Shear Strength of Piles (lb/ft)
		Friction (°)	Cohesion (psf)	Static	Seismic	
Type 1 (Case 1) / 20	20	32	100	1.71	1.17	6.8 / 8000
		20	650	1.63	1.13	15.6 / 2000

Table A1.6: Overall Factor of Safety and Minimum Embedment Depth of Piles (Case 2)

Retaining Wall Type/ Height (feet)	Length/Spacing of Piles (feet)	Soil Properties under Footing on 3H:1V Sloping Ground		FOS (Overall)		Minimum Embedment Depth (feet) / Minimum Shear Strength of Piles (lb/ft)
		Friction (°)	Cohesion (psf)	Static	Seismic	
Type 1 (Case 1) / 20	20	26	100	1.72	1.12	10.4 / 9000
		20	450	1.75	1.14	16.1 / 1500

A2. NON-GRAVITY CANTILEVER RETAINING WALL

Design Examples

The following examples include:

- Solider piles with lagging wall – Design height = 25 feet
- Drilled hole diameter = 2 feet and pile spacing = 8 feet.
- Descending ground slope height = 35 feet
- Comparison of cohesionless and mixed (cohesion and frictional) soils
- Comparison of varying sloping ground surface
- Horizontal seismic coefficient = 0.2

Table A2.1: Soil Profile

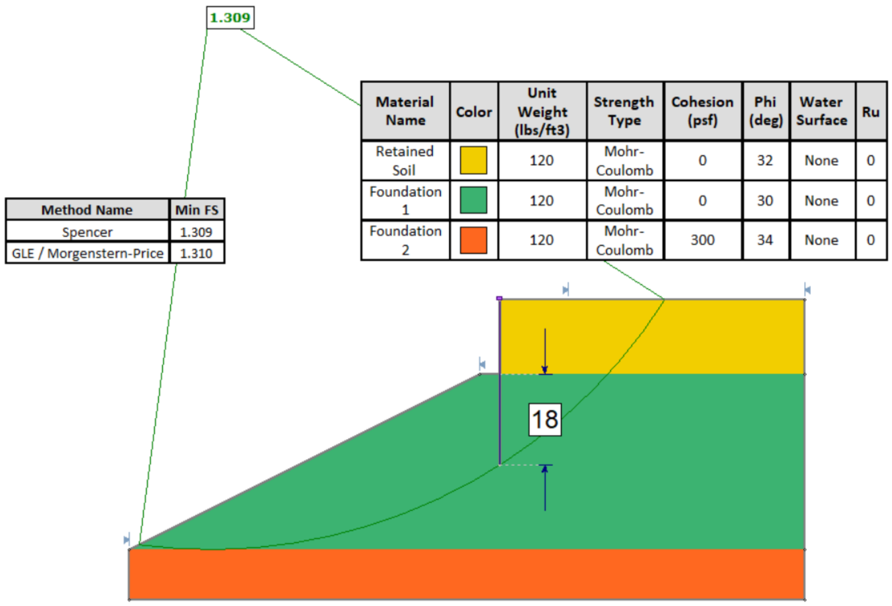
Case	Ground slope incline	Retained Soil Shear Strength	Foundation 1 Shear Strength	Foundation 2 Shear Strength
1A	2H:1V (27 deg)	γ = 120 pcf c' = 0 psf, ϕ' = 32 deg	γ = 120 pcf c' = 0 psf, ϕ' = 30 deg	γ = 120 pcf c' = 300 psf, ϕ' = 34 deg
1B			γ = 120 pcf c' = 50 psf, ϕ' = 30 deg	
2	1H:1V (45 deg)		γ = 120 pcf c' = 300 psf, ϕ' = 34 deg	

Table A2.2: Summary of Results

Case	Static (Service Limit State)				Seismic (Extreme Event Limit State)			
	Minimum Pile Embedment Depth (ft)	Demand Force, kip/pile	Passive Resistance, kip/pile	Passive Resistance FOS	Minimum Pile Embedment Depth (ft)	Demand Force, kip/pile	Passive Resistance, kip/pile	Passive Resistance FOS
1A	18	76	183.4	2.41	25	140	158.9	1.14
1B	14	38	125.3	3.30	22	97.5	124.4	1.28
2	21	47.5	191.9	4.04	22	50	106.6	2.13

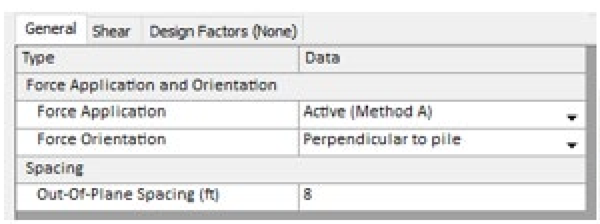
Case 1A: Overall Slope Stability – Static

Estimate Wall Embedment Depth – Static Service Limit State

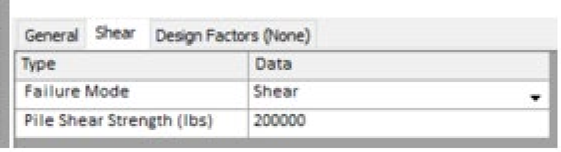


Method Name	Min FS
Spencer	1.309
GLE / Morgenstern-Price	1.310

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0



Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

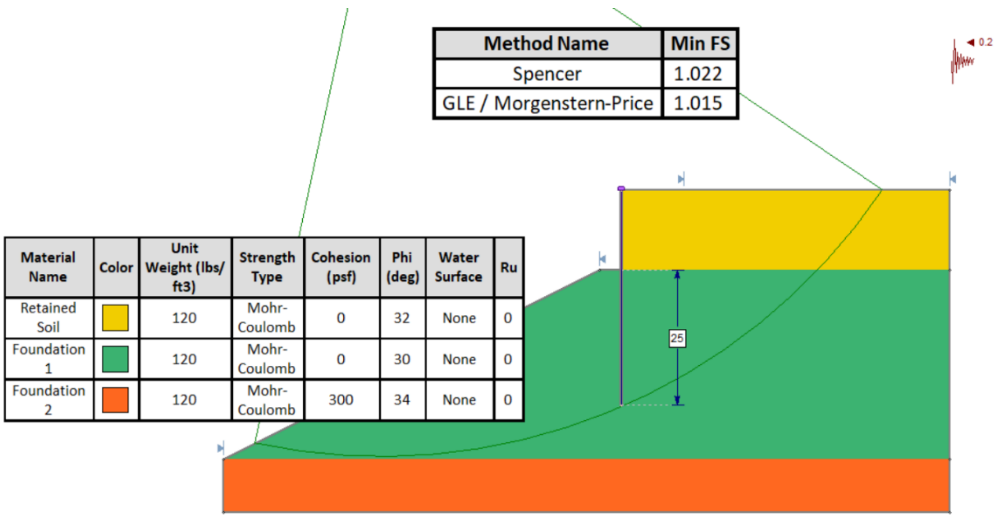


Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	200000

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of the retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element and assign the 8 ft out-of-plane spacing and very large pile shear strength (200,000 lbf)
3. Perform limit equilibrium slope stability analysis.
4. If the potential failure surface intersects the pile, increase the shear strength of the pile to make the potential failure outside the pile element. If the calculated FOS is less than the required minimum FOS, increase the length of the pile until the calculated FOS meets the requirement.
5. The pile embedment depth required for a FOS of 1.3 is 18 ft.

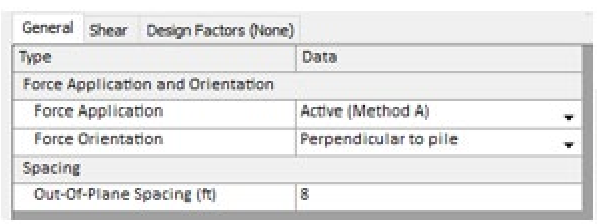
Case 1A: Overall Slope Stability – Seismic

Estimate Wall Embedment Depth – Seismic Extreme Event Limit State



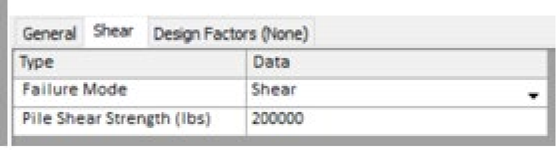
Method Name	Min FS
Spencer	1.022
GLE / Morgenstern-Price	1.015

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0



General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8



General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	200000

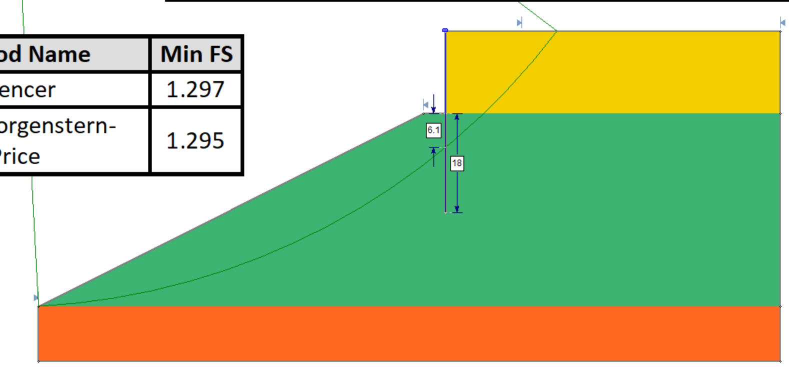
1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of the retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element and assign the 8 ft out-of-plane spacing and very large pile shear strength (200,000 lbf)
3. Perform limit equilibrium slope stability analysis, using k_h = 0.2
4. If the potential failure surface intersects the pile, increase the shear strength of the pile to make the potential failure outside the pile element. If the calculated FOS is less than the required minimum FOS, increase the length of the pile until the calculated FOS meets the requirement.
5. The pile embedment depth required for a FOS of 1.0 is 25 ft.

Case 1A: Compound Slope Stability – Static

a) Estimate Demand Force – Static Service Limit State

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil	(yellow)	120	Mohr-Coulomb	0	32	None	0
Foundation 1	(green)	120	Mohr-Coulomb	0	30	None	0
Foundation 2	(orange)	120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	1.297
GLE / Morgenstern-Price	1.295



General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

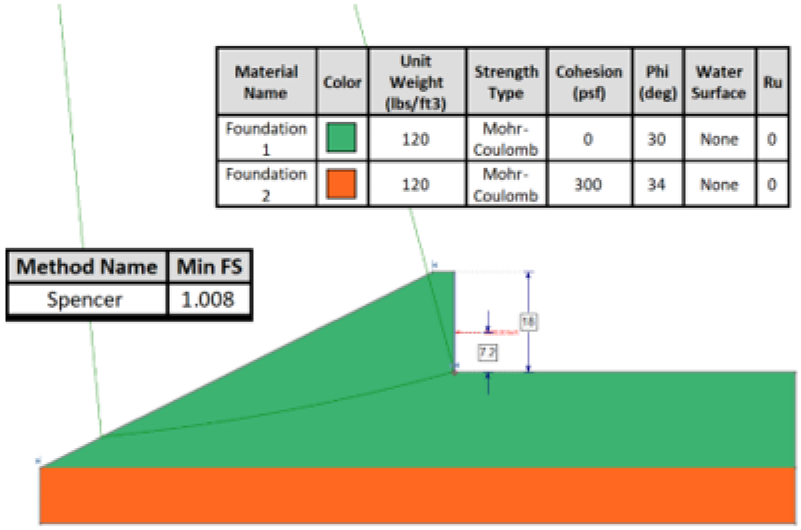
General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	57800

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element and assign the 8 ft out-of-plane spacing. Use pile shear strength 57,800 lbf and pile length obtained from the Global Stability Analysis - Static (18 ft)
3. Perform limit equilibrium slope stability analysis.
4. If the calculated FOS is less than the required minimum FOS and the failure surface passes through the pile element, then increase the pile shear strength in smaller increments until the required FOS is achieved. If the calculated FOS is higher than the required FOS and the failure surface passes outside the pile element, then decrease the pile shear strength until the required FOS is achieved.
5. The pile shear strength required for a FOS of 1.3 is 57,800 lbf.

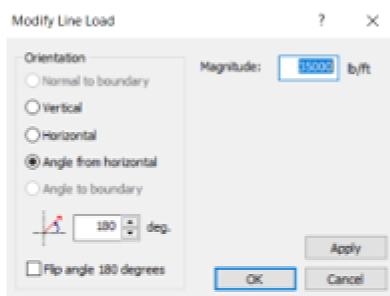
Case 1A: Compound Slope Stability – Static

b) Check Passive Resistance – Static Service Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	1.008



1. In a separate model, remove all earth material from the active side of the wall.
2. Set the failure surface entry point such that it starts at the tip of the embedded pile.
3. Apply a line load perpendicular to the pile at a height 0.4H = 0.4 x 18 ft = 7.2 ft from the base.
4. Perform LE slope stability analysis to determine the passive pressure that corresponds to a FOS of 1.0. Here P_P = 35 kip/ft.
5. From $P_P = 0.5\ \gamma\ H^2\ K_p$, back-calculate K_p = 1.8 (no interface considered)

6. Determine passive resistance below the compound failure surface using Brom's method:

$$Passive\ Resistance = 3\ K_p \left(\frac{D + d}{2}\right) \gamma b(D - d)$$

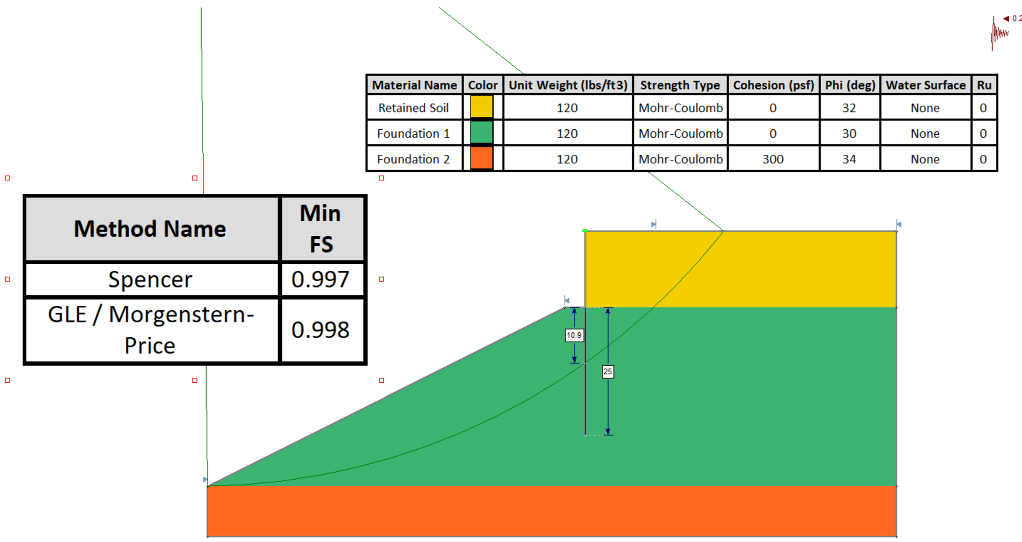
$$= 3 \times 1.8 \left(\frac{18 + 6.4}{2}\right) 120 \times 2(18 - 6.4)$$

$$= 183.4 kip/pile$$

7. FOS = Passive resistance of 183.4 kip per pile divided by demand force of 57.8 kips per pile = 3.17 > minimum required FOS 1.5.

Case 1A: Compound Slope Stability – Seismic

a) Estimate Demand Force – Seismic Extreme Event Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	0.997
GLE / Morgenstern-Price	0.998

General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

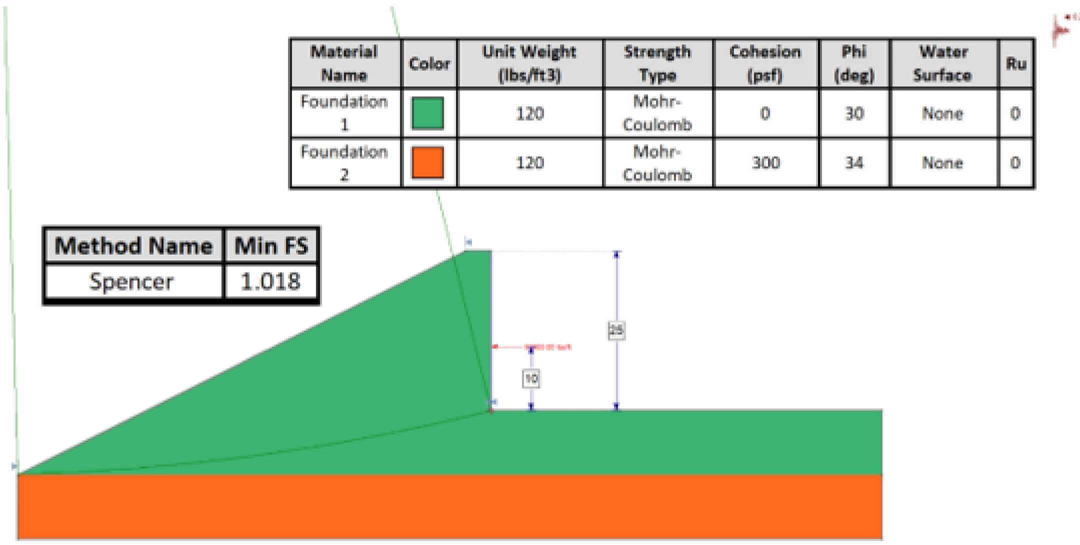
General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	140000

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element, assign the 8 ft out-of-plane spacing. Use pile shear strength 140,000 lbs and pile length obtained from the Global Stability Analysis - Seismic (25 ft)
3. Perform limit equilibrium slope stability analysis, using k_h = 0.2
4. If the calculated FOS is less than the required minimum FOS and the failure surface passes through the pile element, then increase the pile shear strength in smaller increments until the required FOS is achieved. If the calculated FOS is higher than the required FOS and the failure surface passes outside the pile element, then decrease the pile shear strength until the required FOS is achieved.
5. The pile shear strength required for a FOS of 1.0 is 140,000 lbf.

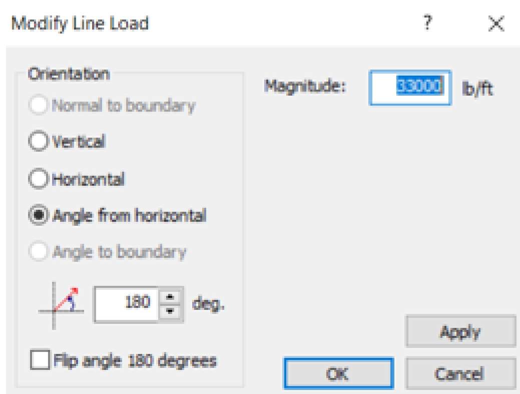
Case 1A: Compound Slope Stability – Seismic

b) Check Passive Resistance – Seismic Extreme Event Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	1.018



1. In a separate model, remove all earth material from the active side of the wall.
2. Set the failure surface entry point such that it starts at the tip of the embedded pile.
3. Apply a line load perpendicular to the pile at a height 0.4H = 0.4 x 25 ft = 10 ft from the base.
4. Perform LE slope stability analysis using k_h = 0.2 to determine the passive pressure that corresponds to a FOS of 1.0. Here P_p = 33 kip/ft.
5. From $P_P = 0.5\ \gamma\ H^2\ K_p$, back-calculate K_p = 0.88 (no interface considered)

6. Determine passive resistance below the compound failure surface using Brom's method:

$$Passive\ Resistance = 3\ K_p \left(\frac{D + d}{2}\right) \gamma b (D - d)$$

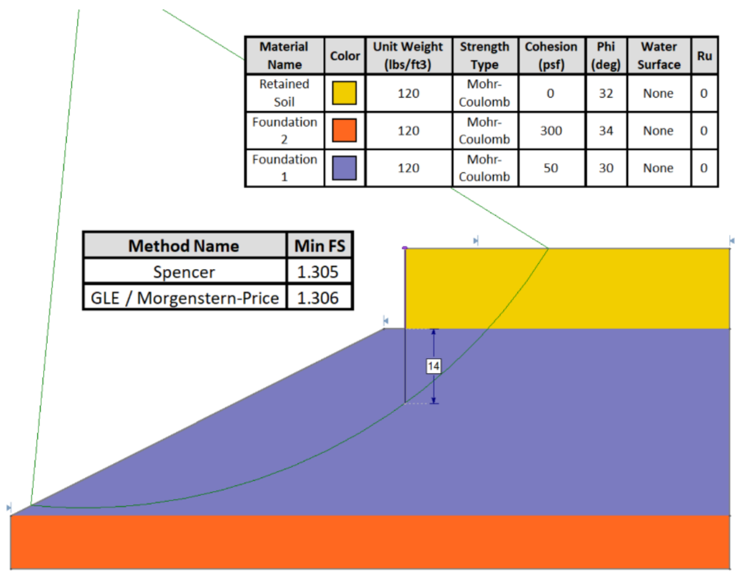
$$= 3 \times 0.88 \left(\frac{25 + 10.9}{2}\right) 120 \times 2(25 - 10.9)$$

$$= 160.4 kip/pile$$

7. FOS = Passive resistance of 160.4 kip per pile divided by demand force of 140 kip per pile = 1.15 > minimum required FOS 1.0.

Case 1B: Overall Slope Stability – Static

Estimate Wall Embedment Depth – Static Service Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Foundation 1		120	Mohr-Coulomb	50	30	None	0

Method Name	Min FS
Spencer	1.305
GLE / Morgenstern-Price	1.306

General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

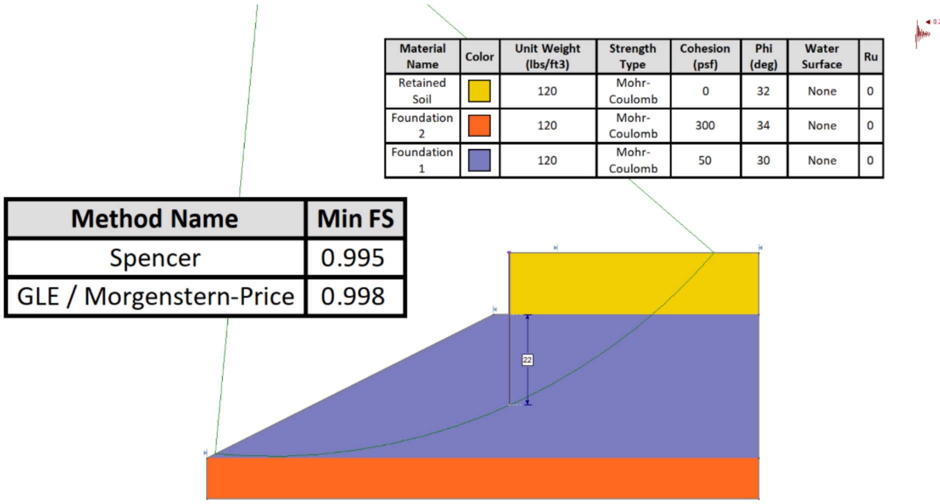
General | Shear | Design Factors (None)

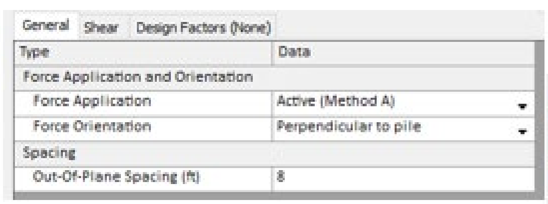
Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	200000

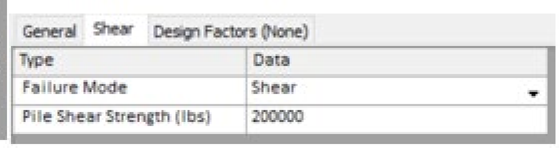
1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element and assign the 8 ft out-of-plane spacing and very large pile shear strength (200,000 lbf)
3. Perform limit equilibrium slope stability analysis.
4. If the potential failure surface intersects the pile, increase the shear strength of the pile to make the potential failure outside the pile element. If the calculated FOS is less than the required minimum FOS, increase the length of the pile until the calculated FOS meets the requirement.
5. The pile embedment depth required for a FOS of 1.3 is 14 ft.

Case 1B: Overall Slope Stability – Seismic

Estimate Wall Embedment Depth – Seismic Extreme Event Limit State



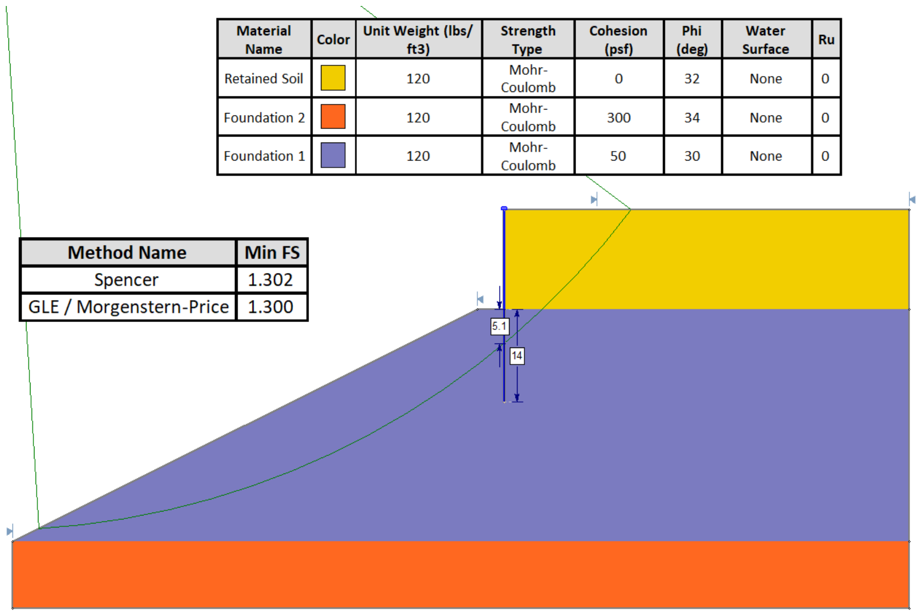




1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element and assign the 8 ft out-of-plane spacing and very large pile shear strength (200,000 lbf)
3. Perform limit equilibrium slope stability analysis, using k_h = 0.2
4. If the potential failure surface intersects the pile, increase the shear strength of the pile to make the potential failure outside the pile element. If the calculated FOS is less than the required minimum FOS, increase the length of the pile until the calculated FOS meets the requirement.
5. The pile embedment depth required for a FOS of 1.0 is 22 ft.

Case 1B: Compound Slope Stability – Static

a) Estimate Demand Force – Static Service Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Foundation 1		120	Mohr-Coulomb	50	30	None	0

Method Name	Min FS
Spencer	1.302
GLE / Morgenstern-Price	1.300

General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

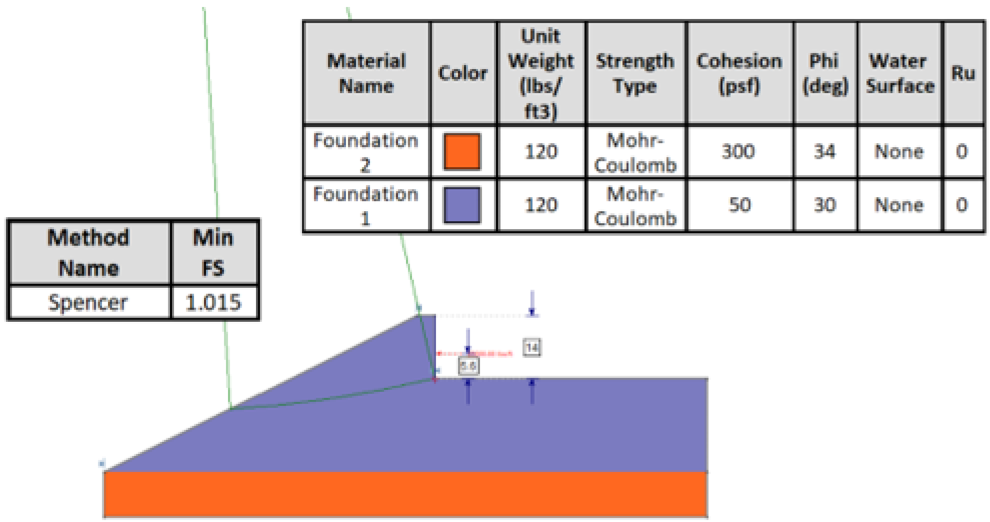
General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	29000

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element, assign the 8 ft out-of-plane spacing. Use pile shear strength 29,000 lbf and pile length obtained from the Global Stability Analysis - Static (14 ft)
3. Perform limit equilibrium slope stability analysis.
4. If the calculated FOS is less than the required minimum FOS and the failure surface passes through the pile element, then increase the pile shear strength in smaller increments until the required FOS is achieved. If the calculated FOS is higher than the required FOS and the failure surface passes outside the pile element, then decrease the pile shear strength until the required FOS is achieved.
5. The pile shear strength required for a FOS of 1.3 is 29,000 lbf.

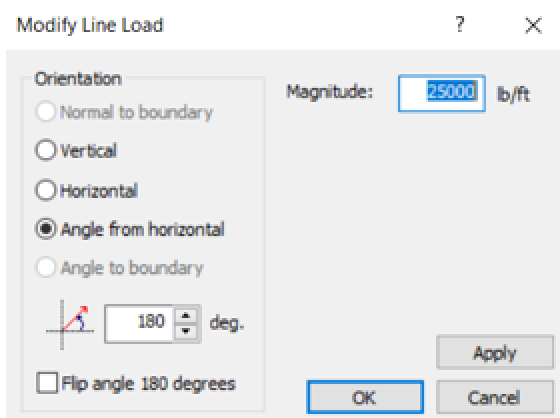
Case 1B: Compound Slope Stability – Static

b) Check Passive Resistance – Static Service Limit State



Material Name	Color	Unit Weight (lbs/ ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Foundation 1		120	Mohr-Coulomb	50	30	None	0

Method Name	Min FS
Spencer	1.015



1. In a separate model, remove all earth material from the active side of the wall.
2. Set the failure surface entry point such that it starts at the tip of the embedded pile.
3. Apply a line load perpendicular to the pile at a height 0.4H = 0.4 x 14 ft = 5.6 ft from the base.
4. Perform LE slope stability analysis to determine the passive pressure that corresponds to a FOS of 1.0. Here P_P = 25 kip/ft.
5. From $P_P = 0.5\ \gamma\ H^2\ K_p$, back-calculate K_p = 2.13 (no interface considered)

6. Determine passive resistance below the compound failure surface using Brom's method:

$$Passive\ Resistance = 3\ K_p \left(\frac{D + d}{2}\right) \gamma b(D - d)$$

$$= 3 \times 2.13 \left(\frac{14 + 5.1}{2}\right) 120 \times 2(14 - 5.1)$$

$$= 130.3 kip/pile$$

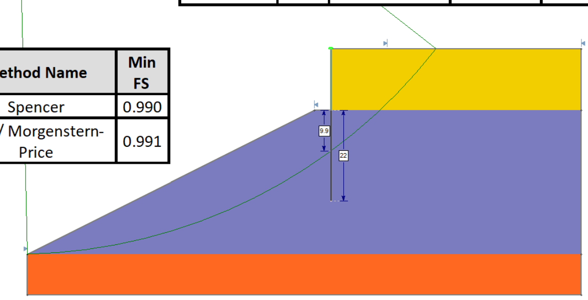
7. FOS = Passive resistance of 130.3 kip per pile divided by demand force of 29 kip per pile = 4.5 > minimum required FOS 1.5.

Case 1B: Compound Slope Stability – Seismic

a) Estimate Demand Force – Seismic Extreme Event Limit State

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Foundation 1		120	Mohr-Coulomb	50	30	None	0

Method Name	Min FS
Spencer	0.990
GLE / Morgenstern-Price	0.991



General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

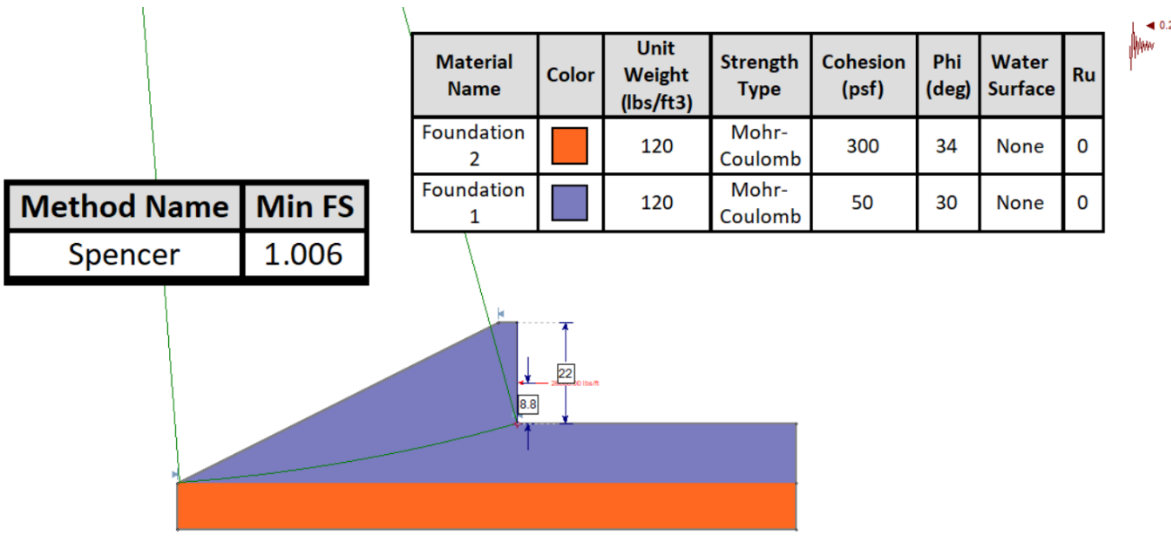
General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	95760

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 2H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element, assign the 8 ft out-of-plane spacing. Use pile shear strength 95,760 lbf and pile length obtained from the Global Stability Analysis - Seismic (22 ft)
3. Perform limit equilibrium slope stability analysis, using k_h = 0.2
4. If the calculated FOS is less than the required minimum FOS and the failure surface passes through the pile element, then increase the pile shear strength in smaller increments until the required FOS is achieved. If the calculated FOS is higher than the required FOS and the failure surface passes outside the pile element, then decrease the pile shear strength until the required FOS is achieved.
5. The pile shear strength required for a FOS of 1.0 is 95,760 lbf.

