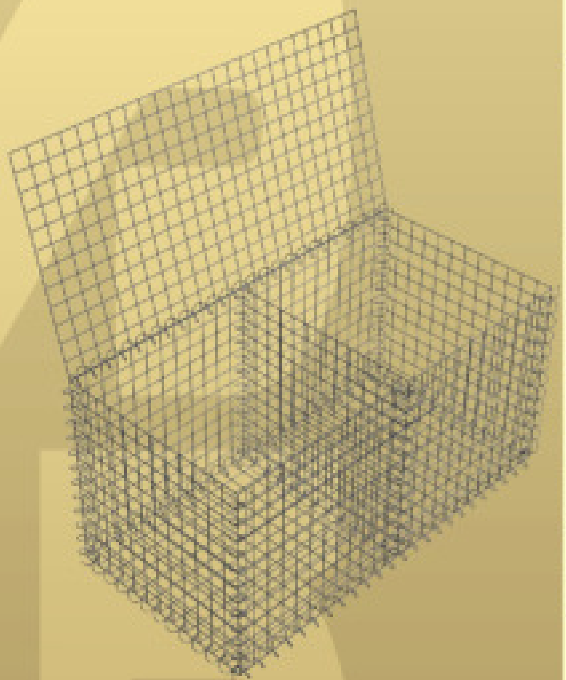
GABION WALLS DESIGN



Gabion Gravity Wall

Mechanically Stabilized Earth (MSE)
Gabion Wall
[Reinforced Soil Wall]

Gabion Walls Installation Guide

Foundation

Foundation Requirements, which must be established by the engineer, will vary with site conditions, height of gabion structure, etc. Generally, the top layer of soil is stripped until a layer of the required bearing soil strength is reached. In some cases, the foundation may consist of suitable fill material compacted to a minimum of 95 percent of Proctor density.

Assembly

To assemble each gabion, fold out the four sides and the ends; fold adjacent sides up and join edges with spiral binders; insert diaphragms at 3-foot centers and fasten them to the base panel with spiral binders. Place the empty gabions in the designed pattern on the foundation. When the entire first course is in position, permanently secure adjacent gabions by installing vertical spiral binders running full height at all corners. Similarly secure both edges of all diaphragms with spiral binders. Crimp ends of all spiral binders. Corner stiffeners are then installed diagonally across the corners on 1-foot centers (not used for gabions less than 3-feet high). The stiffeners must be hooked over crossing wires and crimped closed at both ends. Final gabion alignment must be checked before filling begins.

Filling

Fill material must be as specified by the engineer. It must have suitable compressive strength and durability to resist the loading, as well as the effects of water and weathering. Usually, 3 to 8-inch clean, hard stone is specified. A well graded stone-fill increases density. Place the stone in 12-inch lifts with power equipment, but distribute evenly by hand to minimize voids and ensure a pleasing appearance along the exposed faces. Keep baskets square and diaphragms straight. The fill in adjoining cells should not vary in height by more than 1-foot. Level the final stone layer allowing the diaphragms' tops to be visible. Lower lids and bind along all gabions' edges and at diaphragms' tops with spiral binders. Alternatively, tie or lacing wire can be utilized for this operation.

Successive Courses

Place the next course of assembled empty gabions on top of the filled course. Stagger the joints so that the vertical connections are offset from one another. Bind the empty baskets to the filled ones below the spirals or tie wire at all external bottom edges. Bind vertical edges together with spiral binders and continue with the same steps as for the first layer. Successive courses are placed in like manner until the structure is complete.

Gabion Walls Design Guide

Gravity Wall Design

Gabion Walls are generally analyzed as gravity retaining walls, that is, walls which use their own weight to resist the lateral earth pressures. The use of horizontal layers of welded wire mesh (Anchor Mesh) as horizontal tie-backs for soil reinforcement (MSE Walls) is discussed separately. This material is presented for the use of a qualified engineer familiar with traditional procedures for retaining wall design.

Gabion walls may be stepped on either the front or the back (soil side) face as illustrated in Figure 1. The design of both types is based on the same principles.

Design begins with the selection of trail dimensions for a typical vertical cross section through the wall. Four main steps must then be followed:

1. Determine the forces acting on the wall.
2. Check that resisting moment exceeds the overturning moment by a suitable safety factor.
3. Check that sliding resistance exceeds the active horizontal force by a suitable safety factor.
4. Check that the resultant force falls within the middle third of the wall's base, and that the maximum bearing pressure is within the allowable limit.

These steps are repeated iteratively until a suitable design that meets all criteria is achieved. The wall stability must be checked at the base and at each course. Pertinent equations are given below, and an application is illustrated in Example 1.

