CHAPTER 7 — DESIGN EXAMPLE

A typical application for design of the MSE wall component of an SMSE wall system with extensible geogrid reinforcements and wire facing units is presented in this chapter using the sequential design procedure outlined in chapter 5. This design example is illustrated in figure 25.

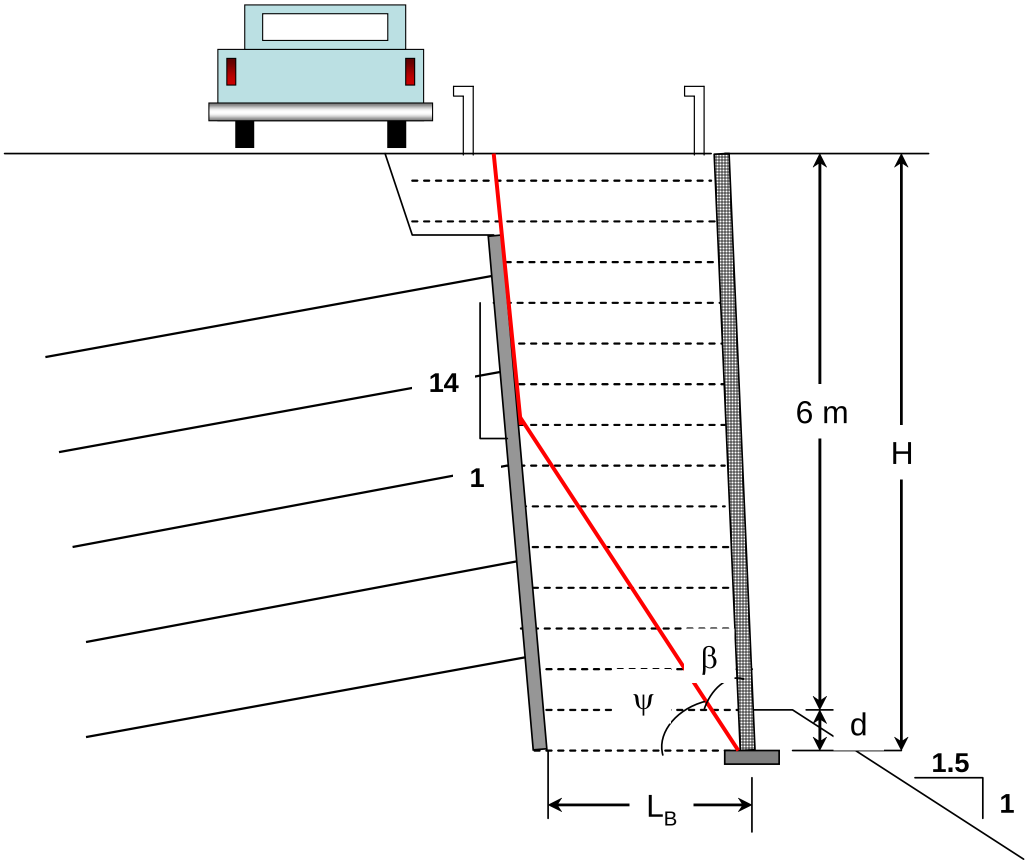


Figure 25. Illustration. Illustration of design example.

7.1 INTERNAL STABILITY DESIGN

Step 1 – Select MSE wall type and trial wall geometry.

The geometry of the MSE wall and details of the preliminary design, including applied loading, are:

- Exposed wall height, H_d = 6 m.
- Slope at toe of wall = 1.5H:1V = 3H:2V. Depth of embedment, $d = H_d/5$ = (6 m)/5 = 1.2 m per table 2 in chapter 3. Verification of this depth of embedment will come later through bearing capacity and global stability analyses. Therefore, the total wall height (H) is 7.2 m.

- MSE facing unit height = 0.46 m. Given the facing unit size, assign a trial vertical spacing of 0.46 m, allowing for the height of one facing unit per each reinforcement, and considering the maximum recommended vertical reinforcement spacing of 0.6 m for SMSE walls.

- Based on the geometrical constraints and need to keep traffic lanes open for construction of the MSE wall, a shoring wall is required. The shoring wall will consist of a soil nail wall with a batter of 1H:14V and a shotcrete facing. The shoring wall will be constructed for partial back-slope shoring, where the upper two MSE reinforcements will extend over the shoring wall interface.