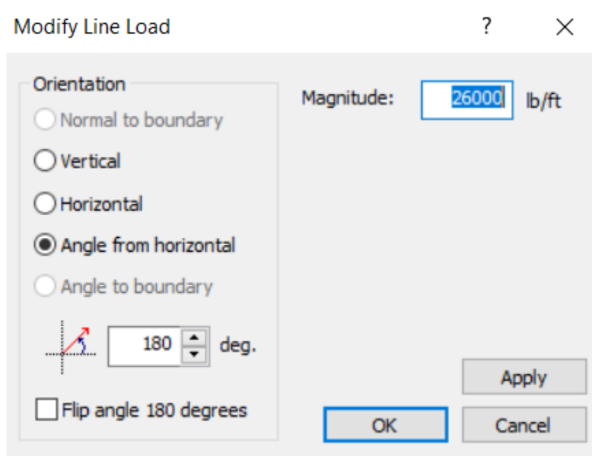
Case 1B: Compound Slope Stability – Seismic

b) Check Passive Resistance – Seismic Extreme Event Limit State



Method Name	Min FS
Spencer	1.006

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Foundation 1		120	Mohr-Coulomb	50	30	None	0



1. In a separate model, remove all earth material from the active side of the wall.
2. Set the failure surface entry point such that it starts at the tip of the embedded pile.
3. Apply a line load perpendicular to the pile at a height 0.4H = 0.4 x 22 ft = 8.8 ft from the base.
4. Perform LE slope stability analysis using k_h = 0.2 to determine the passive pressure that corresponds to a FOS of 1.0. Here P_P = 26 kip/ft.
5. From $P_P = 0.5\,\gamma\,H^2\,K_p$, back-calculate K_p = 0.9 (no interface considered)

6. Determine passive resistance below the compound failure surface using Brom's method:

$$Passive\ Resistance = 3\ K_p \left(\frac{D + d}{2}\right) \gamma b (D - d)$$

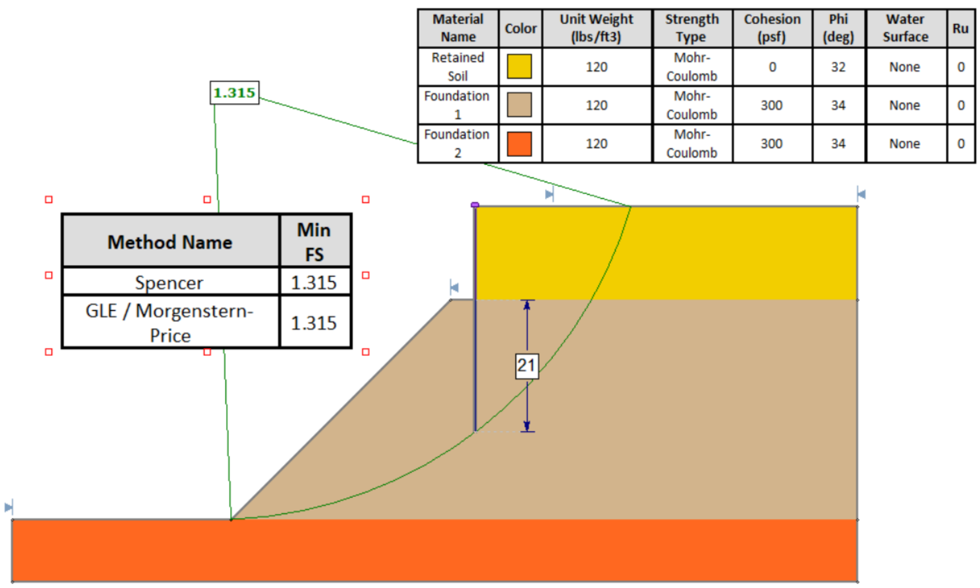
$$= 3 \times 0.9 \left(\frac{22 + 9.9}{2}\right) 120 \times 2(22 - 9.9)$$

$$= 125\ kip/pile$$

7. FOS = Passive resistance of 125 kip per pile divided by demand force of 95.76 kip per pile = 1.3 > minimum required FOS 1.0.

Case 2: Overall Slope Stability – Static

Estimate Wall Embedment Depth – Static Service Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 1		120	Mohr-Coulomb	300	34	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	1.315
GLE / Morgenstern-Price	1.315

General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

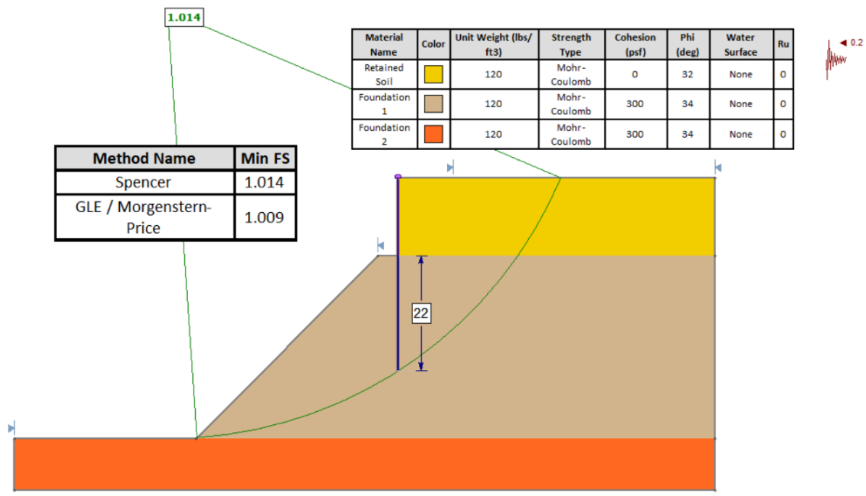
General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	200000

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 1H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element and assign the 8 ft out-of-plane spacing and very large pile shear strength (200,000 lbf)
3. Perform limit equilibrium slope stability analysis.
4. If the potential failure surface intersects the pile, increase the shear strength of the pile to make the potential failure outside the pile element. If the calculated FOS is less than the required minimum FOS, increase the length of the pile until the calculated FOS meets the requirement.
5. The pile embedment depth required for a FOS of 1.3 is 21 ft.

Case 2: Overall Slope Stability – Seismic

Estimate Wall Embedment Depth – Seismic Extreme Event Limit State



General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

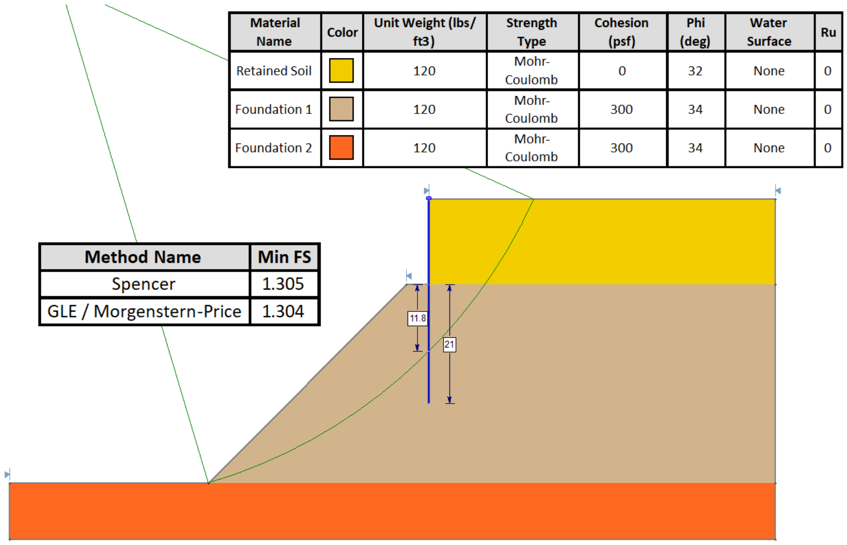
General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	200000

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 1H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element and assign the 8 ft out-of-plane spacing and very large pile shear strength (200,000 lbf)
3. Perform limit equilibrium slope stability analysis, using k_h = 0.2
4. If the potential failure surface intersects the pile, increase the shear strength of the pile to make the potential failure outside the pile element. If the calculated FOS is less than the required minimum FOS, increase the length of the pile until the calculated FOS meets the requirement.
5. The pile embedment depth required for a FOS of 1.0 is 22 ft.

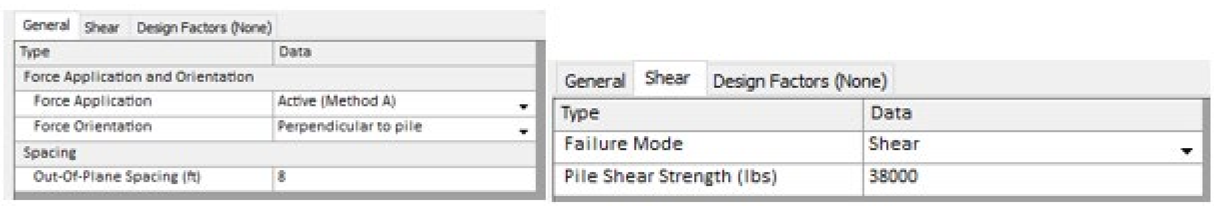
Case 2: Compound Slope Stability – Static

a) Estimate Demand Force – Static Service Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 1		120	Mohr-Coulomb	300	34	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	1.305
GLE / Morgenstern-Price	1.304



General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	38000

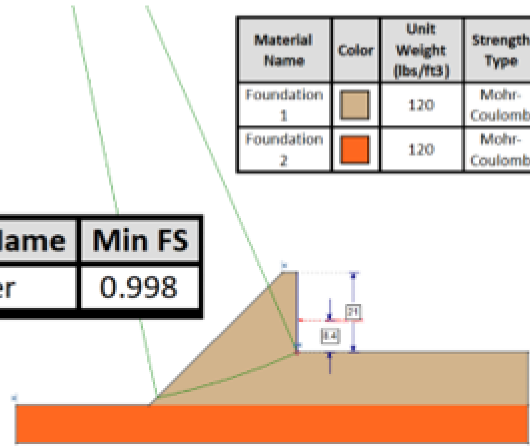
1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 1H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element, assign the 8 ft out-of-plane spacing. Use pile shear strength 38,000 lbf and pile length obtained from the Global Stability Analysis - Static (21 ft)
3. Perform limit equilibrium slope stability analysis.
4. If the calculated FOS is less than the required minimum FOS and the failure surface passes through the pile element, then increase the pile shear strength in smaller increments until the required FOS is achieved. If the calculated FOS is higher than the required FOS and the failure surface passes outside the pile element, then decrease the pile shear strength until the required FOS is achieved.
5. The pile shear strength required for a FOS of 1.3 is 38,000 lbf.

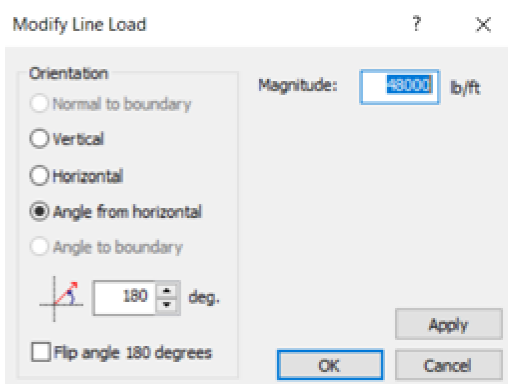
Case 2: Compound Slope Stability – Static

b) Check Passive Resistance – Static Service Limit State

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 1		120	Mohr-Coulomb	300	34	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	0.998





1. In a separate model, remove all earth material from the active side of the wall.
2. Set the failure surface entry point such that it starts at the tip of the embedded pile.
3. Apply a line load perpendicular to the pile at a height 0.4H = 0.4 x 21 ft = 8.4 ft from the base.
4. Perform LE slope stability analysis to determine the passive pressure that corresponds to a FOS of 1.0. Here P_P = 48 kip/ft.
5. From $P_P = 0.5\,\gamma\,H^2\,K_p$, back-calculate K_p = 1.81 (no interface considered)

6. Determine passive resistance below the compound failure surface using Brom's method:

$$Passive\ Resistance = 3\ K_p\left(\frac{D+d}{2}\right)\gamma b(D-d)$$

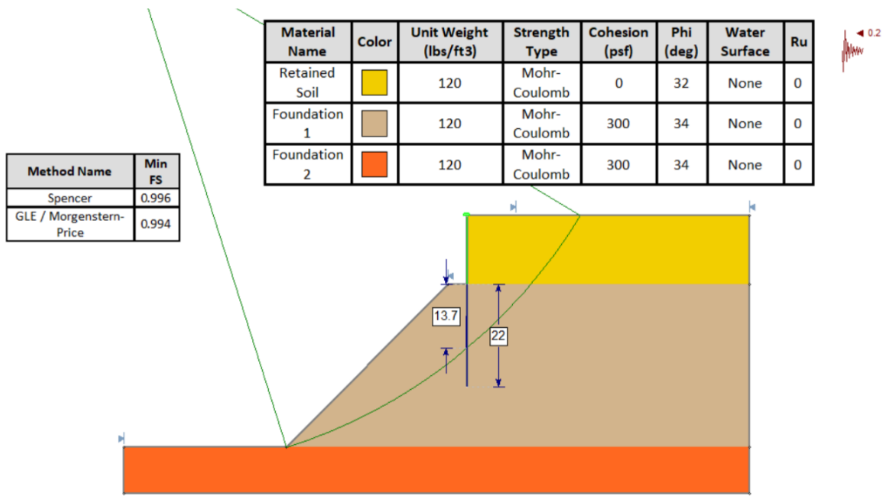
$$= 3 \times 1.81\left(\frac{21+11.8}{2}\right)120 \times 2(21-11.8)$$

$$= 196.6\ kip/pile$$

7. FOS = Passive resistance of 196.6 kip per pile divided by demand force of 38 kip per pile = 5.17 > minimum required FOS 1.5.

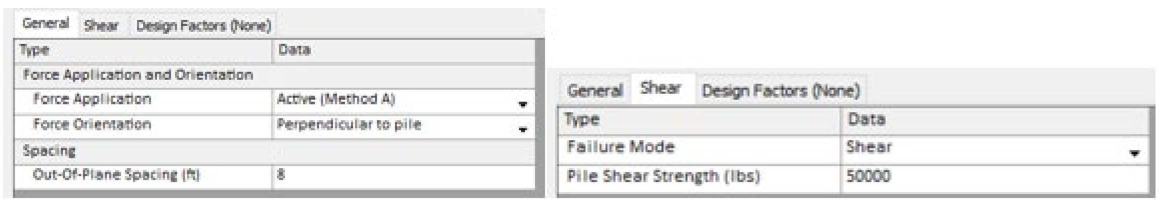
Case 2: Compound Slope Stability – Seismic

a) Estimate Demand Force – Seismic Extreme Event Limit State



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Retained Soil		120	Mohr-Coulomb	0	32	None	0
Foundation 1		120	Mohr-Coulomb	300	34	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0

Method Name	Min FS
Spencer	0.996
GLE / Morgenstern-Price	0.994



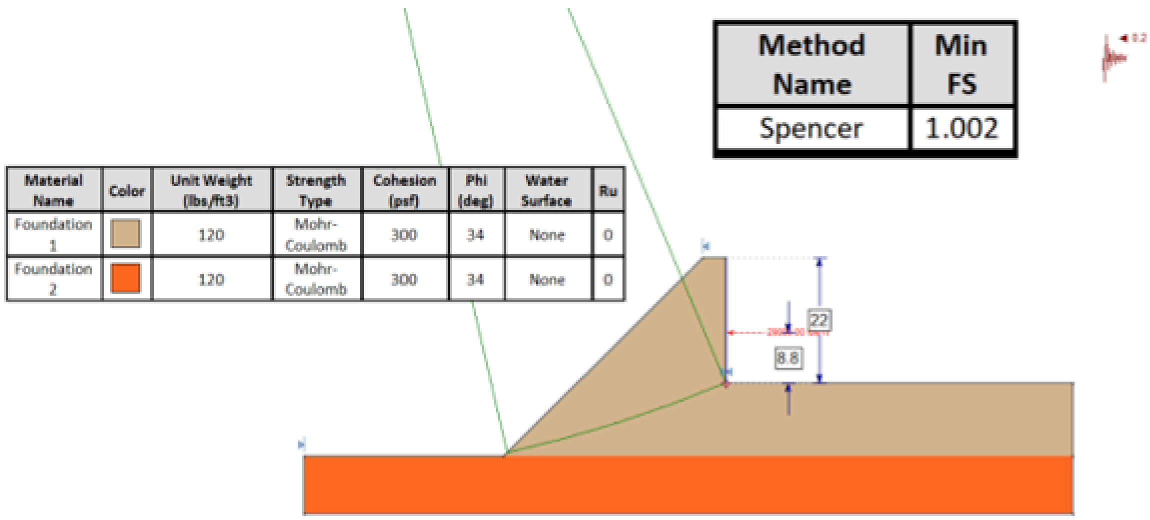
Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	50000

1. Model the retained soil, retaining wall and ground condition in front of the retaining wall. In this example the height of the retaining wall is 15 ft. The ground in front of retaining wall has 1H:1V slope with a slope height of 35 ft.
2. Assign soil properties using Tables 2.1. Create pile wall using pile/micro pile element, assign the 8 ft out-of-plane spacing. Use pile shear strength 50,000 lbf and pile length obtained from the Global Stability Analysis - Seismic (22 ft)
3. Perform limit equilibrium slope stability analysis, using k_h = 0.2
4. If the calculated FOS is less than the required minimum FOS and the failure surface passes through the pile element, then increase the pile shear strength in smaller increments until the required FOS is achieved. If the calculated FOS is higher than the required FOS and the failure surface passes outside the pile element, then decrease the pile shear strength until the required FOS is achieved.
5. The pile shear strength required for a FOS of 1.0 is 50,000 lbf.

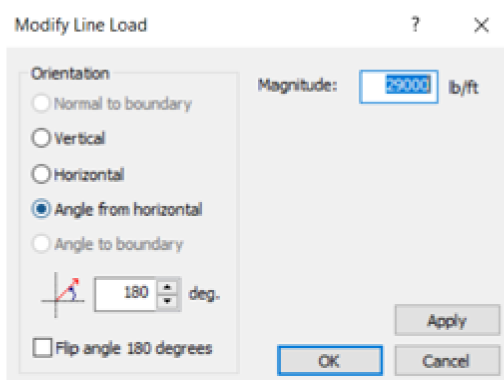
Case 2: Compound Slope Stability – Seismic

b) Check Passive Resistance – Seismic Extreme Event Limit State



Method Name	Min FS
Spencer	1.002

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 1		120	Mohr-Coulomb	300	34	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0



1. In a separate model, remove all earth material from the active side of the wall.
2. Set the failure surface entry point such that it starts at the tip of the embedded pile.
3. Apply a line load perpendicular to the pile at a height 0.4H = 0.4 x 22 ft = 8.8 ft from the base.
4. Perform LE slope stability analysis using k_h = 0.2 to determine the passive pressure that corresponds to a FOS of 1.0. Here P_P = 29 kip/ft.
5. From $P_P = 0.5\,\gamma\,H^2\,K_p$, back-calculate K_p = 1.0 (no interface considered)

6. Determine passive resistance below the compound failure surface using Brom's method:

$$Passive\ Resistance = 3\ K_p \left(\frac{D + d}{2}\right) \gamma b(D - d)$$

$$= 3 \times 1.0 \left(\frac{22 + 13.7}{2}\right) 120 \times 2(22 - 13.7)$$

$$= 106.6\ kip/pile$$

7. FOS = Passive resistance of 106.6 kip per pile divided by demand force of 50 kip per pile = 2.132 > minimum required FOS 1.0.

A3. GROUND ANCHORED WALL

Design Examples

The following examples include:

- Comparison of cohesionless and mixed (cohesion and frictional) soils
- Comparison of varying sloping ground surface

Soldier Pile Wall with Ground Anchor

- Design Height, H 25 ft
- Descending Slope Height 35 ft
- Application of P_{AEP} 0.4H (static and seismic)
- Application of P_P 0.33H (static and seismic)
- Horizontal Seismic Coeff, k_h 0.2 (assume seismic movement > 2 inches tolerable)
- Pile width, b 2 ft
- Pile spacing 8 ft

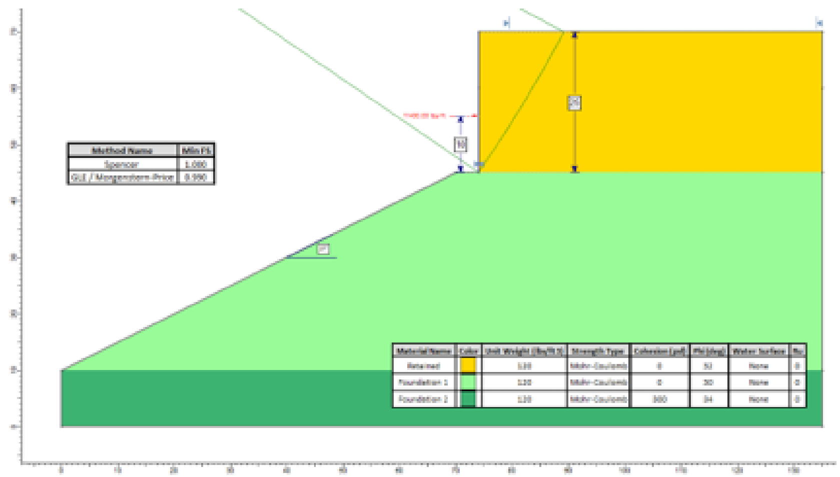
Case	Ground slope incline	Retained Soil Shear Strength	Foundation 1 Shear Strength	Foundation 2 Shear Strength
1A	2H:1V (27 deg)	γ = 120 pcf c' = 0 psf, ϕ' = 32 deg	γ = 120 pcf c' = 0 psf, ϕ' = 30 deg	γ = 120 pcf c' = 300 psf, ϕ' = 34 deg
1B			γ = 120 pcf c' = 50 psf, ϕ' = 30 deg	
2	1H:1V (45 deg)		γ = 120 pcf c' = 300 psf, ϕ' = 34 deg	

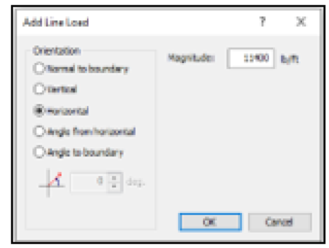
Summary of Results

Case	Static (Service Limit State)				Seismic (Extreme Limit State)			
	P_{AEP}, k/ft	Min. Pile Depth, ft	Demand Force, k/pile	Passive Resistance, k/pile	P_{AE}, k/ft	Min. Pile Depth, ft	Demand Force, k/pile	Passive Resistance, k/pile
1A	15.2	21	49	178	16.5	26	146	157
1B	15.2	17	18	100	16.5	24	107	134
2	15.2	24	47	201	16.5	23	58	95

Case 1A: Overall Global Slope Stability - Static Service Limit State

a) Estimate Ground Anchor Stabilization Force





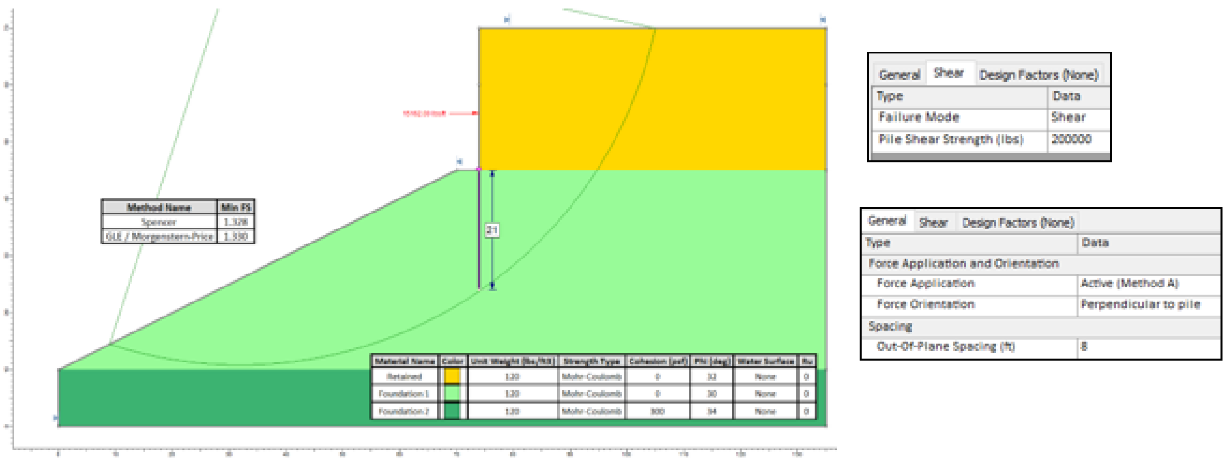
1. Assign long-term soil properties - see above figure
2. Set the search limits to force the exiting failure through the base
3. Apply a line load (required stabilizing force) with a horizontal orientation on the face of the retained soil face. The load is applied at 0.4 H = 0.4 x 25ft = 10 ft from the base.
4. Perform limit equilibrium (LE) slope stability analysis, using Method 1 to determine P_{AEP}:

   P_{AEP} = 1.33 x PA = 1.33 x 11,400 lbf/ft = 15,162 lbf/ft (governs)

   From Method 2, P_{AEP} = 14,400 lbf/ft

Case 1A: Overall Global Slope Stability - Static Service Limit State

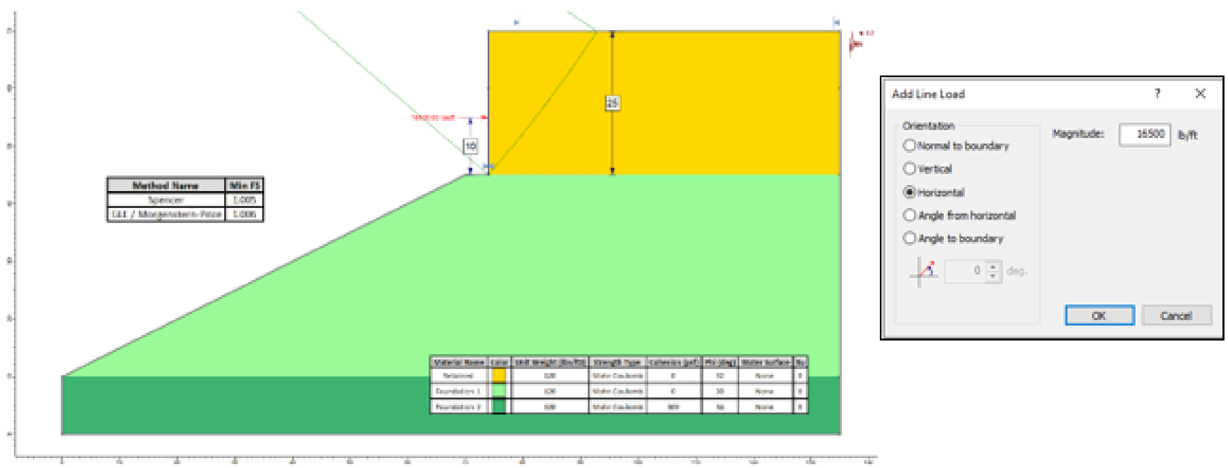
b) Estimate Wall Embedment Depth



1. Model a vertical pile element at 8 ft spacing with large pile shear strength (200,000 lbf)
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis. A pile embedment of 21 feet results in FoS > 1.3

Case 1A: Overall Global Slope Stability - Seismic Extreme Event Limit State

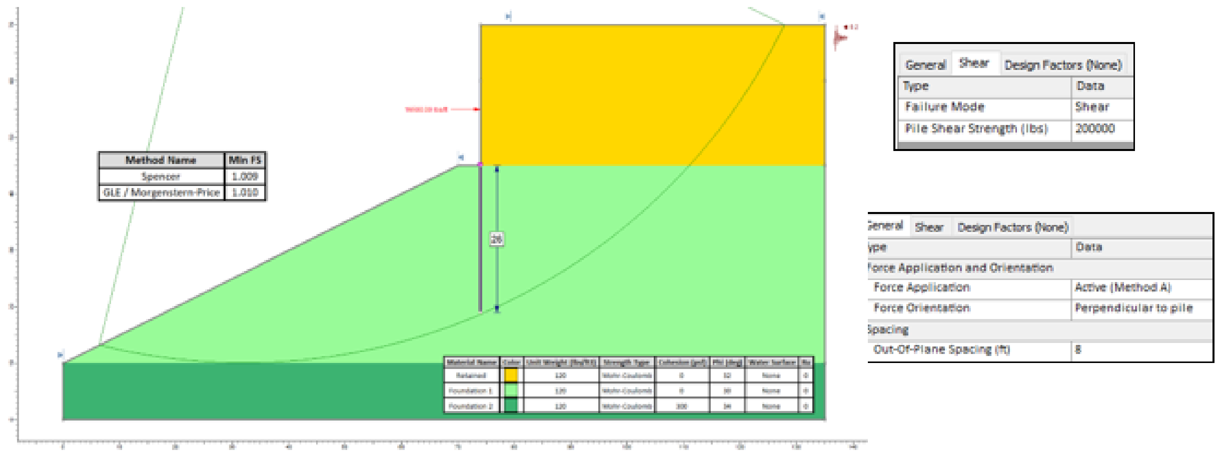
a) Estimate Ground Anchor Stabilization Force



1. Assign long-term soil properties - see figure
2. Set the search limits to force the exiting failure through the base
3. Apply a line load (required stabilizing force) with a horizontal orientation on the face of the retained soil face. The load is applied at 0.4 H = 0.4 x 25ft = 10 ft from the base.
4. Perform limit equilibrium (LE) slope stability analysis, using k_h = 0.2 to determine P_{AEP} for FoS = 1.0: 8 P_{AEP} = 16,500 lbf/ft

Case 1A: Overall Global Slope Stability - Seismic Extreme Event Limit State

b) Estimate Wall Embedment Depth

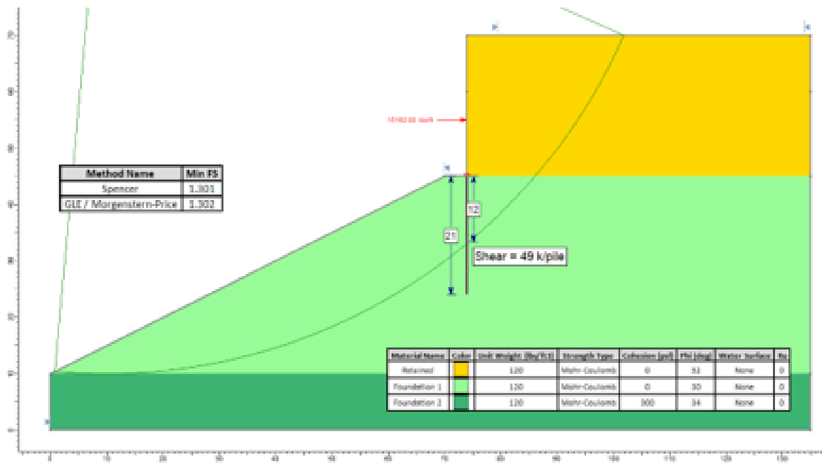


1. Model a vertical pile element at 8 ft spacing with large pile shear strength (200,000 lbf)
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis, using k_h = 0.2. A pile embedment of 26 feet results in FoS > 1.0

   (pile length from seismic governs design for global stability)

Case 1A: Compound Slope Stability - Static Service Limit State

a) Estimate Demand Force



General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	49000

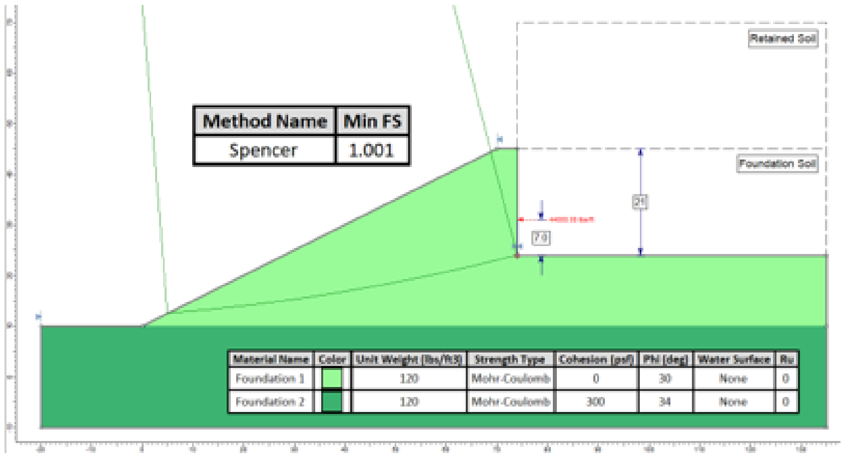
General | Shear | Design Factors (None)

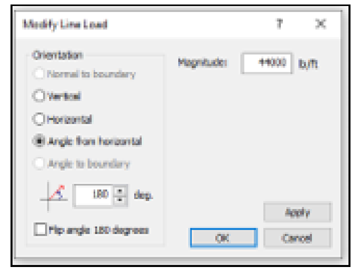
Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

1. In a separate analysis, model the P_{AEP} and wall length/spacing determined from Steps 3 to 5 from the static global slope stability analyses.
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis, modifying the pile shear strength to 49 k to allow failure to occur within the pile element for a FoS > 1.3.