Mechanically Stabilized Earth (MSE) Walls Soil Reinforcement

When required, flat layers of welded wire mesh (Anchor Mesh) are specified as soil reinforcement to secure the gabion wall into the backfill. In such cases, the Anchor Mesh must be joined securely to the gabion wall facing with spirals or tie wire at the specified elevations as layers of backfill are placed and compacted.

Forces Acting on the Wall

As shown in Figure 1, the main forces acting on gabion walls are the vertical forces from the weight of the gabions and the lateral earth pressure acting on the back face. These forces are used herein to illustrate the main design principles. If other forces are encountered, such as vehicular loads or seismic loads, they must also be included in the analysis.

The weight of a unit length (one foot) of wall is simply the product of the wall cross section and the density of the gabion fill. The latter value may be conservatively taken as 100 lb/ft^3 for typical material (W_g).

The lateral earth pressure is usually calculated by the Coulomb equation. Although based on granular material, it is conservative for cohesive material. According to Coulomb theory, the total active force of the triangular pressure distribution acting on the wall is:

$$P_a = K_a w_s H^2 / 2$$

Equation 1

Where w_s is the soil density, H is the wall height, and K_a is the coefficient of active soil pressure. The soil density is often taken as 120 lb/ft^3 where a specific value is not available.

If a uniformly distributed surcharge pressure (q) is present on top of the backfill surface, it may be treated as an equivalent layer of soil that creates a uniform pressure over the entire height of the wall. Equation 1 is modified to:

$$P_a = K_a (w_s H^2 / 2 + qH)$$

Equation 1A

The pressure coefficient is K_a is given by:

$$K_a = \frac{\cos^2(\phi - \beta)}{\cos^2\beta \cos(\delta + \beta)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \alpha)}{\cos(\delta + \beta)\cos(\alpha - \beta)}}\right]^2}$$

Equation 2

Where:

α = slope angle of backfill surface

β = acute angle of back face slope with vertical (-value where as in Fig. 1A; + value when as in Fig. 1B)

δ = angle of wall friction

ϕ = angle of internal friction of soil

P_a is inclined to a line normal to the slope of the back face by the angle δ. However, because the effect of wall friction is small, δ is usually taken as zero. Typical values of ϕ for various soils are given in Table I. Values of K_a for various combinations of ß, δ, and α are given in Table II.

The horizontal component of P_a is:

$$P_h = P_a \cos\beta$$

Equation 3

The vertical component of P_a is usually neglected in design because it reduces the overturning moment and increases the sliding resistance.

Overturning Moment Check

The active soil pressure forces tend to overturn the wall, and this must be properly balanced by the resisting moment developed from the weight of the wall and other forces. Using basic principles of statics, moments are taken about the toe of the wall to check overturning.

This check may be expressed as

$$M_r \geq SF_o M_o$$

Equation 4

Where M_r is the resisting moment, M_o is the overturning moment, and SF_o is the safety factor against overturning (typically 2.0). Each moment is obtained by summing the products of each appropriate force times its perpendicular distance the toe of the wall.

Neglecting wall friction, the active earth force acts normal to the slope of the back face at a distance H/3 above the base. When a surcharge is present, the distance of the total active force above the toe becomes

$$d_a = \frac{H(H + 3q / w_s)}{3(H + 2q / w_s)} + B \sin\beta$$

Equation 5

The overturning moment is

$$M_o = d_a P_h$$

Equation 6

The weight of the gabion wall (W_g) acts vertically through the centroid of its cross section area. The horizontal distance to this point from the toe of the wall (d_g) may be obtained from the statical moment of wall areas. That is, moments of areas about the toe are taken, then divided by the total area, as shown in Example 1.

The resisting moment is the sum of the products of vertical forces or weights per unit length (W) and their distance (d) from the toe of the wall:

$$M_r = \sum dW$$

Equation 7

For the simple gravity wall, the resisting moment is provided entirely by the weight of the wall and

$$M_r = d_g W_g$$

Equation 7A

Sliding Resistance Check

The tendency of the active earth pressure to cause the wall to slide horizontally must be opposed by the frictional resistance at the base of the wall. This may be expressed as

$$\mu W_v \geq SF_s P_h$$

Equation 8

Where μ is the coefficient of the sliding friction (tan of angle of friction of soil), W_v is the sum of the vertical forces (W_g in this case), and SF_s is the safety factor against sliding (typically 1.5).

Check Bearing Pressure

First check to determine if the resultant vertical force lies within the middle third of the base. If B denotes the width of the base, the eccentricity, e, of the vertical force from the midwidth of the base is

$$e = B/2 - (M_r - M_o)/W_v$$

Equation 9

For the resultant force to lie in the middle third:

$$-B/6 \leq e \leq B/6$$

Equation 10

The maximum pressure under the base, P, is then

$$P = (W_v / B)(1 + 6e/B)$$

Equation 11

The maximum pressure must not exceed the allowable soil bearing pressure, P_b:

$$P \leq P_b$$

Equation 12

The safety factor must be included in P_b.