- The MSE wall facing will be installed near-vertically.

- Provide a minimum horizontal bench of 1.2 m wide in front of the wall since it is founded on a slope.(2)

- Based on site access restrictions and trial wall geometry, a base width of 2.2 m for the MSE wall component is selected, which is approximately equivalent to the minimum required reinforcement length of 0.3*H*.

- Geogrid reinforcements will have 100 percent coverage.

- Wall to be designed for traffic surcharge, q = 12 kPa.

Step 2 – Estimate the location of the critical failure surface.

Per figure 14 in section 5.3, the critical failure surface may be approximated using the theoretical active failure surface within the reinforced soil mass at the base of the wall, with the remaining portion intersecting the interface of the shoring and MSE wall components. In order to estimate the location of the critical failure surface, the engineering properties of the reinforced fill and foundation soils must be established, as follows, based on the results of a site-specific geotechnical investigation:

- Reinforced fill parameters: $\phi' = 34^{\circ}$, $\gamma = 18.5 \text{ kN/m}^3$ for reinforced backfill meeting the specifications presented in section 3.3.1.

- For extensible reinforcements, $\psi = 45^{\circ} + \phi'/2 = 62^{\circ}$.

- Foundation parameters: $\phi'_f = 35^{\circ}$ (colluvial clayey gravel, dense), $c_f = 10$ kPa, and $\gamma_f = 19 \text{ kN/m}^3$.

Step 3 – Calculate internal stability with respect to rupture of the reinforcements.

The calculation for reinforcement rupture is as follows:

- Lateral stress ratio (K_r/K_a) is one for extensible reinforcements, per figure 16 in chapter 5.

- Calculate the active earth pressure coefficient, K_a:

$$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right) = 0.283$$

- At each reinforcement level, calculate the horizontal stress, σ_h, along the potential failure line from the weight of the reinforced fill, plus uniform surcharge loads, and concentrated surcharge loads ($\Delta\sigma_h$, $\Delta\sigma_v$) using equations 3 and 4 in chapter 5. The horizontal stress at each reinforcement level is presented in figure 26. Using the horizontal stress, σ_h, calculate the maximum tension per unit width of wall at each reinforcement level based on the vertical reinforcement spacing, s_v (0.46 m), using equation 5 in chapter 5. Figure 26 summarizes the reinforcement rupture calculations conducted for this design example.

Based on reinforcement rupture calculations, the lowermost reinforcement requires an allowable strength of approximately 19 kN/m. Geogrid with a lower allowable strength may be installed near to the top of the wall. However, for this example, assume use of a geogrid with an allowable tensile strength of 25 kN/m (Geogrid 25) for all reinforcement layers.

Step 4 – Calculate the required total tensile capacity of MSE reinforcements.

Calculate the required pullout force, T_{max}, for MSE reinforcements in the resistant zone per equation 14 in chapter 5. The pullout force calculation for this design example is presented in figure 27. The required pullout force per unit width of wall is approximately 136 kN/m.

Step 5 – Calculate the pullout resistance of MSE reinforcements in the resistant zone.

Calculate the total pullout resistance of the designed MSE reinforcements, and compare the result to the required pullout capacity, T_{max}, calculated in step 4, above:

- Based on the designed reinforcement vertical spacing of 0.46 m, calculate the length of embedment, L_{ei}, of each reinforcement layer within the resistant zone using equation 18 in chapter 5, modified geometrically due to the shoring wall batter. The embedment length calculations are provided in figure 28.

- At each reinforcement layer within the resistant zone, calculate the pullout resistance, F_{PO}, per equation 19 in chapter 5:

$$F_{PO} = \frac{1}{FS_p} F^* \sigma_{vi} L_{ei} C R_c \alpha \le T_{allowable}$$

  - Due to the narrow wall width and potential for arching at the wall base, the factor of safety against reinforcement pullout, FS_p, is taken as 2.0, per section 3.2.

  - Assume $F^* = 0.8 \tan\phi'$ = 0.8 tan (34°) = 0.54, for geogrid reinforcement in granular soil.

