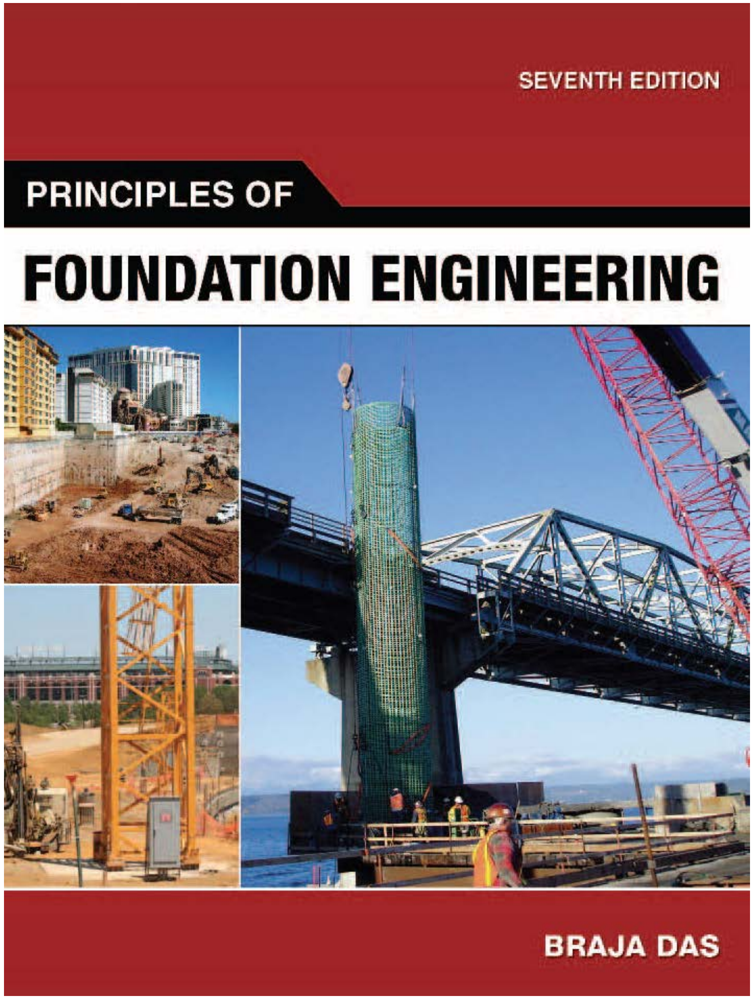

Chapter 8:

Retaining Walls

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Type of Retaining Walls

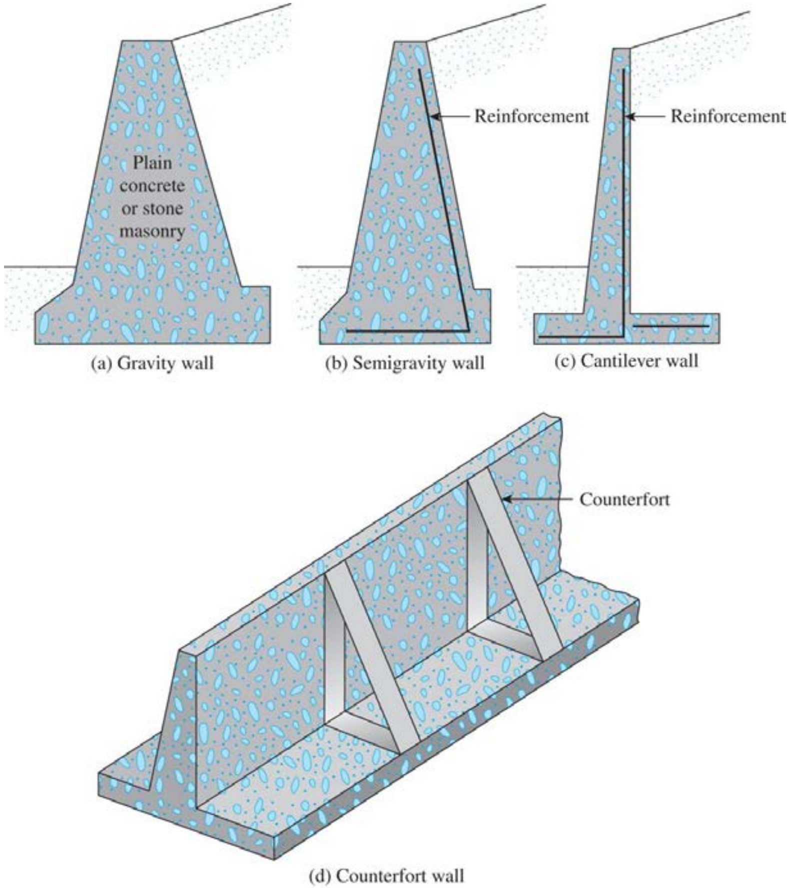


Figure 8.1 Types of retaining wall

Figure 8.2 A cantilever retaining wall under construction (*Courtesy of Dharma Shakya, Geotechnical Solutions, Inc., Irvine, California*)

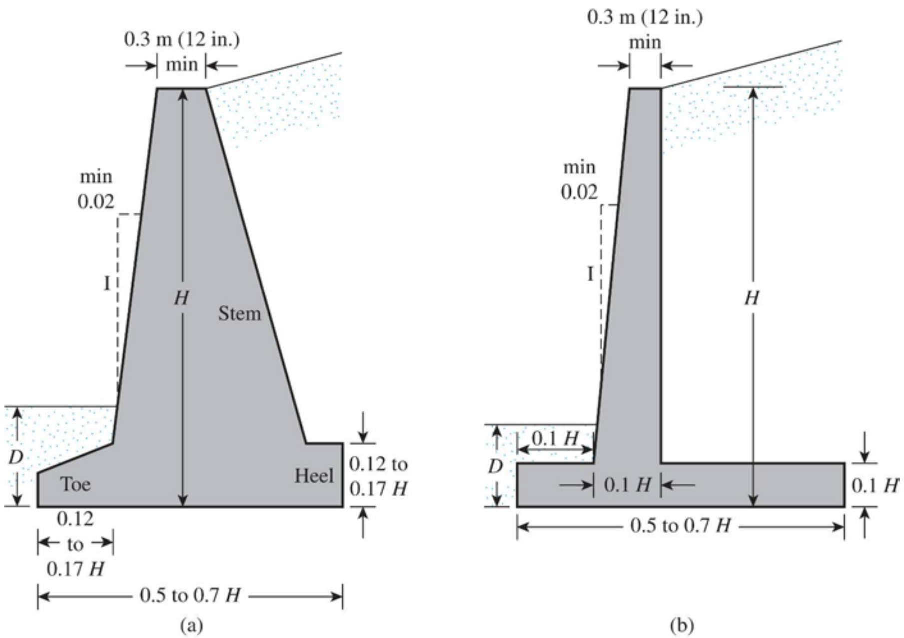


Figure 8.3 Approximate dimensions for various components of retaining wall for initial stability checks: (a) gravity wall; (b) cantilever wall

Application of Lateral Earth Pressure Theories to Design

$$\eta = 45 + \frac{\alpha}{2} + \frac{\phi'}{2} - \frac{1}{2}\sin^{-1}\left(\frac{\sin\alpha}{\sin\phi'}\right)$$

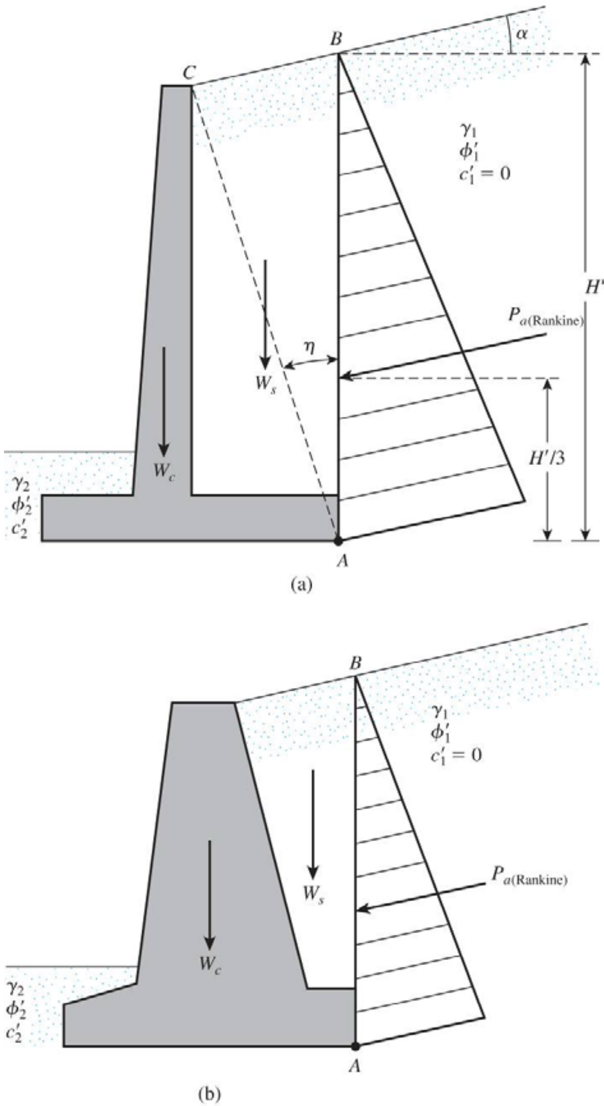


Figure 8.4 Assumption for the determination of lateral earth pressure: (a) cantilever wall; (b) and (c) gravity wall