Example 1:

Given Data (Refer to Cross Section, page 5)

Wall Height………………………	H	=	9 ft
Surcharge…………………………	q	=	300 psf
Backfill slope angle………………	α	=	0 deg
Back Face slope angle……………	β	=	-6 deg
Soil friction angle…………………	ϕ	=	35 deg
Soil density………………………..	w_s	=	120 pcf
Gabion fill density………………..	w_g	=	100 pcf
Soil bearing pressure……………..	P_b	=	4000 psf

Determine if safety factors are within limits:

Pressure coefficient from Equation 2 is K_a=0.23

Active earth force, P_a, from Equation 1A is

$$\begin{aligned} P_a &= 0.23(120x9^2 + 300x9) \\ &= 1{,}739\, lb/ft \end{aligned}$$

Horizontal component from Equation 3 is

$$\begin{aligned} P_h &= 1739 \cos 6 \\ &= 1{,}730\, lb/ft \end{aligned}$$

Vertical distance to P_h from Equation 5 is

$$\begin{aligned} d_a &= \frac{9(9 + 3 \times 300/120)}{3(9 + 2 \times 300/120)} + 6\sin(-6) \\ &= 2.91\, ft \end{aligned}$$

Overturning moment from Equation 6 is

$$\begin{aligned} M_o &= 2.91 \times 1730 \\ &= 5034\, ft - lb/ft \end{aligned}$$

Weight of gabions for a 1-ft unit length is

$$\begin{aligned} W_g &= (18 + 13.5 + 9)100 \\ &= 40.5 \times 100 \\ &= 4050\, lb/ft \end{aligned}$$

Horizontal distance to W_g is

$$\begin{aligned} dg &= \Sigma Ax / \Sigma A \\ &= \begin{bmatrix} 18(3\cos 6 + 1.5\sin 6) + 13.5(3.75\cos 6 \\ + 4.5\sin 6) + 9(4.5\cos 6 + 7.5\sin 6) \end{bmatrix} / 40.5 \\ &= 3.96\, ft \end{aligned}$$