- Reinforcement effective unit perimeter, $C = 2$.
- Scale effect correction factor, α, to account for a nonlinear stress reduction over the embedded length of highly extensible reinforcements. Use 0.8 for geogrids.
- Coverage ratio, $R_c = 1$.
- The vertical stress, σ_{vi}, excludes surcharge loading.

The calculated pullout resistance at each reinforcement level is summarized in figure 28. The total pullout capacity of the reinforcements, sum of F_{P0} at each reinforcement level, of 221 kN/m is greater than T_{max} (136 kN/m), calculated above in step 4. Therefore, the reinforcement design for the MSE wall component of the shoring wall is considered adequate to achieve internal stability (e.g., $FS > 1.5$).

7.2 EXTERNAL STABILITY DESIGN

After internal design of the MSE wall portion of the SMSE wall system is complete per steps 1 through 5 outlined in section 7.1, then design of the MSE wall component with regard to external stability is conducted. This includes evaluation of the wall with regard to bearing capacity and settlement.

7.2.1 Bearing Capacity Check

- Check the MSE wall for bearing capacity stability by calculating the vertical stress at the base of the wall, σ_v, using equation 27 in chapter 5.

$$\sigma_v = \frac{W_1 + (q \cdot L_1)}{L_1} = \frac{(18.5\ \text{kN/m}^3 \cdot 7.2\ \text{m} \cdot 2.2\ \text{m}) + 12\ \text{kPa} \cdot 2.2\ \text{m})}{2.2\ \text{m}} = 145\ \text{kPa}$$

- Calculate the ultimate bearing capacity of the soil using classical soil mechanics according to equation 28 in chapter 5. Use figure 21 in chapter 5 to estimate the bearing capacity factors, N_{cq} and $N_{\gamma q}$, for a footing adjacent to sloping ground:
  - Slope stability factor: $N_s = 0$ for base width less than height of slope.
  - Distance of foundation from edge of slope: $b/B = 1.2\ \text{m}/2.2\ \text{m} = 0.55$.
  - Foundation depth divided by width: $D_f/B = 1.2\ \text{m}/2.2\ \text{m} = 0.55$.
  - Inclination of slope: $i = \tan^{-1}(1/1.5) = 33.7^o$.
  - Bearing capacity factors N_{cq} and $N_{\gamma q}$ are estimated as 5.5 and 40, respectively, using figure 21.

- The ultimate bearing capacity is calculated as:

$$q_{ult} = (10\,\text{kPa} \cdot 5.5) + 0.5(2.2\,\text{m})(19\,\text{kN/m}^3)(40) = 891\,\text{kPa}$$

- Apply a factor of safety to the ultimate bearing capacity, q_{ult}, to calculate the allowable bearing capacity, q_a:

$$q_a = \frac{q_{ult}}{FS_{bc}} = \frac{891\,\text{kPa}}{2.5} = 356\,\text{kPa}$$

- Compare the allowable bearing pressure to the calculated vertical stress. If the vertical stress is less than the allowable bearing capacity, the MSE wall is stable with regard to bearing capacity of the foundation:

$$\sigma_v = 145\,\text{kPa} \leq 356\text{ kPa} = q_a\text{, therefore O.K.}$$

If the recommended bearing capacity is not achieved, the base width of the MSE wall component should be increased or foundation improvement measures implemented.

7.2.2 Settlement Check

Check settlement of the wall and foundation using guidelines presented in other references.(17)

7.3 GLOBAL STABILITY DESIGN

Global stability design of the SMSE wall system includes checking the following failure mechanisms: failure along the shoring/MSE interface and global stability external to the SMSE wall system under static and pseudo-static loading conditions.

7.3.1 MSE Wall/Shoring Interface Stability Check

As a first evaluation, assume zero shear strength along the interface (i.e., full development of a tension crack). This may be approximated by applying a distributed load in place of the MSE wall component. The distributed load, σ_v, is calculated in step 6 above in section 7.1 (i.e., 145 kPa). Figure 29 presents results of interface shear stability for this design example, evaluated using *Slide*, a limit equilibrium stability software program.(15) The factor of safety against failure for this mechanism is about 1.5, which is considered acceptable. Therefore, no further analysis of this failure mechanism is required.