Case 1A: Compound Slope Stability - Static Service Limit State

b) Check Passive Resistance





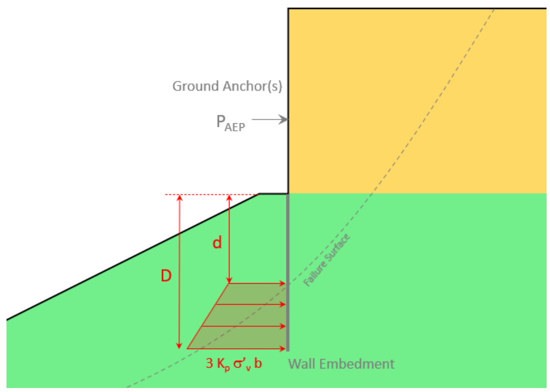
1. In a separate model, remove all earth material from the active side of the wall.
2. Set the search limits to force the entry failure through the bottom of the embedded wall. Use a circular failure search.
3. Apply a line load with a horizontal orientation on the face of the retained soil face. The load is applied at 1/3 x H = 1/3 x 21ft = 7 ft from the base
4. Perform LE slope stability analysis to determine P_P = 44 k/ft that computes a FoS of 1.0.
5. From $P_P = 0.5\,\gamma\,H^2\,K_p$, back-calculate K_p = 1.66

6. Determine the passive resistance force below the failure surface computed in Step 3.

$$Passive\ Resistance = 3\ K_p \left(\frac{D+d}{2}\right) \gamma b (D-d)$$

$$= 3 \times 1.66 \left(\frac{21+12}{2}\right) 120 \times 2(21-12)$$

$$= 178k/pile$$

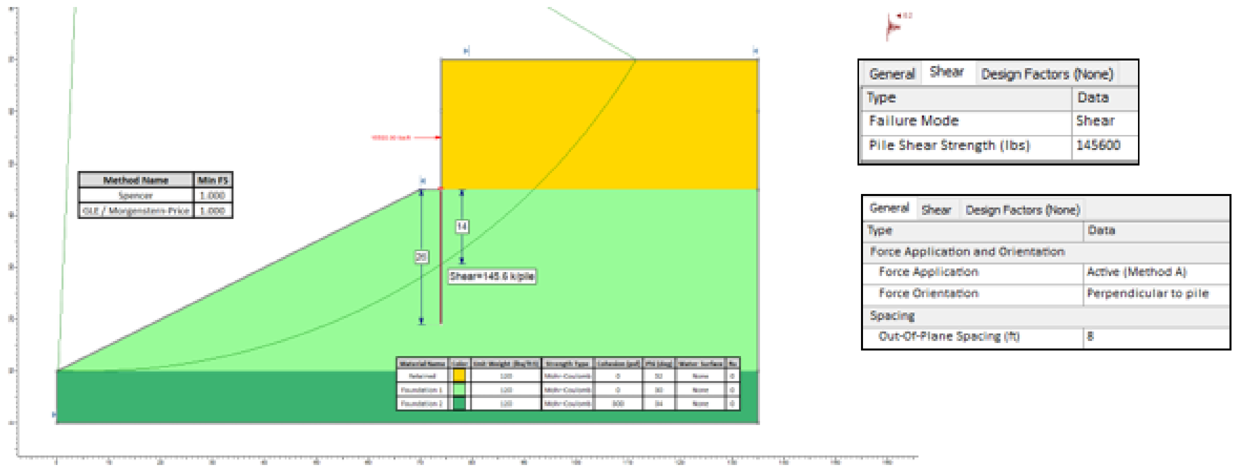


7. Passive resistance of 178 k per pile divided by demand force of 49 k per pile = 3.6

Greater than minimum required 1.5 FoS.

Case 1A: Compound Slope Stability - Seismic Extreme Event Limit State

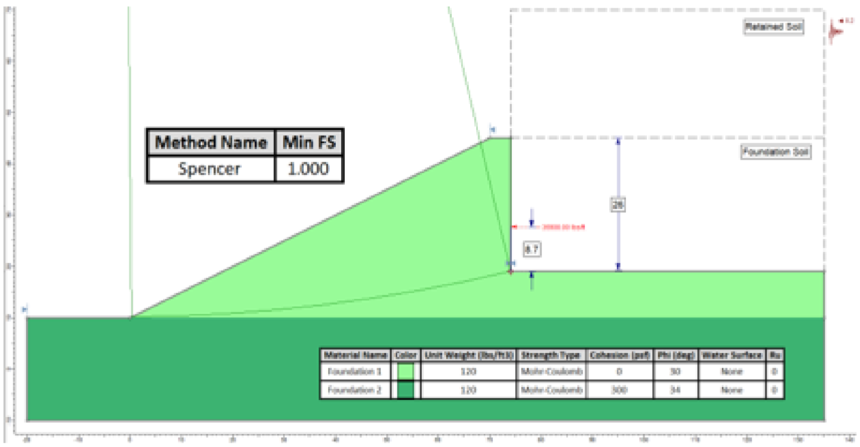
Estimate Demand Force

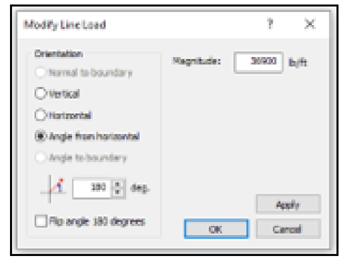


1. In a separate analysis, model the P_{AEP} and wall length/spacing determined from Steps 3 to 5 from the seismic global slope stability analyses.
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis using k_h = 0.2. Modifying the pile shear strength to 145.6 k to allow failure to occur within the pile element for a FoS > 1.0.

Case 1A: Compound Slope Stability - Seismic Extreme Event Limit State

Check Passive Resistance





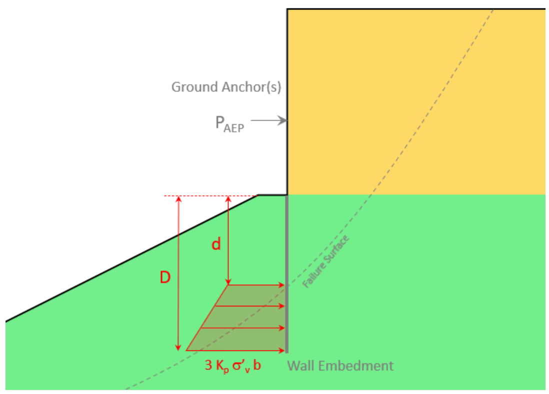
1. In a separate model, remove all earth material from the active side of the wall.
2. Set the search limits to force the entry failure through the bottom of the embedded wall. Use a circular failure search.
3. Apply a line load with a horizontal orientation on the face of the retained soil face. The load is applied at 1/3 H = 1/3 x 26ft = 8.7 ft from the base
4. Perform LE slope stability analysis using k_h = 0.2 to determine P_P = 36.9 k/ft that computes a FoS of 1.0.
5. From $P_P = 0.5\,\gamma\,H^2\,K_{pe}$, back-calculate K_{pe} = 0.91

6. Determine the passive resistance force below the failure surface computed in Step 3:

$$Passive\ Resistance = 3\ K_p \left(\frac{D+d}{2}\right) \gamma b (D-d)$$

$$= 3 \times 0.99 \left(\frac{26+14}{2}\right) 120 \times 2(26-14)$$

$$= 157 k/pile$$

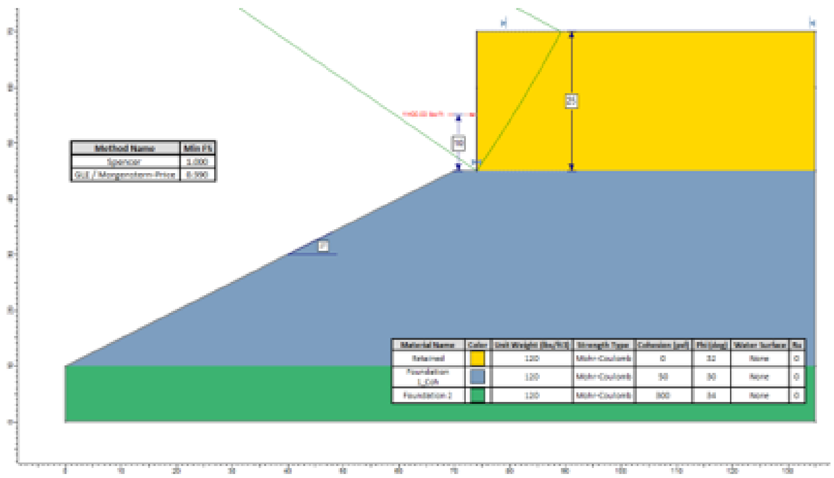


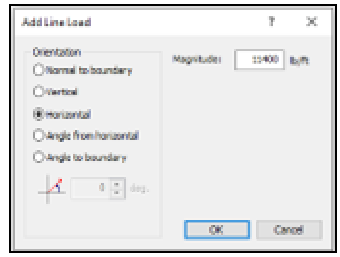
7. Passive resistance of 157 k per pile divided by demand force of 146 k per pile = 1.1

   Greater than minimum required 1.0 FoS

Case 1B: Overall Global Slope Stability - Static Service Limit State

a) Estimate Ground Anchor Stabilization Force





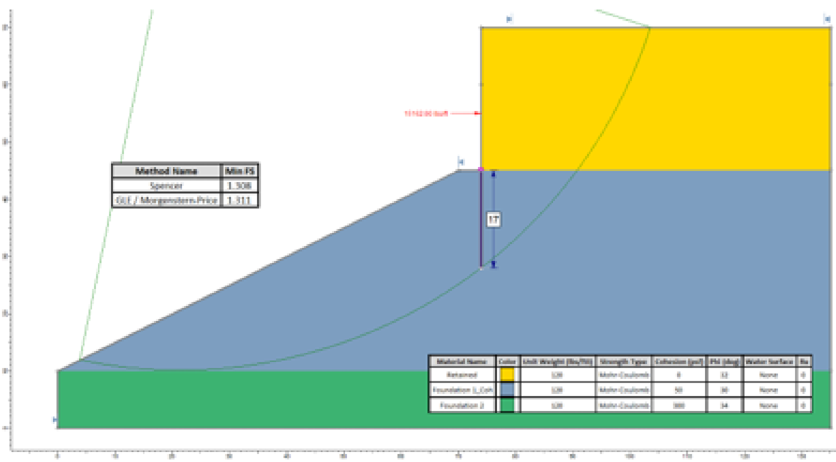
1. Assign long-term soil properties - see figure
2. Set the search limits to force the exiting failure through the base.
3. Apply a line load (required stabilizing force) with a horizontal orientation on the face of the retained soil face. The load is applied at 0.4 H = 0.4 x 25ft = 10 ft from the base.
4. Perform limit equilibrium (LE) slope stability analysis, using Method 1 to determine P_{AEP}:

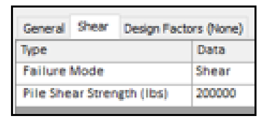
   P_{AEP} = 1.33 x PA = 1.33 x 11,400 lbf/ft = 15,162 lbf/ft (governs)

   From Method 2, P_{AEP} = 14,400 lbf/ft

Case 1B: Overall Global Slope Stability - Static Service Limit State

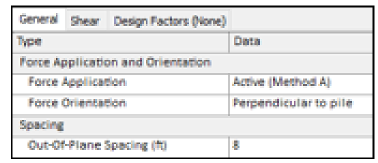
b) Estimate Wall Embedment Depth





General | Shear | Design Factors (None)

Type	Data
Failure Mode	Shear
Pile Shear Strength (lbs)	200000



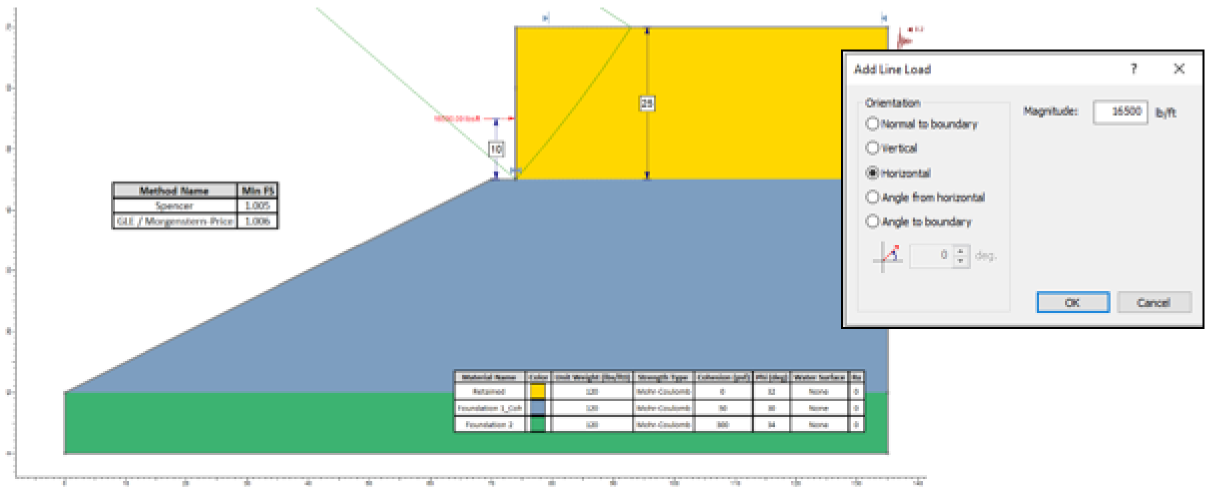
General | Shear | Design Factors (None)

Type	Data
Force Application and Orientation	
Force Application	Active (Method A)
Force Orientation	Perpendicular to pile
Spacing	
Out-Of-Plane Spacing (ft)	8

1. Model a vertical pile element at 8 ft spacing with large pile shear strength (200,000 lbf)
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis. A pile embedment of 17 feet results in FoS > 1.3

Case 1B: Overall Global Slope Stability - Seismic Extreme Event Limit State

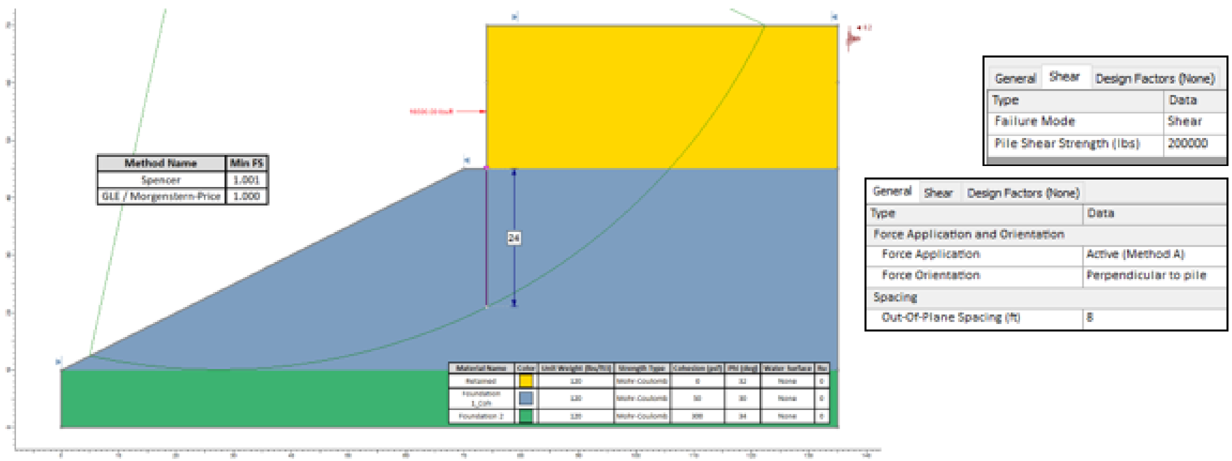
a) Estimate Ground Anchor Stabilization Force



1. Assign long-term soil properties - see figure
2. Set the search limits to force the exiting failure through the base
3. Apply a line load (required stabilizing force) with a horizontal orientation on the face of the retained soil face. The load is applied at 0.4 H = 0.4 x 25ft = 10 ft from the base.
4. Perform limit equilibrium (LE) slope stability analysis, using k_h = 0.2 to determine P_{AEP} for FoS = 1.0: P_{AEP} = 16,500 lbf/ft

Case 1B: Overall Global Slope Stability - Seismic Extreme Event Limit State

b) Estimate Wall Embedment Depth

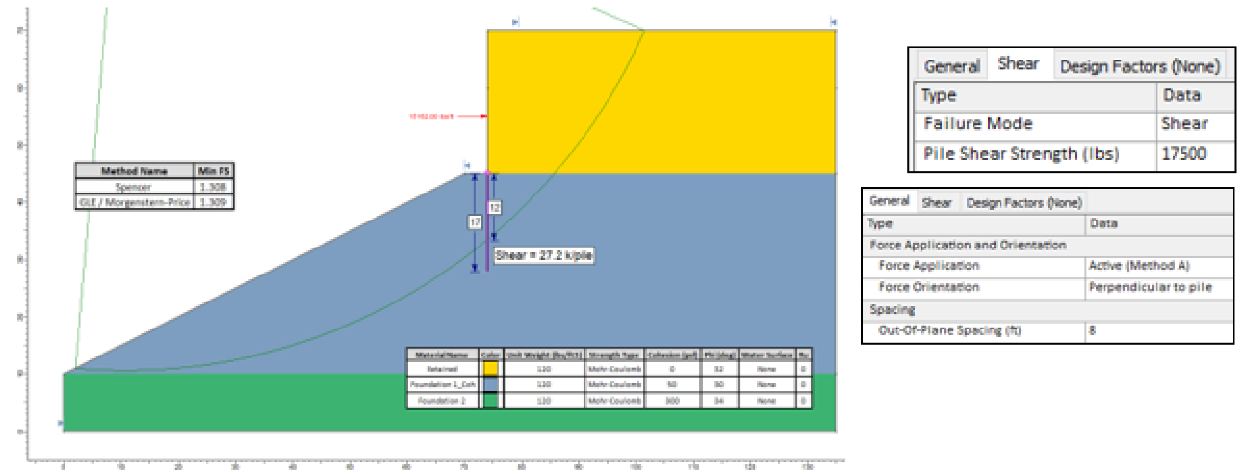


1. Model a vertical pile element at 8 ft spacing with large pile shear strength (200,000 lbf)
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis, using $k_h = 0.2$. A pile embedment of 24 feet results in FoS > 1.0

   (pile length from seismic governs design for global stability)

Case 1B: Compound Slope Stability - Static Service Limit State

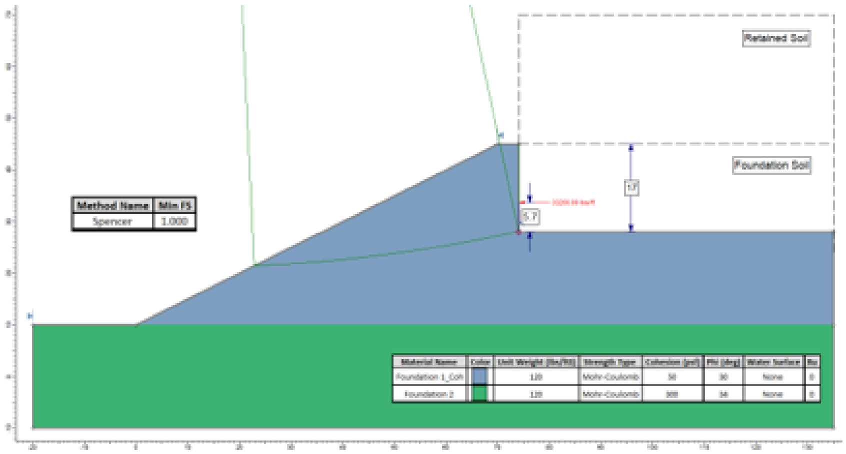
a) Estimate Demand Force

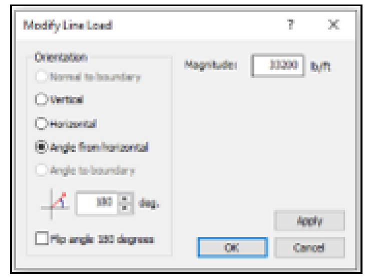


1. In a separate analysis, model the P_{AEP} and wall length/spacing determined from Steps 3 to 5 from the static global slope stability analyses.
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis, modifying the pile shear strength to 17.5 k to allow failure to occur within the pile element for a FoS > 1.3.

Case 1B: Compound Slope Stability - Static Service Limit State

b) Check Passive Resistance





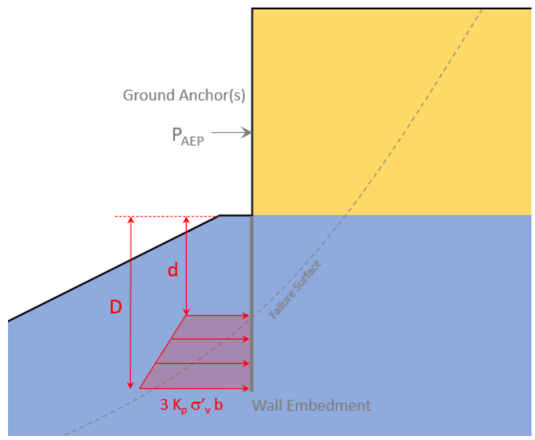
1. In a separate model, remove all earth material from the active side of the wall.
2. Set the search limits to force the entry failure through the bottom of the embedded wall. Use a circular failure search.
3. Apply a line load with a horizontal orientation on the face of the retained soil face. The load is applied at 1/3 H = 1/3 x 17ft = 5.7 ft from the base
4. Perform LE slope stability analysis to determine P_P = 33.2 k/ft that computes a FoS of 1.0.
5. From $P_P = 0.5\ \gamma\ H^2\ K_p$, back-calculate K_p = 1.91

6. Determine the passive resistance force below the failure surface computed in Step 3:

$$Passive\ Resistance = 3\ K_p \left(\frac{D+d}{2}\right) \gamma b (D-d)$$

$$= 3 \times 1.91 \left(\frac{17+12}{2}\right) 120 \times 2(17-12)$$

$$= 100k/pile$$

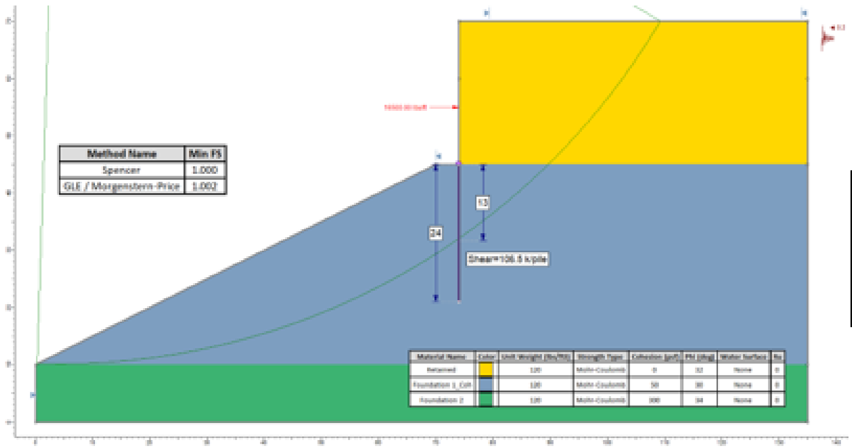


7. Passive resistance of 100 k per pile divided by demand force of 17.5 k per pile = 5.7

   Greater than minimum required 1.5 FoS

Case 1B: Compound Slope Stability - Seismic Extreme Event Limit State

a) Estimate Demand Force



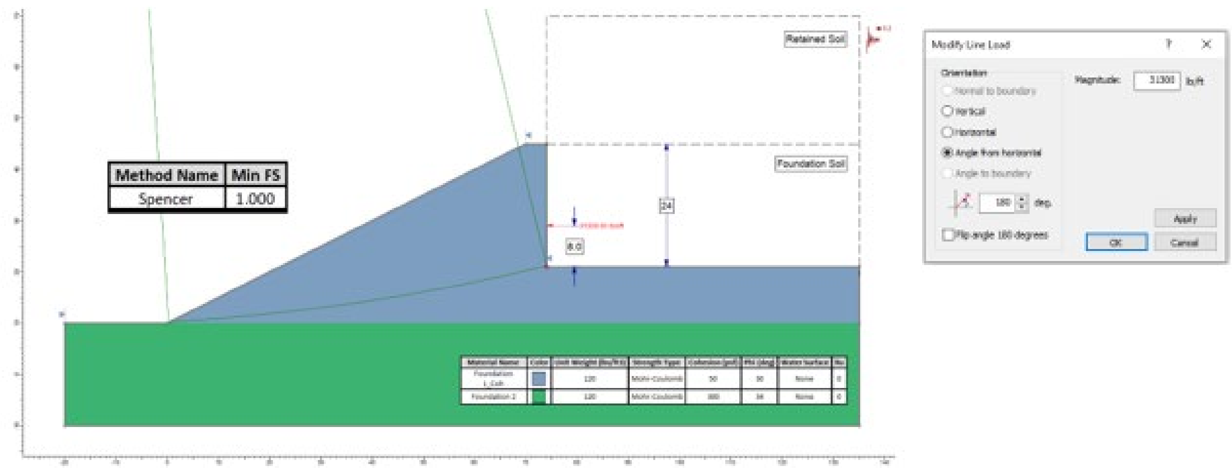
General	Shear	Design Factors (None)
Type		Data
Failure Mode		Shear
Pile Shear Strength (lbs)		106500

General	Shear	Design Factors (None)
Type		Data
Force Application and Orientation		
Force Application		Active (Method A)
Force Orientation		Perpendicular to pile
Spacing		
Out-Of-Plane Spacing (ft)		8

1. In a separate analysis, model the P_{AEP} and wall length/spacing determined from Steps 3 to 5 from the seismic global slope stability analyses.
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis using k_h = 0.2. Modifying the pile shear strength to 106.5 k to allow failure to occur within the pile element for a FoS > 1.0.

Case 1B: Compound Slope Stability - Seismic Extreme Event Limit State

b) Check Passive Resistance



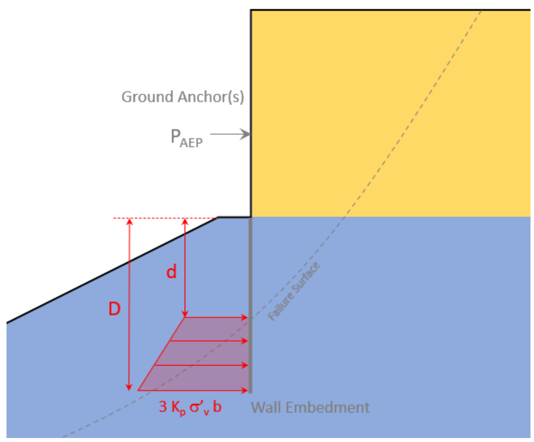
1. In a separate model, remove all earth material from the active side of the wall.
2. Set the search limits to force the entry failure through the bottom of the embedded wall. Use a circular failure search.
3. Apply a line load with a horizontal orientation on the face of the retained soil face. The load is applied at 1/3 H = 1/3 x 24ft = 8 ft from the base
4. Perform LE slope stability analysis using k_h = 0.2 to determine P_P = 31.3 k/ft that computes a FoS of 1.0.
5. From $P_P = 0.5\ \gamma\ H^2\ K_{pe}$, back-calculate K_{pe} = 0.91

6. Determine the passive resistance force below the failure surface computed in Step 3:

$$Passive\ Resistance = 3\ K_p \left(\frac{D+d}{2}\right) \gamma b(D-d)$$

$$= 3 \times 0.91 \left(\frac{24+13}{2}\right) 120 \times 2(24-13)$$

$$= 133k/pile$$

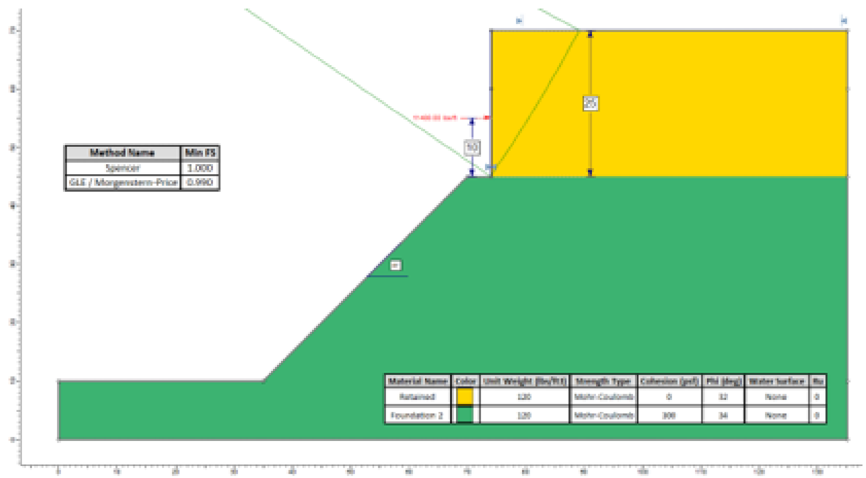


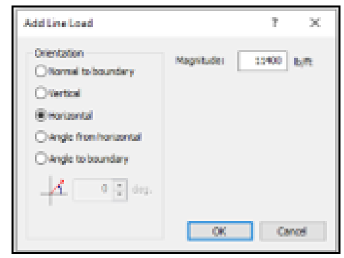
7. Passive resistance of 133 k per pile divided by demand force of 106.5 k per pile = 1.2

   Greater than minimum required 1.0 FoS

Case 2: Compound Slope Stability - Static Service Limit State

a) Estimate Ground Anchor Stabilization Force





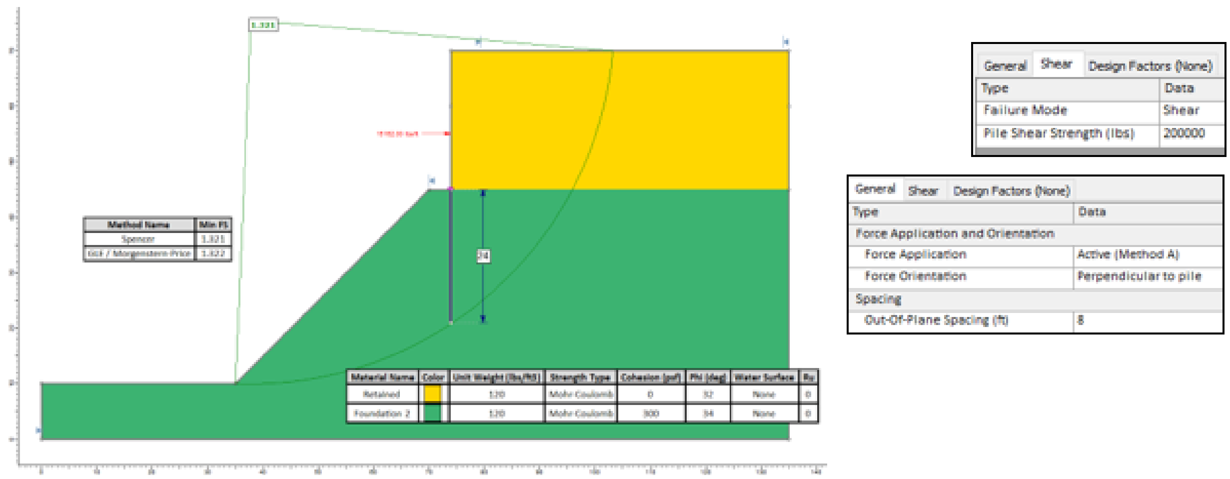
1. Assign long-term soil properties - see figure
2. Set the search limits to force the exiting failure through the base
3. Apply a line load (required stabilizing force) with a horizontal orientation on the face of the retained soil face. The load is applied at 0.4 H = 0.4 x 25ft = 10 ft from the base.
4. Perform limit equilibrium (LE) slope stability analysis, using Method 1 to determine P_{AEP}:

   P_{AEP} = 1.33 x PA = 1.33 x 11,400 lbf/ft = 15,162 lbf/ft (governs)

   From Method 2, P_{AEP} = 14,400 lbf/ft

Case 2: Compound Slope Stability - Static Service Limit State

b) Estimate Wall Embedment Depth

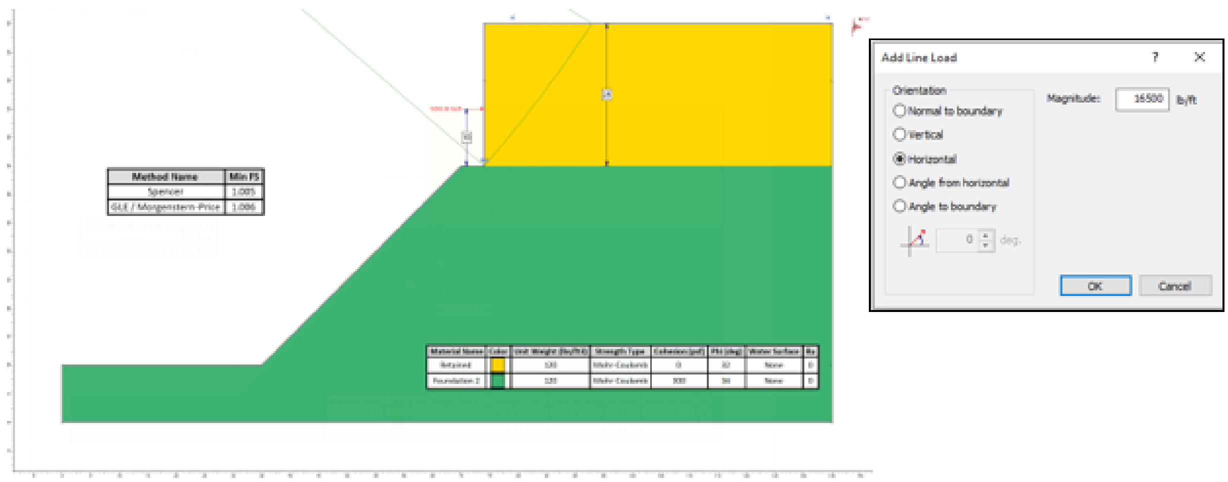


1. Model a vertical pile element at 8 ft spacing with large pile shear strength (200,000 lbf)
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis. A pile embedment of 24 feet results in FoS > 1.3

   (pile length from static governs design for global stability)

Case 2: Overall Global Slope Stability - Seismic Extreme Event Limit State

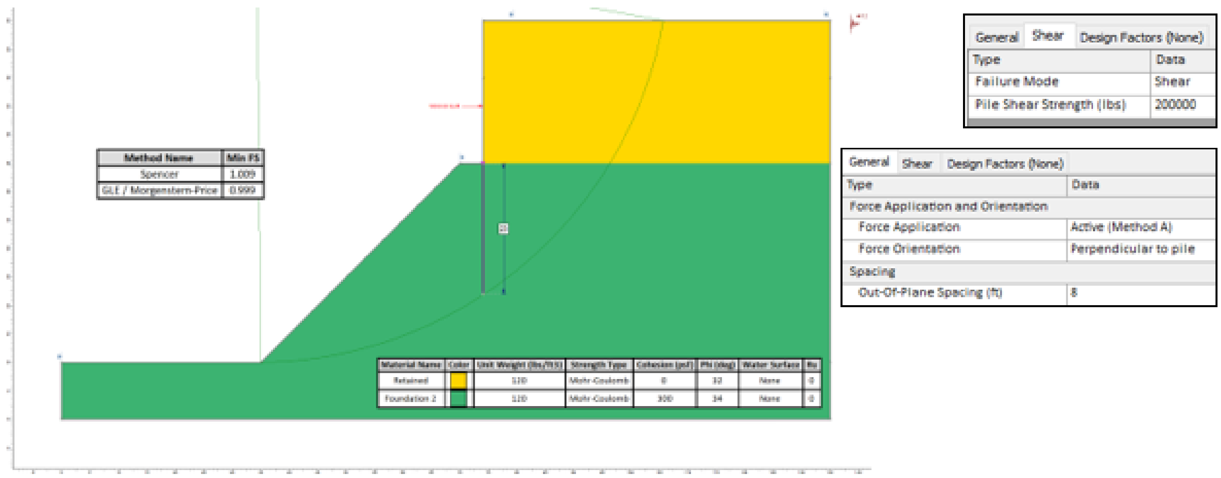
a) Estimate Ground Anchor Stabilization Force



1. Assign long-term soil properties - see figure
2. Set the search limits to force the exiting failure through the base.
3. Apply a line load (required stabilizing force) with a horizontal orientation on the face of the retained soil face. The load is applied at 0.4 H = 0.4 x 25ft = 10 ft from the base.
4. Perform limit equilibrium (LE) slope stability analysis, using k_h = 0.2 to determine P_{AEP} for FoS = 1.0: P_{AEP} = 16,500 lbf/ft

Case 2: Overall Global Slope Stability - Seismic Extreme Event Limit State

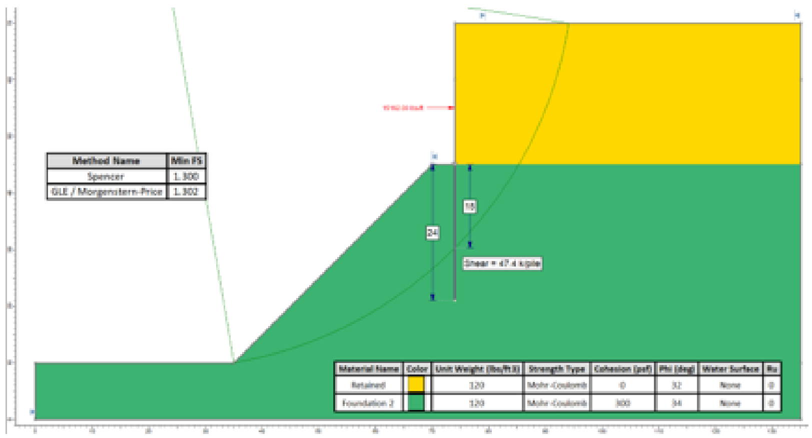
Estimate Wall Embedment Depth



1. Model a vertical pile element at 8 ft spacing with large pile shear strength (200,000 lbf)
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis, using k_h = 0.2. A pile embedment of 23 feet results in FoS > 1.0

Case 2: Compound Slope Stability - Static Service Limit State

a) Estimate Demand Force



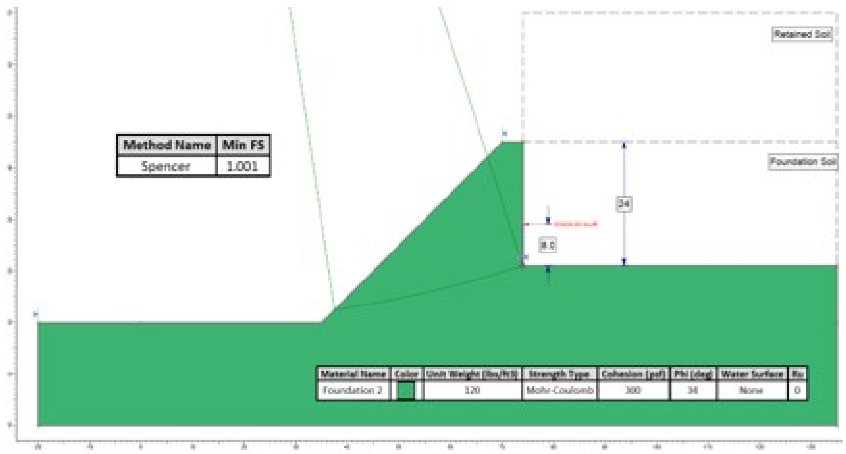
General	Shear	Design Factors (None)
Type	Data	
Failure Mode	Shear	
Pile Shear Strength (lbs)	47400	

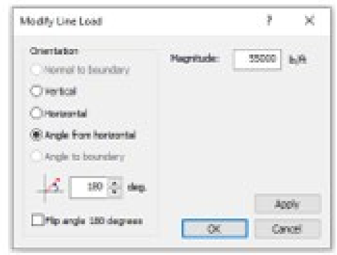
General	Shear	Design Factors (None)
Type	Data	
Force Application and Orientation		
Force Application	Active (Method A)	
Force Orientation	Perpendicular to pile	
Spacing		
Out-Of-Plane Spacing (ft)	8	

1. In a separate analysis, model the P_{AEP} and wall length/spacing determined from Steps 3 to 5 from the static global slope stability analyses.
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis, modifying the pile shear strength to 47.4 k to allow failure to occur within the pile element for a FoS > 1.3.

Case 2: Compound Slope Stability - Static Service Limit State

b) Check Passive Resistance





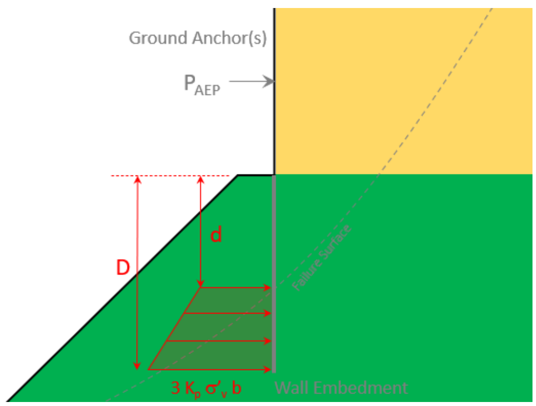
1. In a separate model, remove all earth material from the active side of the wall.
2. Set the search limits to force the entry failure through the bottom of the embedded wall. Use a circular failure search.
3. Apply a line load with a horizontal orientation on the face of the retained soil face. The load is applied at 1/3 H = 1/3 x 24ft = 8 ft from the base
4. Perform LE slope stability analysis to determine P_P = 55 k/ft that computes a FoS of 1.0.
5. From $P_P = 0.5\,\gamma\,H^2\,K_p$, back-calculate K_p = 1.59

6. Determine the passive resistance force below the failure surface computed in Step 3:

$$Passive\ Resistance = 3\ K_p \left(\frac{D+d}{2}\right) \gamma b (D-d)$$

$$= 3 \times 1.59 \left(\frac{24+15}{2}\right) 120 \times 2(24-15)$$

$$= 201k/pile$$

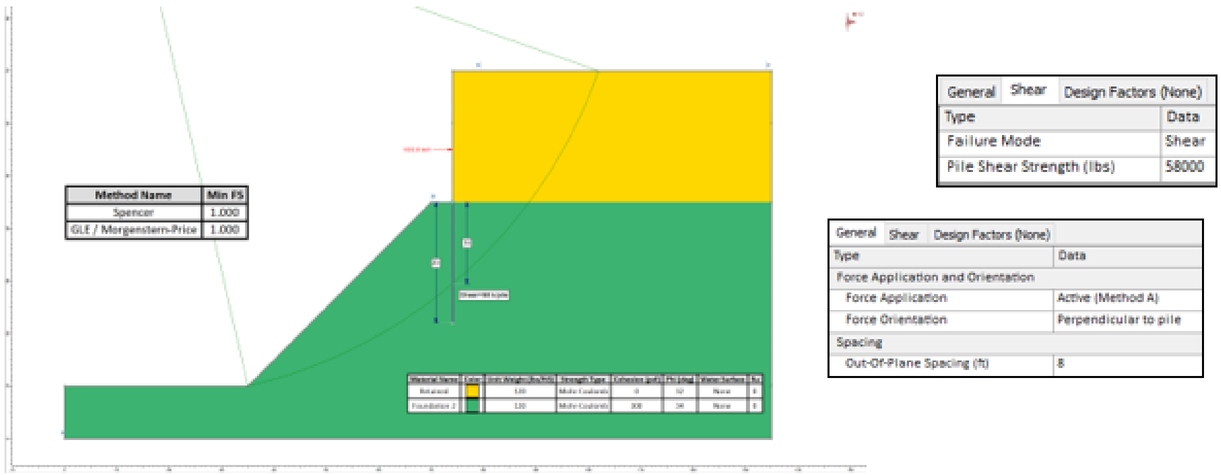


7. Passive resistance of 201 k per pile divided by demand force of 47.4 k per pile = 4.2

Greater than minimum required 1.5 FoS.

Case 2: Compound Slope Stability - Seismic Extreme Event Limit State

a) Estimate Demand Force

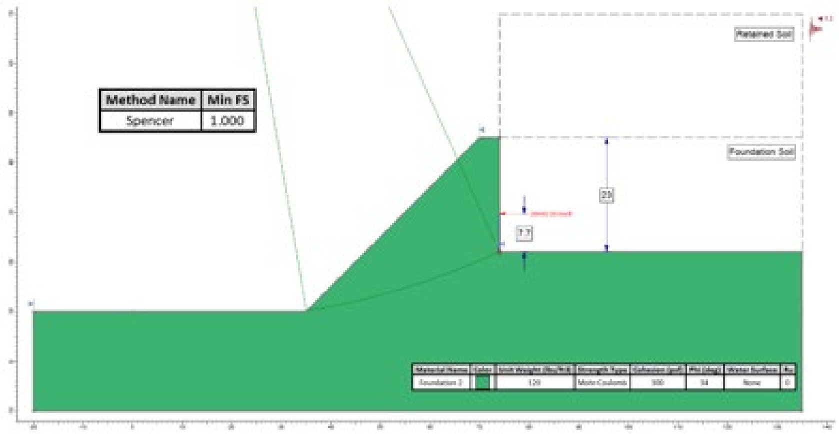


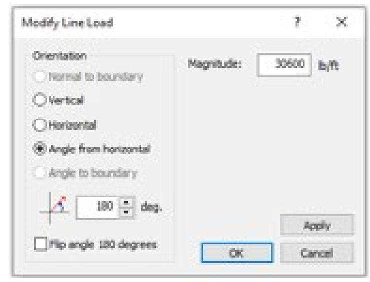
1. In a separate analysis, model the P_{AEP} and wall length/spacing determined from Steps 3 to 5 from the seismic global slope stability analyses.
2. Set the entry failure search limits behind the retaining wall, and the exit failure search limits in front of the wall. Use a circular failure search.
3. Perform LE slope stability analysis using k_h = 0.2. Modifying the pile shear strength to

   58 k to allow failure to occur within the pile element for a FoS > 1.0.

Case 2: Compound Slope Stability - Seismic Extreme Event Limit State

b) Check Passive Resistance





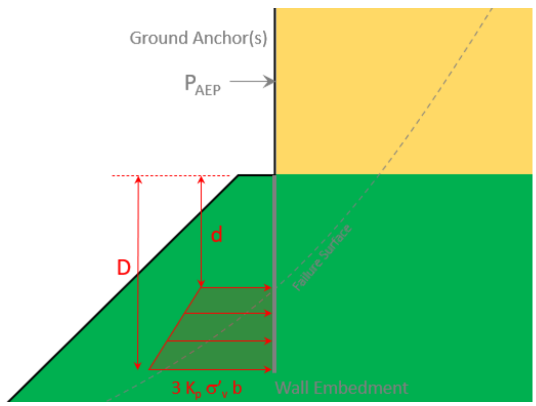
1. In a separate model, remove all earth material from the active side of the wall.
2. Set the search limits to force the entry failure through the bottom of the embedded wall. Use a circular failure search.
3. Apply a line load with a horizontal orientation on the face of the retained soil face. The load is applied at 1/3 H = 1/3 x 23ft = 7.7 ft from the base
4. Perform LE slope stability analysis using k_h = 0.2 to determine P_P = 30.6 k/ft that computes a FoS of 1.0.
5. From $P_P = 0.5\ \gamma\ H^2\ K_{pe}$, back-calculate K_{pe} = 0.96

6. Determine the passive resistance force below the failure surface computed in Step 3:

$$Passive\ Resistance = 3\ K_p \left(\frac{D + d}{2}\right) \gamma b(D - d)$$

$$= 3 \times 0.96 \left(\frac{23 + 16}{2}\right) 120 \times 2(23 - 16)$$

$$= 95k/pile$$



7. Passive resistance of 95 k per pile divided by demand force of 58 k per pile = 1.6

Greater than minimum required 1.0 FoS.

A4. MECHANICALLY STABILIZED EMBANKMENT (MSE)

Method 2 *– with representative engineering properties of the reinforcements.*

This method models the reinforcements using representative engineering properties. These properties are estimated based on the properties of the bottom three rows of reinforcements. The steps for the analysis are as outlined below:

1. Model the MSE reinforcements (refer to Figure 4.1), ensuring the length matches that determined in the global stability analysis. Include at least the bottom three rows of reinforcements.
2. Set the shear strength of the MSE backfill to apparent cohesion of 0 and apparent friction angle of 34 degrees.
3. Develop representative engineering properties for the reinforcements as outlined in Table 4.1. Refer to the design example for guidance.
4. Conduct stability analysis for both static and pseudo-seismic scenarios.
5. If the calculated FoS falls below the required minimum FoS, adjust the reinforcement length.
6. The required reinforcement length is determined from the outcome of Step 5.

Representative Engineering Properties of the Reinforcements

Slide 2		**Slope W**	
General	**Input Values**	**Pullout Resistance Inputs**	**Input Values**
Force Application	Active Method	Interface Adhesion	0
Force Orientation	Parallel to Reinforcement	Interface Shear Angle	$\tan^{-1}(F^*)$: refer to Table A.4.4
Strip Coverage	50% (R_c = 0.5)	Surface Area Factor	2
Allowable Tensile Strength = $A_c f_y/b$	$A_c f_y/b$ (refer to Table A.4.2)	Reduction Factor	$(1/R_c)\gamma/\varphi$ (refer to Table A.4.1)
Pullout and Striping		**Tensile Capacity Inputs**	
Anchorage: Slope Face Connection Strength and Connection Strength	Constant/same as Tensile Strength	Tensile Capacity	$A_c f_y/b$ (refer to Table A.4.2)
Strength Model	Linear	Reduction Factor	$(1/R_c)g/j$ refer to Table A.4.1
Adhesion	0	**Calculation Settings**	
Friction Angle	$\tan^{-1}(F^*)$: refer to Table A.4.4	F of S Dependent	No
Design Factors / Partial Factor (defined)		**Installation Specifications**	**Installation Specifications**
Tensile and Plate Strength	γ/φ refer to Table A.4.1	Face Anchorage	Yes
Bond Strength =	γ/φ refer to Table A.4.1		

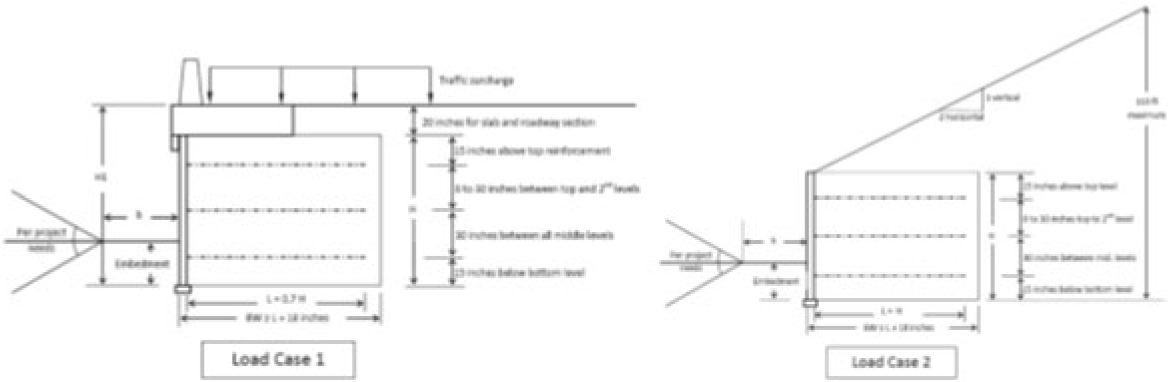


Figure 4.1: Reinforcement Layout (Bridge Design Aids 3-8, 2013 - Attachment 1)

Method 3 *– With Engineering Properties for Each Row of Reinforcements*

This method involves modeling the reinforcements with specific engineering properties assigned to each row. The engineering properties are determined based on the type and depth (overburden) of the reinforcements using steel reinforcements presented from Bridge Design Aids 3-8 (2013) Attachment 3, Steel Soil Reinforcement Tables. The required tensile strength and interface friction angles for each row of reinforcements are summarized in Appendix 4, Tables A.4.2, and A.4.3.

The steps for the analysis are as outlined below:

1. Model the MSE reinforcements, ensuring the length matches that determined in the global stability analysis.
2. Set the shear strength of the MSE backfill to apparent cohesion of 0 and apparent friction angle of 34 degrees.
3. Establish engineering properties for each row of the reinforcements using Appendix Tables A.4.2, and A.4.3, and Table 4.1. Refer to design examples for guidance.
4. Conduct the stability analysis for both static and pseudo-seismic scenarios.
5. If the calculated FoS is falls below the required minimum FoS, adjust the reinforcement length accordingly.
6. The required reinforcement length is determined from the outcome of Step 5.

Design Examples

For the design example, level ground and 3(H) to 1(V) slope ground in front of a wall were modeled using Slide 2. Model parameters including the soil properties, wall geometry, and reinforcements are presented below:

Soil Profile

Ground condition in front of a wall		
	Level Ground	3(H) to 1(V)
Wall Height (ft)	20	20
Foundation Slope Height (ft)	35	35
Soil Property: Unit Weight (kcf)/Cohesion (ksf)/Friction Angle (degree)		
MSE Backfill	0.12/0.0/34	0.12/0.0/34
Retained Soil	0.12/0.0/30	0.12/0.0/30
1st Foundation Soil Layer	0.12/0.0/30	0.12/0.0/30
2nd Foundation Soil Layer	0.12/0.30/34	0.12/0.30/34

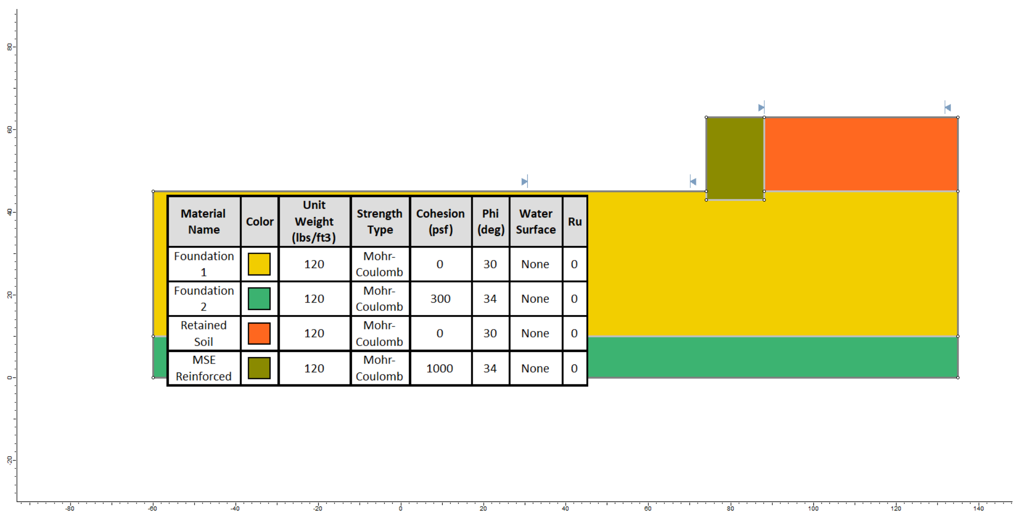
H1 (H)	16´-8" (15´-0")	19´-2" (17´-6")	21´-8" (20´-0")	24´-2" (22´-6")
BW (L)	13´-6" (12´-0")	15´-6" (14´-0")	17´-6" (16´-0")	18´-6" (17´-0")
	Top 4-W15xW15@6 3 of 4-W15xW15@6 1 of 4-W20xW15@9 Bot. 4-W20xW15@9	Top 4-W15xW15@[illegible] 4 of 4-W15xW15@[illegible] 1 of 4-W20xW15@[illegible] Bot. 4-W20xW15@[illegible]	Top 4-W15xW15@6 4 of 4-W15xW15@18 2 of 4-W20xW15@24 Bot. 4-W20xW15@24	Top 4-W15xW15@6 4 of 4-W15xW15@18 3 of 4-W20xW15@24 Bot. 4-W20xW15@24

Example Configuration: 3 of 4-W20xW15@24
3 of = 3 levels of reinforcement mats with
4-W20x = 4 longitudinal wires W20 sized by
W15@24 = W15 sized transverse wires at 24-inch spacing

BDA 3-8: Attachment 3 – Steel Soil Reinforcement Table

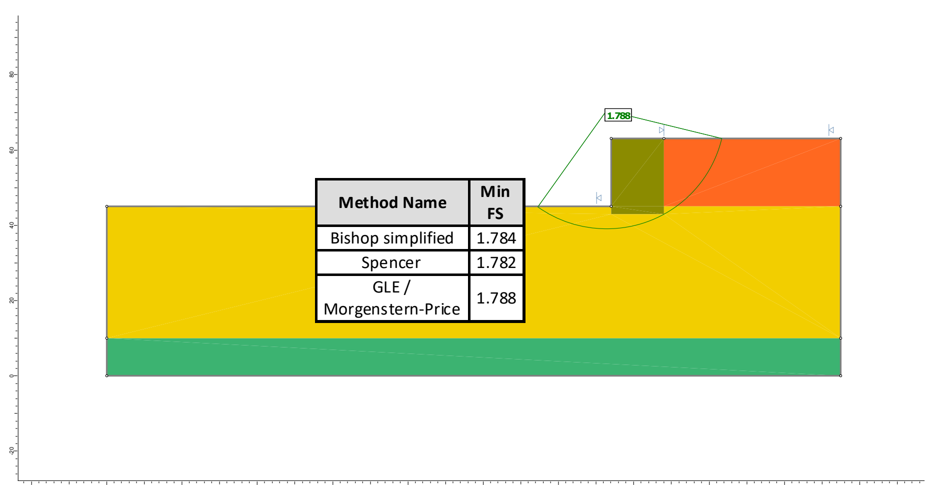
Global Stability Analysis: MSE wall on Level Ground – Static

1. Model an MSE wall block with a height equal to the maximum representative MSE wall design height (H) and a width equal to 0.7 times H.
2. Assign the shear strength of the block as apparent cohesion = 1,000 psf and apparent friction angle = 34 degrees.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Retained Soil		120	Mohr-Coulomb	0	30	None	0
MSE Reinforced		120	Mohr-Coulomb	1000	34	None	0

3. Perform stability analysis for static case.

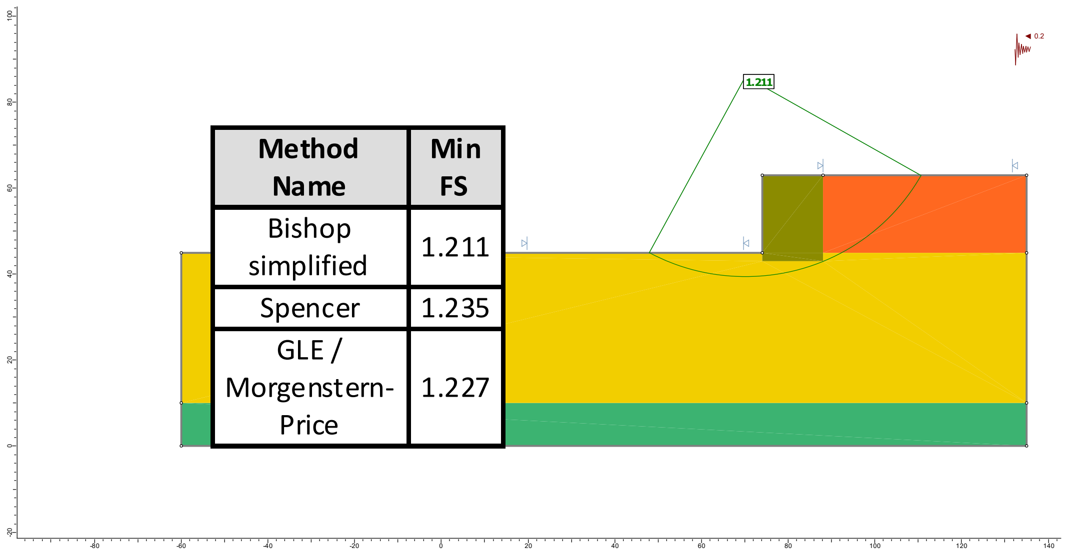


Method Name	Min FS
Bishop simplified	1.784
Spencer	1.782
GLE / Morgenstern-Price	1.788

4. If the critical failure surface intersects the MSE block, increase the shear strength of the block to shift the critical failure surface outside the block.
5. If the calculated FoS is less than the required minimum FoS, increase the width of the MSE block until the calculated FOS meets the requirement: The calculated FoS = 1.78.
6. The required reinforcement length for global stability is determined as the width of the MSE block from Step 5: The required reinforcement length = 0.7 times H = 14 feet.

Overall Stability Analysis: MSE wall on Level Ground – Seismic K_h = 0.2

1. Perform stability analysis for seismic case.



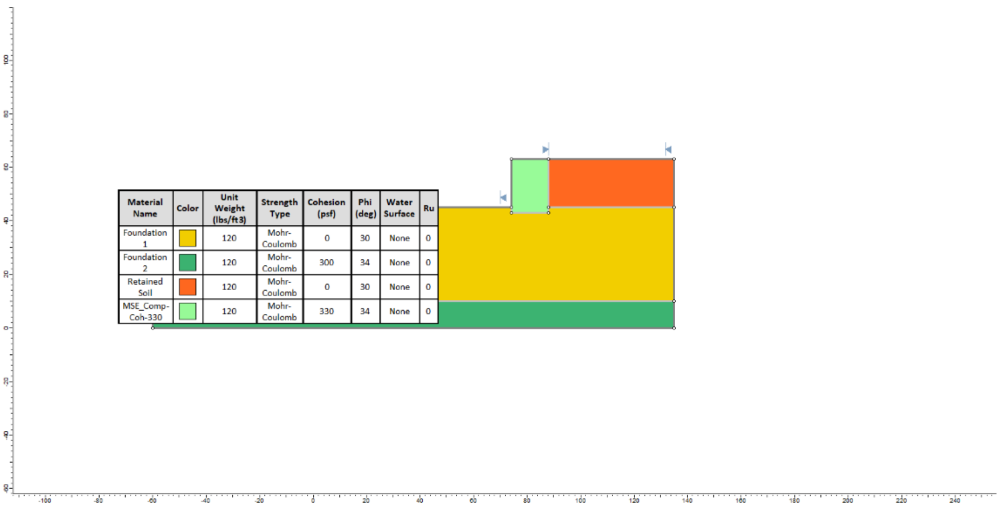
Method Name	Min FS
Bishop simplified	1.211
Spencer	1.235
GLE / Morgenstern-Price	1.227

2. If the potential failure surface intersects the MSE block, increase the shear strength of the block to shift the potential failure surface outside the block.
3. If the calculated FoS is less than the required minimum FoS, increase the width of the MSE block until the calculated FOS meets the requirement: The calculated FoS = 1.23.
4. The required reinforcement length for global stability is determined as the width of the MSE block from Step 5: The required reinforcement length = 14 feet.