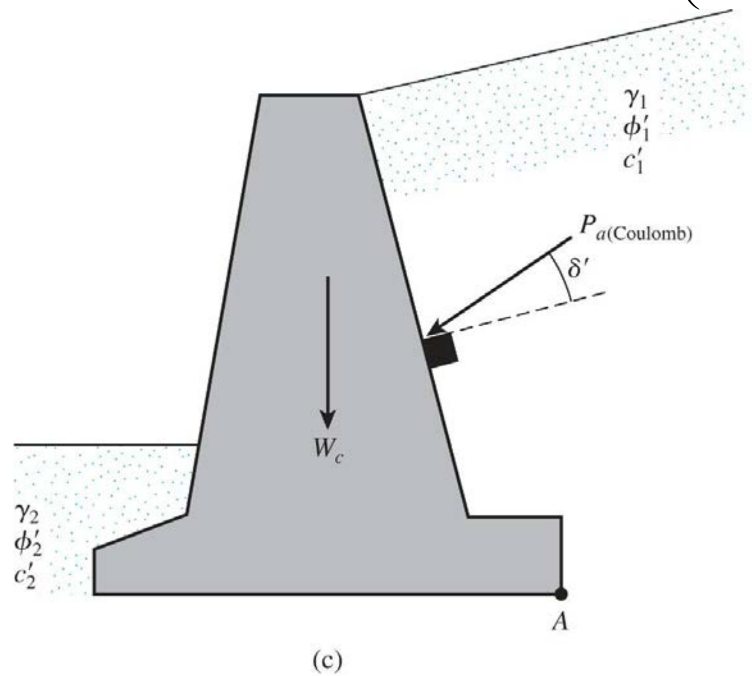


Figure 8.4 *(continued)*

Backfill Material	Range of δ' (deg)
Gravel	27-30
Coarse Sand	20-28
Fine Sand	15-25
Stiff Clay	15-20
Silty Clay	12-16

Stability of Retaining Walls
(General)

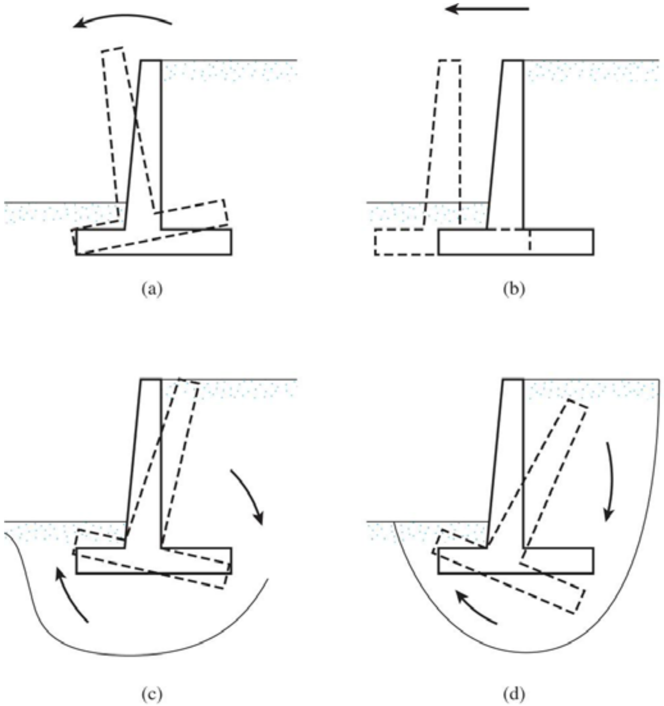


Figure 8.5 Failure of retaining wall:
(a) by overturning; (b) by sliding;
(c) by bearing capacity failure;
(d) by deep-seated shear failure

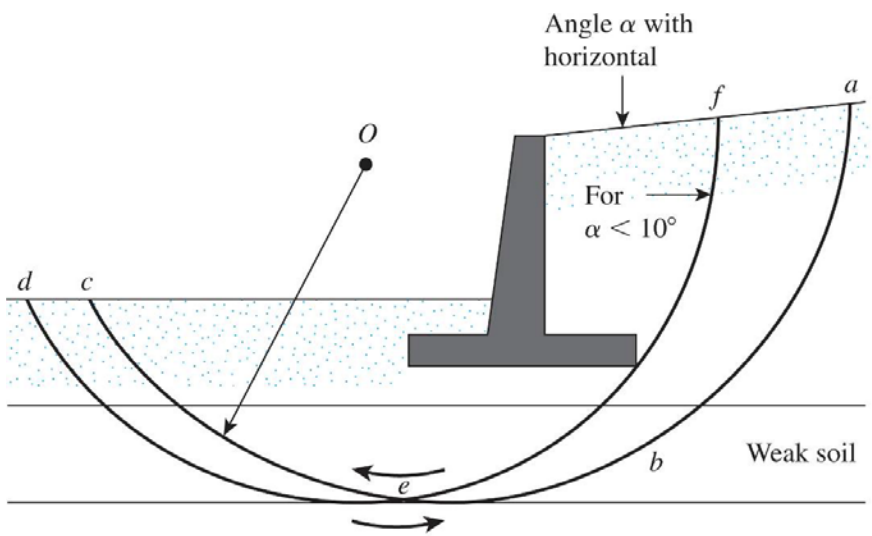


Figure 8.6 Deep-seated shear failure

Stability of Retaining Walls
(Overturning)

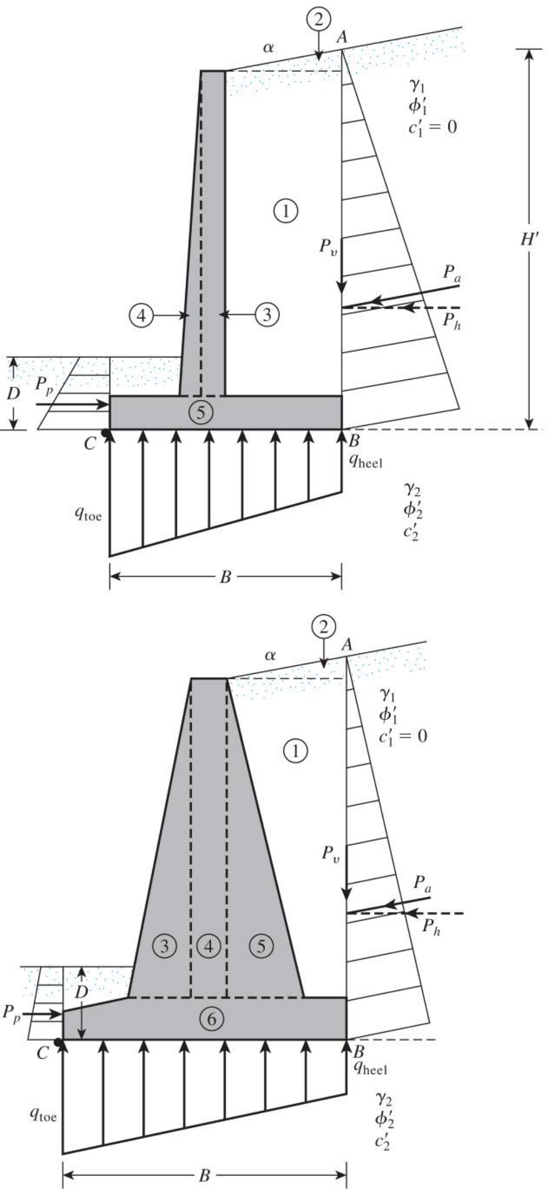


Figure 8.7 Check for overturning, assuming that the Rankine pressure is valid

$$P_p = \frac{1}{2} K_p \gamma_2 D^2 + 2c_2' \sqrt{K_p} D$$

$$FS_{(overturning)} = \frac{\sum M_R}{\sum M_O} = \frac{\text{sum of the moments of forces tending to overturn about point C}}{\text{sum of the moments of forces tending to resist overturning about point C}}$$

Overturning moment, $\sum M_O = P_h \left(\frac{H'}{3}\right)$ where, $P_h = P_a \cos\alpha$

$P_v = P_a \sin\alpha$ $M_v = P_v B = P_a \sin\alpha\, B$ where B = width of base slab

$$FS_{(overturning)} = \frac{\sum M_R}{\sum M_O} = \frac{M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_v}{P_a \cos\alpha \left(H'/3\right)}$$

or

$$FS_{(overturning)} = \frac{\sum M_R}{\sum M_O} = \frac{M_1 + M_2 + M_3 + M_4 + M_5 + M_6}{P_a \cos\alpha \left(H'/3\right) - M_v}$$

Minimum desirable FS = 2 to 3

Stability of Retaining Walls
(Sliding along the base)

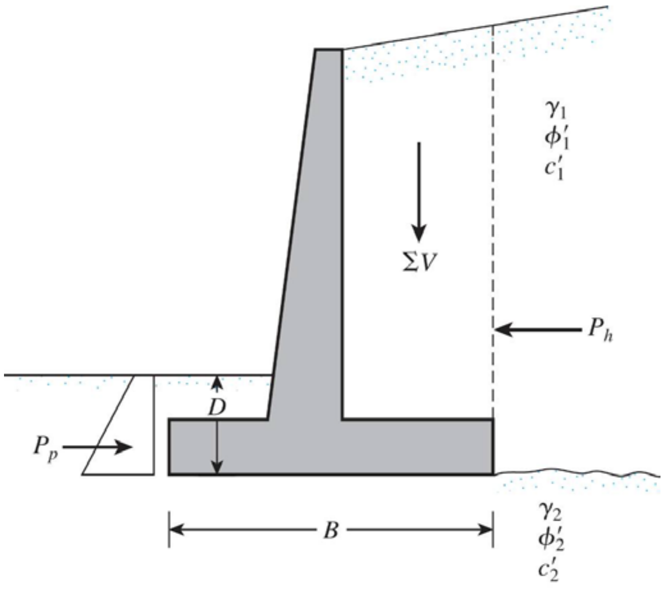


Figure 8.8 Check for sliding along the base

$$FS_{(sliding)} = \frac{F_{R'}}{F_d}$$

$F_{R'}$ = sum of horizontal resisting forces

F_d = sum of horizontal driving forces

$$s = \sigma' \tan \delta' + c'_a$$

δ' = angle of friction between the soil and base slab

c'_a = adhesion between the soil and base slab

Maximum resisting force that can be derived from soil along bottom of wall

$$R' = \text{s (area of cross section)} = \text{s (Bx1)} = B\sigma' \tan\delta' + B\,c'_a$$

$$B\sigma' = \text{sum of vertical force} = \sum V$$

$$R' = \left(\sum V\right) \tan \delta' + Bc'_a$$

$$\sum F_{R'} = \left(\sum V\right) \tan \delta' + Bc'_a + P_p$$

$$\sum F_d = P_a \cos \alpha$$

$$FS_{(sliding)} = \frac{F_{R'}}{F_d} = \frac{\left(\sum V\right) \tan \delta' + Bc'_a + P_p}{P_a \cos \alpha}$$

Minimum desirable FS = 1.5

Stability of Retaining Walls

(Sliding along the base)