If the factor of safety calculated above is less than acceptable for the specific project, additional analyses should be conducted to evaluate the interface stability. First, the interface should be modeled with a nominal width using an interface friction angle corresponding to the estimated friction angle between the reinforced fill and the shoring wall, as summarized in table 3 (chapter 5). For a rough shotcrete surface against clean gravel or gravel-sand mixtures, as anticipated for the reinforced fill zone of the MSE wall, the interface friction angle is in the range of 29 to 31 degrees. The interface should then be analyzed using the failure surface illustrated in figure 23 presented in chapter 5. If an adequate factor of safety is still not achieved, consider modifications to the shoring wall geometry (i.e., stepped interface), or implementing foundation improvement measures.

7.3.2 Stability External to SMSE Wall System

Once a design is developed for the shoring wall component, stability analysis of the combined SMSE wall system is required to check the various global failure mechanisms. Analyses should include pseudo-static analysis of the SMSE wall system under the design seismic acceleration, where a factor of safety greater than 75 percent of the static factor of safety for the same failure mechanism is considered acceptable. This analysis has not been included in this report, as it follows common practice and is not unique to SMSE wall systems.

REINFORCEMENT RUPTURE CALCULATION

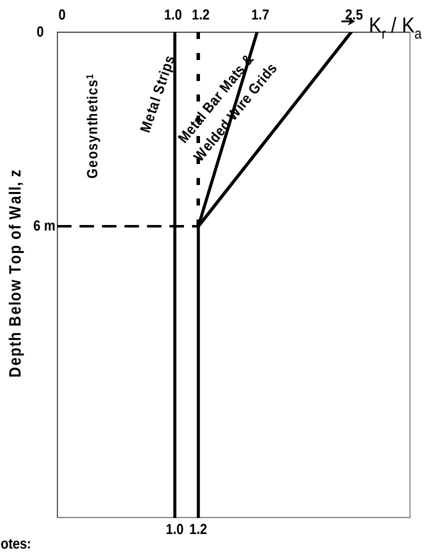
Wall Parameters:	
Wall height (m):	6
Embedment depth (m):	1.2
Soil unit weight (kN/m3):	18.5
MSE wall batter (deg):	0
Inclination of MSE facing (degrees	90
Friction angle (degrees):	34

Reinforcement Input Parameters:	
Reinforcement spacing (s)[1] (m):	0.46
Coverage Ratio (R_c):	1
Reinforcement type:	Geogrid

Loading Input Parameters:	
Uniform surcharge, q (kPa):	12

Earth Pressure Calculation:	
K_a =	0.283

🟩 Input Fields
☐ Calculated Fields



Notes:
1. Does not include polymer strip reinforcement.

Layer (Bottom-upward):	z (m)	K_r/K_a [2]	K_r	$\Delta\sigma_v$ [3]	σ_v at reinforcement level (kPa)	$\Delta\sigma_h$ [4]	σ_h at reinforcement level (kPa)	T_i at reinforcement level (kN/m)
1	7.2	1.00	0.283	0.0	145.2	0.0	41.1	18.9
2	6.74	1.00	0.283	0.0	136.7	0.0	38.6	17.8
3	6.28	1.00	0.283	0.0	128.2	0.0	36.2	16.7
4	5.82	1.00	0.283	0.0	119.7	0.0	33.8	15.6
5	5.36	1.00	0.283	0.0	111.2	0.0	31.4	14.5
6	4.9	1.00	0.283	0.0	102.7	0.0	29.0	13.3
7	4.44	1.00	0.283	0.0	94.1	0.0	26.6	12.2
8	3.98	1.00	0.283	0.0	85.6	0.0	24.2	11.1
9	3.52	1.00	0.283	0.0	77.1	0.0	21.8	10.0
10	3.06	1.00	0.283	0.0	68.6	0.0	19.4	8.9
11	2.6	1.00	0.283	0.0	60.1	0.0	17.0	7.8
12	2.14	1.00	0.283	0.0	51.6	0.0	14.6	6.7
13	1.68	1.00	0.283	0.0	43.1	0.0	12.2	5.6
14	1.22	1.00	0.283	0.0	34.6	0.0	9.8	4.5
15	0.76	1.00	0.283	0.0	26.1	0.0	7.4	3.4
16	0.3	1.00	0.283	0.0	17.6	0.0	5.0	2.3

Notes:
1. Vertical reinforcement spacing to be consistent with selection of wall facing.
2. Ratio to be input based on type of reinforcement selected and use of figure above.
3. Calculate the increment of vertical stress due to concentrated loads at the surface using the 2:1 method at each reinforcement layer.
4. Calculate the increment of horizontal stress (if any) due to concentrated loads at the surface.