Compound Stability Analysis: MSE wall on Level Ground – Static

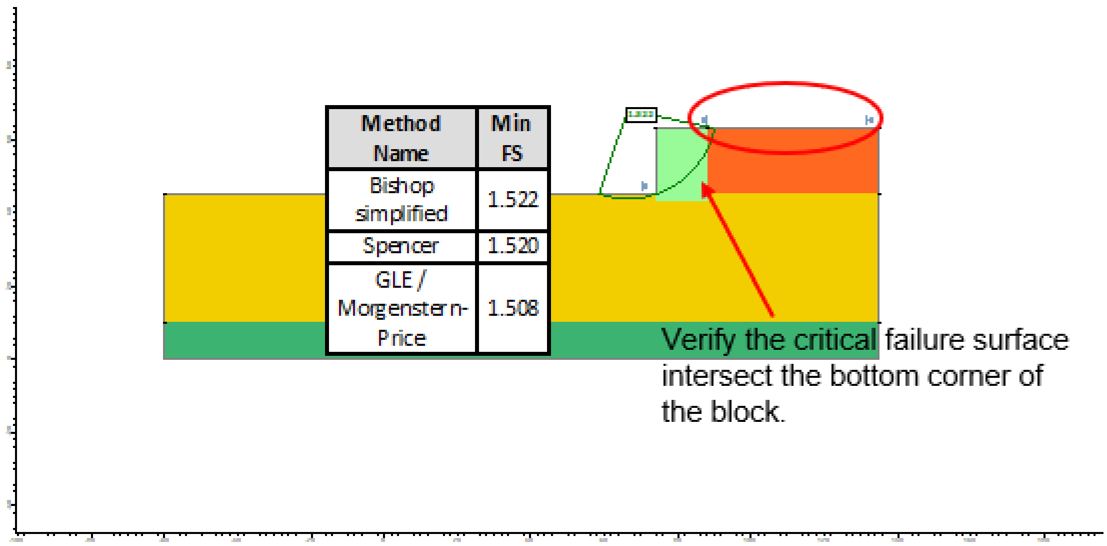
Method 1

1. Model an MSE wall block with a height equal to the maximum representative MSE wall design height (H) and a width equal to the reinforcement length estimated from the global stability analysis.
2. Assign the shear strength of the block as apparent cohesion = 350 psf and apparent friction angle = 34 degrees.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Retained Soil		120	Mohr-Coulomb	0	30	None	0
MSE_Comp-Coh-330		120	Mohr-Coulomb	330	34	None	0

3. Set and adjust search limits to ensure that the critical failure surface passes through the bottom corner of the MSE block.
4. Perform the stability analysis for the static case.
5. If the calculated FoS is less than the required minimum FoS and the potential failure surface passes around the mid-height of the block, adjust the search limits to guide potential failure surfaces through the bottom corner of the block.

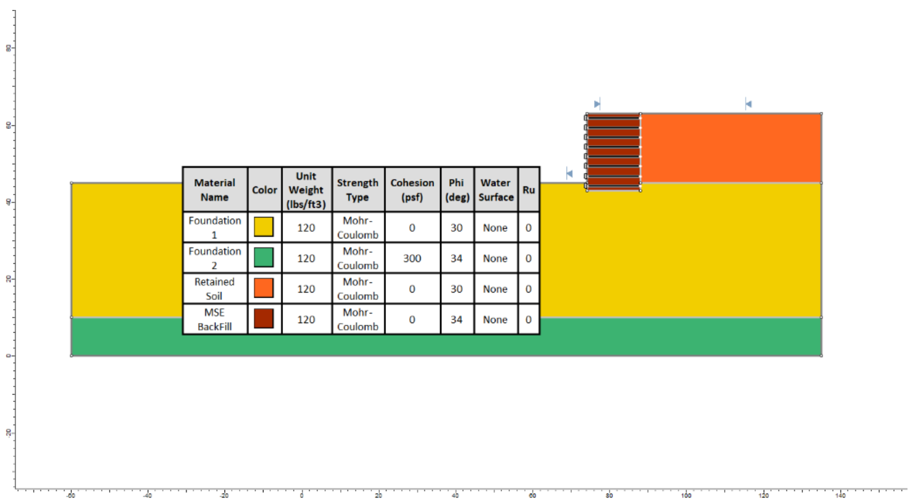


6. If the calculated FoS is less than the required minimum FoS, increase the width of the MSE block until the calculated FOS meets the requirement: The calculated FoS = 1.5.
7. The required reinforcement length for global stability is determined as the width of the MSE block from Step 5. The required reinforcement length = 14 feet.

Compound Stability Analysis for an MSE wall on Level Ground – Static

Method 2

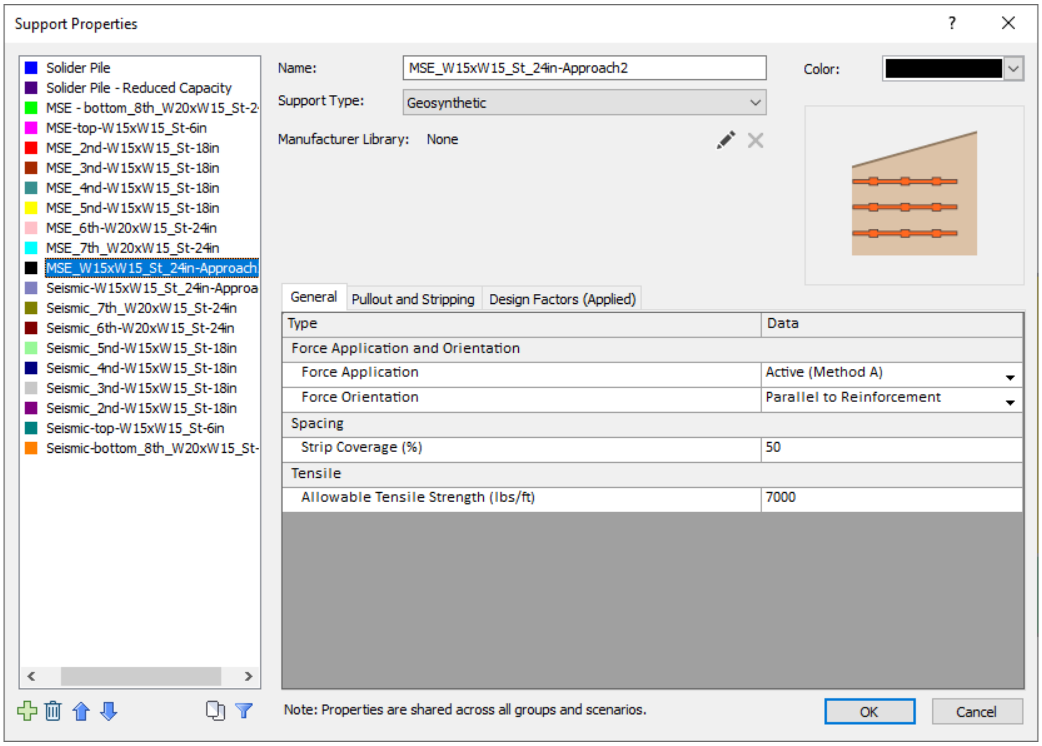
1. Model the MSE reinforcements. ensuring the length matches that determined in the global stability analysis. It is not necessary to model all reinforcements, but for this example, all reinforcements are included.
2. Set the shear strength of the MSE backfill to apparent cohesion of 0 and apparent friction angle of 34 degrees.



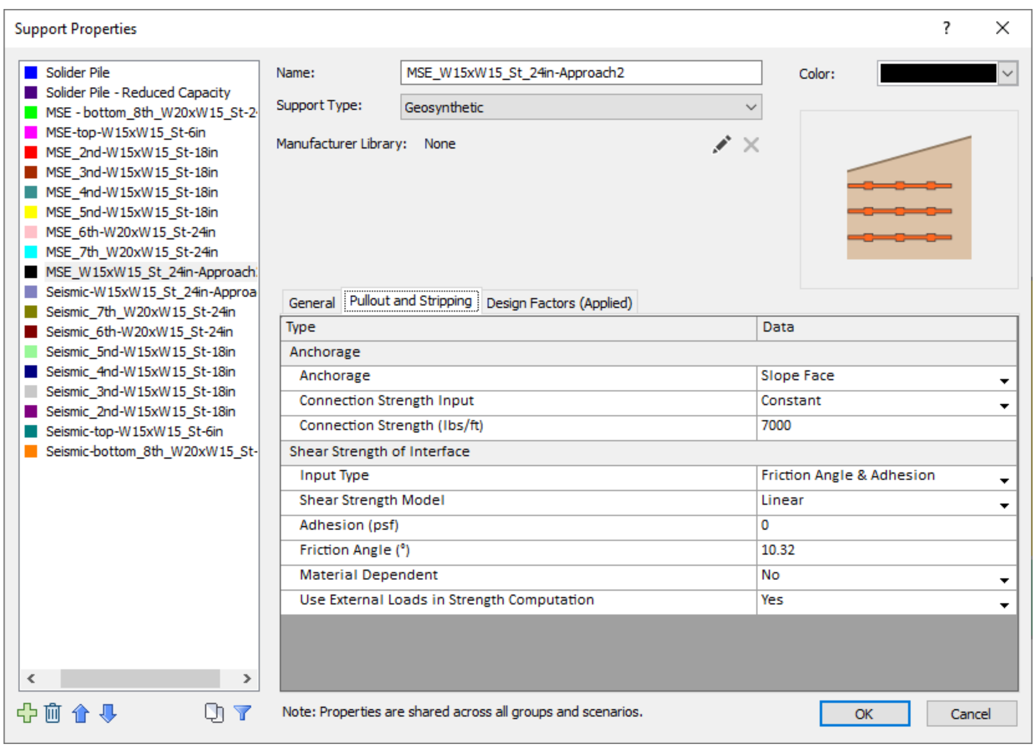
3. Determine the representative engineering properties of the reinforcements as outlined in the table below.

Reinforcement Input – Slide 2

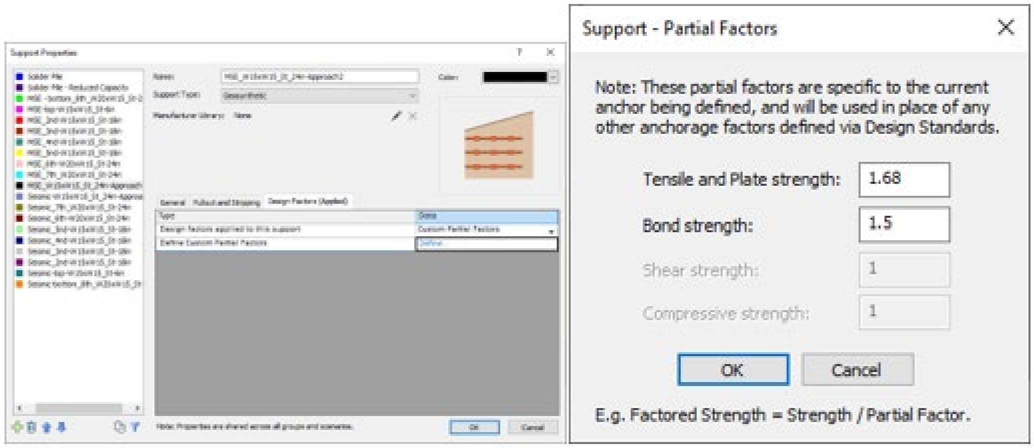
General	Input -Static	Input - Seismic
Force Application	Active Method	Active Method
Force Orientation	Parallel to Reinforcement	Parallel to Reinforcement
Strip Coverage	50% (R_c = 0.5)	50% (R_c = 0.5)
Allowable Tensile Strength = $A_c f_y / b$	7000 lbf/ft	7000 lbf/ft
Pullout and Striping		
Anchorage: Slope Face Connection Strength and Connection Strength	Constant and 7000 lbf/ft	Constant and 7000 lbf/ft
Strength Model	Linear	Linear
Adhesion	0	0
Friction Angle	$\tan^{-1}(F^*)$ = 10.32 degrees: refer to Table A.4.4	$\tan^{-1}(F^*)$ = 8.3 degrees: refer to Table A.4.4
Design Factors / Partial Factor (defined)		
Tensile and Plate Strength = γ/φ	1.68	1.17
Bond Strength = γ/φ	1.5	0.83



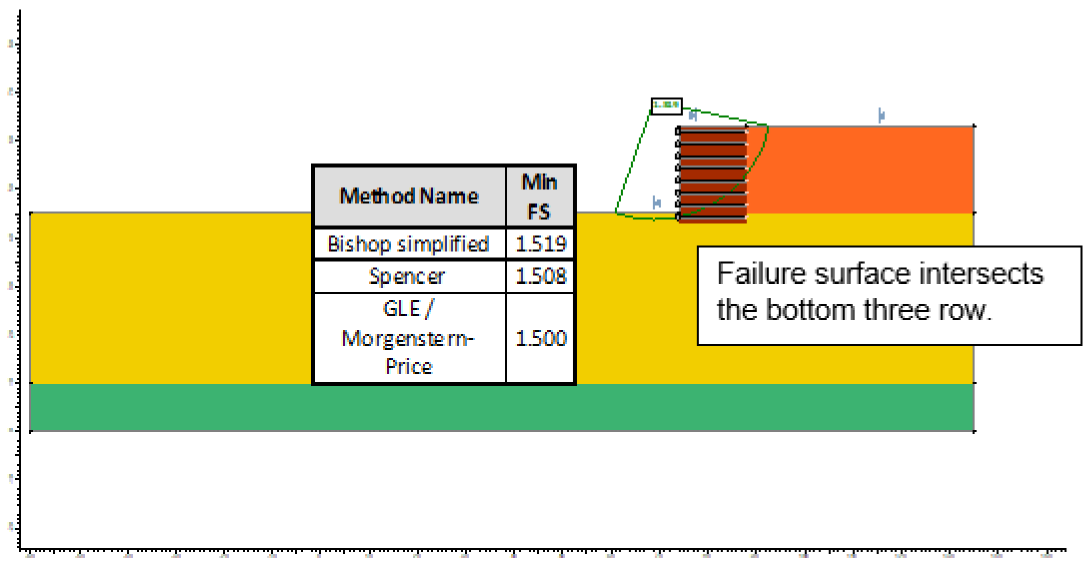
Support Properties
Solider Pile
Solider Pile - Reduced Capacity
MSE - bottom_8th_W20xW15_St-2
MSE-top-W15xW15_St-6in
MSE_2nd-W15xW15_St-18in
MSE_3nd-W15xW15_St-18in
MSE_4nd-W15xW15_St-18in
MSE_5nd-W15xW15_St-18in
MSE_6th-W20xW15_St-24in
MSE_7th_W20xW15_St-24in
MSE_W15xW15_St_24in-Approach
Seismic-W15xW15_St_24in-Approa
Seismic_7th_W20xW15_St-24in
Seismic_6th-W20xW15_St-24in
Seismic_5nd-W15xW15_St-18in
Seismic_4nd-W15xW15_St-18in
Seismic_3nd-W15xW15_St-18in
Seismic_2nd-W15xW15_St-18in
Seismic-top-W15xW15_St-6in
Seismic-bottom_8th_W20xW15_St-
Name: MSE_W15xW15_St_24in-Approach2
Color:
Support Type: Geosynthetic
Manufacturer Library: None
General
Pullout and Stripping
Design Factors (Applied)
Type
Data
Force Application and Orientation
Force Application
Active (Method A)
Force Orientation
Parallel to Reinforcement
Spacing
Strip Coverage (%)
50
Tensile
Allowable Tensile Strength (lbs/ft)
7000
Note: Properties are shared across all groups and scenarios.
OK
Cancel



Support Properties
Solider Pile
Solider Pile - Reduced Capacity
MSE - bottom_8th_W20xW15_St-2
MSE-top-W15xW15_St-6in
MSE_2nd-W15xW15_St-18in
MSE_3nd-W15xW15_St-18in
MSE_4nd-W15xW15_St-18in
MSE_5nd-W15xW15_St-18in
MSE_6th-W20xW15_St-24in
MSE_7th_W20xW15_St-24in
MSE_W15xW15_St_24in-Approach
Seismic-W15xW15_St_24in-Approa
Seismic_7th_W20xW15_St-24in
Seismic_6th-W20xW15_St-24in
Seismic_5nd-W15xW15_St-18in
Seismic_4nd-W15xW15_St-18in
Seismic_3nd-W15xW15_St-18in
Seismic_2nd-W15xW15_St-18in
Seismic-top-W15xW15_St-6in
Seismic-bottom_8th_W20xW15_St-
Name: MSE_W15xW15_St_24in-Approach2
Color:
Support Type: Geosynthetic
Manufacturer Library: None
General
Pullout and Stripping
Design Factors (Applied)
Type
Data
Anchorage
Anchorage
Slope Face
Connection Strength Input
Constant
Connection Strength (lbs/ft)
7000
Shear Strength of Interface
Input Type
Friction Angle & Adhesion
Shear Strength Model
Linear
Adhesion (psf)
0
Friction Angle (°)
10.32
Material Dependent
No
Use External Loads in Strength Computation
Yes
Note: Properties are shared across all groups and scenarios.
OK
Cancel



4. Conduct the stability analysis for both static and pseudo-seismic scenarios.

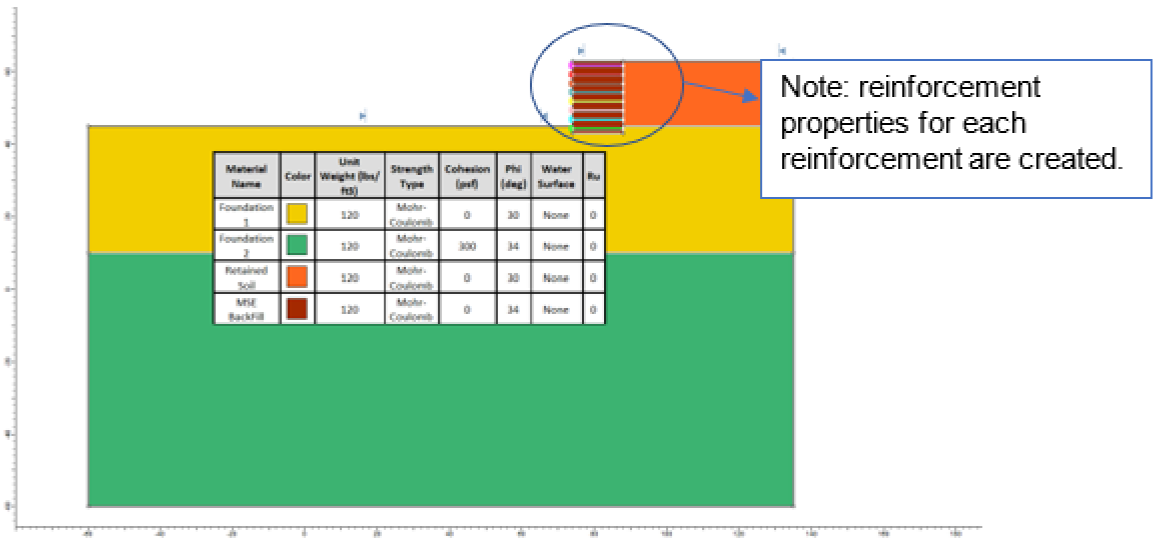


5. If the calculated FoS is less than the required minimum FoS, increase the reinforcement length: The calculated FoS for static = 1.5
6. The required reinforcement length is determined from the outcome of Step 5.

Compound Stability Analysis: MSE wall on Level Ground – Static

Method 3

1. Model the MSE reinforcements. ensuring the length matches that determined in the global stability analysis.
2. Set the shear strength of the MSE backfill to apparent cohesion of 0 and apparent friction angle of 34 degrees.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 1		120	Mohr-Coulomb	0	30	None	0
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Retained Soil		120	Mohr-Coulomb	0	30	None	0
MSE BackFill		120	Mohr-Coulomb	0	34	None	0

3. Determine engineering properties for each row of the reinforcements using Appendix Tables A.4.2, and A.4.3, and Table 4.1.

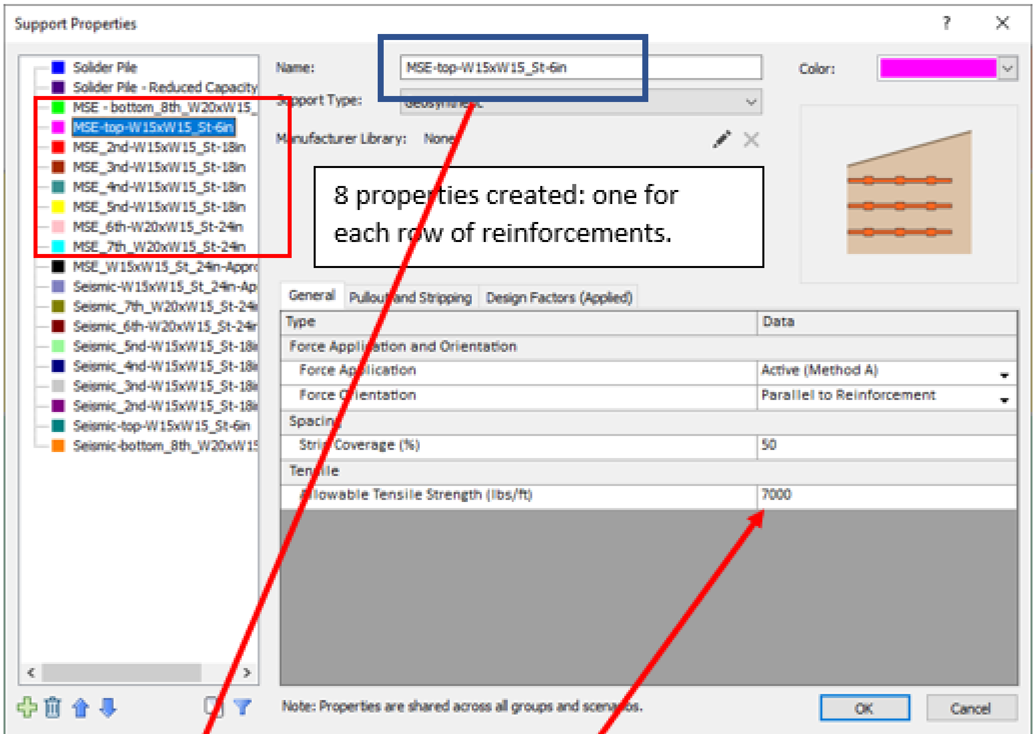


Table A.x.2: Data Summary for Caltrans Pre-Designed MSE Wall Steel Wire Mats

Longitudinal Bars (Tensile Strength)		Transverse Bars (Pullout Capacity)	
Steel Bar Size[1]	W15, W20, and W25	Steel Bar size[1]	W15
Spacing per Mat	5 at 6 in. or 3 at 10 in.	Spacing (St)	6, 9, 18, 24 and 30 in.
Mat Width (b)	30 in. (2.5 ft.)		
fy	65 ksi	Fy	65 ksi
Corrosion Rate[2]	1.1 mil/year	Corrosion Rate	Not Considered
Galvanizing[2]	Effective for 10 years		
Loss of bar Diameter[3]	0.143 in.		
W15 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.437 in. 0.294 in. 0.0679 in^2 **7 kips/ft**	W15 Nominal Diameter (t)	0.437 in.
W20 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.5046 in. 0.3616 in. 0.1027 in^2 **10.7 kips/ft**		
W25 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.5642 in. 0.4212 in. 0.1393 in^2 **14.5 kips/ft**		

1. Nominal Diameter of W15 = 0.437 in. and Nominal Cross-Sectional Area of W15 = 0.15 in^2
2. Per AASHTO CA 11.10.6.4.2a, galvanizing = 10 years, Corrosion Rate = 1.1 mils/year
3. Loss of Diameter = 1.1 x 65 year (75year – 10year) x **2 sides** /1000 = 0.143 in.
4. Corrected bar Diameter = nominal diameter – loss of bar diameter

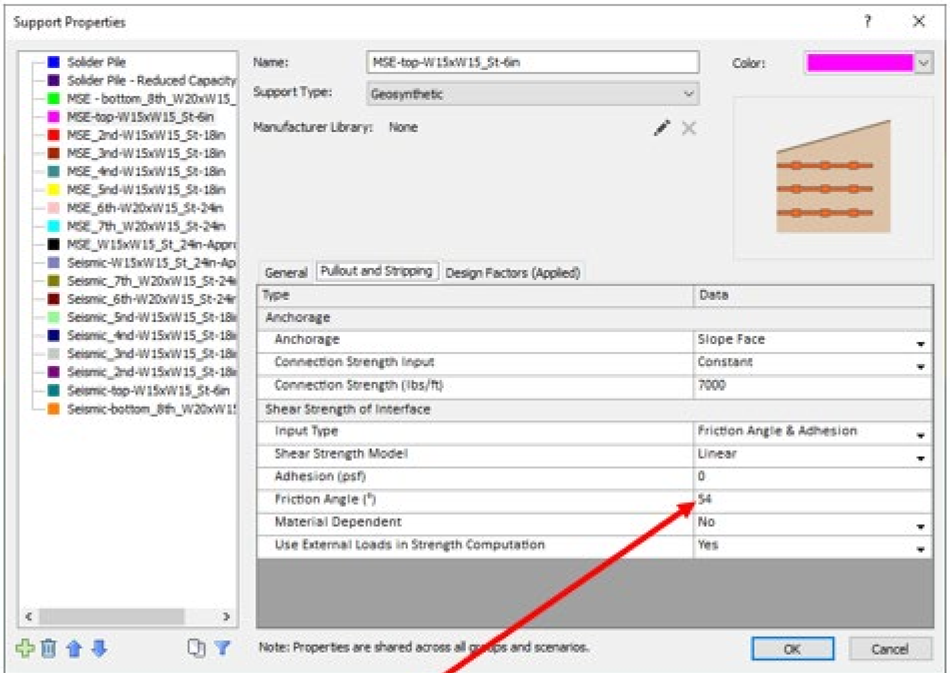
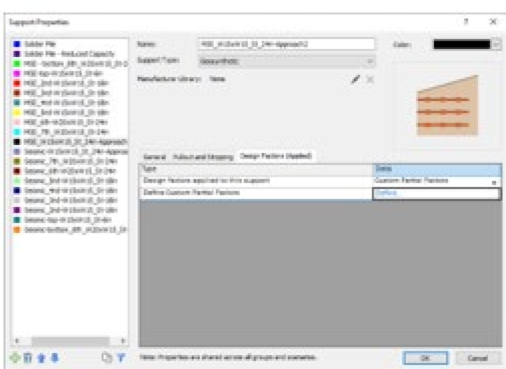
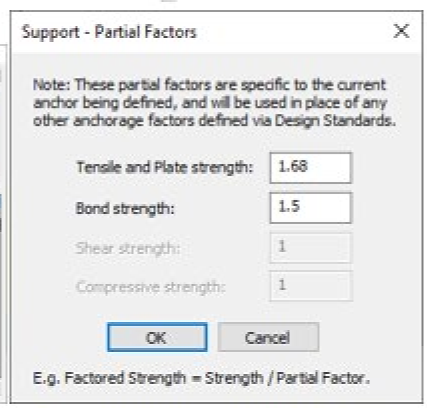


Table A.x.3_a: Converted δ from F* Calculated based on Varying Transverse Bar Spacing (St) -Static

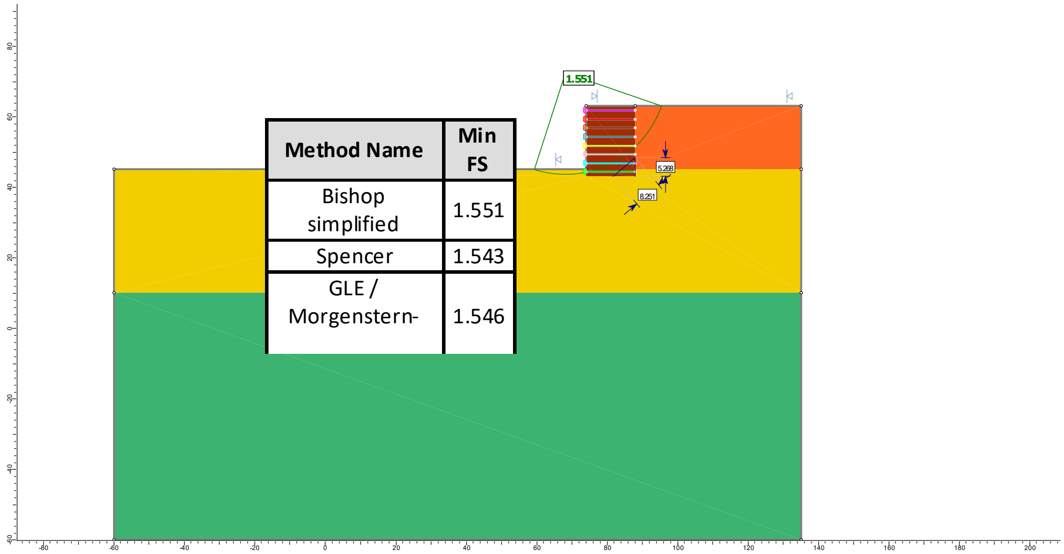
Transverse Spacing (St)	6 in.		in.		18 in.		24 in.	
Depth (ft)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)
1.25	1.41	54.68	0.94	43.25	0.47	25.19	0.35	19.43
3.75	1.32	52.86	0.88	41.35	0.44	23.75	0.33	18.26
6.25	1.23	50.87	0.82	39.33	0.41	22.28	0.31	17.08
8.75	1.14	48.69	0.76	37.19	0.38	20.77	0.28	15.88
11.25	1.05	46.31	0.70	34.91	0.35	19.24	0.26	14.67
13.75	0.96	43.71	0.64	32.51	0.32	17.67	0.24	13.44
16.25	0.86	40.88	0.58	29.97	0.29	16.08	0.22	12.20
18.75	0.77	37.73	0.52	27.29	0.26	14.46	0.19	10.95
21.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
23.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
26.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
28.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
31.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
33.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
36.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
38.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
41.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32

The first row with 6- in W15 transverse spacing: W15xW15@6





4. Conduct the stability analysis for both static and pseudo-seismic scenarios.



5. If the calculated FoS is less than the required minimum FoS, increase the reinforcement length: The calculated FoS = 1.54.
6. The required reinforcement length is determined from the outcome of Step 5.

Compound Stability Analysis: MSE wall on Level Ground – Seismic K_h = 0.2

1. Use the same inputs as the static case, except for applying the K_h value and different reduction factors and interface friction angles for reinforcements.

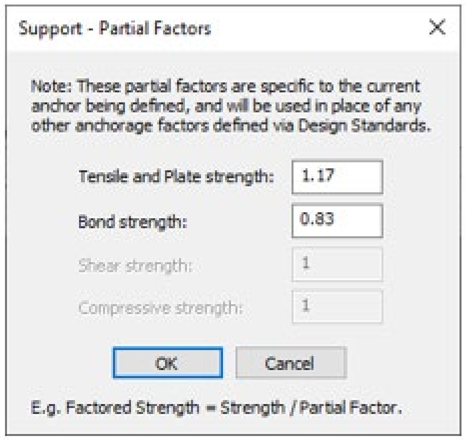


Table A.x.3_b: Converted δ from F* Calculated based on Varying Transverse Bar Spacing (St) -Seismic

Transverse Spacing (St)	6 in.		9 in.		18 in.		24 in.	
Depth (ft)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)
1.25	1.13	48.47	0.75	36.97	0.38	20.62	0.28	15.76
3.75	1.06	46.56	0.70	35.15	0.35	19.39	0.26	14.79
6.25	0.98	44.52	0.66	33.24	0.33	18.15	0.25	13.81
8.75	0.91	42.32	0.61	31.26	0.30	16.88	0.23	12.82
11.25	0.84	39.95	0.56	29.18	0.28	15.60	0.21	11.83
13.75	0.76	37.41	0.51	27.01	0.25	14.30	0.19	10.82
16.25	0.69	34.68	0.46	24.76	0.23	12.99	0.17	9.81
18.75	0.62	31.76	0.41	22.43	0.21	11.66	0.15	8.80
21.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
23.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
26.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
28.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
31.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
33.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
36.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
38.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
41.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29

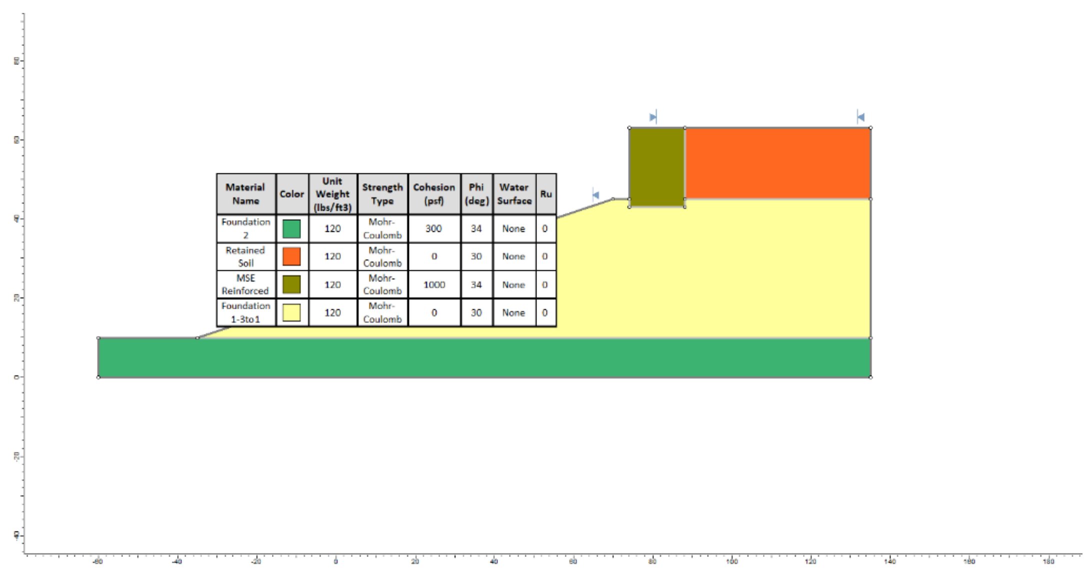
2. Use the same inputs as the static case, except for applying the K_h value and different reduction factors and interface friction angles for reinforcements.
3. Run slope stability analysis and verify if a calculated minimum factor of safety (FoS) is equal to or greater than a required FoS.