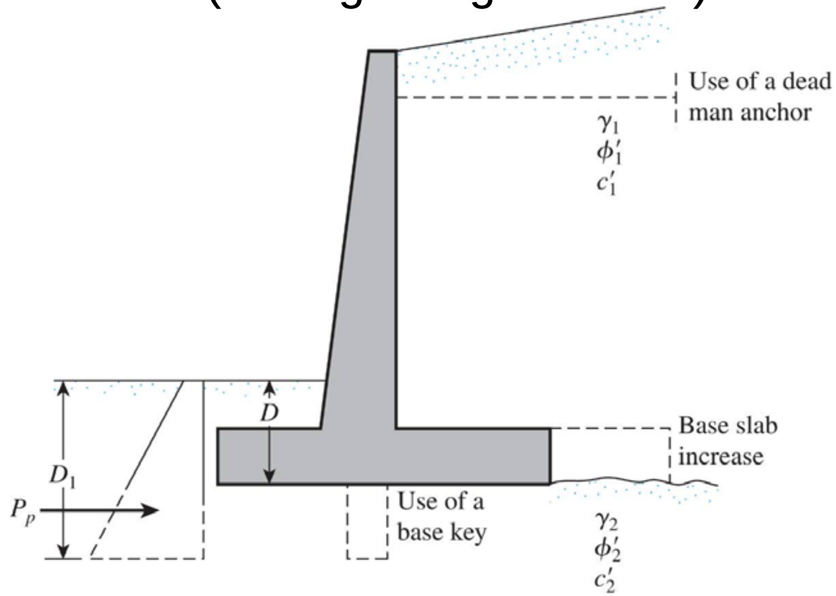


Figure 8.9 Alternatives for increasing the factor of safety with respect to sliding

Alternatives for sliding design

1) Increase the width of the base slab (heel of the footing)

2)Use a key to the base slab

$$P_p = \frac{1}{2}\gamma_2 D_1^2 K_p + 2c_2' D_1 \sqrt{K_p} \qquad \text{where } K_p = \tan^2\left(45 + \frac{\phi_2'}{2}\right)$$

3) Use a deadman anchor at the stem of the retaining wall

Stability of Retaining Walls

(Sliding along the base)

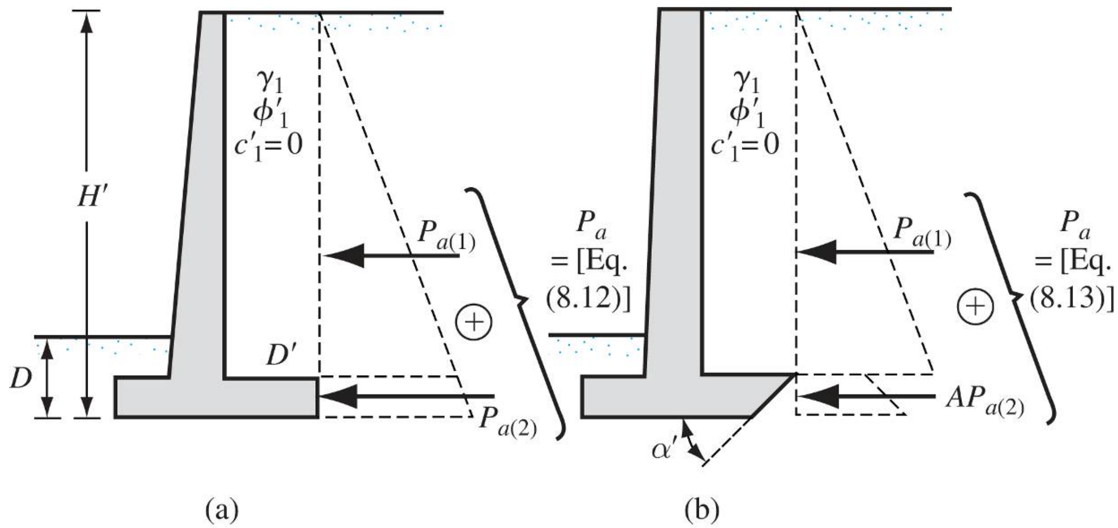


Figure 8.10 Retaining wall with sloped heel

$$P_a = P_{a(1)} + A\, P_{a(2)}$$

$$P_{a(1)} = \frac{1}{2}\gamma_1 K_a (H'-D')^2 \qquad Pa = \frac{1}{2}\gamma_1 K_a H'^2$$

$$\text{Therefore, } P_{a(2)} = \frac{1}{2}\gamma_1 K_a \left[H'^2 - (H'-D')^2\right] \qquad \text{(Figure 8.10a)}$$

$$P_{a(2)} = \frac{1}{2}\gamma_1 K_a \left[(H'-D')^2\right] + \frac{A}{2}\gamma_1 K_a \left[H'^2 - (H'-D')^2\right] \qquad \text{(Figure 8.10b)}$$

Table 8.2 Variation of A with ϕ_1' (for $\alpha' = 45°$)

Soil friction angle, ϕ_1' (deg)	A
20	0.28
25	0.14
30	0.06
35	0.03
40	0.018

Stability of Retaining Walls
(Bearing capacity failure)

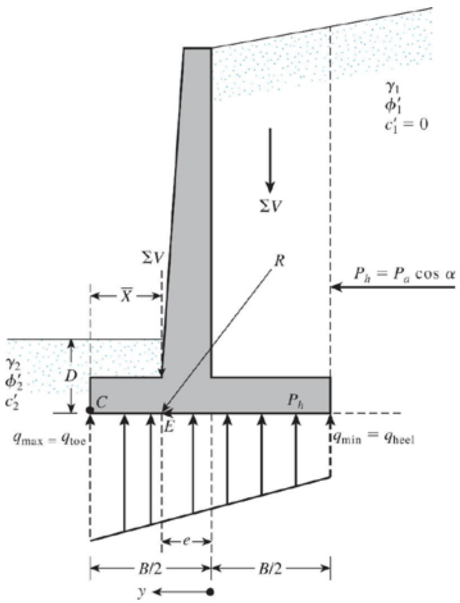


Figure 8.11 Check for bearing capacity failure

$$R = \sum V + P_h = \sum V + P_a \cos\alpha$$

Net moment of the forces about point C is: $M_{net} = \sum M_R - \sum M_O$

$$\overline{CE} = \overline{X} = \frac{M_{net}}{\sum V} \qquad e = \frac{B}{2} - \overline{CE}$$

Pressure distribution under the base slab:

$$q = \frac{\sum V}{A} \pm \frac{M_{net}\, y}{I}$$

M_{net} = moment $= \left(\sum V\right)e$

I = moment of inertia per unit length of the base section

$$= \frac{1}{12}(1)B^3$$

$$q_{max} = q_{toe} = \frac{\sum V}{(B)(1)} = \frac{e\left(\sum V\right)\frac{B}{2}}{\left(\frac{1}{12}\right)B^3} = \frac{\sum V}{B}\left(1 + \frac{6e}{B}\right)$$

$$q_{min} = q_{heel} = \frac{\sum V}{B}\left(1 - \frac{6e}{B}\right)$$

$$q_u = c'_2 N_c F_{cd} F_{ci} + q N_q F_{qd} F_{qi} + \frac{1}{2}\gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i}$$