Resisting moment from Equation 7 is

$$M_r = 3.96x4050$$
$$= 16{,}038\ ft - lb/ft$$

Safety factor against overturning from Equation 4 is

$$SF_O = M_r / M_O$$
$$= 16.038/5034$$
$$= 3.19 > 2.00$$

OK

Safety factor against sliding from Equation 8 is

$$SF_S = \mu W_g / P_h$$
$$= \tan 35x4050/1730$$
$$= 1.64 > 1.50$$

OK

Reaction eccentricity from Equation 9 is

$$e = 6/2 - (16038 - 5034)/4050$$
$$= 0.283\ ft$$

Limit of eccentricity from Equation 10 is

$$-1 \le e \le 1\,ft$$

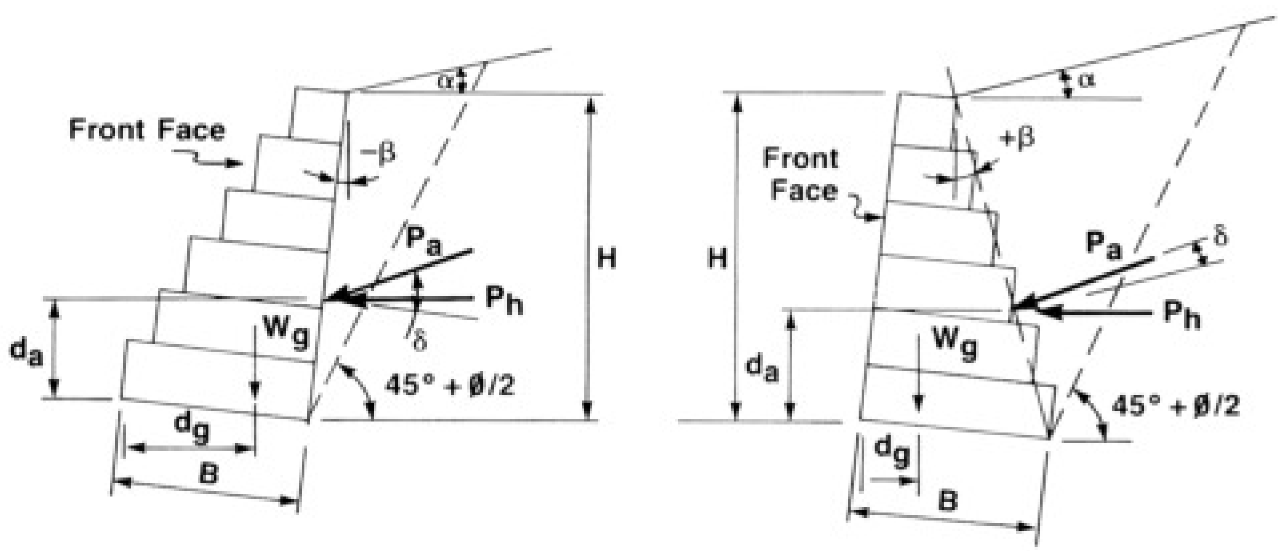
OK

Maximum base pressure from Equation 11 is

$$p = (4050/6)(1 + 6x.283/6)$$
$$= 866\ psf < 4000\ psf$$

OK

All safety factors are within limits. Stability checks at intermediate levels in the walls show similar results.