Compound Stability Analysis: MSE wall on Level Ground – Seismic K_h = 0.2

1. Use the same inputs as the static case, except for applying the K_h value and different reduction factors and interface friction angles for reinforcements.
2. Run slope stability analysis and verify if a calculated minimum factor of safety (FoS) is equal to or greater than a required FoS.

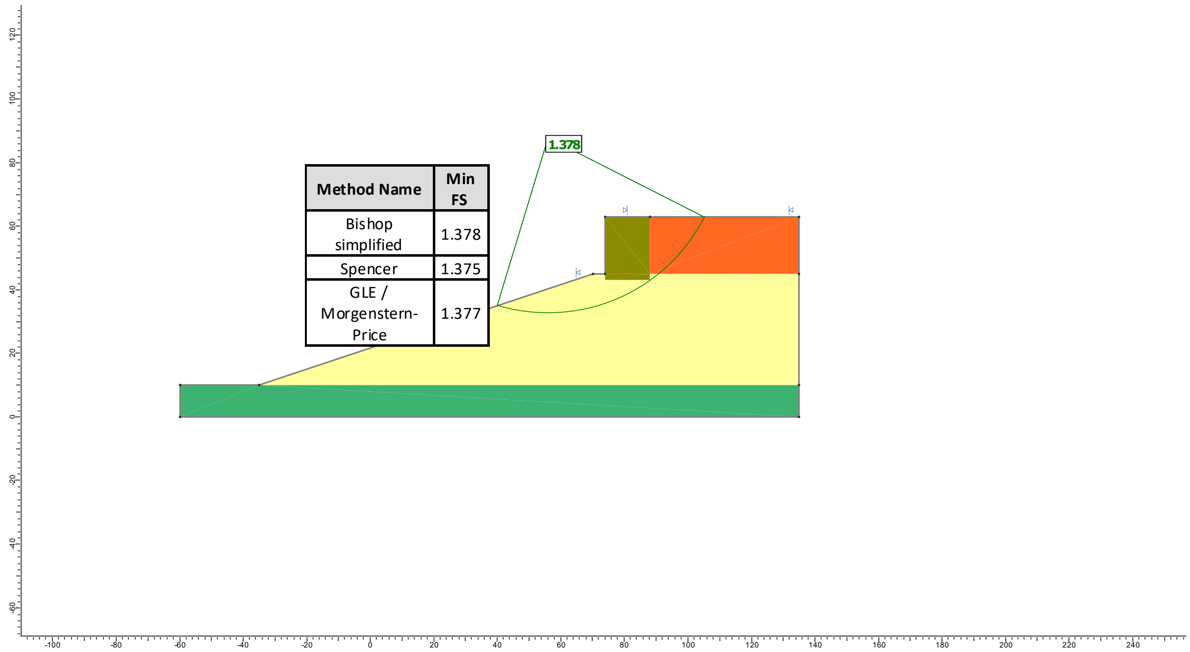
Global Stability Analysis: MSE wall on 3(H) to1(V) Slope Ground – Static

1. Model an MSE wall block with a height equal to the maximum representative MSE wall design height (H) and a width equal to 0.7 times H (= 14ft).
2. Set the shear strength of the block to apparent cohesion of 1,000 psf and apparent friction angle of 34 degrees.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Retained Soil		120	Mohr-Coulomb	0	30	None	0
MSE Reinforced		120	Mohr-Coulomb	1000	34	None	0
Foundation 1-3to1		120	Mohr-Coulomb	0	30	None	0

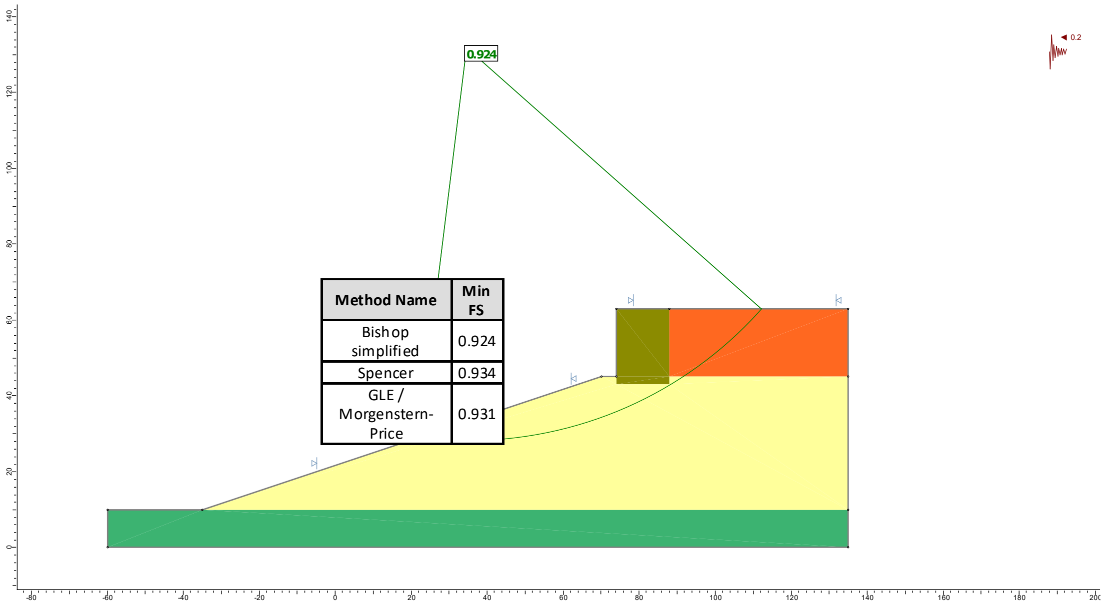
3. Conduct stability analysis for static case.



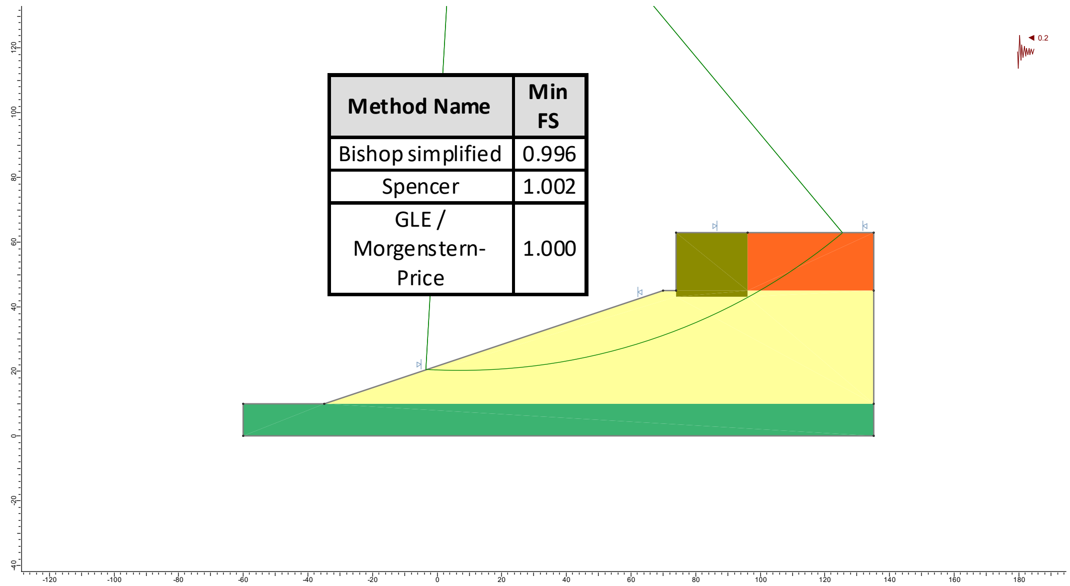
4. If the potential failure surface intersects the MSE block, increase the shear strength of the block to shift the potential failure surface outside the block.
5. If the calculated FoS is less than the required minimum FoS, increase the width of the MSE block until the calculated FOS meets the requirement: The calculated FoS = 1.37
6. The required reinforcement length for global stability is determined as the width of the MSE block from Step 5: The required reinforcement length = 0.7 times H = 14 feet.

Overall Stability Analysis: MSE wall on 3(H) to1(V) Slope Ground – Seismic K_h = 0.2

1. Conduct stability analysis for seismic scenario.



2. If the potential failure surface intersects the MSE block, increase the shear strength of the block to drive the potential failure surface outside the block.
3. If the calculated FoS is less than the required minimum FoS, increase the width of the MSE block until the calculated FOS meets the requirement: The calculated FoS is less than 1.0. Increase a width of block to 1.1 times H (=22ft). Note the required minimum FoS was set to 1.0 (ky = 0.2) to perform the seismic displacement analysis.



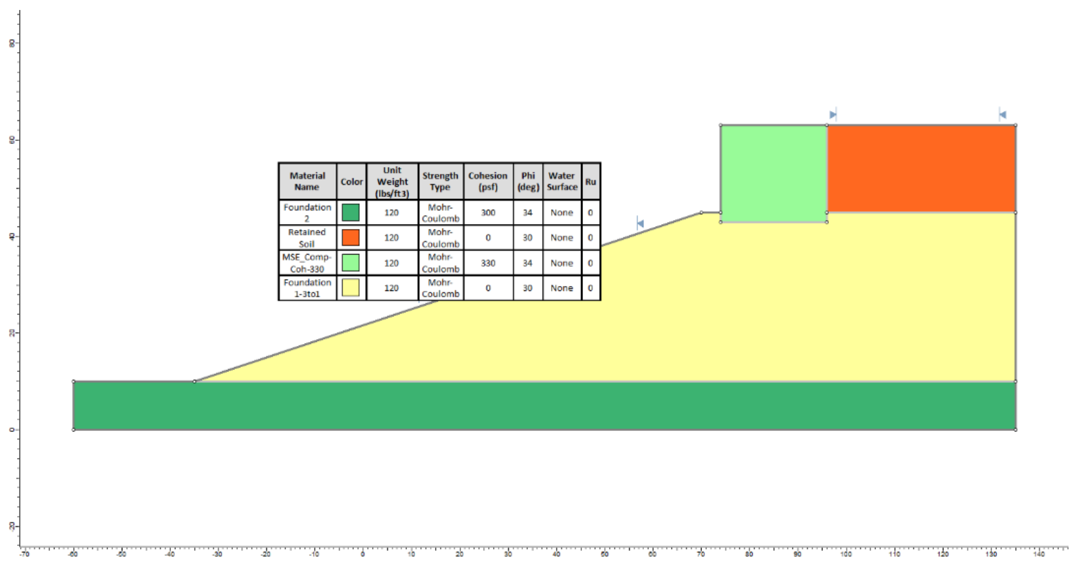
Method Name	Min FS
Bishop simplified	0.996
Spencer	1.002
GLE / Morgenstern-Price	1.000

4. The required reinforcement length = 1.1 times H = 22 feet: This reinforcement length shall be used for the following compound stability analysis.

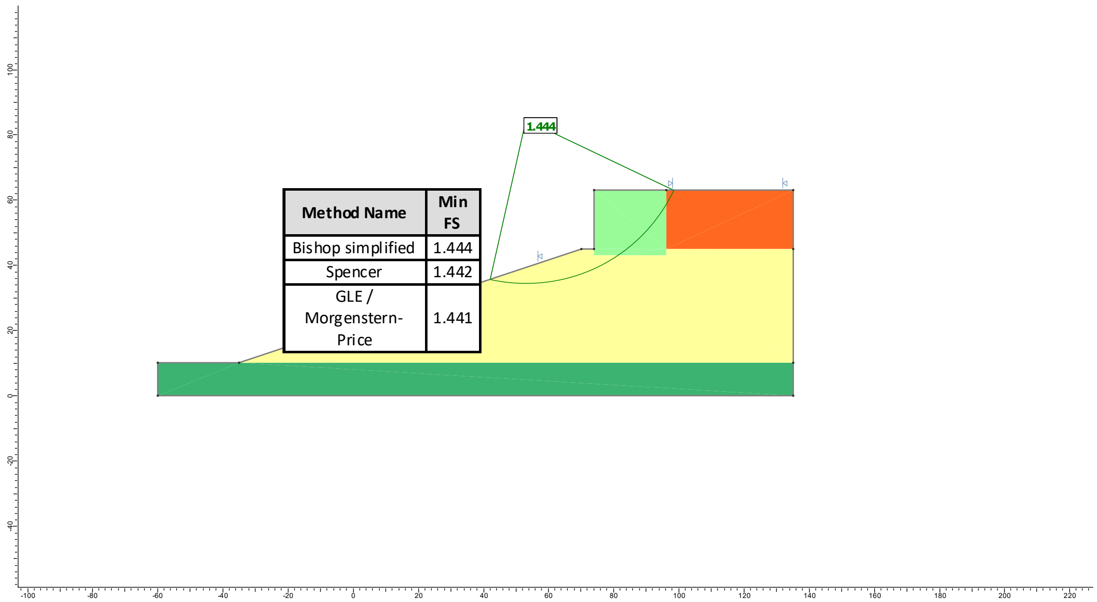
Compound Stability Analysis: MSE wall on 3(H) to1(V) Slope Ground – Static

Method 1

1. Model an MSE wall block with a height equal to the maximum representative MSE wall design height (H) and a width equal to the reinforcement length estimated from the global (seismic) stability analysis: 22 ft from global seismic analysis.
2. Set the shear strength of the block to apparent cohesion of 350 psf and apparent friction angle of 34 degrees.



3. Set and adjust search limits to ensure that potential failure surfaces passes through the bottom corner of the MSE block.
4. Conduct the stability analysis for both static and seismic scenarios.
5. If the calculated FoS is less than the required minimum FoS and the potential failure surface passes around the mid-height of the block, adjust the search limits to guide potential failure surfaces through the bottom corner of the block.

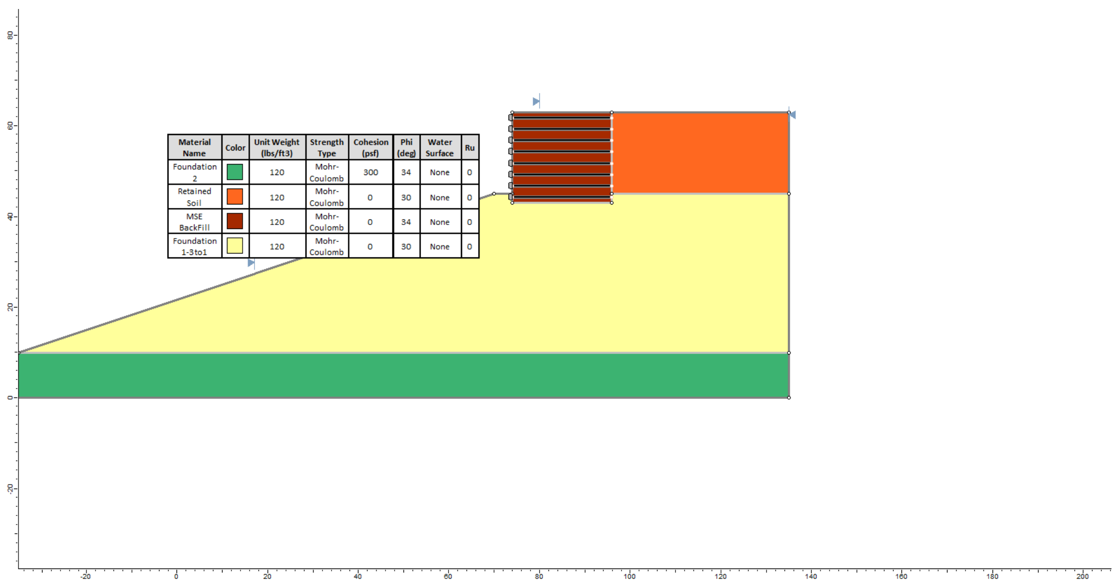


6. If the calculated FoS is less than the required minimum FoS for the potential failure surface passing through the bottom corner of the block, increase the width of the MSE block until the calculated FOS meets the requirement: The calculated FoS = 1.44.
7. The required reinforcement length is determined as the width of the MSE block from Step 6: The required reinforcement length = 22 ft.

Compound Stability Analysis: MSE wall on 3(H) to1(V) Slope Ground – Static

Method 2

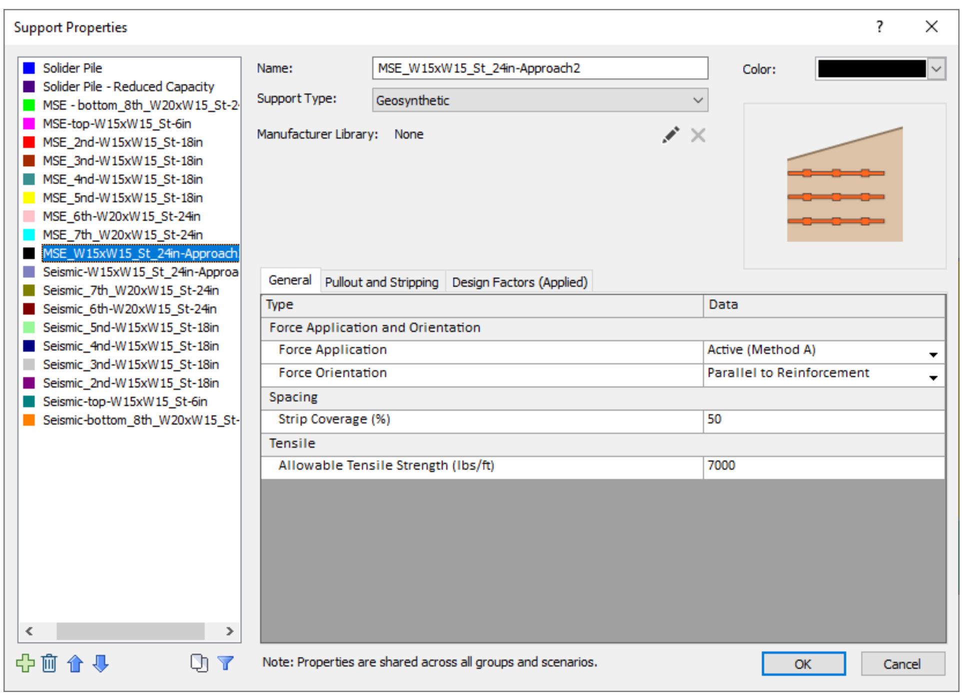
1. Model the MSE reinforcements, ensuring the length matches that determined in the global (seismic) stability analysis. Reinforcement Length = 22 ft from global seismic analysis.
2. Set the shear strength of the MSE backfill to apparent cohesion of 0 and apparent friction angle of 34 degrees.

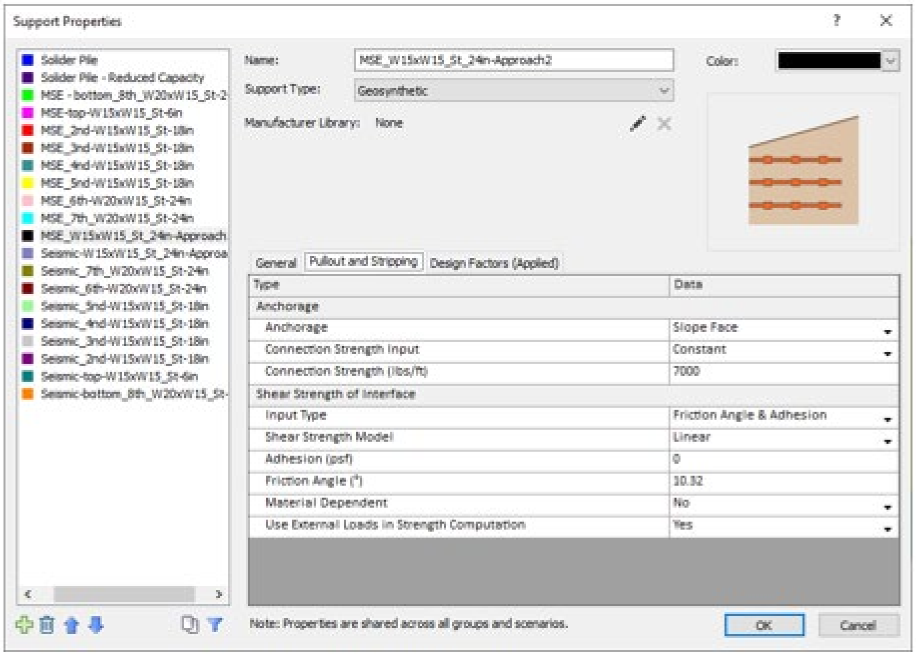


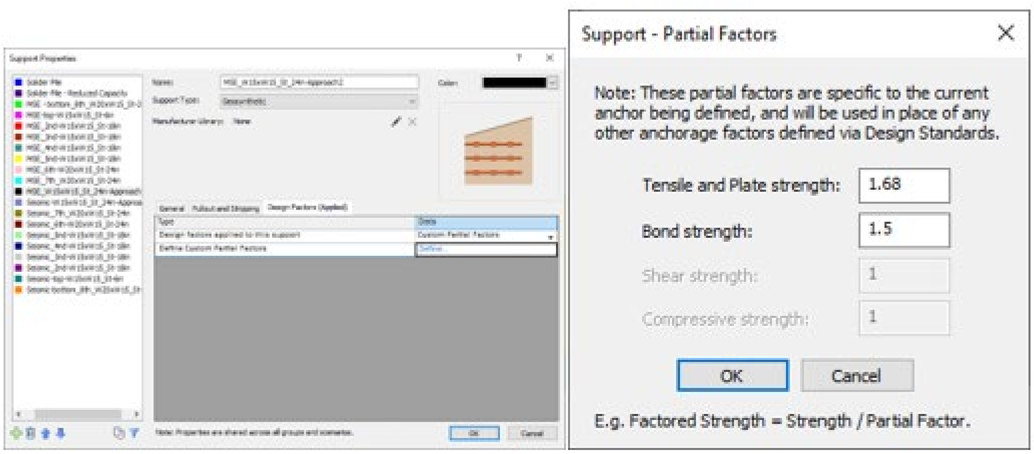
3. Determine the representative engineering properties of the reinforcements as outlined in the table below.

Reinforcement Input – Slide 2

General	**Input -Static**	**Input - Seismic**
Force Application	Active Method	Active Method
Force Orientation	Parallel to Reinforcement	Parallel to Reinforcement
Strip Coverage	50% (R_c = 0.5)	50% (R_c = 0.5)
Allowable Tensile Strength = $A_c f_y / b$	7000 lbf/ft	7000 lbf/ft
Pullout and Striping		
Anchorage: Slope Face Connection Strength and Connection Strength	Constant and 7000 lbf/ft	Constant and 7000 lbf/ft
Strength Model	Linear	Linear
Adhesion	0	0
Friction Angle	$\tan^{-1}(F^*)$ = 10.32 degrees: refer to Table A.x.4	$\tan^{-1}(F^*)$ = 8.3 degrees : refer to Table A.x.4
Design Factors / Partial Factor (defined)		
Tensile and Plate Strength = γ/φ	1.68	1.17
Bond Strength = γ/φ	1.5	0.83





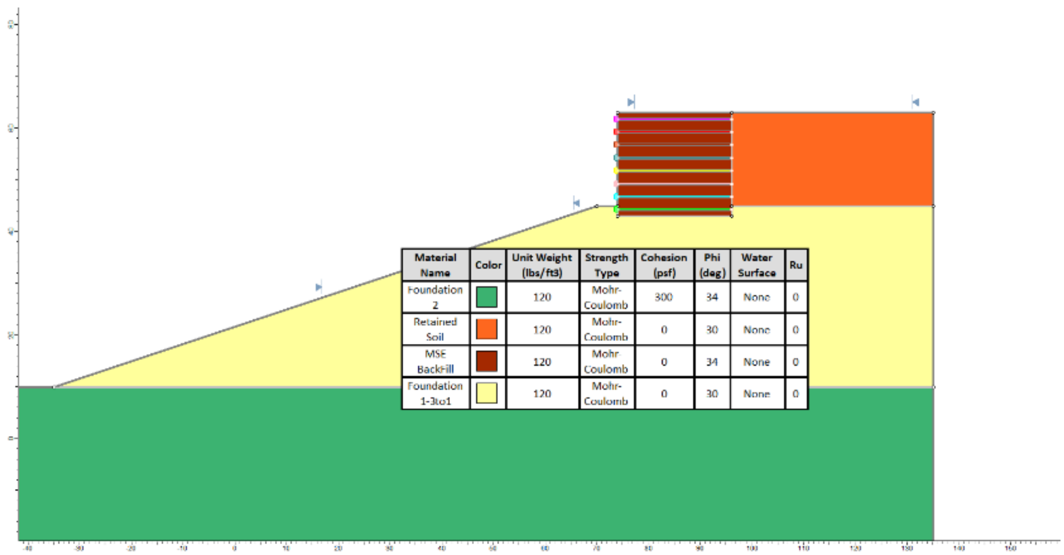


4. Conduct the stability analysis for both static and pseudo-seismic scenarios.
5. If the calculated FoS is less than the required minimum FoS, increase the reinforcement length: The calculated FoS = 1.5.
6. The required reinforcement length is determined from outcome of Step 5.

Compound Stability Analysis: MSE wall on 3(H) to1(V) Slope Ground – Static

Method 3

1. Model the MSE reinforcements, ensuring the length matches that determined in the global (seismic) stability analysis. Reinforcement Length = 22 ft from global seismic analysis.
2. Set the shear strength of the MSE backfill to apparent cohesion of 0 and apparent friction angle of 34 degrees.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Retained Soil		120	Mohr-Coulomb	0	30	None	0
MSE BackFill		120	Mohr-Coulomb	0	34	None	0
Foundation 1-3to1		120	Mohr-Coulomb	0	30	None	0

3. Determine engineering properties for each row of the reinforcements using Appendix Tables A.4.2, and A.4.3, and Table 4.1

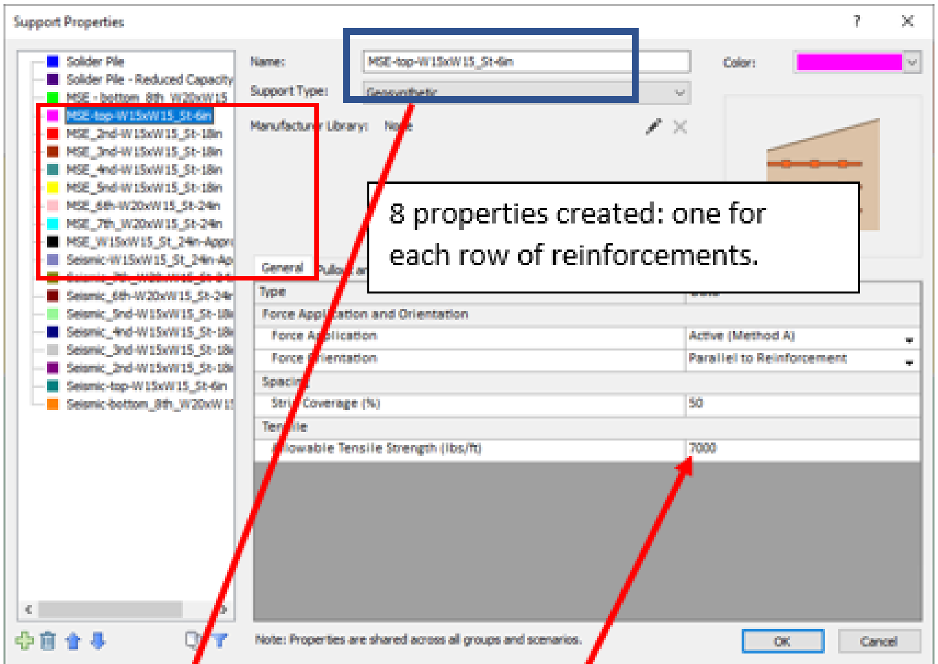


Table A.x.2: Data Summary for Caltrans Pre-Designed MSE Wall Steel Wire Mats

Longitudinal Bars (Tensile Strength)		Transverse Bars (Pullout Capacity)	
Steel Bar Size[1]	W15, W20, and W25	Steel Bar size[1]	W15
Spacing per Mat	5 at 6 in. or 3 at 10 in.	Spacing (St)	6, 9, 18, 24 and 30 in.
Mat Width (b)	30 in. (2.5 ft.)		
fy	65 ksi	Fy	65 ksi
Corrosion Rate[2]	1.1 mil/year	Corrosion Rate	Not Considered
Galvanizing[2]	Effective for 10 years		
Loss of bar Diameter[3]	0.143 in.		
W15 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.437 in. 0.294 in. 0.0679 in^2 **7 kips/ft**	W15 Nominal Diameter (t)	0.437 in.
W20 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.5046 in. 0.3616 in. 0.1027 in^2 **10.7 kips/ft**		
W25 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.5642 in. 0.4212 in. 0.1393 in^2 **14.5 kips/ft**		

1. Nominal Diameter of W15 = 0.437 in. and Nominal Cross-Sectional Area of W15 = 0.15 in^2
2. Per AASHTO CA 11.10.6.4.2a, galvanizing = 10 years, Corrosion Rate = 1.1 mils/year
3. Loss of Diameter = 1.1 x 65 year (75year – 10year) x **2 sides** /1000 = 0.143 in.
4. Corrected bar Diameter = nominal diameter – loss of bar diameter

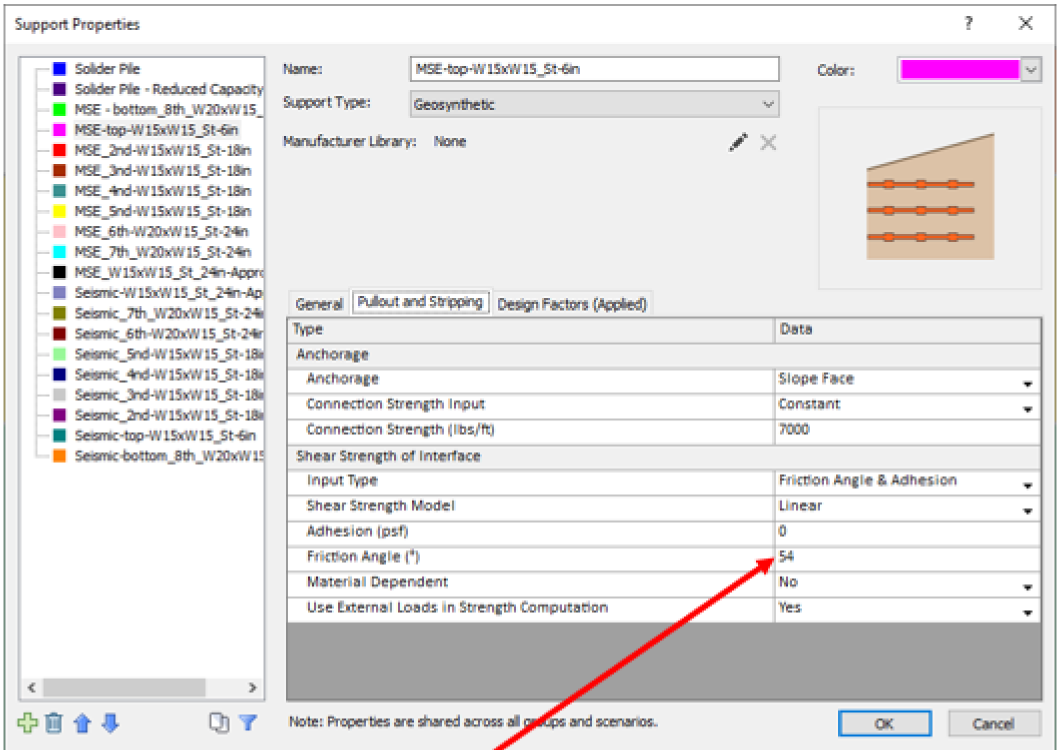
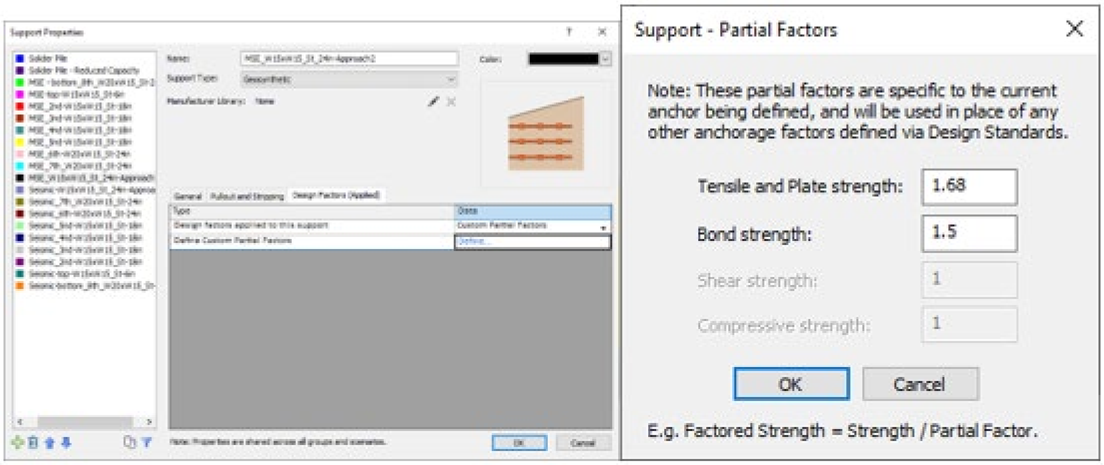


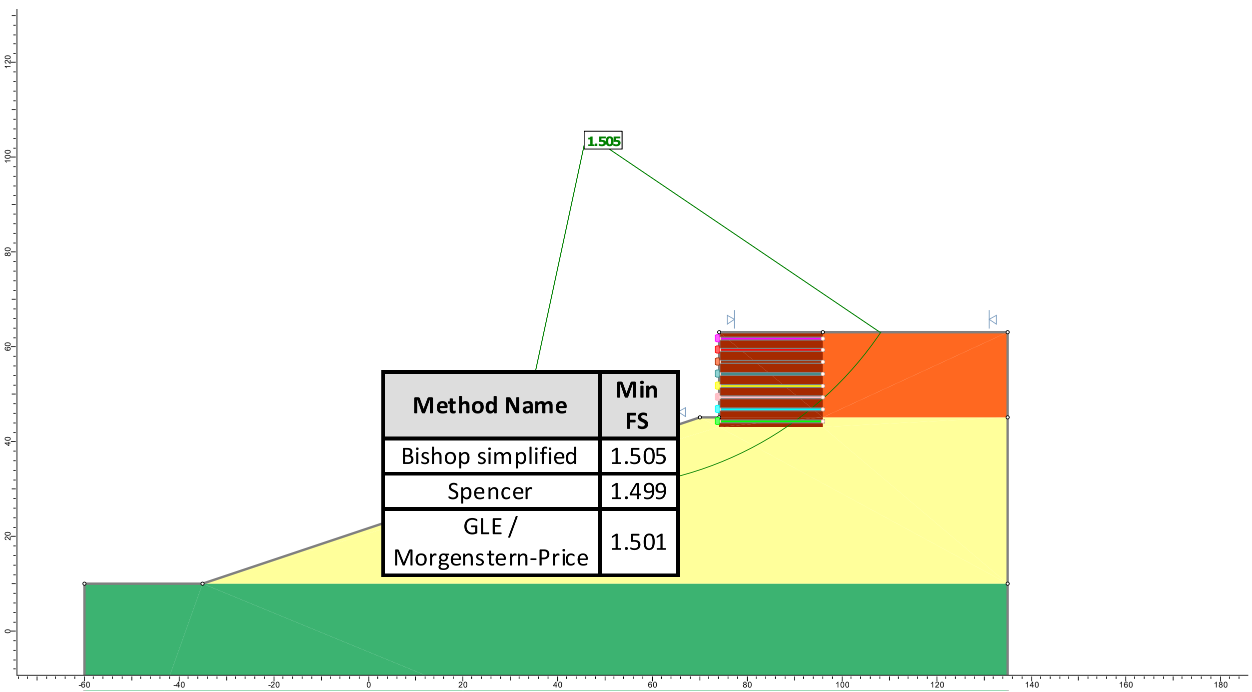
Table A.x.3_a: Converted δ from F* Calculated based on Varying Transverse Bar Spacing (St) -Static

Transverse Spacing (St)	6 in.		[illegible] in.		18 in.		24 in.	
Depth (ft)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)
1.25	1.41	54.68	0.94	43.25	0.47	25.19	0.35	19.43
3.75	1.32	52.86	0.88	41.35	0.44	23.75	0.33	18.26
6.25	1.23	50.87	0.82	39.33	0.41	22.28	0.31	17.08
8.75	1.14	48.69	0.76	37.19	0.38	20.77	0.28	15.88
11.25	1.05	46.31	0.70	34.91	0.35	19.24	0.26	14.67
13.75	0.96	43.71	0.64	32.51	0.32	17.67	0.24	13.44
16.25	0.86	40.86	0.58	29.97	0.29	16.08	0.22	12.20
18.75	0.77	37.73	0.52	27.29	0.26	14.46	0.19	10.95
21.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
23.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
26.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
28.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
31.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
33.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
36.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
38.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
41.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32

The first row with 6- in W15 transverse spacing: W15xW15@6



4. Perform the stability analysis for both static and pseudo-seismic scenarios.



5. If the calculated FoS is less than the required minimum FoS, increase the reinforcement length: The calculated FoS = 1.5.
6. The required reinforcement length is determined from outcome of Step 5.