$$FS_{(\text{bearing capacity})} = \frac{q_u}{q_{max}}$$

Minimum desirable FS = 3

Construction Joints for Retaining Walls

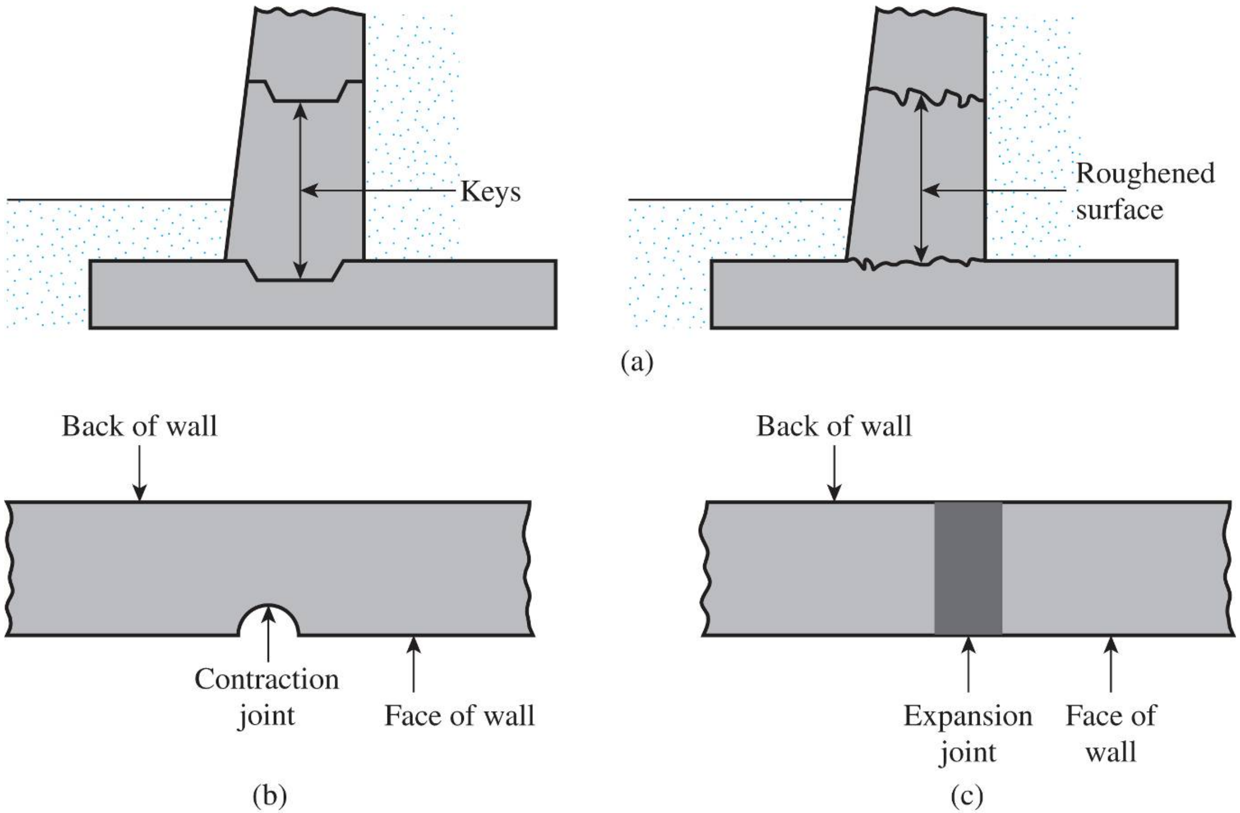


Figure 8.14 (a) Construction joints; (b) contraction joint; (c) expansion joint

Drainage from the backfill behind Retaining Walls

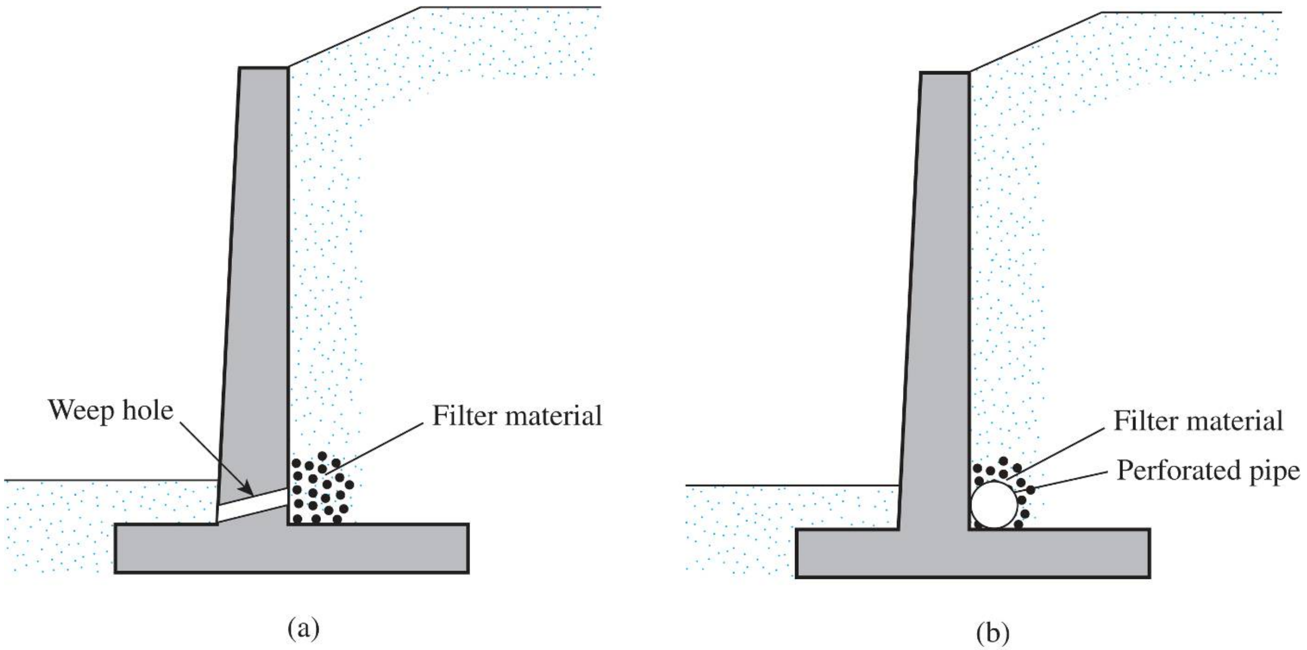


Figure 8.15 Drainage provisions for the backfill of a retaining wall: (a) by weep holes; (b) by a perforated drainage pipe

The grain size distribution of the filter material should be such that:

(a) The soil to be protected is not washed into the filter

(b) excessive hydrostatic pressure head is not created in the soil with a lower hydraulic conductivity (Backfill material)

$$\frac{D_{15(F)}}{D_{85(B)}} < 5 \ \text{(to satisfy condition (a))}$$

$$\frac{D_{15(F)}}{D_{15(B)}} > 4 \ \text{(to satisfy condition (b))}$$

Subscripts F and B refer to the filter and base material, respectively.

Gravity Retaining Wall design for Earthquake Conditions

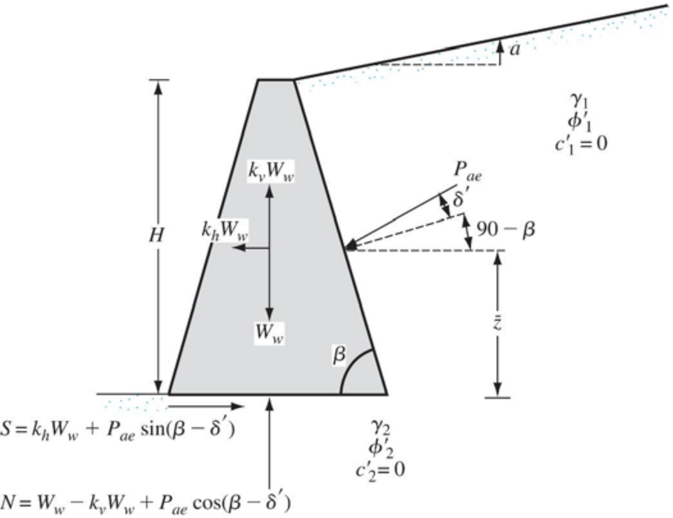


Figure 8.17 Stability of a retaining wall under earthquake forces

Forces acting on the retaining wall

W_w = weight of the wall

P_{ae} = active force with earthquake conditions taken into consideration

$$W_w = \left[\frac{1}{2}\gamma_1 H^2 (1-k_v) K_{ae}\right] C_{IE}$$

$$C_{IE} = \frac{\sin(\beta-\delta') - \cos(\beta-\delta')\tan\phi_2'}{(1-k_v)(\tan\phi_2' - \tan\theta')}$$

$$\theta' = \tan-1\left(\frac{k_k}{1-k_v}\right)$$

1) Determine the tolerable displacement of the wall, Δ

2) Obtain a design value of k_k from

$$k_k = A_a\left(\frac{0.2A_v^2}{A_a\Delta}\right)^{0.25}$$

(A_a and A_v are effective acceleration coefficients and Δ is displacement in inches)

A_a and A_v are given by Applied Technology Coulcil for various regions of United States

3) Assume that $k_v = 0$, and with values of k_k obtained, calculate K_{ae}

4) Use the value of K_{ae} determined in step 3 to obtain the weight of the wall (W_w)

5) Apply a factor of safety to the value of W_w obtained in Step 4.

Practice Problem #1: For the cantilever retaining wall shown in Figure P8.1, the following data is giver:

$$\text{Wall dimensions}: H = 8\text{m};\ x_1 = 0.4\text{m};\ x_2 = 0.6\text{m};\ x_3 = 1.5\text{m};$$

$$x_4 = 3.5\text{m};\ x_5 = 0.96\text{m};\ D = 1.75\text{m};\ \alpha = 10^0$$

$$\textit{Soil}\ \text{properties}: \gamma_1 = 16.8\ \text{kN/m}^3;\ \phi_1' = 32^0;$$

$$\gamma_2 = 17.6\ \text{kN/m}^3;\ \phi_2' = 28^0;\ c_2' = 30 kN/m^2$$

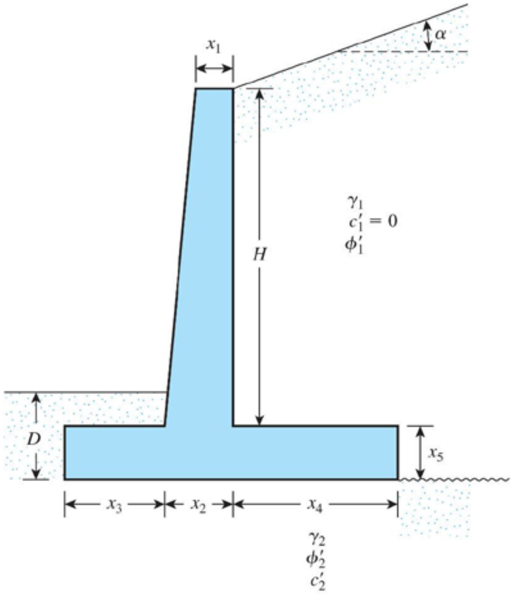


Figure P8.1

Calculate the factor of safety with respect to overturning, sliding, and bearing capacity

Mechanically Stabilized Retaining Walls

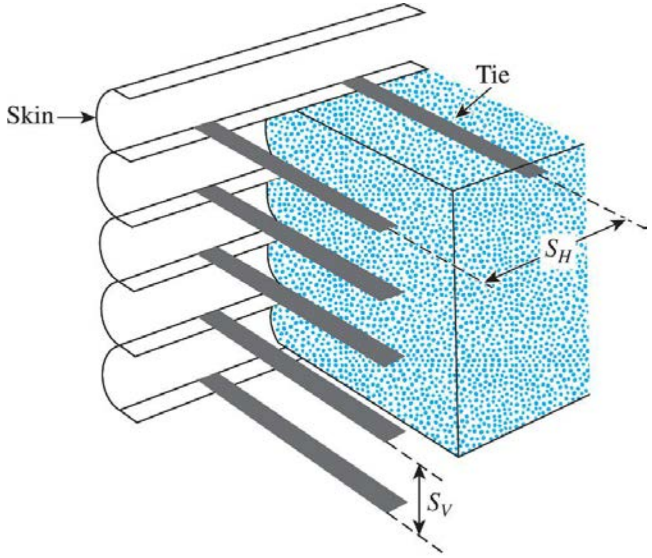


Figure 8.25 Reinforced-earth retaining wall

- Backfill – granular soil
- Reinforcing strips – thin, wide strips placed at regular intervals
- A cover or skin on the front of the wall

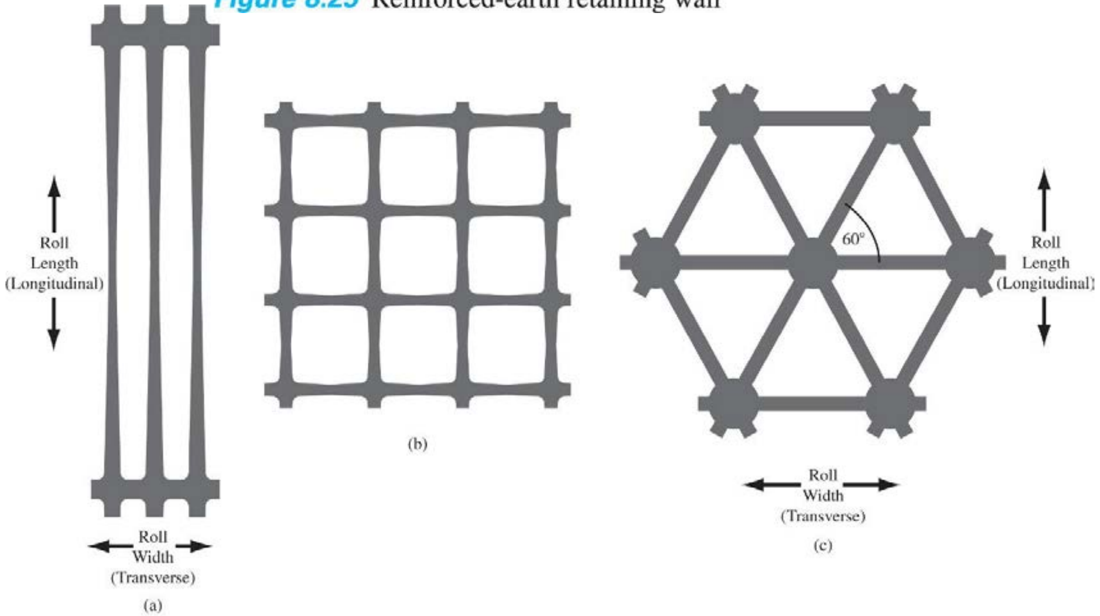


Figure 8.22 Geogrid: (a) uniaxial; (b) biaxial; (c) with triangular apertures (*Courtesy of Tensar International Corporation*)