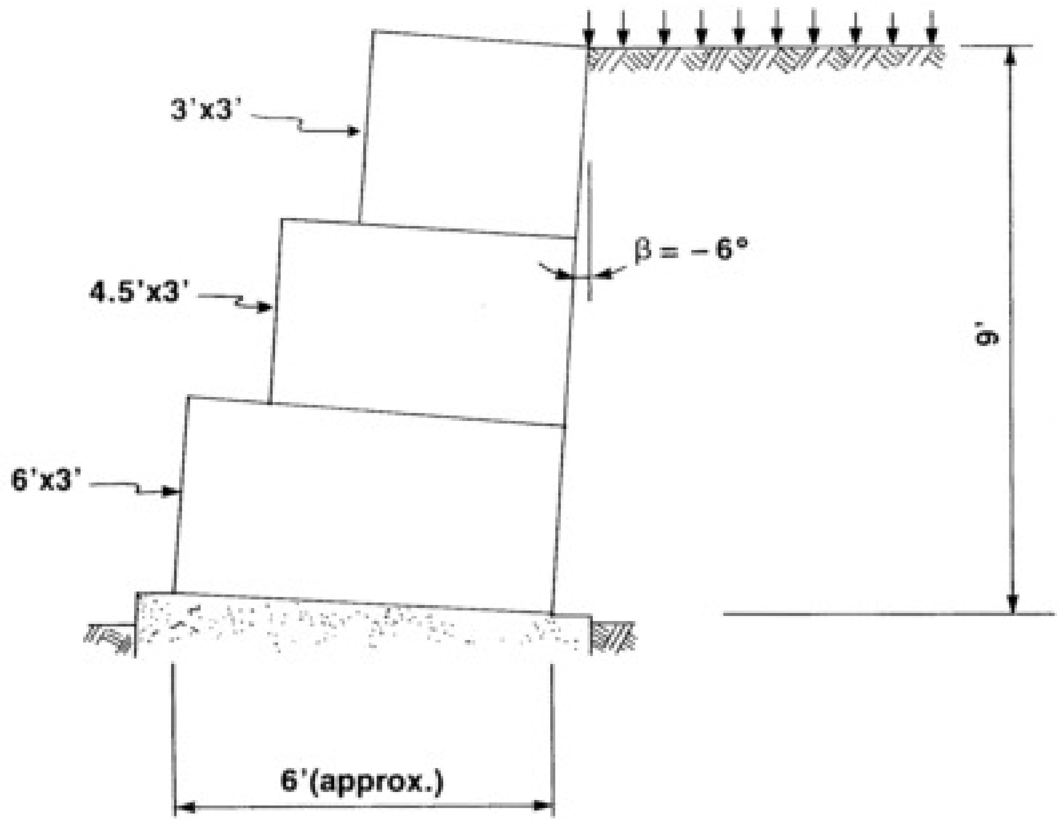


A. Stepped Front Face

B. Stepped Back Face

Gravity Wall Design

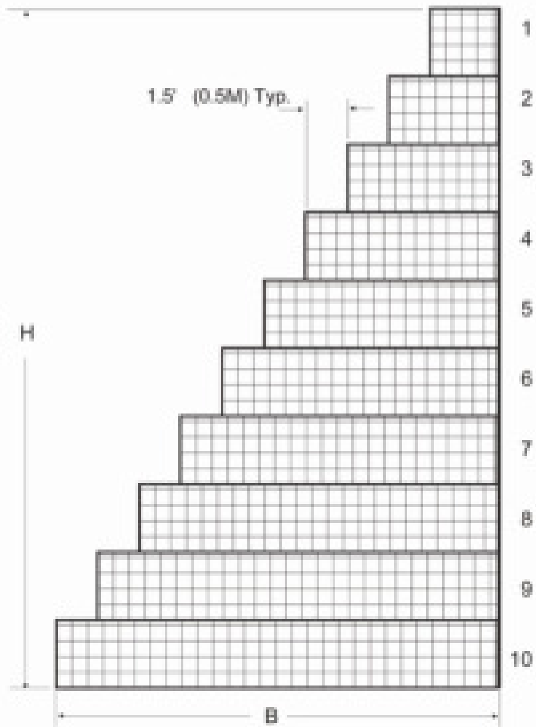
Figure 1



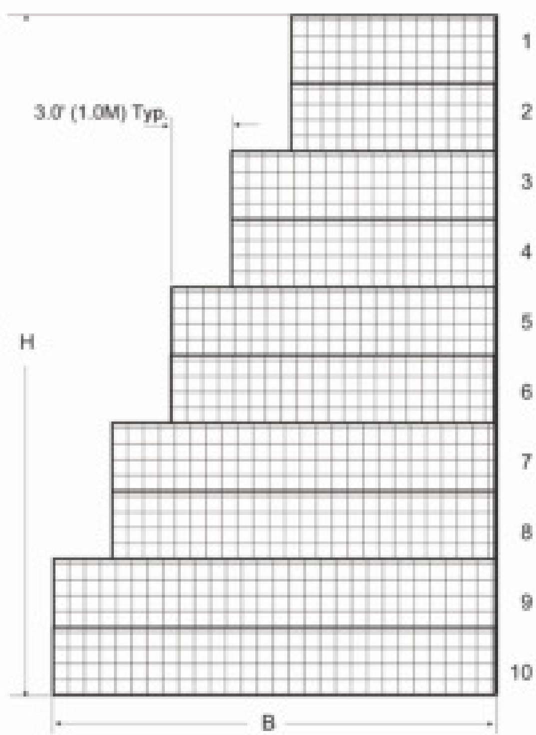
Cross Section for Example 1

GABION GRAVITY WALLS QUICK CROSS SECTION DESIGN GUIDE

GABION GRAVITY WALL WITHOUT SURCHARGE



GABION GRAVITY WALL WITH SURCHARGE



NO. OF COURSES	ENGLISH FEET		METRIC METERS	
	H	B	H	B
1	3.0	3.0	1.0	1.0
2	6.0	4.5	2.0	1.5
3	9.0	6.0	3.0	2.0
4	12.0	7.5	4.0	2.5
5	15.0	9.0	5.0	3.0
6	18.0	10.5	6.0	3.5
7	21.0	12.0	7.0	4.0
8	24.0	13.5	8.0	4.5
9	27.0	15.0	9.0	5.0
10	30.0	16.5	10.0	5.5
	H	B	H	B
1	3.0	6.0	1.0	2.0
2	6.0	6.0	2.0	2.0
3	9.0	9.0	3.0	3.0
4	12.0	9.0	4.0	3.0
5	15.0	12.0	5.0	4.0
6	18.0	12.0	6.0	4.0
7	21.0	15.0	7.0	5.0
8	24.0	15.0	8.0	5.0
9	27.0	18.0	9.0	6.0
10	30.0	18.0	10.0	6.0

To increase the efficiency of MSE gabion walls, layers of wire mesh (Anchor Mesh) may be attached to the back face and embedded in the backfill. The Anchor Mesh layers in this reinforced soil wall will resist the active soil force, by a combination of friction on the wire surface and mechanical interlock with the soil. Reinforced soil walls generally use a single thickness of gabions. Design consists of (1) walls stability checks similar to that for gravity walls, assuming the gabions and the reinforced soil act together as one unit, and (2) checks for strength and pullout resistance of the reinforcement layers, to ensure such action. The considerations that differ from gravity wall design are discussed below.

Walls will typically be 6 degrees from vertical. To simplify calculations, assume wall is vertical for certain calculations as indicated in Example 2.

In checking overturning, sliding and bearing, the weight of the soil in the reinforced zone is included with the weight of the wall.

The tensile force in each layer of reinforcement is assumed to resist the active earth force over an incremental height of wall. Its calculated value must be limited to the tensile strength of the mesh divided by the safety factor (typically 1.85). Therefore: 3000/1.85=1620 lb/ft.

As in gravity wall design, the wall is designed to resist the force generated by a sliding wedge of soil as defined by Coulomb. The reinforcement at each layer must ext end past the wedge by at least 3-feet, and by a distance sufficient to provide anchorage in the adjacent soil. Generally, this results in a B distance 0.5 to 0.7 times the height of the wall.

Additional equations used in the design of MSE walls, derived from statics are given in Example 2.