Engineering Properties of Reinforcements and Parameter Study for Overall Stability Analysis.

1. Equivalent Factor of Safety (FoS)

The geotechnical stability analysis follows the allowable/working stress design (WSD) method, while the structure reinforcement design follows the load and resistance factor design (LRFD) method. To model reinforcements properly in the stability analysis, an equivalent factor of safety (FoS) is calculated to incorporate load and resistance factors as detailed in Table A.4.1. The calculated FoS is then applied to tensile strength and pullout resistance as partial/reduction factors in the slope stability analysis.

Table A4.1: Equivalent Factor of Safety

Static[1]		**Static FoS**	**Seismic**[2]		**Seismic FoS**
Load Factor (γ)	1.35		Load Factor (γ)	1.0	
Pullout		1.5 (1.35/0.9)	Pullout		0.83 (1/1.2)
Resistance Factors (φ)	0.9		Resistance Factors (φ)	1.2	
Tensile		1.68 (1.35/0.8)	Tensile		1.17 (1/0.85)
Resistance Factors (φ)	0.8		Resistance Factors (φ)	0.85	

1. CA Amendment Table 11.5.7-1
2. AASHTO 11.5.8

2. Caltrans MSE Wall Reinforcement Data and Tensile Capacities

According to Bridge Design Aids 3-8 (2013) Attachment 3, Steel Reinforcement Tables and XS Sheet, 13-020-2: Mechanically Stabilized Embankment-Details No. 2, Caltrans MSE walls use steel wire mats comprising W15, W20 and W25 for longitudinal bar and W15 for transverse bars.

The tensile strength of the reinforcement is determined based on the corrosion-corrected longitudinal bar diameter and cross-sectional area, while the pullout capacity of reinforcement is determined based on transverse bar diameters and spacing before corrosion correction (FHWA GEC 11, Figure 3.4). The spacing of transverse bar (St) varies with depth. Information for steel wire mats is summarized in Table A.4.2.

Table A4.2: Data Summary for Caltrans Pre-Designed MSE Wall Steel Wire Mats

Longitudinal Bars (Tensile Strength)		**Transverse Bars (Pullout Capacity)**	
Steel Bar Size[1]	W15, W20, and W25	Steel Bar size[1]	W15
Spacing per Mat	5 at 6 in. or 3 at 10 in.	Spacing (St)	6, 9, 18, 24 and 30 in.
Mat Width (b)	30 in. (2.5 ft.)		
fy	65 ksi	Fy	65 ksi
Corrosion Rate[2]	1.1 mil/year	Corrosion Rate	Not Considered
Galvanizing[2]	Effective for 10 years		
Loss of bar Diameter[3]	0.143 in.		
W15 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.437 in. 0.294 in. 0.0679 in^2 **7 kips/ft**	W15 Nominal Diameter (t)	0.437 in.
W20 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.5046 in. 0.3616 in. 0.1027 in^2 **10.7 kips/ft**		
W25 Nominal Diameter Corrected bar Diameter[4] Corrected Area[4] **Tensile Capacity[5]**	0.5642 in. 0.4212 in. 0.1393 in^2 **14.5 kips/ft**		

1. Nominal Diameter of W15 = 0.437 in. and Nominal Cross-Sectional Area of W15 = 0.15 in^2
2. Per AASHTO CA 11.10.6.4.2a, galvanizing = 10 years, Corrosion Rate = 1.1 mils/year
3. Loss of Diameter = 1.1 x 65-year (75year – 10year) x **2 sides** /1000 = 0.143 in.
4. Corrected bar Diameter = nominal diameter – loss of bar diameter
5. Tensile Capacity = # of bar (4) x fy (65ksi) x corrected Area / Mat Width (2.5)

The following adjustments to the reinforcement input for slope stability analysis are proposed to ensure equivalent pullout resistance and tensile strength of the reinforcements per AASHTO and FHWA.

3. Pullout Resistance: Soil/Reinforcement Interface Friction Angle (d)

Pullout Resistance per a unit length of reinforcement is defined as the following per AASHTO 11.10.6.3.2 and 11.10.7.2

$P_r = F^* a \sigma_v C R_c$ (Static) $P_r = 0.8F^* a \sigma_v C R_c$ (Seismic)

Where,

a = 1.0 for scale effect correction factor (steel)
C = 2 for surface area geometry factor (two sides)
R_c = 0.5 for reinforcement coverage ratio (30-inch mat width over 60-inch spacing)

According to AASHTO Figure 11.10.6.3.2, the pullout resistance factor (F*) for the steel wire mat varies from 20(t/St) at the top of the wall (zero depth) to 10(t/St) at a depth of 20 feet and remains constant below the depth of 20 feet. F* can be interpolated between the top of the wall and 20 feet. Note that the nominal transverse bar diameter (t) of W15 is 0.437 inches, and corrosion correction should not be applied for the calculation of F*.

Since the slope stability program computes the pullout resistance of the reinforcements via soil/reinforcement interface friction angles (δ) instead of F*, the δ was computed for each depth (level) of transverse bar spacings (St) of the reinforcements, and presented in Table A.4.3 using the following correlation:

$\delta = \tan^{-1}(F^*)$

Tensile strengths from Table A.4.1 and δ from Table A.4.3 can be used to establish the engineering properties of the reinforcements for Method 3.

Table A4.3_a: Converted δ from F* Calculated based on Varying Transverse Bar Spacing (St) -Static

Transverse Spacing (St)	**6 in.**		**9 in.**		**18 in.**		**24 in.**	
Depth (ft)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)
1.25	1.41	54.68	0.94	43.25	0.47	25.19	0.35	19.43
3.75	1.32	52.86	0.88	41.35	0.44	23.75	0.33	18.26
6.25	1.23	50.87	0.82	39.33	0.41	22.28	0.31	17.08
8.75	1.14	48.69	0.76	37.19	0.38	20.77	0.28	15.88
11.25	1.05	46.31	0.70	34.91	0.35	19.24	0.26	14.67
13.75	0.96	43.71	0.64	32.51	0.32	17.67	0.24	13.44
16.25	0.86	40.86	0.58	29.97	0.29	16.08	0.22	12.20
18.75	0.77	37.73	0.52	27.29	0.26	14.46	0.19	10.95
21.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
23.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
26.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
28.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
31.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
33.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
36.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
38.75	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32
41.25	0.73	36.07	0.49	25.90	0.24	13.65	0.18	10.32

Table A4.3_b: Converted δ from F* Calculated based on Varying Transverse Bar Spacing (St) -Seismic

Transverse Spacing (St)	**6 in.**		**9 in.**		**18 in.**		**24 in.**	
Depth (ft)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)	F*	δ (deg)
1.25	1.13	48.47	0.75	36.97	0.38	20.62	0.28	15.76
3.75	1.06	46.56	0.70	35.15	0.35	19.39	0.26	14.79
6.25	0.98	44.52	0.66	33.24	0.33	18.15	0.25	13.81
8.75	0.91	42.32	0.61	31.26	0.30	16.88	0.23	12.82
11.25	0.84	39.95	0.56	29.18	0.28	15.60	0.21	11.83
13.75	0.76	37.41	0.51	27.01	0.25	14.30	0.19	10.82
16.25	0.69	34.68	0.46	24.76	0.23	12.99	0.17	9.81
18.75	0.62	31.76	0.41	22.43	0.21	11.66	0.15	8.80
21.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
23.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
26.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
28.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
31.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
33.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
36.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
38.75	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29
41.25	0.58	30.23	0.39	21.23	0.19	10.99	0.15	8.29

For Method 2, the bottom three rows are assumed to affect the stability analysis, the following representative engineering properties of the reinforcements are proposed for the analysis.

Table A4.4-a: Simplified Interface Friction Angle for Two Ranges of MSE Wall Design Height

Load Case 1 – level ground on top of walls			
H (ft.)	St (in.)	F* (pullout resistance factor)	Interface Friction Angle (d)
Up to 17.5	9	15 (t/St) = 15*(0.437/9) = 0.73	$\tan^{-1}(F^*)$ = 36 degrees
20 to 42.5	24 to 30	10 (t/St) = 0.18 to 0.15	10.32 degrees
Load Case 2 – 2(H) to 1(V) sloping ground on top of walls			
Up to 15	18	15 (t/St) = 15*(0.437/18) = 0.36	$\tan^{-1}(F^*)$ = 20 degrees
17.5 to 42.5	24 to 30	10 (t/St) = 0.18 to 0.15	8.3 degrees

4. Estimation of Equivalent Cohesion of 350 psf

To simplify the model of the reinforcements in the stability analysis, an equivalent cohesion representing the resistance of the Caltrans MSE steel reinforcements was assessed. The evaluations were based on the minimum of the allowable pullout resistance and allowable tensile resistance. For the pullout resistance, the embedded lengths (Le) ranging from 1 to 6 feet were evaluated and compared to the tensile resistance.

The following steps were used to estimate the equivalent cohesions:

1. Calculate the allowable tensile strength and allowable pullout resistance (Le from 1 to 6 feet): Table A.4.6-a.
2. Selected a minimum value from Step 1: Table A.4.6-a.
3. Calculate equivalent cohesion values for each Le by dividing the value from Step 2 with a vertical spacing of the reinforcement of 2.5 feet: Table A.4.6-b.
4. Evaluate an average Le of potential failure surfaces from the parameter study performed: Table A.4.10
5. Select a representative cohesion that can apply to the simplified analysis method.

In addition to the above steps, the following facts were also considered when evaluating a representative cohesion.

- The equivalent cohesion was computed based on the vertical spacing of the reinforcements, although it acts along the potential failure surface in the stability analysis.
- The equivalent cohesion was computed based on the allowable resistance of the reinforcements, and it is further divided by the calculated FoS in the stability analysis.

Based on the steps above an equivalent cohesion of 350 psf is recommended for Method 1 – compound stability analysis.

The following tables present a summary of equivalent cohesions for the three design height ranges.

Table A4.5-a: Equivalent Cohesion for Compound Slope Stability Analysis (Load Case 1 – Level Ground & Static)

H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
<18		0.29		0.57		0.81		0.83		0.83		0.83
18<H<32	1	0.15	2	0.31	3	**0.46**	4	0.61	5	0.75	6	0.81
32<H<42.5		0.22		0.44		0.66		0.82		0.83		0.83

Table A4.5-b: Equivalent Cohesion for compound slope stability check (Load Case 1 – Level Ground & Seismic)

H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
<18		0.41		0.83		1.17		1.20		1.20		1.20
18<H<32	1	0.22	2	0.44	3	**0.66**	4	0.88	5	1.08	6	1.17
32<H<42.5		0.32		0.63		0.95		1.19		1.20		1.20

Table A4.5-c: Equivalent Cohesion for compound slope stability check (Load Case 2- Sloping Ground & Static)

H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
<27		0.15		0.29		**0.44**		0.59		0.74		0.81
27<H<42.5	1	0.22	2	0.44	3	0.65	4	0.80	5	0.83	6	0.83

Table A4.5-d: Equivalent Cohesion for compound slope stability check (Load Case 2- Sloping Ground & Seismic)

H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
<27		0.21		0.43		**0.64**		0.85		1.06		1.18
27<H<42.5	1	0.31	2	0.63	3	0.94	4	1.16	5	1.20	6	1.20

Table A4.6-a: Step 1-Pullout Resistance vs Tensile Resistance for varying depths (Load Case 1: t = 0.437 and St = 9 or 24 in.) – Static

St	Depth (ft)	s_v (ksf)	F*	δ Degree	Le (ft)	Pullout_Allowable (ksf)	Tensile_Allowable (ksf)	Coh[1] (ksf)
9	11.25	1.35	0.70	34.91	3.00	1.88	2.07	0.75
9	13.75	1.65	0.64	32.51	3.00	2.10	2.07	0.83
9	16.25	1.95	0.58	29.97	3.00	2.25	2.07	0.83
9	18.75	2.25	0.52	27.29	3.00	2.32	2.07	0.83
24	21.25	2.55	0.18	10.32	3.00	0.93	2.07	0.37
24	23.75	2.85	0.18	10.32	3.00	1.04	2.07	0.42
24	26.25	3.15	0.18	10.32	3.00	1.15	2.07	0.46
24	28.75	3.45	0.18	10.32	3.00	1.26	2.07	0.50
24	31.25	3.75	0.18	10.32	3.00	1.37	2.07	0.55
24	33.75	4.05	0.18	10.32	3.00	1.47	2.07	0.59
24	36.25	4.35	0.18	10.32	3.00	1.58	2.07	0.63
24	38.75	4.65	0.18	10.32	3.00	1.69	2.07	0.68
24	41.25	4.95	0.18	10.32	3.00	1.80	2.07	0.72

1. Equivalent cohesion (Coh) = min(Pullout, Tensile)/spacing (2.5ft) for Le
2. If Le > 6 ft, tensile resistance controls the reinforcement capacity

Table A4.6-b: Step 2-Equivalent Cohesion value for compound slope stability check (Load Case 1: t = 0.437 and St = 9 or 24 in.) - Static

St	H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
9	11.25	1.0	0.25	2.0	0.50	3.0	0.75	4.0	0.83	5.0	0.83	6.0	0.83
9	13.75	1.0	0.28	2.0	0.56	3.0	0.83	4.0	0.83	5.0	0.83	6.0	0.83
9	16.25	1.0	0.30	2.0	0.60	3.0	0.83	4.0	0.83	5.0	0.83	6.0	0.83
9	18.75	1.0	0.31	2.0	0.62	3.0	0.83	4.0	0.83	5.0	0.83	6.0	0.83
H	**18.00**		**0.29**		**0.57**		**0.81**		**0.83**		**0.83**		**0.83**
24	21.25	1.0	0.12	2.0	0.25	3.0	0.37	4.0	0.50	5.0	0.62	6.0	0.74
24	23.75	1.0	0.14	2.0	0.28	3.0	0.42	4.0	0.55	5.0	0.69	6.0	0.83
24	26.25	1.0	0.15	2.0	0.31	3.0	0.46	4.0	0.61	5.0	0.76	6.0	0.83
24	28.75	1.0	0.17	2.0	0.34	3.0	0.50	4.0	0.67	5.0	0.83	6.0	0.83
24	31.25	1.0	0.18	2.0	0.36	3.0	0.55	4.0	0.73	5.0	0.83	6.0	0.83
H	**32.00**		**0.15**		**0.31**		**0.46**		**0.61**		**0.75**		**0.81**
24	33.75	1.0	0.20	2.0	0.39	3.0	0.59	4.0	0.79	5.0	0.83	6.0	0.83
24	36.25	1.0	0.21	2.0	0.42	3.0	0.63	4.0	0.83	5.0	0.83	6.0	0.83
24	38.75	1.0	0.23	2.0	0.45	3.0	0.68	4.0	0.83	5.0	0.83	6.0	0.83
24	41.25	1.0	0.24	2.0	0.48	3.0	0.72	4.0	0.83	5.0	0.83	6.0	0.83
H	**42.50**		**0.22**		**0.44**		**0.66**		**0.82**		**0.83**		**0.83**

Table A4.6-c: Step 1-Pullout Resistance vs Tensile Resistance for varying depths (Load Case 1: t = 0.437 and St = 9 or 24 in.) – Seismic

St	Depth (ft)	s_v (ksf)	F*	δ Degree	Le (ft)	Pullout_Allowable (ksf)	Tensile_Allowable (ksf)	Coh[1] (ksf)
9	11.25	1.35	0.56	29.18	3.00	2.72	2.99	1.09
9	13.75	1.65	0.51	27.01	3.00	3.04	2.99	1.20
9	16.25	1.95	0.46	24.76	3.00	3.25	2.99	1.20
9	18.75	2.25	0.41	22.43	3.00	3.36	2.99	1.20
24	21.25	2.55	0.15	8.29	3.00	1.34	2.99	0.54
24	23.75	2.85	0.15	8.29	3.00	1.50	2.99	0.60
24	26.25	3.15	0.15	8.29	3.00	1.66	2.99	0.66
24	28.75	3.45	0.15	8.29	3.00	1.82	2.99	0.73
24	31.25	3.75	0.15	8.29	3.00	1.97	2.99	0.79
24	33.75	4.05	0.15	8.29	3.00	2.13	2.99	0.85
24	36.25	4.35	0.15	8.29	3.00	2.29	2.99	0.92
24	38.75	4.65	0.15	8.29	3.00	2.45	2.99	0.98
24	41.25	4.95	0.15	8.29	3.00	2.61	2.99	1.04

1. Equivalent cohesion (Coh) = min(Pullout, Tensile)/spacing (2.5ft) for Le
2. If Le > 6 ft, tensile resistance controls the reinforcement capacity

Table A4.6-d: Step 2-Equivalent Cohesion value for compound slope stability check (Load Case 1: t = 0.437 and St = 9 or 24 in.) – Seismic

St	H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
9	11.25	1.00	0.36	2.00	0.73	3.00	1.09	4.00	1.20	5.00	1.20	6.00	1.20
9	13.75	1.00	0.41	2.00	0.81	3.00	1.20	4.00	1.20	5.00	1.20	6.00	1.20
9	16.25	1.00	0.43	2.00	0.87	3.00	1.20	4.00	1.20	5.00	1.20	6.00	1.20
9	18.75	1.00	0.45	2.00	0.90	3.00	1.20	4.00	1.20	5.00	1.20	6.00	1.20
H	**18.00**		**0.41**		**0.83**		**1.17**		**1.20**		**1.20**		**1.20**
24	21.25	1.00	0.18	2.00	0.36	3.00	0.54	4.00	0.72	5.00	0.90	6.00	1.07
24	23.75	1.00	0.20	2.00	0.40	3.00	0.60	4.00	0.80	5.00	1.00	6.00	1.20
24	26.25	1.00	0.22	2.00	0.44	3.00	0.66	4.00	0.88	5.00	1.11	6.00	1.20
24	28.75	1.00	0.24	2.00	0.48	3.00	0.73	4.00	0.97	5.00	1.20	6.00	1.20
24	31.25	1.00	0.26	2.00	0.53	3.00	0.79	4.00	1.05	5.00	1.20	6.00	1.20
H	**32.00**		**0.22**		**0.44**		**0.66**		**0.88**		**1.08**		**1.17**
24	33.75	1.00	0.28	2.00	0.57	3.00	0.85	4.00	1.14	5.00	1.20	6.00	1.20
24	36.25	1.00	0.31	2.00	0.61	3.00	0.92	4.00	1.20	5.00	1.20	6.00	1.20
24	38.75	1.00	0.33	2.00	0.65	3.00	0.98	4.00	1.20	5.00	1.20	6.00	1.20
24	41.25	1.00	0.35	2.00	0.69	3.00	1.04	4.00	1.20	5.00	1.20	6.00	1.20
H	**42.50**		**0.32**		**0.63**		**0.95**		**1.19**		**1.20**		**1.20**

Table A4.7-a: Step 1-Pullout Resistance vs Tensile Resistance for varying depths (Load Case 2: t = 0.437 and St = 18 or 24 in.) – Static

St	Depth[1] (ft)	s_V[2] (ksf)	F*	δ Degree	Le (ft)	Pullout_Allowable (ksf)	Tensile_Allowable (ksf)	Coh[1] (ksf)
18	11.25	1.63	0.35	19.24	3.00	1.13	2.07	0.45
18	13.75	1.93	0.32	17.67	3.00	1.23	2.07	0.49
24	16.25	2.23	0.22	12.20	3.00	0.96	2.07	0.38
24	18.75	2.53	0.19	10.95	3.00	0.98	2.07	0.39
24	21.25	2.83	0.18	10.32	3.00	1.03	2.07	0.41
24	23.75	3.13	0.18	10.32	3.00	1.14	2.07	0.46
24	26.25	3.43	0.18	10.32	3.00	1.25	2.07	0.50
24	28.75	3.73	0.18	10.32	3.00	1.36	2.07	0.54
24	31.25	4.03	0.18	10.32	3.00	1.47	2.07	0.59
24	33.75	4.33	0.18	10.32	3.00	1.58	2.07	0.63
24	36.25	4.63	0.18	10.32	3.00	1.68	2.07	0.67
24	38.75	4.93	0.18	10.32	3.00	1.79	2.07	0.72
24	41.25	5.23	0.18	10.32	3.00	1.90	2.07	0.76

1. Equivalent cohesion (Coh) = min (Pullout, Tensile)/spacing (2.5ft) for Le
2. Weight of 2(H) to 1(V) ground slope above the top of walls considered (Assumed Wall L = 0.7* H = 0.7*12 = 0.27 ksf)
3. If Le > 6 ft, tensile resistance controls the reinforcement capacity.

Table A4.7-b: Step 2-Equivalent Cohesion value for compound slope stability check (Load Case 2: t = 0.437 and St = 18 or 24 in.) – Static

St	H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
18	11.25	1.00	0.15	2.00	0.30	3.00	0.45	4.00	0.61	5.00	0.76	6.00	0.83
18	13.75	1.00	0.16	2.00	0.33	3.00	0.49	4.00	0.65	5.00	0.82	6.00	0.83
24	16.25	1.00	0.13	2.00	0.26	3.00	0.38	4.00	0.51	5.00	0.64	6.00	0.77
24	18.75	1.00	0.13	2.00	0.26	3.00	0.39	4.00	0.52	5.00	0.65	6.00	0.78
24	21.25	1.00	0.14	2.00	0.27	3.00	0.41	4.00	0.55	5.00	0.69	6.00	0.82
24	23.75	1.00	0.15	2.00	0.30	3.00	0.46	4.00	0.61	5.00	0.76	6.00	0.83
24	26.25	1.00	0.17	2.00	0.33	3.00	0.50	4.00	0.67	5.00	0.83	6.00	0.83
H	**27.00**		**0.15**		**0.29**		**0.44**		**0.59**		**0.74**		**0.81**
24	28.75	1.00	0.18	2.00	0.36	3.00	0.54	4.00	0.72	5.00	0.83	6.00	0.83
24	31.25	1.00	0.20	2.00	0.39	3.00	0.59	4.00	0.78	5.00	0.83	6.00	0.83
24	33.75	1.00	0.21	2.00	0.42	3.00	0.63	4.00	0.83	5.00	0.83	6.00	0.83
24	36.25	1.00	0.22	2.00	0.45	3.00	0.67	4.00	0.83	5.00	0.83	6.00	0.83
24	38.75	1.00	0.24	2.00	0.48	3.00	0.72	4.00	0.83	5.00	0.83	6.00	0.83
24	41.25	1.00	0.25	2.00	0.51	3.00	0.76	4.00	0.83	5.00	0.83	6.00	0.83
H	**42.50**		**0.22**		**0.44**		**0.65**		**0.80**		**0.83**		**0.83**

Table A4.7-c: Step 1-Pullout Resistance vs Tensile Resistance for varying depths (Load Case 2: t = 0.437 and St = 18 or 24 in.) – Seismic

St	Depth[1] (ft)	s_v[2] (ksf)	F*	δ Degree	Le (ft)	Pullout_Allowable (ksf)	Tensile_Allowable (ksf)	Coh[1] (ksf)
18	11.25	1.63	0.28	15.60	3.00	1.64	2.99	0.66
18	13.75	1.93	0.25	14.30	3.00	1.77	2.99	0.71
24	16.25	2.23	0.17	9.81	3.00	1.39	2.99	0.56
24	18.75	2.53	0.15	8.80	3.00	1.41	2.99	0.57
24	21.25	2.83	0.15	8.29	3.00	1.49	2.99	0.60
24	23.75	3.13	0.15	8.29	3.00	1.65	2.99	0.66
24	26.25	3.43	0.15	8.29	3.00	1.80	2.99	0.72
24	28.75	3.73	0.15	8.29	3.00	1.96	2.99	0.78
24	31.25	4.03	0.15	8.29	3.00	2.12	2.99	0.85
24	33.75	4.33	0.15	8.29	3.00	2.28	2.99	0.91
24	36.25	4.63	0.15	8.29	3.00	2.44	2.99	0.97
24	38.75	4.93	0.15	8.29	3.00	2.59	2.99	1.04
24	41.25	5.23	0.15	8.29	3.00	2.75	2.99	1.10

1. Equivalent cohesion (Coh) = min(Pullout, Tensile)/spacing (2.5ft) for Le
2. 2. Weight of 2(H) to 1(V) ground slope above the top of walls considered (Assumed Wall L = 0.7* H = 0.7*12 = 0.27 ksf)
3. If Le > 6 ft, tensile resistance controls the reinforcement capacity.

Table A4.7-b: Step 2-Equivalent Cohesion value for compound slope stability check (Load Case 2: t = 0.437 and St = 18 or 24 in.) – Seismic

St	H (ft)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)	Le (ft)	Coh (ksf)
18	11.25	1.00	0.22	2.00	0.44	3.00	0.66	4.00	0.87	5.00	1.09	6.00	1.20
18	13.75	1.00	0.24	2.00	0.47	3.00	0.71	4.00	0.95	5.00	1.18	6.00	1.20
24	16.25	1.00	0.19	2.00	0.37	3.00	0.56	4.00	0.74	5.00	0.93	6.00	1.11
24	18.75	1.00	0.19	2.00	0.38	3.00	0.57	4.00	0.75	5.00	0.94	6.00	1.13
24	21.25	1.00	0.20	2.00	0.40	3.00	0.60	4.00	0.79	5.00	0.99	6.00	1.19
24	23.75	1.00	0.22	2.00	0.44	3.00	0.66	4.00	0.88	5.00	1.10	6.00	1.20
24	26.25	1.00	0.24	2.00	0.48	3.00	0.72	4.00	0.96	5.00	1.20	6.00	1.20
H	**27.00**		**0.21**		**0.43**		**0.64**		**0.85**		**1.06**		**1.18**
24	28.75	1.00	0.26	2.00	0.52	3.00	0.78	4.00	1.05	5.00	1.20	6.00	1.20
24	31.25	1.00	0.28	2.00	0.57	3.00	0.85	4.00	1.13	5.00	1.20	6.00	1.20
24	33.75	1.00	0.30	2.00	0.61	3.00	0.91	4.00	1.20	5.00	1.20	6.00	1.20
24	36.25	1.00	0.32	2.00	0.65	3.00	0.97	4.00	1.20	5.00	1.20	6.00	1.20
24	38.75	1.00	0.35	2.00	0.69	3.00	1.04	4.00	1.20	5.00	1.20	6.00	1.20
24	41.25	1.00	0.37	2.00	0.73	3.00	1.10	4.00	1.20	5.00	1.20	6.00	1.20
H	**42.50**		**0.31**		**0.63**		**0.94**		**1.16**		**1.20**		**1.20**

5 Comparison/Parameter Study

A parameter study was conducted to compare three compound stability analysis methods and validate the simplified method, Method 1, as a reasonable and practical modeling and analysis approach for the MSE wall compound stability. The soil profiles, wall heights, and foundation slope conditions used for the study are summarized in Table B.x.1. Additionally, the steel reinforcement data are provided in Table B.x.2.