- **Metal Strips**
- **Nonbiodegradable Fabrics**
- **Geogrids**

Figure 8.26 Reinforced-earth retaining wall (with metallic strip) under construction (*Courtesy of Braja M. Das, Henderson, NV*)

Figure 8.27 Another view of the retaining wall shown in Figure 8.26 (*Courtesy of Braja M. Das, Henderson, NV*)

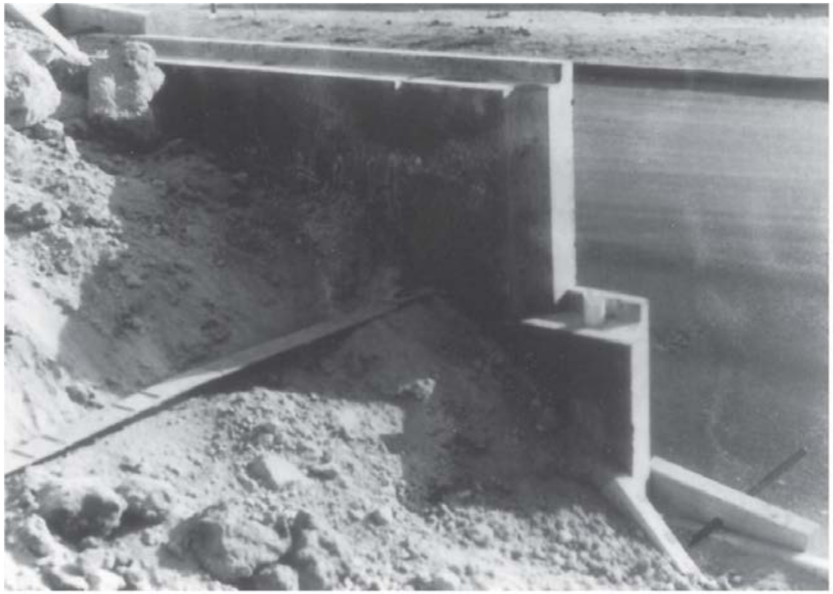


Figure 8.28 Metallic strip attachment to the precast concrete slab used as the skin (*Courtesy of Braja M. Das, Henderson, NV*)

Properties of Geogrids

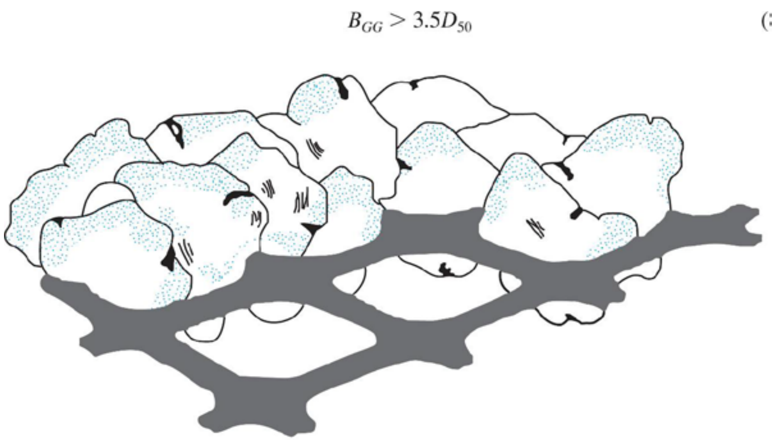


Figure 8.23 Geogrid apertures allowing interlocking with surrounding soil

Table 8.4 Properties of TENSAR Biaxial Geogrids

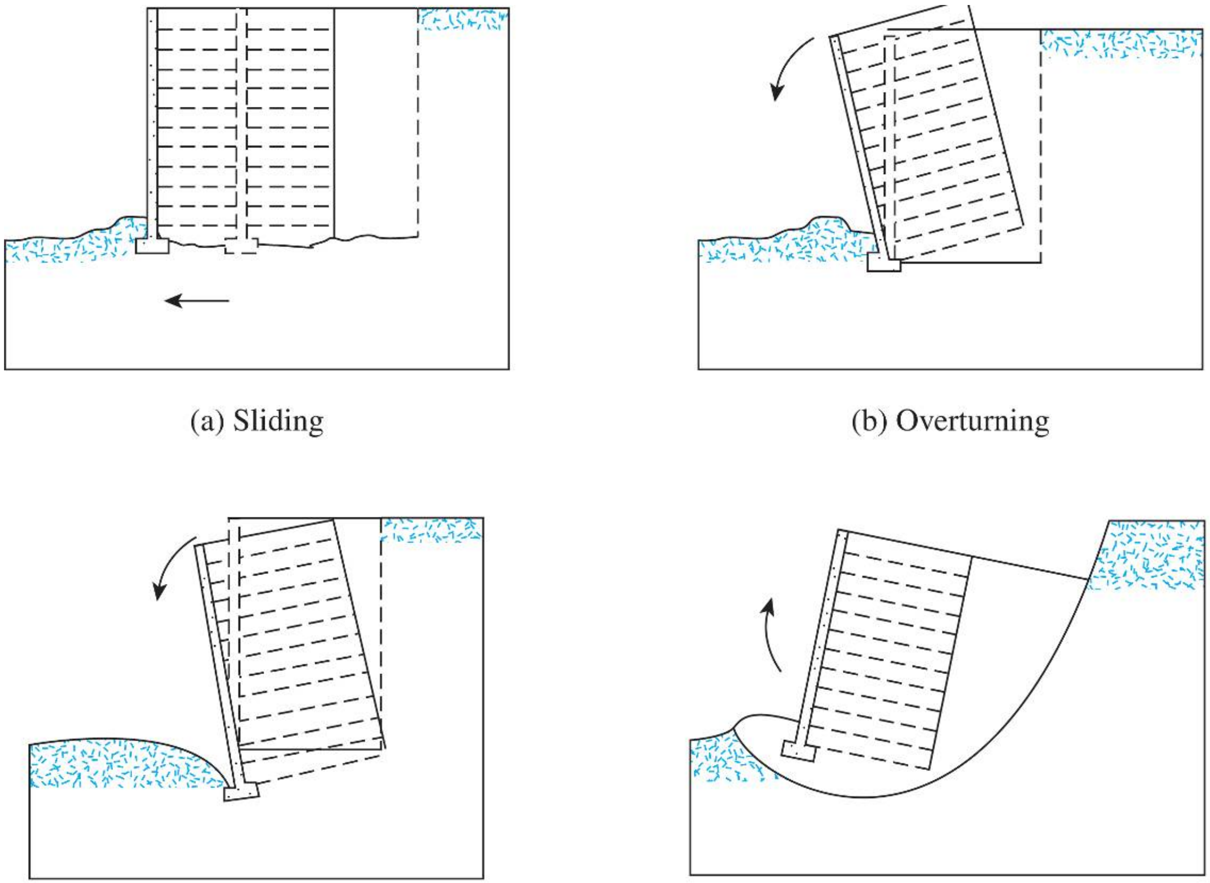
Property	Geogrid		
	BX1000	**BX1100**	**BX1200**
Aperture size			
Machine direction	25 mm (1 in.) (nominal)	25 mm (1 in.) (nominal)	25 mm (1 in.) (nominal)
Cross-machine direction	33 mm (1.3 in.) (nominal)	33 mm (1.3 in.) (nominal)	33 mm (1.3 in.) (nominal)
Open area	70% (minimum)	74% (nominal)	77% (nominal)
Junction			
Thickness	2.3 mm (0.09 in.) (nominal)	2.8 mm (0.11 in.) (nominal)	4.1 mm (0.16 in.) (nominal)
Tensile modulus			
Machine direction	182 kN/m (12,500 lb/ft) (minimum)	204 kN/m (14,000 lb/ft) (minimum)	270 kN/m (18,500 lb/ft) (minimum)
Cross-machine direction	182 kN/m (12,500 lb/ft) (minimum)	292 kN/m (20,000 lb/ft) (minimum)	438 kN/m (30,000 lb/ft) (minimum)
Material			
Polypropylene	97% (minimum)	99% (nominal)	99% (nominal)
Carbon black	2% (minimum)	1% (nominal)	1% (nominal)

Table 8.5 Properties of TENSAR Geogrids with Triangular Apertures

Geogrid	Property	Longitudinal	Diagonal	Transverse	General
TX 160	Rib pitch, mm (in.)	40 (1.60)	40 (1.60)	—	
	Mid-rib depth, mm (in.)	—	1.8 (0.07)	1.5 (0.06)	
	Mid-rib width, mm (in.)	—	1.1 (0.04)	1.3 (0.05)	
	Nodal thickness, mm (in.)				3.1 (0.12)
	Radial stiffness at low strain, kN/m @ 0.5% strain (lb/ft @ 0.5% strain)				430 (29,500)
TX 170	Rib pitch, mm (in.)	40 (1.60)	40 (1.60)	—	
	Mid-rib depth, mm (in.)	—	2.3 (0.09)	1.8 (0.07)	
	Mid-rib width, mm (in.)	—	1.2 (0.05)	1.3 (0.05)	
	Nodal thickness, mm (in.)				4.1 (0.16)
	Radial stiffness at low strain, kN/m @ 0.5% strain (lb/ft @ 0.5% strain)				475 (32,500)

General Design Considerations

- Satisfying *internal stability* requirements
- Checking the *external stability* of the wall



(a) Sliding

(b) Overturning

(c) Bearing capacity

(d) Deep-seated stability

Figure 8.24 External stability checks (After Transportation Research Board, 1995) (From Transportation Research Circular 444: Mechanically Stabilized Earth Walls. Transportation Research Board, National Research Council, Washington, D.C., 1995, Figure 3, p. 7. Reproduced with permission of the Transportation Research Board.)