Figure 26. Calculation. Reinforcement rupture calculation for the design example.

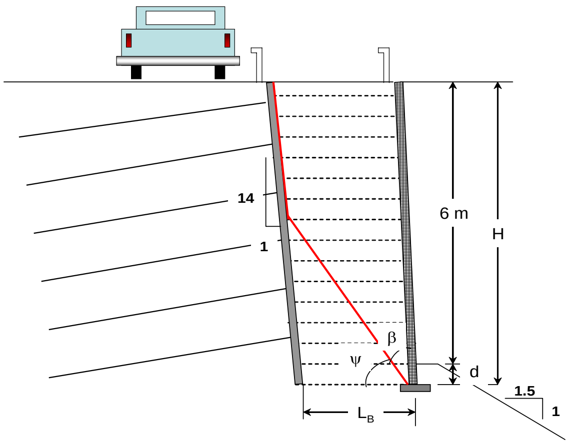
REQUIRED PULLOUT CAPACITY OF REINFORCEMENTS IN RESISTANT ZONE

Equations:

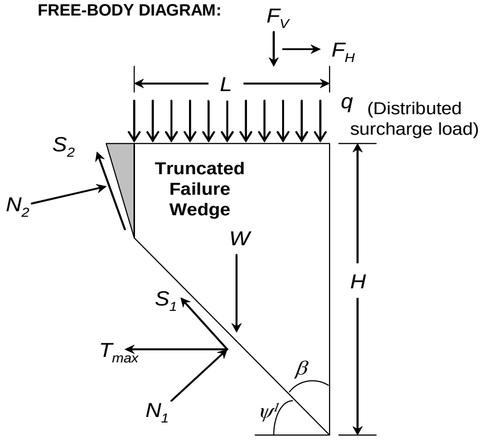
$$T_{\max} = \frac{L\left(\gamma\left(H - \frac{L}{2\tan\beta}\right) + q\right) + F_V}{\tan\left(\phi' + \beta\right)} + F_H$$

Extensible Reinforcements:

FAILURE SURFACE APPROXIMATION:



FREE-BODY DIAGRAM:



Wall Parameters:	
Wall height, H (includes embedment) (m):	7.2
Wall length at base, L_B (m):	2.2
Shoring wall batter, 1H:?V:	14
Length of truncated wedge, L (m):	2.5
Soil unit weight (kN/m^3):	18.5
Friction angle (degrees):	34