Example 2:

Given Data (See Cross Section, page 10)

Wall Height……………	H =	24 ft (21 ft+3 ft embedment)
Wall Thickness…………	T =	3 ft
Surcharge………………	Q =	300 psf
Backfill slope angle……	α =	0 deg
Back Face slope angle…	β =	-6 deg
Soil friction angle………	ϕ =	35 deg
Soil density……………	Ws =	120 pcf
Gabion fill density……	Wg =	100 pcf
Soil bearing pressure…	Pb =	4000 psf

(1) Determine if safety factors are within limits:

The trial value for dimension B was selected as 16.5 approximately 0.7H. Also see note near the end of part 2 below on trial selection of B to provide adequate embedment length. In these calculations, positive values are used for the sin and tan of β and the sign in the equation changed as necessary.

Pressure coefficient from Equation 2 is K_a=0.23

Active earth force, P_a, from Equation 1A is

$$P_a = 0.23(120 \times 24^2/2 + 300 \times 24)$$
$$= 9605\, lb/ft$$

Vertical distance to P_a from Equation 5 is

$$d_a = \frac{24(24 + 3 \times 300/120)}{3(24 + 2 \times 300/120)}$$
$$= 9.22\, ft$$

Overturning moment from Equation 6 is

$$M_o = 9.22 \times 9605$$
$$= 88{,}600\, ft - lb/ft$$

Weight of gabions is

$$W_g = (3 \times 24 \times 100$$
$$= 7200\, lb/ft$$

Horizontal distance to Wg is

$$d_g = t/2 + (H/2)\tan\beta$$
$$= 3/2 + (24/2)\tan 6$$
$$= 2.76\, ft$$

Weight of surcharge is

$$W_g = qb$$
$$= q(B - t - H\tan\beta)$$
$$= 300(1.65 - 3 - 24\tan 6)$$
$$= 300(10.98)$$
$$= 3290\, lb/ft$$

Horizontal distance to W_q is

$$d_q = b/2 + H\tan\beta + t$$
$$= 10.98/2 + 24\tan 6 + 3$$
$$= 11.01\, ft$$

Weight of soil wedge is

$$W_s = (H\tan\beta/2 + b)Hw_s$$
$$= (24\tan 6/2 + 10.98)24x120$$
$$= 35{,}250\, lb/ft$$

Horizontal distance to W_S is

$$d_s = \left[\frac{(H^2 \tan\beta)(H \tan\beta/3 + t) + (Hb)}{(b/2 + H \tan\beta + t)}\right] w_s / W_s$$

$$= \left[\frac{(24^2 \tan 6)(24 \tan 6/3 + 3) + (24x10.98)}{(10.98/2 + 24 \tan 6 + 3)}\right] \frac{120}{35250}$$

$$= 10.67\, ft$$

Resisting moment from Equation 7 is

$$M_r = W_s d_s + W_g d_g + W_q d_q$$
$$= 35{,}250 \times 10.67 + 7200 \times 2.76 + 3290 \times 11.01$$
$$= 432{,}200\, ft - lb/ft$$

Safety factor against overturning from Equation 4 is

$$SF_O = M_r / M_O$$
$$= 432{,}200 / 88{,}600$$
$$= 4.88 > 2.00$$

OK

Total vertical weight is

$$W_v = W_s + W_g + W_q$$
$$= 35{,}250 + 7200 + 3290$$
$$= 45{,}740\, lb/ft$$

Safety factor against sliding from Equation 8 is

$$SF_s = \mu Wv / P_h$$
$$= \tan 35 \times 45{,}740 / 9605$$
$$= 3.33 > 1.50$$

OK

Reaction eccentricity from Equation 9 is

$$e = 16.5/2 - (432{,}200 - 88{,}600) 45{,}740$$
$$= 0.738\, ft$$

Limit of eccentricity from Equation 10 is

$$-2.75 \le e \le 2.75\, ft$$

OK

Maximum base pressure from Equation 11 is

$$p = (45{,}740/16.5)(1 + 6 \times 0.738/16.5)$$
$$= 3520\, psf < 4000\, psf$$

OK

All safety factors are within limits. Stability checks at intermediate levels in the walls show similar results.

(2) Determine if reinforcement mesh is satisfactory

The pressure on any layer a distance z (ft) below the surface is

$$f_v = w_s z + q$$
$$= 120\, z + 300\, psf$$

The tensile strength on any layer of reinforcement in a vertical segment of soil of thickness S_V (ft), centered about the reinforcement layer, is

$$T = S_v K_a f_v$$
$$= 0.23 S_v f_v$$

Calculate T for each layer as follows

z (ft)	S_V (ft)	F_V (psf)	T (lb/ft)	T<1620 lb/ft?
3	4.5	660	683	Y
6	3.0	1020	704	Y
9	3.0	1380	952	Y
12	3.0	1740	1200	Y
15	3.0	2100	1449	Y
18	3.0	2460	1697	N
21	3.0	2820	1946	N
24	1.5	3180	1097	Y

The tensile force at 18 and 21 ft exceeded the limit. Therefore, insert an intermediate layer at 19.5 and 22.5 ft.