Retaining Walls with Metallic Strip Reinforcement

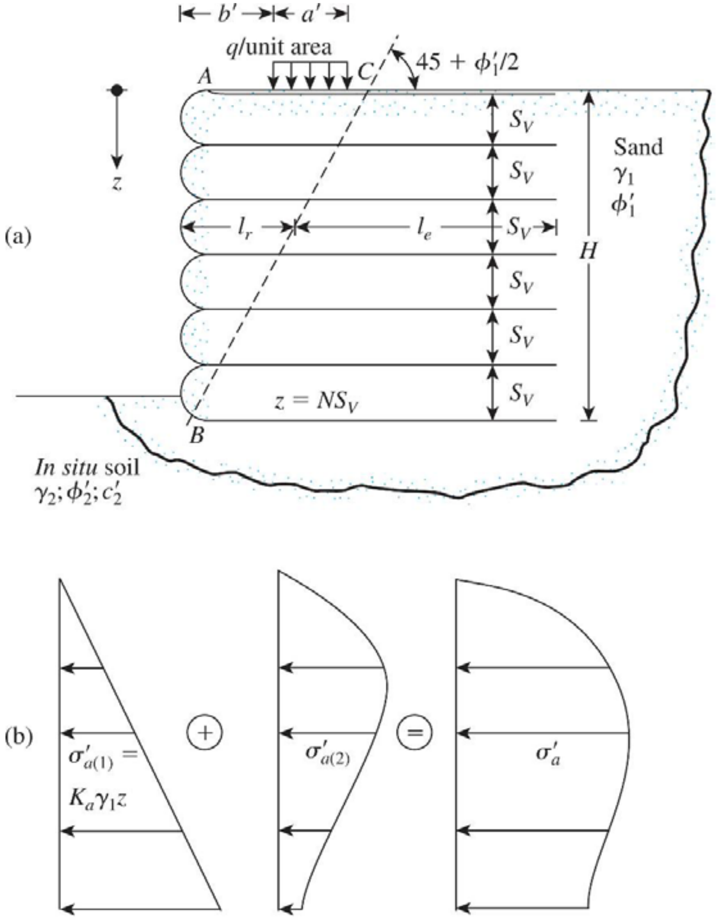


Figure 8.29 Analysis of a reinforced-earth retaining wall

Rankine active pressure theory:

$$\sigma'_a = \sigma'_0 K_a - 2c'\sqrt{K_a}$$

$$K_a = \tan^2\left(45 - \frac{\phi'_1}{2}\right)$$

$$\sigma'_{a(1)} = \gamma_1 z K_a$$

$$\sigma'_0 = \sigma'_{0(1)} + \sigma'_{0(2)} = \gamma_1 z \ \text{(due to soil)} + \text{due to surcharge}$$

According to Laba and Kennedy (1986) using 2 : 1 method of stress distribution

$$\sigma'_{0(2)} = \frac{qa'}{a' + z} \quad (\text{for } z \le 2b')$$

and

$$\sigma'_{0(2)} = \frac{qa'}{a' + \frac{z}{2} + b'} \quad (\text{for } z > 2b')$$

Retaining Walls with Metallic Strip Reinforcement

$$\sigma'_a = \sigma'_{a(1)} + \sigma'_{a(2)} = K_a \gamma_1 z + \sigma'_{a(2)}$$

Laba and Kennedy (1986):

$$\sigma'_{a(2)} = M\left[\frac{2q}{\pi}(\beta - \sin\beta\cos 2\alpha)\right] \qquad (\beta \text{ in radians})$$

$$\text{where, } M = 1.4 - \frac{0.4b'}{0.14H} \geq 1$$

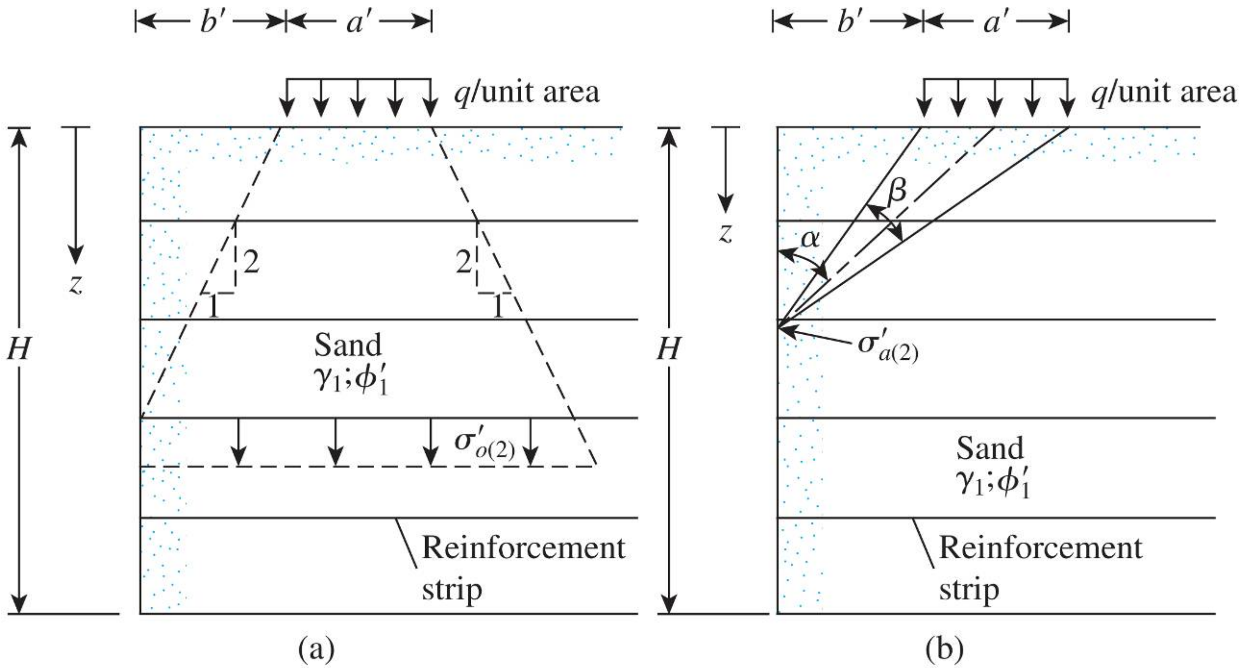


Figure 8.30 (a) Notation for the relationship of $\sigma'_{o(2)}$ in Eqs. (8.33) and (8.34); (b) notation for the relationship of $\sigma'_{a(2)}$ in Eqs. (8.36) and (8.37)

Retaining Walls with Metallic Strip Reinforcement

Tie Force

Tie force per unit length of the wall developed at any depth, z, is:

T = active earth pressure at depth "z" X area of the wall to be supported by the tie

$$= \sigma_a^{'} \text{ X } (S_V S_H)$$

Factor of Safety against Tie failure – Tie Break

$$FS_{(B)} = \frac{\text{yield or breaking strength of each tie}}{\text{maximum force in any tie}} = \frac{w\,t\,f_y}{\sigma_a^{'}\,S_V S_H}$$

w = width of each tie

t = thickness of each tie

f_y = yield or breaking strength of the tie material

Recommended FS = 2.5 to 3

Factor of Safety against Tie failure – Pullout

$$FS_{(P)} = \frac{\text{maximum friction force, } F_R}{\text{maximum force in any tie}} = \frac{2 l_e \text{ w } \sigma_0^{'} \tan\phi_\mu^{'}}{\sigma_a^{'} S_V S_H}$$

le = effective length

$\sigma_0^{'}$ = effective vertical pressure at a depth z

$\phi_\mu^{'}$ = soil - tie friction angle

Total Length of Tie

Total length of tie, $L = l_r + l_e$ = length within the Rankine failure zone + effective length

$$l_e = \frac{FS_{(P)}\,\sigma_a^{'}\,S_V S_H}{2\text{ w }\sigma_0^{'}\tan\phi_\mu^{'}} \qquad l_r = \frac{(H - z)}{\tan\left(45 + \frac{\phi_1^{'}}{2}\right)}$$

Design Procedure using Metallic Strip Reinforcement

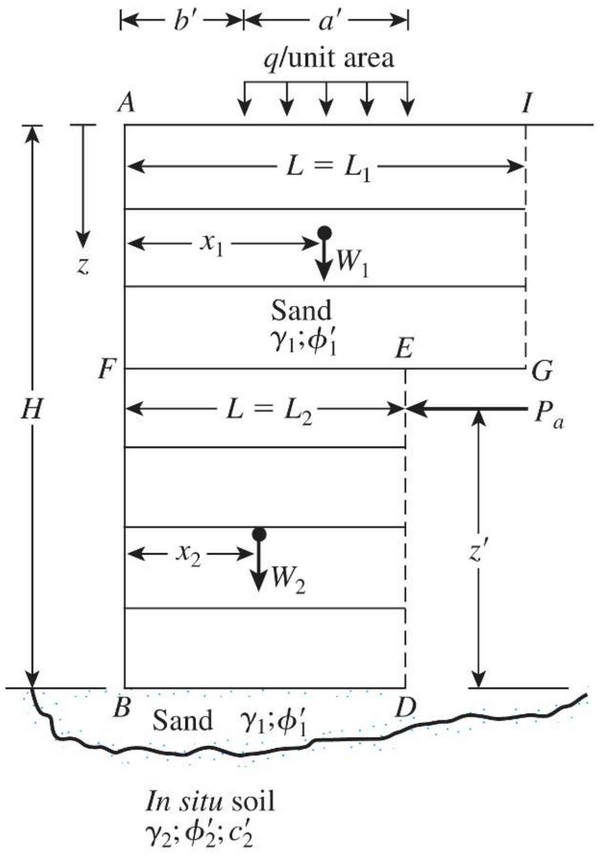


Figure 8.31 Stability check for the retaining wall

General Design Considerations

1) Height of the wall, H

2) Unit weight of the granular backfill material, γ_1

3) Angle of friction of the granular backfill material, $\phi_1^{'}$

4) Soil - tie friction angle, $\phi_\mu^{'}$

5) Required Factor of safety, $FS_{(B)}$ and $FS_{(P)}$

Design Procedure using Metallic Strip Reinforcement

Internal Stability

1) Assume values of horizontal and vertical tie spacing, S_H and S_V. Also assume the width of reinforcing strip, w.