Table A4.8: Soil Profiles for Parameter Study

	Level Ground	3(H) to 1(V)	2(H) to 1(V)	1(H) to 1(V)	2(H) to 1(V)	2(H) to 1(V)
Wall Height (ft)	20	20	20	20	10	42.5
Foundation Slope Height (ft)	35	35	35	35	35	85
Soil Property: Unit Weight (kcf)/Cohesion (ksf)/Friction Angle (degree)						
MSE Backfill	0.12/0.0/34	0.12/0.0/34	0.12/0.0/34	0.12/0.0/34	0.12/0.0/34	0.12/0.0/34
Retained Soil	0.12/0.0/30	0.12/0.0/30	0.12/0.0/30	0.12/0.0/30	0.12/0.0/30	0.12/0.0/30
1st Foundation Soil Layer	0.12/0.0/30	0.12/0.0/30	0.12/0.2/32	0.12/0.4/42	0.12/0.1/32	0.12/0.1/36 & 0.12/0.4/32
2nd Foundation Soil Layer	0.12/0.3/34	0.12/0.3/34	0.12/0.3/34	0.12/0.3/34	0.12/0.3/34	0.12/0.3/34

Table A4.9: Steel Soil Reinforcement Details for Parameter Study - BDA 3-8: Attachment 3

H1 (H)	16'-8" (15'-0")	19'-2" (17'-6")	21'-8" (20'-0")	24'-2" (22'-6")
BW (L)	13'-6" (12'-0")	15'-6" (14'-0")	17'-6" (16'-0")	18'-6" (17'-0")
	Top 4-W15xW15@6 3 of 4-W15xW15@6 1 of 4-W20xW15@9 Bot. 4-W20xW15@9	Top 4-W15xW15@6 4 of 4-W15xW15@6 1 of 4-W20xW15@9 Bot. 4-W20xW15@9	Top 4-W15xW15@6 4 of 4-W15xW15@18 2 of 4-W20xW15@24 Bot. 4-W20xW15@24	Top 4-W15xW15@6 4 of 4-W15xW15@18 3 of 4-W20xW15@24 Bot. 4-W20xW15@24

H1 (H)	6'-8" (5'-0")	9'-2" (7'-6")	11'-8" (10'-0")	14'-2" (12'-6")
BW (L)	9'-6" (8'-0")	9'-6" (8'-0")	9'-6" (8'-0")	11'-6" (10'-0")
	Top 4-W15xW15@6 Bot. 4-W15xW15@6	Top 4-W15xW15@6 1 of 4-W15xW15@6 Bot. 4-W15xW15@6	Top 4-W15xW15@6 2 of 4-W15xW15@6 Bot. 4-W20xW15@9	Top 4-W15xW15@6 3 of 4-W15xW15@6 Bot. 4-W20xW15@9

H1 (H)	36'-8" (35'-0")	39'-2" (37'-6")	41'-8" (40'-0")	44'-2" (42'-6")
BW (L)	26'-6" (25'-0")	29'-6" (28'-0")	30'-6" (29'-0")	33'-6" (32'-0")
	Top 4-W15xW15@18 4 of 4-W15xW15@18 4 of 4-W20xW15@24 4 of 6-W25xW15@30 Bot. 6-W25xW15@30	Top 4-W15xW15@18 4 of 4-W15xW15@18 5 of 4-W20xW15@24 4 of 6-W25xW15@30 Bot. 6-W25xW15@30	Top 4-W15xW15@18 4 of 4-W15xW15@18 5 of 4-W20xW15@24 5 of 6-W25xW15@30 Bot. 6-W25xW15@30	Top 4-W15xW15@18 4 of 4-W15xW15@18 5 of 4-W20xW15@24 6 of 6-W25xW15@30 Bot. 6-W25xW15@30

Example Configuration: 3 of 4-W20xW15@24
3 of = 3 levels of reinforcement mats with
4-W20x = 4 longitudinal wires W20 sized by
W15@24 – W15 sized transverse wires at 24-inch spacing

Based on the above design data, MSE walls are analyzed, and graphical results are summarized in Table B.x.3. The table presents calculated FoS and the location of critical failure surface. Note that all three approaches will provide almost identical results.

Table A.4.10-a: Factor of Safety and Potential Failure Plane for Wall Height of 20 feet

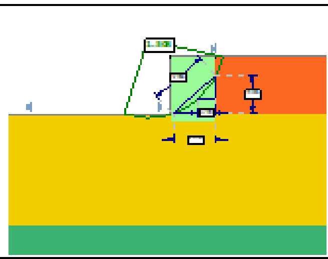
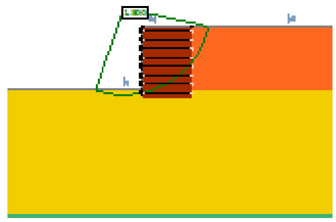
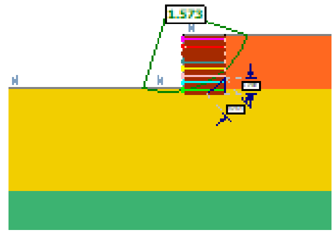
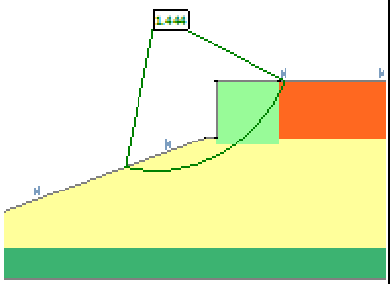
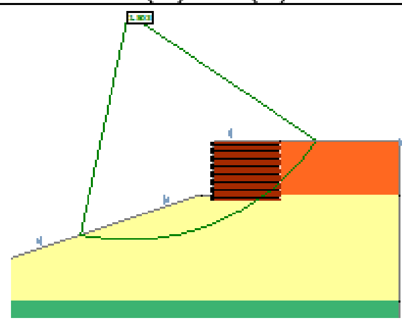
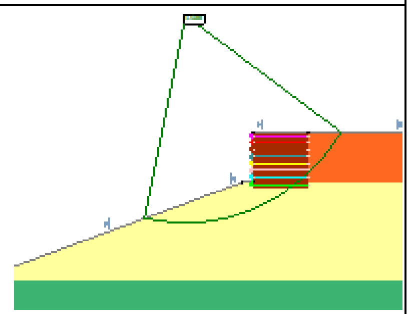
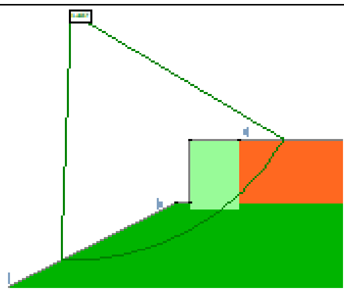
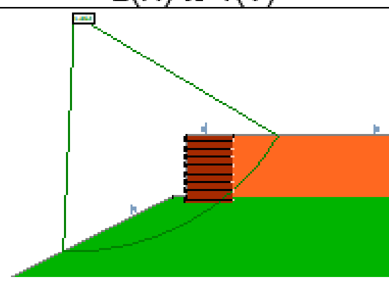
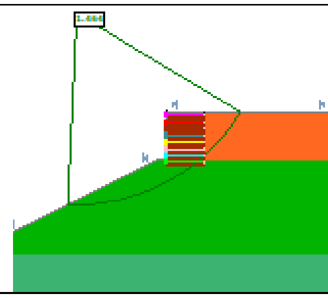
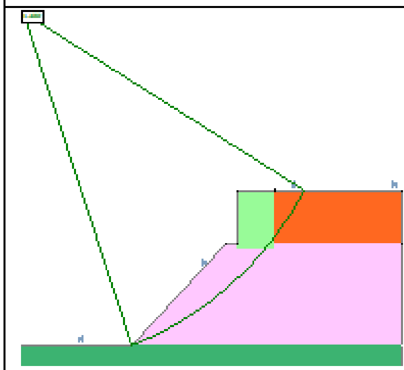
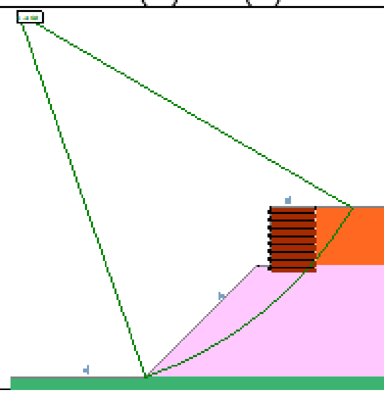
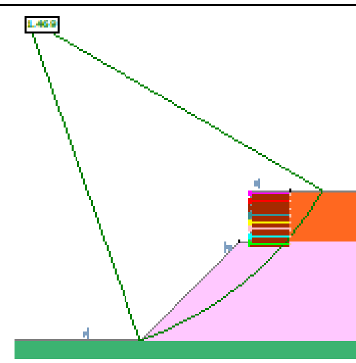
<table>
<tr><td colspan="3">Wall Height = 20 ft & Foundation Slope Height = 35 feet</td></tr>
<tr><td colspan="3">Level Ground</td></tr>
<tr><td>Method 1</td><td>Method 2</td><td>Method 3</td></tr>
<tr><td></td><td></td><td>
</td></tr>
<tr><td colspan="3">3(H) to 1(V)</td></tr>
<tr><td>
</td><td></td><td></td></tr>
<tr><td colspan="3">2(H) to 1(V)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">1(H) to 1(V)</td></tr>
<tr><td></td><td></td><td>
</td></tr>
</table>

Table A4.10-b: Factor of Safety and Potential Failure Plane for Wall Height of 10 feet

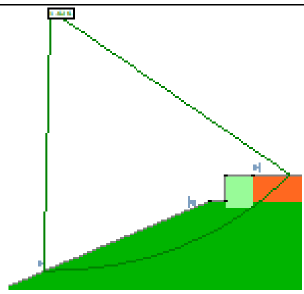
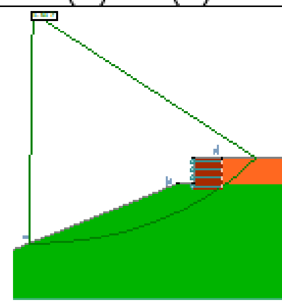
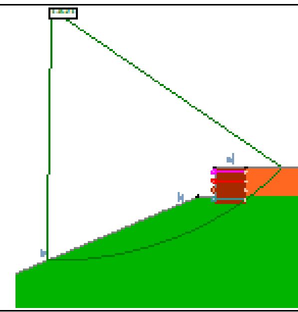
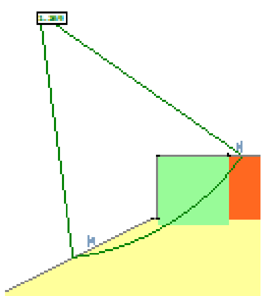
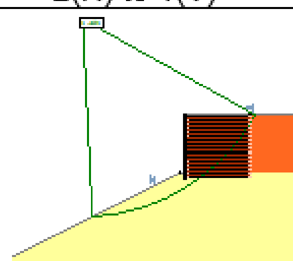
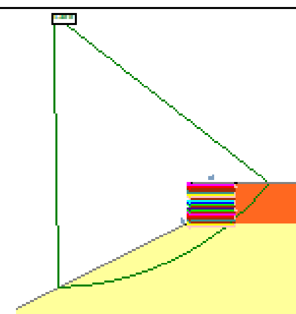
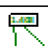
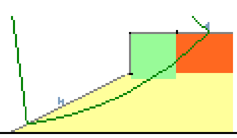
Wall Height = 10 ft & Foundation Slope Height = 35 feet		
2(H) to 1(V)		
		

Table A.4.10-c: Factor of Safety and Potential Failure Plane for Wall Height of 42.5 feet

Wall Height = 42.5 ft & Foundation Slope Height = 85 feet		
2(H) to 1(V)		
		
 Search Limit modified to model appropriate potential compound slope failure plane 		

A5. SOIL NAIL WALL

Design Example

For this design example, a slope stability analysis program, Slide2 was used. the soil, soil nail properties and wall geometry are summarized in Tables A5.2, A5.3, and A5.4.

Table A5.2: Soil Nail Wall - Soil Profile

Wall Height: 20 feet/Foundation Height and Slope= 35 feet and 2(H) to 1(V)				
	Unit Weight (kcf)	Cohesion (ksf)	Friction Angle (degree)	Bond Strength (psi)
Retained Soil	0.12	0.1	34	12
1st Foundation Soil Layer	0.12	0	30	12
2nd Foundation Soil Layer	0.12	0.3	34	12

Table A5.3: Soil Nail Data

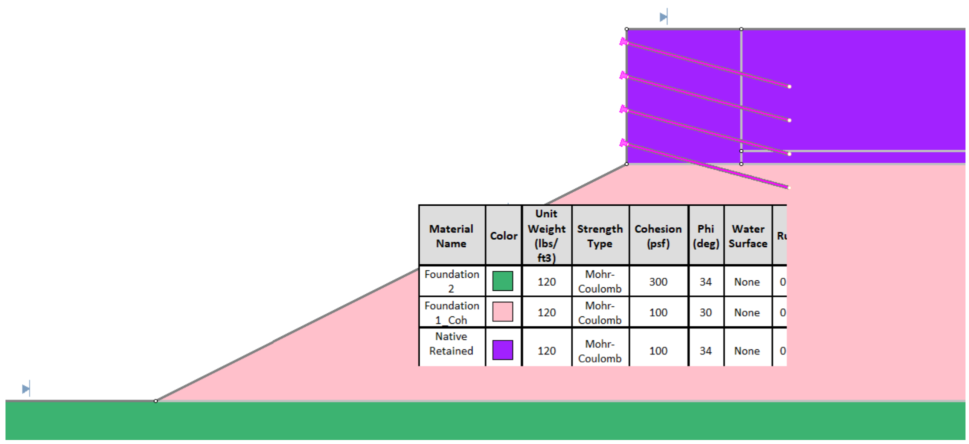
Soil Nail	
fy (ksi)	65
d (in) - Nail Diameter	1
Allowable Facing Resistance (kips) – Static/Seismic	30.2/40.2
Vertical Spacing (ft)	5
Horizontal Spacing (ft)	5
Length (ft)	25

Table A5.4: Soil Nail Wall – Soil Nail and Facing Engineering Properties

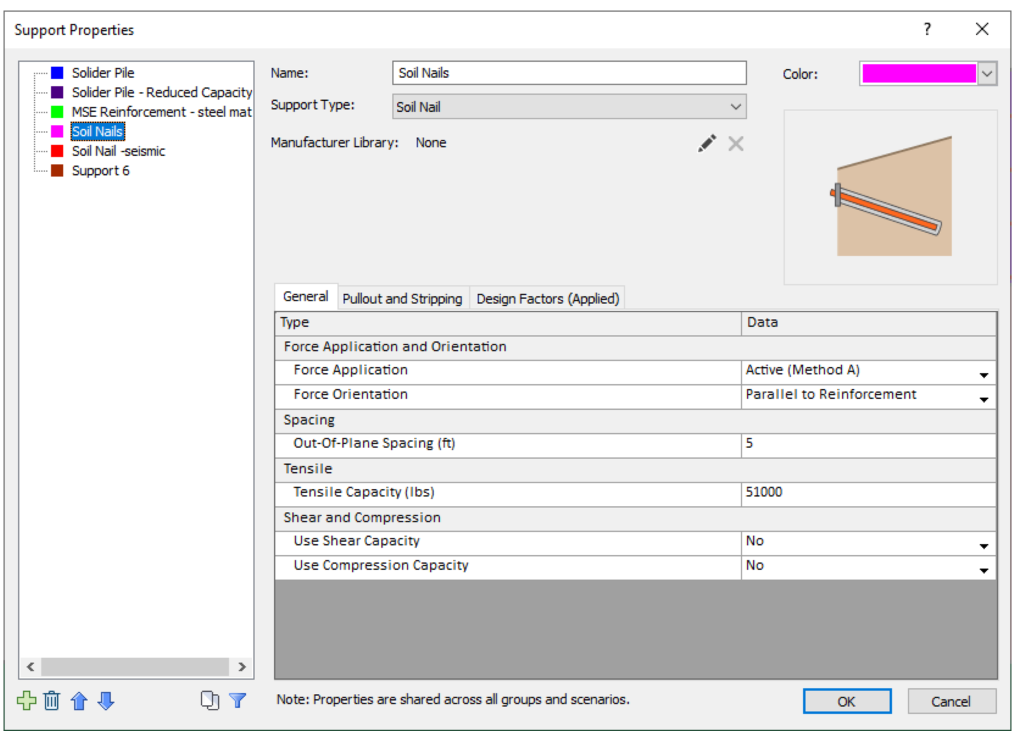
Snail Input		Slide2 Inputs	
fy (ksi) - Nails	65	Tensile Capacity (lbs)	fy x $\pi d^2/4$ x 1,000 = 51,000
d (in) - Nail Diameter	1		
Allowable Facing Resistance (kips)	30 (Static) 42 (Seismic)	Plate Capacity (lbs)	Allowable Facing Resistance x 1,000 x Partial Factor = 30,000 x 1.8 = 54,000 (Static) 42,000 x 1.35 = 56,700 (Seismic)
fs (psi) - Bond Strength	12	Bond Strength (lbs/ft)	fs x πD x 12 = 2,714
D (in) - Drilled Hole Diameter	6		

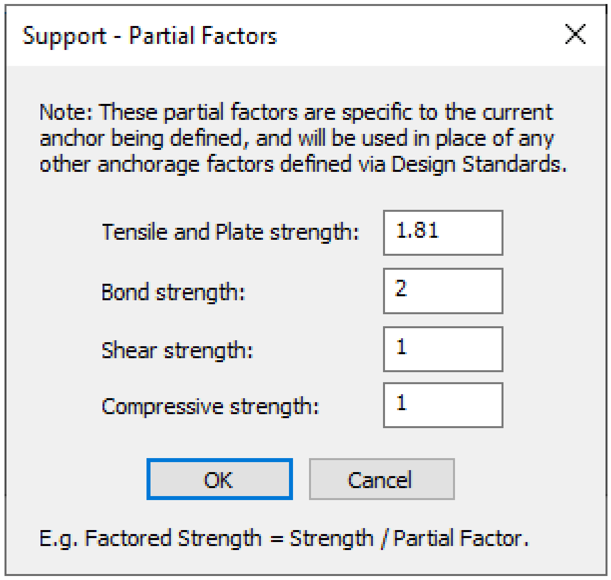
Global/Compound Stability Analysis for Soil Nail Walls – Static

1. Model soil nail reinforcements and wall geometry.
2. Assign the shear strength of soil layers as presented in Table 5.2.

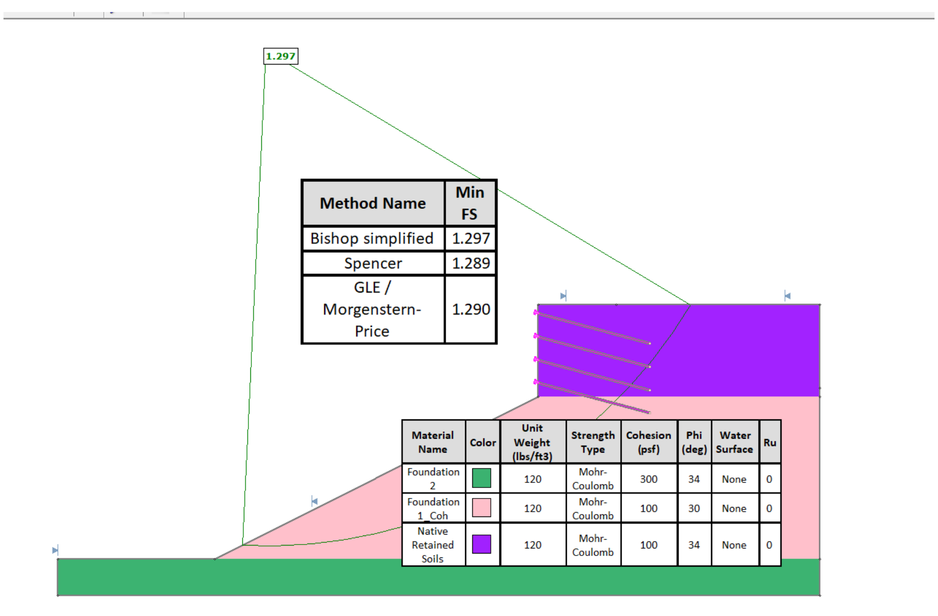


3. Determine the engineering properties of soil nails per Tables 5.3 and 5.4.





4. Conduct the stability analysis for the static scenario.



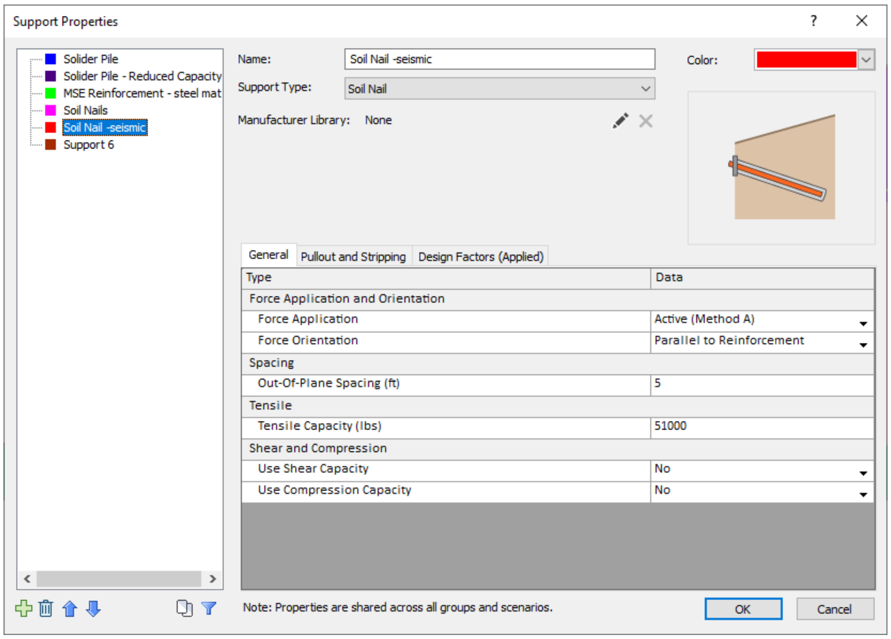
Method Name	Min FS
Bishop simplified	1.297
Spencer	1.289
GLE / Morgenstern-Price	1.290

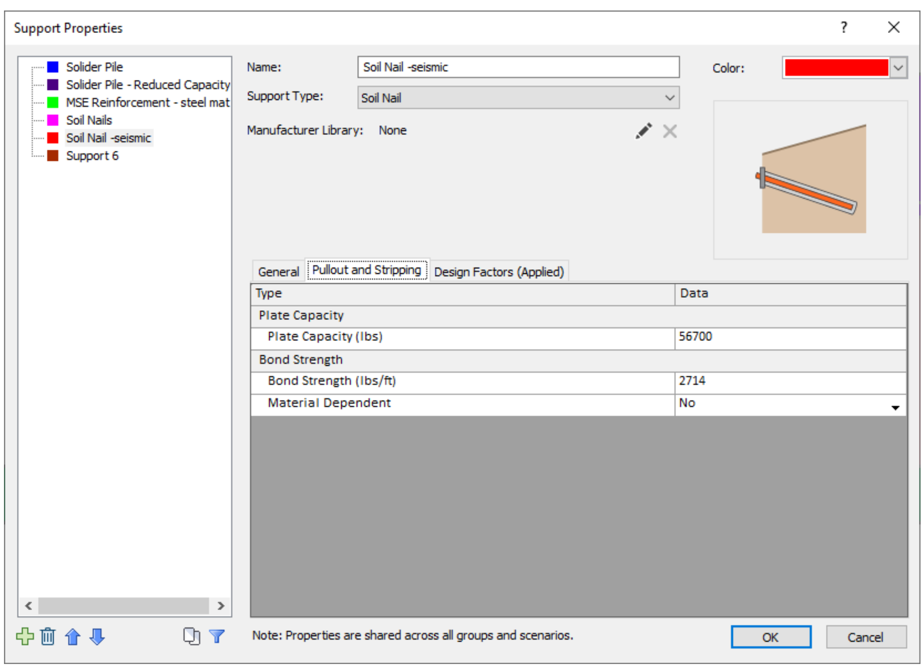
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Foundation 1_Coh		120	Mohr-Coulomb	100	30	None	0
Native Retained Soils		120	Mohr-Coulomb	100	34	None	0

5. If the calculated FoS is less than the required minimum FoS, increase the reinforcement parameters including length, spacing, etc.: The calculated FoS = 1.3.

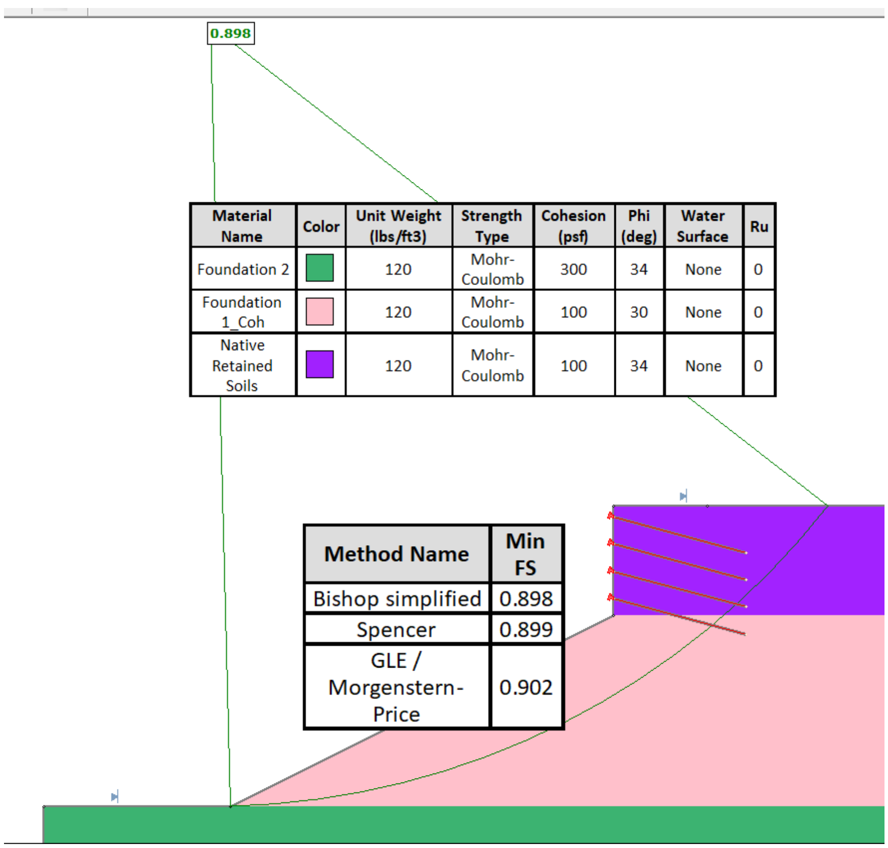
Global/Compound Stability Analysis for Soil Nail Walls – Seismic with K_h = 0.2

1. Model soil nail reinforcements and wall geometry.
2. Assign the shear strength of soil layers as presented in Table 5.2.
3. Determine the engineering properties of soil nails per Tables 5.3 and 5.4.





4. Conduct the stability analysis for the seismic scenario.



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Foundation 2		120	Mohr-Coulomb	300	34	None	0
Foundation 1_Coh		120	Mohr-Coulomb	100	30	None	0
Native Retained Soils		120	Mohr-Coulomb	100	34	None	0

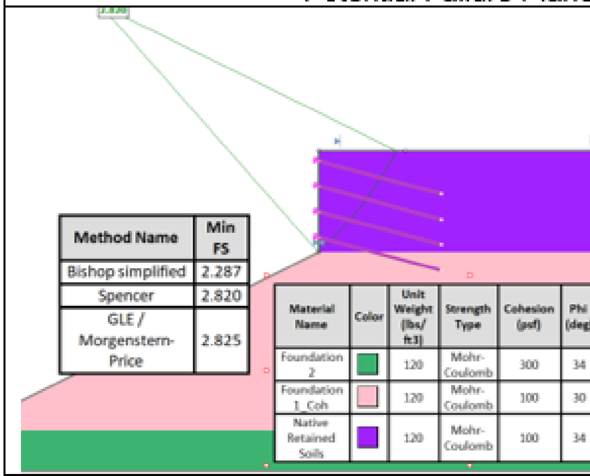
Method Name	Min FS
Bishop simplified	0.898
Spencer	0.899
GLE / Morgenstern-Price	0.902

5. If the calculated FoS is less than the required minimum FoS, increase the reinforcement parameters including length, spacing, etc.: The calculated FoS = 0.9. Need to adjust reinforcement parameters until the calculated FoS meets the required minimum FoS.

Comparison Study

To ensure that the engineering properties of soil nails and facing work properly in slope stability program, a comparison study was performed using Snail and Slide 2 and the results are presented in Table A.5.5

Table A.5.5: Soil Nail Wall – Comparison between Snail and Slide

<table>
<tr><th>Slide 2 Results</th><th>Snail Results</th></tr>
<tr><td colspan="2">Potential Failure Plane above Toe of Wall – Static</td></tr>
<tr><td>
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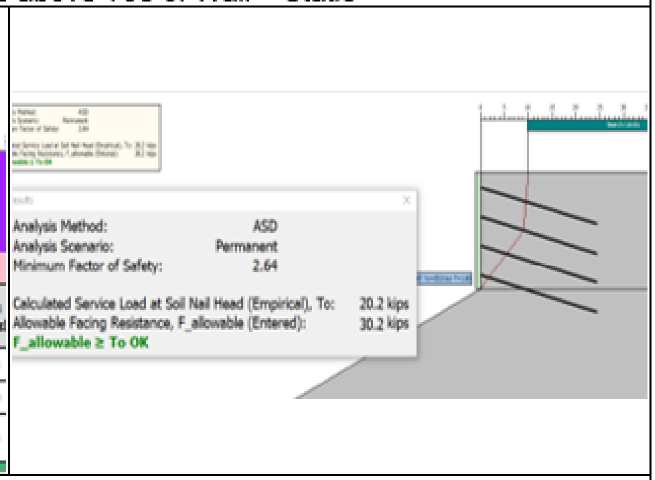
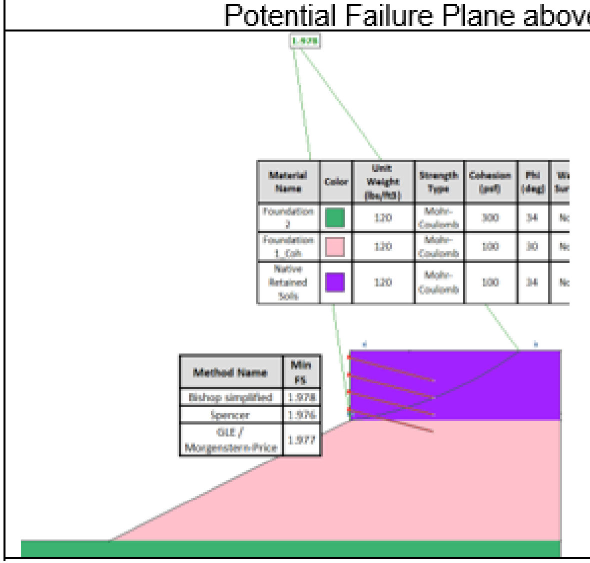
<td>
</td></tr>
<tr><td colspan="2">Potential Failure Plane above Toe of Wall – Seismic (K_h = 0.2)</td></tr>
<tr><td>
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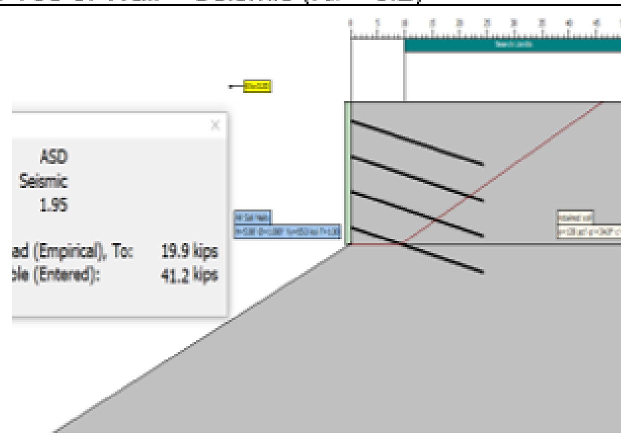
<td>
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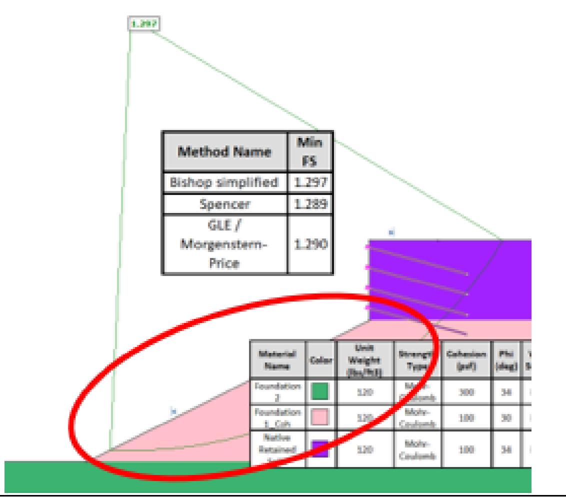
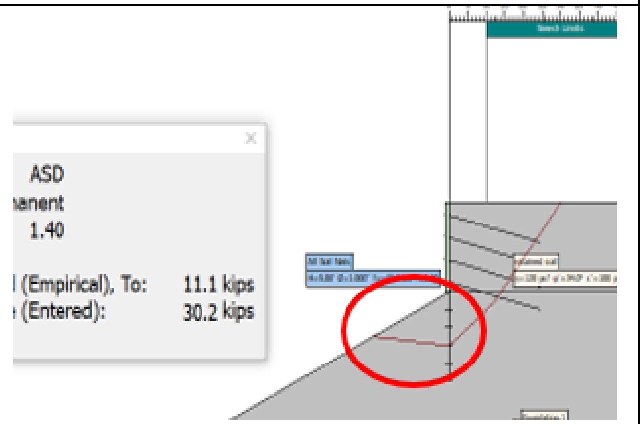
Potential Failure Plane Below Toe of Wall – Static





Potential Failure Plane Below Toe of Wall – Seismic