Recalculate the following revised table:

z (ft)	S_V (ft)	F_V (psf)	T (lb/ft)	T<1620 lb/ft?
3	4.5	660	683	Y
6	3.0	1020	704	Y
9	3.0	1380	952	Y
12	3.0	1740	1200	Y
15	3.0	2100	1449	Y
18	2.25	2460	1273	Y
19.5	1.5	2640	911	Y
21	1.5	2820	973	Y
22.5	1.5	3000	1035	Y
24	0.75	3180	549	Y

The tensile force is now within allowable limits at all layers.

The minimum embedment length past the wedge to provide a safety factor of 1.5 against pullout in any layer is

$$L_{em} = 1.5T/(2\Gamma f_v \tan\phi)$$

Where Γ is a "scale correction factor" assumed as 0.65.

$$L_{em} = 1.5T/(2x0.65 f_v \tan 35)$$
$$= 1.65T / f_v$$

At the top of the wall, the distance, X, to the wedge failure plane from the back of the wall is

$$X = H \tan(45 - \phi/2) - H \tan\beta$$
$$= 24 \tan(27.5) - 24 \tan(6)$$
$$= 11.54\,ft$$

At any layer, the length of embedment past the wedge is

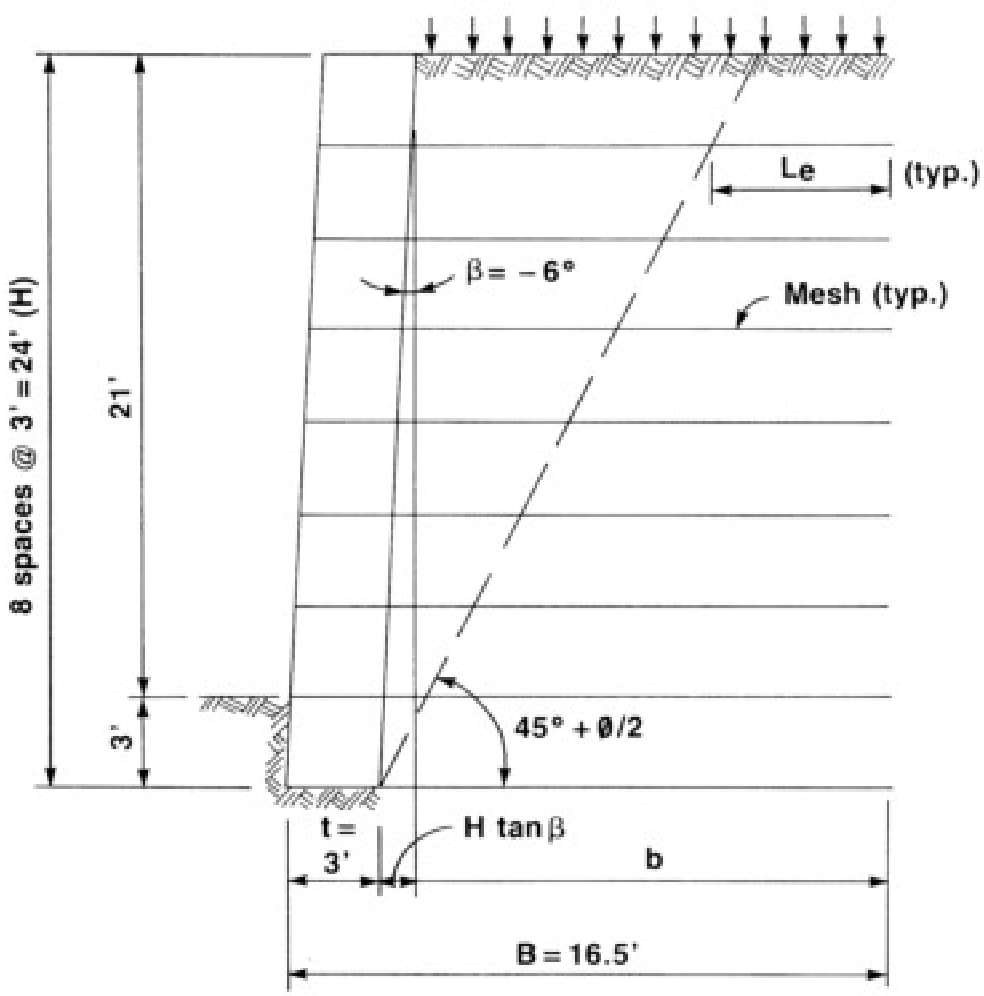
$$L_e = B - t - X(H - z)/H$$
$$= 16.5 - 3 - 11.54(24 - z)/24$$
$$= 1.956 + 0.481z$$

[Note: L_e can be calculated for the top layer of reinforcement initially, when selecting B, to make sure it is at least 3-feet. If not, increase B for the trial design.]