2) Calculate lateral earth pressure, σ_a'

3) Calculate the tie forces at various levels

4) For the known values of $FS_{(B)}$, calculate the thickness of ties, t, required to resist the tie breakout:

$$T = \sigma_a' S_V S_H = \frac{w\,t\,f_y}{FS_{(B)}} \qquad \Rightarrow t = \frac{(\sigma_a' S_V S_H)(FS_{(B)})}{w\,f_y}$$

The convention is to keep the magnitude of t the same at all levels, so σ_a' should be equal to $\sigma_{a(max)}'$

5) For the known values of ϕ_μ', determine the length L of the ties at various levels

6) The magnitudes of S_V, S_H, t, w, and L may be changed to obtain the most economical design

Design Procedure using Metallic Strip Reinforcement

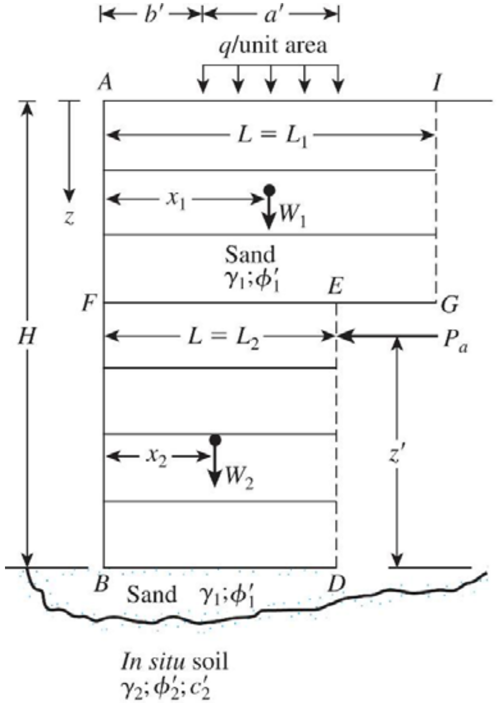


Figure 8.31 Stability check for the retaining wall

External Stability

1) Check for overturning

$$M_0 = P_a z' \qquad \text{where, } P_a = \text{active force} = \int_0^H \sigma_a' dz$$

$$M_R = W_1 x_1 + W_2 x_2 + ... + qa'\left(b' + \frac{a'}{2}\right)$$

$$FS_{(OVERTURNING)} = \frac{M_R}{M_0} = \frac{W_1 x_1 + W_2 x_2 + ... + qa'\left(b' + \frac{a'}{2}\right)}{\left(\int_0^H \sigma_a' dz\right) z'}$$

2) check for sliding

$$FS_{(SLIDING)} = \frac{(W_1 + W_2 + ... + qa')\left[\tan\left(k\phi_1'\right)\right]}{P_a} \qquad \text{where } k \approx \frac{2}{3}$$

3) check for ultimate bearing capacity

$$q_u = c_2' N_c + \frac{1}{2}\gamma_2 L_2 N_\gamma \qquad \text{(bearing capacity factors corresponds to soil friction angle } \phi_2'\text{)}$$

vertical stress at z = H is : $\sigma_{0(H)}' = \gamma_1 H + \sigma_{0(2)}'$

$$FS_{(BEARING\ CAPACITY)} = \frac{q_{ult}}{\sigma_{0(H)}'}$$

Design Procedure using Geotextile Reinforcement

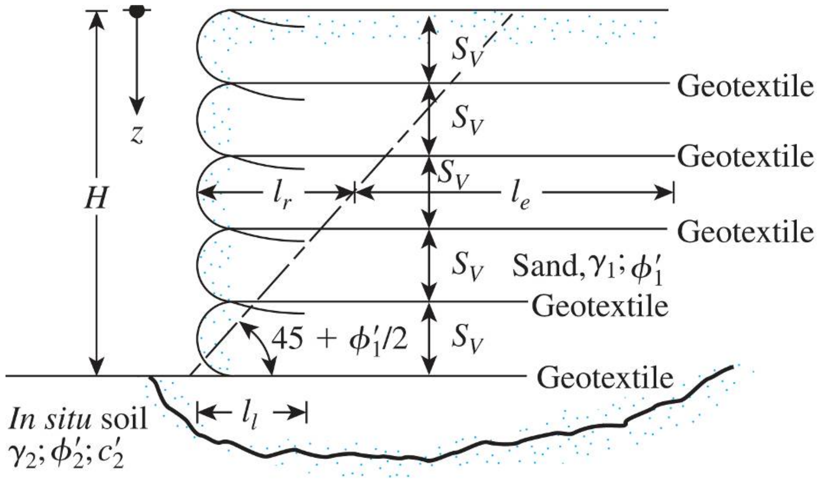


Figure 8.33 Retaini
geotextile reinforcem

Figure 8.34 Construction of a geotextile-reinforced retaining wall (*Courtesy of Jonathan T. H. Wu, University of Colorado at Denver, Denver, Colorado*)

Internal Stability

1) Determine active pressure distribution, $\sigma_a' = K_a \sigma_0' = K_a \gamma_1 z$

$$K_a = \tan^2\left(45 - \phi_1'/2\right) \qquad \gamma 1 = \text{unit weight of granular backfill} \qquad \phi_1' = \text{friction angle of granular backfill}$$

2) Allowable tensile strength for retaining wall construction (Koerner, 2005):

$$T_{all} = \frac{\text{Tult}}{RF_{id} \text{ x } RF_{cr} \text{ x } RF_{cbd}}$$

where, Tall = ultimate tensile strength

RF_{id} = reduction factor for installation damage (1.1 to 2)

RF_{cr} = reduction factor for creep (2 to 4)

RF_{cbd} = reduction factor for chemical and biological degradation (1 to 1.5)

Design Procedure using Geotextile Reinforcement

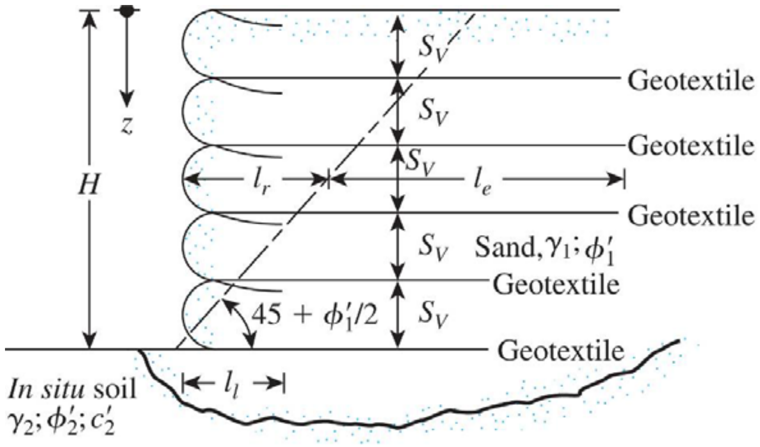


Figure 8.33 Retaining wall with geotextile reinforcement

Internal Stability

3) Vertical spacing of the layers at any depth z:

$$S_V = \frac{T_{all}}{\sigma'_a FS_{(B)}} = \frac{T_{all}}{(\gamma_1 z K_a) FS_{(B)}}$$

[$FS_{(B)}$ values typically 1.3 to 1.5]

4) Total length of each layer of geotextile, $L = l_r + l_e$

where, $l_r = \dfrac{(H - z)}{\tan\left(45 + \dfrac{\phi'_1}{2}\right)}$ and $l_e = \dfrac{S_V \sigma'_a \left[FS_{(P)}\right]}{2\sigma'_0 \tan\phi'_F}$ where, $\sigma'_a = \gamma_1 z K_a$; $\sigma'_0 = \gamma_1 z$; $FS_{(P)} = 1.3$ to 1.5; $\phi'_F \approx \dfrac{2}{3}\phi'_1$

5) Lap length, $l_l = \dfrac{S_V \sigma'_a FS_{(P)}}{4\sigma'_0 \tan\phi'_F}$

External Stability

Check for (a) overturning, (b) sliding, and (c) bearing capacity

Design Procedure using Geogrid Reinforcement

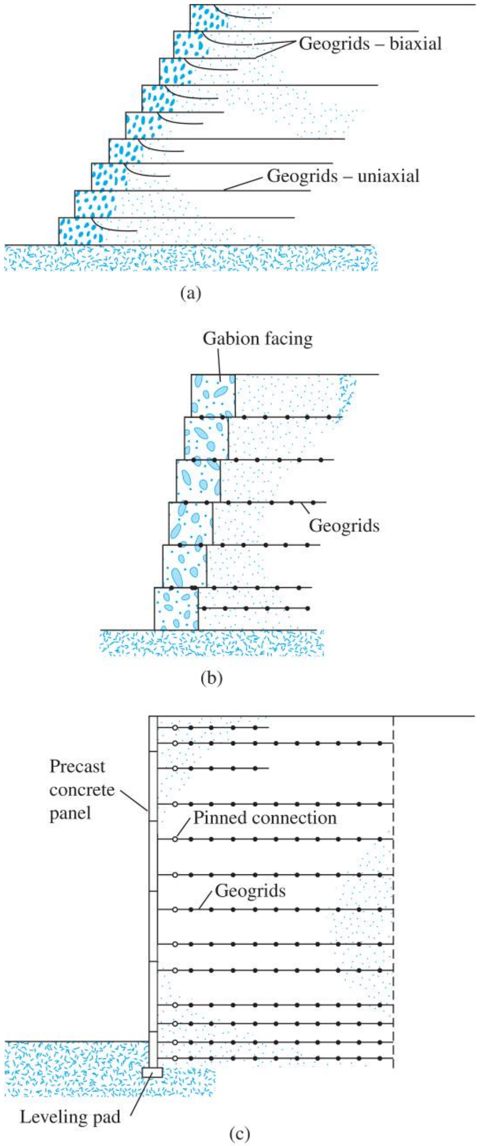


Figure 8.38 Typical schematic diagrams of retaining walls with geogrid reinforcement: (a) geogrid wraparound wall; (b) wall with gabion facing; (c) concrete panel-faced wall (After The Tensar Corporation, 1986)