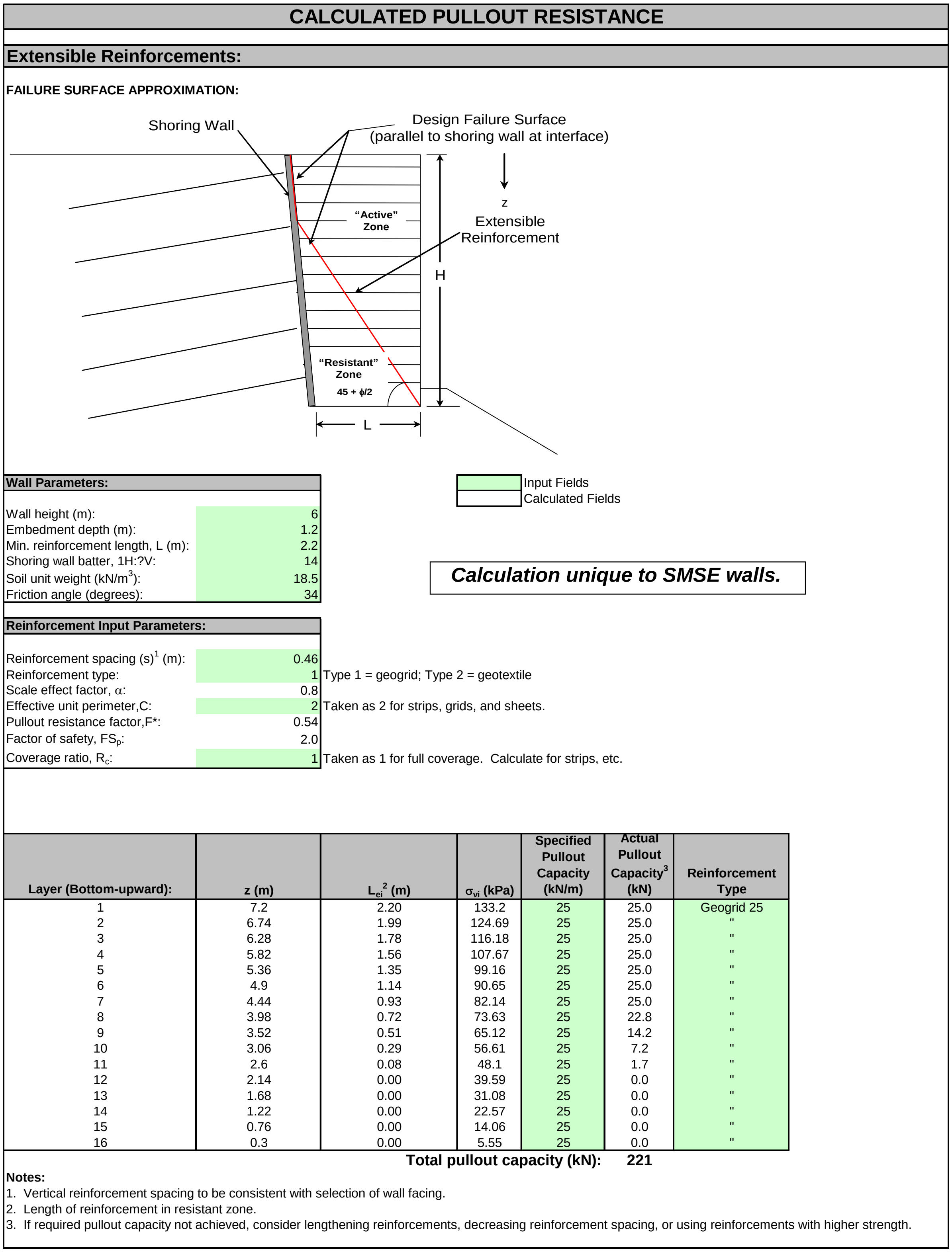
Loading:	
Conc. vert. load, F_V (kN/m):	0
Conc. horiz. load, F_H (kN/m):	0
Surcharge, q (kPa):	12

Calculations:	
β (degrees) =	28.0
T_{max}(kN/m):	136

🟩	Input Fields
☐	Calculated Fields

Calculation unique to SMSE walls.

Figure 27. Calculation. Required total tensile capacity of MSE reinforcements for design example.



CALCULATED PULLOUT RESISTANCE

Extensible Reinforcements:

FAILURE SURFACE APPROXIMATION:

Wall Parameters:	
Wall height (m):	6
Embedment depth (m):	1.2
Min. reinforcement length, L (m):	2.2
Shoring wall batter, 1H:?V:	14
Soil unit weight (kN/m^3):	18.5
Friction angle (degrees):	34