Calculate L_e and L_{em} for each layer as follows:

z (ft)	F_v (psf)	T (lb/ft)	L_e (ft)	L_{em} (ft)	L_e>L_{em}?
3	660	683	3.40	1.71	Y
6	1020	704	4.84	1.14	Y
9	1380	952	6.29	1.14	Y
12	1740	1200	7.73	1.14	Y
15	2100	1449	9.17	1.14	Y
18	2460	1273	10.62	0.85	Y
19.5	2640	911	11.34	0.59	Y
21	2820	973	12.06	0.59	Y
22.5	3000	1035	12.78	0.59	Y
24	3180	549	13.50	0.28	Y

The embedded length of reinforcement in each layer is greater than the minimum required for pullout and is also at least 3-feet. Reinforcement design is satisfactory with mesh added at the 19.5 and 22.5-foot levels.



Cross Section for Example 2

Table I

Angles of Internal Friction and Unit Weights of Soil*

Soil Type	Soil Condition	Angle of Internal Friction ϕ (deg)	Soil Density, w (lb/ft^3)
Course sand, sand & gravel	Compact soil	40	140
	Loose	35	90
Medium sand	Compact soil	40	130
	Loose	30	90
Fine silty sand, sandy silt	Compact soil	30	130
	Loose	25	85
Uniform silt	Compact soil	30	135
	Loose	25	85
Clay-silt	Soft/medium	20	90/120
Silty clay	Soft/medium	15	90/120
Clay	Soft/medium	0/10	90/120

*F.S. Merritt, Ed., "Standard Handbook for Civil Engineers" McGraw-Hill, 1983

Table II

Active Pressure Coefficient, K_a

β	α	$\phi = 10$	$\phi = 15$	$\phi = 20$	$\phi = 25$	$\phi = 30$	$\phi = 35$	$\phi = 40$
-6	0	0.68	0.56	0.45	0.37	0.29	0.23	0.18
-6	5	0.74	0.6	0.49	0.39	0.31	0.24	0.19
-6	10	0.94	0.67	0.53	0.42	0.33	0.26	0.2
-6	15		0.89	0.59	0.46	0.35	0.27	0.21
-6	20			0.82	0.52	0.39	0.29	0.22
-6	25				0.75	0.44	0.32	0.24
-6	30					0.67	0.37	0.26
-6	35						0.58	0.3
-6	40							0.49
0	0	0.7	0.59	0.49	0.41	0.33	0.27	0.22
0	5	0.77	0.63	0.52	0.43	0.35	0.28	0.23
0	10	0.97	0.7	0.57	0.46	0.37	0.3	0.24
0	15		0.93	0.64	0.5	0.4	0.32	0.25
0	20			0.88	0.57	0.44	0.34	0.27
0	25				0.82	0.5	0.38	0.29
0	30					0.75	0.44	0.32
0	35						0.67	0.37
0	40							0.59
5	0	0.73	0.62	0.52	0.44	0.37	0.31	0.25
5	5	0.8	0.67	0.56	0.47	0.39	0.32	0.26
5	10	1	0.74	0.61	0.5	0.41	0.34	0.28
5	15		0.98	0.68	0.55	0.45	0.36	0.29
5	20			0.94	0.62	0.49	0.39	0.31
5	25				0.89	0.56	0.43	0.34
5	30					0.83	0.5	0.37
5	35						0.76	0.43
5	40							0.68
10	0	0.76	0.65	0.56	0.48	0.41	0.34	0.29
10	5	0.83	0.7	0.6	0.51	0.43	0.36	0.3
10	10	1.05	0.78	0.65	0.55	0.46	0.38	0.32
10	15		1.04	0.74	0.6	0.5	0.41	0.34
10	20			1.02	0.68	0.55	0.44	0.36
10	25				0.98	0.63	0.49	0.39
10	30					0.92	0.57	0.43
10	35						0.86	0.5
10	40							0.79
15	0	0.79	0.69	0.6	0.52	0.45	0.39	0.33
15	5	0.87	0.75	0.65	0.56	0.48	0.41	0.35
15	10	1.1	0.83	0.71	0.6	0.51	0.43	0.37
15	15		1.11	0.8	0.66	0.55	0.47	0.39
15	20			1.1	0.75	0.61	0.51	0.42
15	25				1.08	0.7	0.56	0.45
15	30					1.04	0.65	0.5
15	35						0.98	0.58
15	40							0.91

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