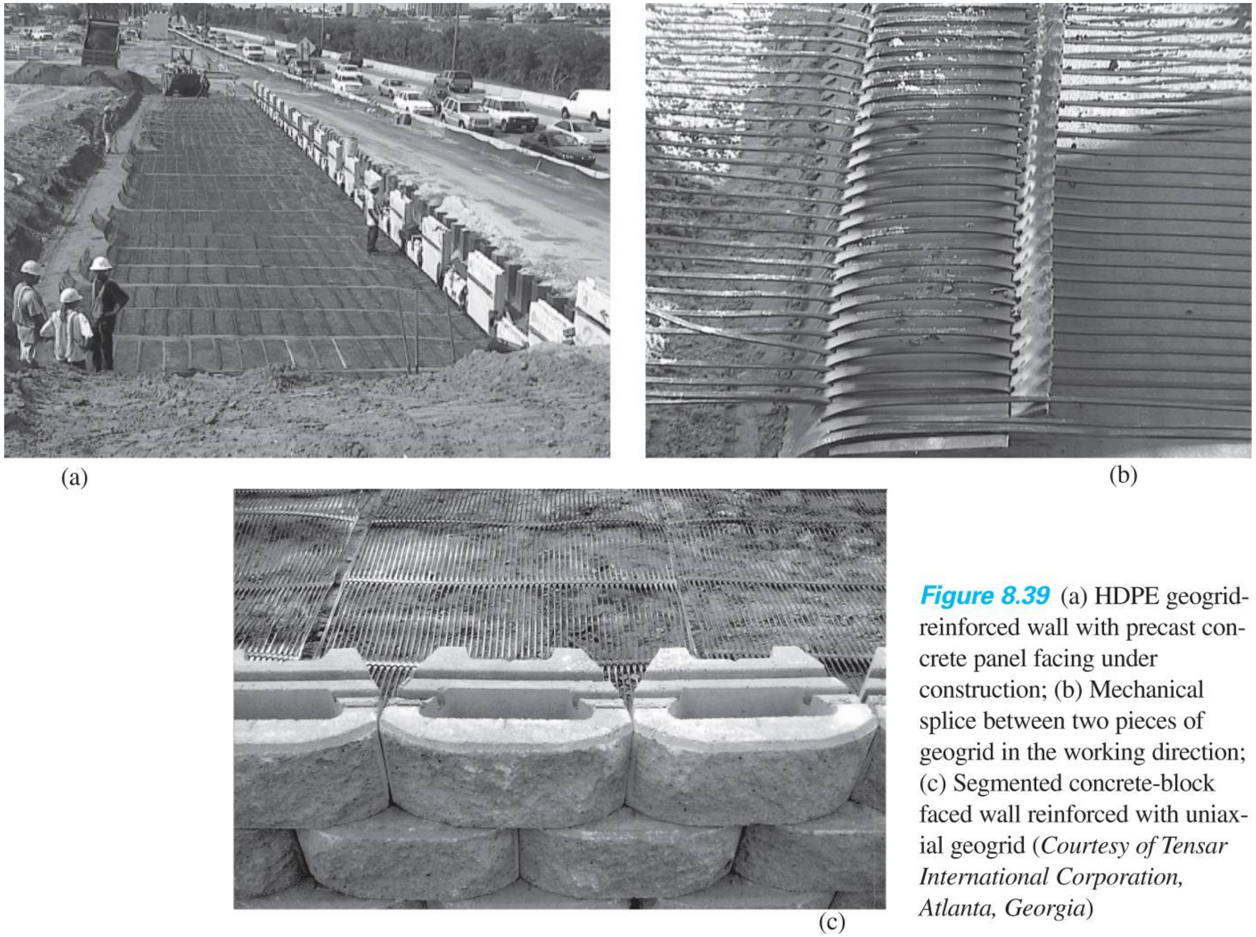


Figure 8.39 (a) HDPE geogrid-reinforced wall with precast concrete panel facing under construction; (b) Mechanical splice between two pieces of geogrid in the working direction; (c) Segmented concrete-block faced wall reinforced with uniaxial geogrid (*Courtesy of Tensar International Corporation, Atlanta, Georgia*)

Design Procedure using Geogrid Reinforcement

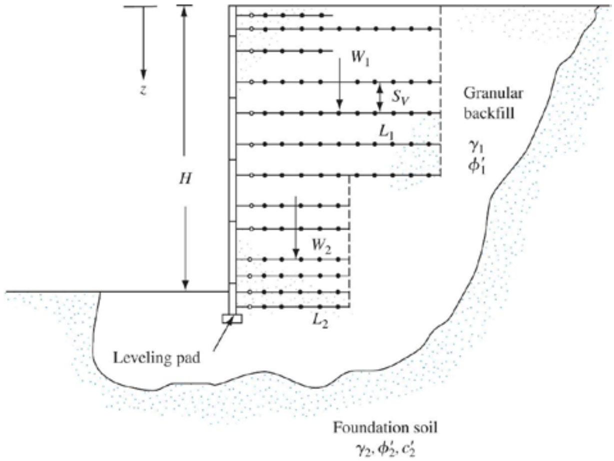


Figure 8.41 Design of geogrid-reinforced retaining wall

Internal Stability

1) Determine active pressure at any depth, z, $\sigma_a' = K_a \gamma_1 z$

$$K_a = \tan^2\left(45 - \phi_1'/2\right)$$

γ_1 = unit weight of granular backfill ϕ_1' = friction angle of granular backfill

2) Select a geogrid with allowable tensile strength for retaining wall construction (Koerner, 2005):

$$T_{all} = \frac{Tult}{RF_{id} \text{ x } RF_{cr} \text{ x } RF_{cbd}}$$

where, Tall = ultimate tensile strength

RF_{id} = reduction factor for installation damage (1.1 to 1.4)

RF_{cr} = reduction factor for creep (2 to 3)

RF_{cbd} = reduction factor for chemical and biological degradation (1.1 to 1.5)

Design Procedure using Geogrid Reinforcement

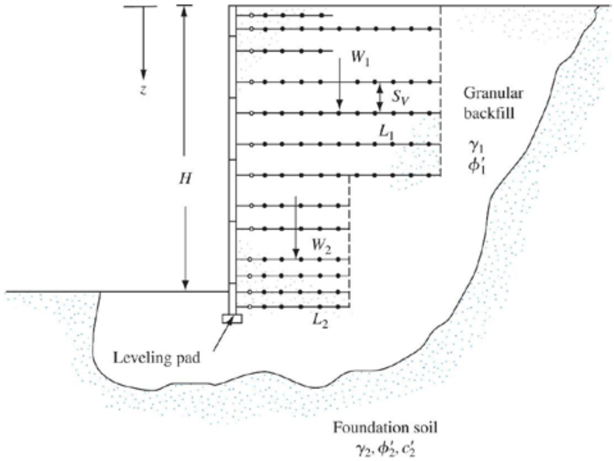


Figure 8.41 Design of geogrid-reinforced retaining wall

Internal Stability

3) Vertical spacing of the layers at any depth z :

$$S_V = \frac{T_{all} C_r}{\sigma'_a FS_{(B)}} = \qquad \text{where, } C_r = \text{coverage ratio}$$

4) Total length of each layer of geotextile, $L = l_r + l_e$

$$\text{where, } l_r = \frac{(H - z)}{\tan\left(45 + \frac{\phi'_1}{2}\right)} \qquad \text{and } l_e = \frac{S_V K_a \left[FS_{(P)}\right]}{2 C_r C_i \tan\phi'_1}$$

Type of material	Ci=interaction coefficient
Gravel, Sandy gravel	0.75 – 0.8
Well graded sand, gravelly sand	0.70 – 0.75
Fine Sand, Silty sand	0.55 – 0.60

External Stability

Check for (a) overturning, (b) sliding, and (c) bearing capacity

Practice Problem : A reinforced earth retaining wall (Figure 8.29) is to be 10 m high. Given :

Backfill : unit weight $(\gamma_1) = 16\ \text{kN/m}^3$, soil friction angle $(\phi_1' = 34^0)$

Reinforcement : vertical spacing $(S_V) = 1\text{m}$, horizontal spacing $(S_H) = 1.25\ \text{m}$, width of reinforcement $(w) = 120\ \text{mm}$

$$f_y = 260\ \text{MN/m2}, \phi_\mu = 250, FS_{(P)} = 3, FS_{(B)} = 3$$

Determine (a) required thickness of ties, and (b) required maximum length of ties

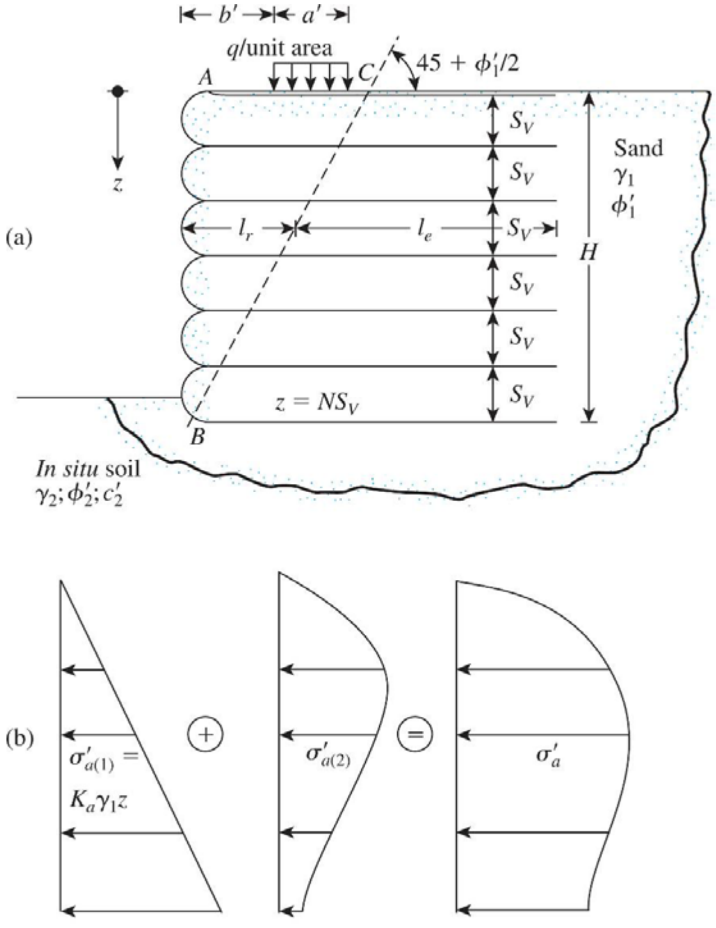


Figure 8.29 Analysis of a reinforced-earth retaining wall