🟩 Input Fields

☐ Calculated Fields

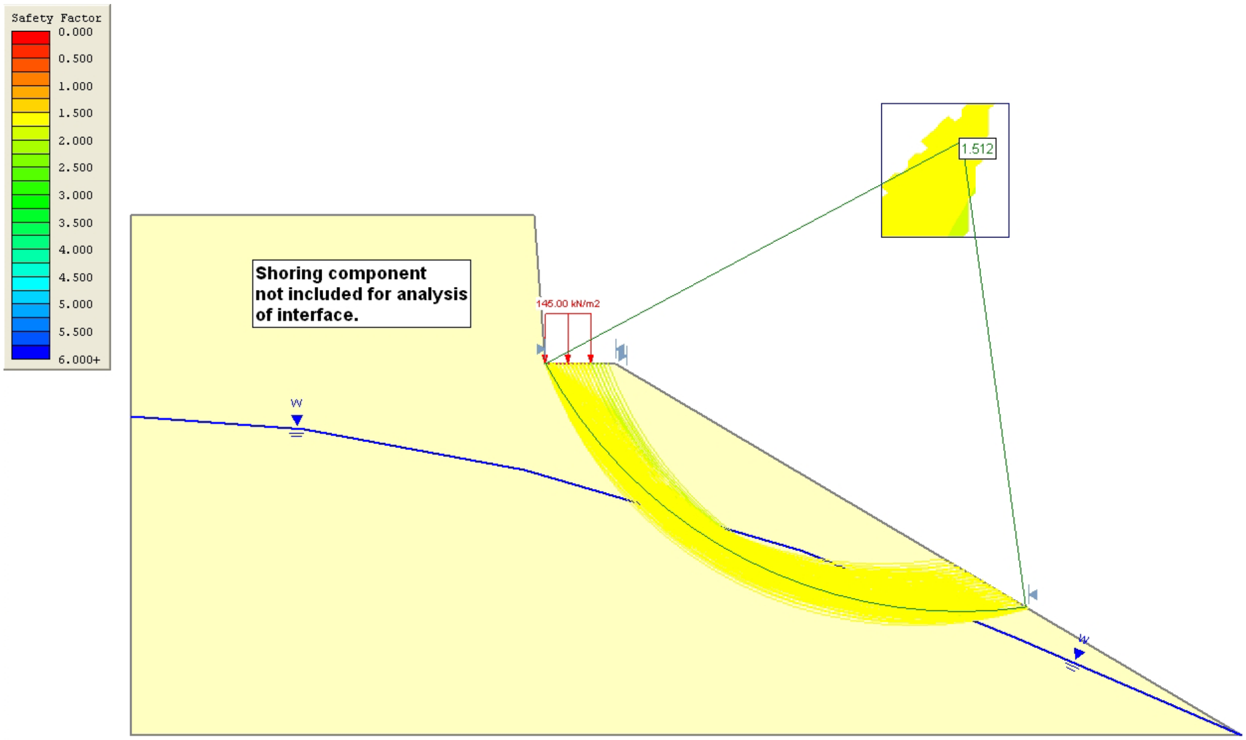
Calculation unique to SMSE walls.

Reinforcement Input Parameters:		
Reinforcement spacing (s)[1] (m):	0.46	
Reinforcement type:	1	Type 1 = geogrid; Type 2 = geotextile
Scale effect factor, α:	0.8	
Effective unit perimeter,C:	2	Taken as 2 for strips, grids, and sheets.
Pullout resistance factor,F*:	0.54	
Factor of safety, FS$_p$:	2.0	
Coverage ratio, R$_c$:	1	Taken as 1 for full coverage. Calculate for strips, etc.

Layer (Bottom-upward):	z (m)	L$_{ei}$^{2} (m)	σ$_{vi}$ (kPa)	Specified Pullout Capacity (kN/m)	Actual Pullout Capacity^3 (kN)	Reinforcement Type
1	7.2	2.20	133.2	25	25.0	Geogrid 25
2	6.74	1.99	124.69	25	25.0	"
3	6.28	1.78	116.18	25	25.0	"
4	5.82	1.56	107.67	25	25.0	"
5	5.36	1.35	99.16	25	25.0	"
6	4.9	1.14	90.65	25	25.0	"
7	4.44	0.93	82.14	25	25.0	"
8	3.98	0.72	73.63	25	22.8	"
9	3.52	0.51	65.12	25	14.2	"
10	3.06	0.29	56.61	25	7.2	"
11	2.6	0.08	48.1	25	1.7	"
12	2.14	0.00	39.59	25	0.0	"
13	1.68	0.00	31.08	25	0.0	"
14	1.22	0.00	22.57	25	0.0	"
15	0.76	0.00	14.06	25	0.0	"
16	0.3	0.00	5.55	25	0.0	"
				Total pullout capacity (kN):	**221**	

Notes:
1. Vertical reinforcement spacing to be consistent with selection of wall facing.
2. Length of reinforcement in resistant zone.
3. If required pullout capacity not achieved, consider lengthening reinforcements, decreasing reinforcement spacing, or using reinforcements with higher strength.

Figure 28. Calculation. Pullout resistance calculation for design example.



Shoring component not included for analysis of interface.

Figure 29. Screenshot. Interface stability check for the design example.