3.13.2 Temporary Geotextile Retaining Wall Design Procedure

This Design Guide contains a step-by-step procedure, related equations, typical design assumptions recommended for the design of temporary geotextile retaining walls, and an example. See Sections 2.3.6.4.3 and 3.13.2 of the Bridge Manual for an overview of temporary geotextile wall usage, detailing requirements and other related policies.

1. Establish Wall Retention Geometry

   a. Determine the bottom of the wall elevations, top of the wall profile, and backslope angle/height. Normally, very minor and, in some cases, no embedment should be specified at the base of the geotextile wall. The offset of the wall relative to the centerline of the roadway is controlled by the stage construction limits of the proposed structure and proposed pavement edge. A geotextile wall requires at least 1 ½ ft. of embankment cover above the top of the wall to allow roadway sub-base and pavement construction as well as ensure anchorage for the top geotextile layer. Once the wall offset and embankment cover requirements have been established, the top of the wall elevations can be computed using an appropriate stable slope angle behind/above the wall. A 2:1 slope is most often used, but when the embankment height becomes larger and may be exposed to prolonged weathering or instability, other angles may be appropriate.

   b. Select geotextile reinforcement vertical spacing. The vertical spacing of the geotextile reinforcement is most commonly selected as 12 in. because this height fits well with the required compaction lift thickness and the ability of the temporary forming system to resist the lateral earth pressures. In cases where the calculated stress in the fabric may be high (requiring a more expensive geotextile), a smaller reinforcement spacing can be specified in the lower portion of the wall. Larger spacings have been specified for shorter walls or to finish out the top soil reinforcement row.

   c. Select the soil reinforcement length required to satisfy external stability. Just like MSE walls, reinforced block walls, and other internally reinforced structures, geotextile walls shall be evaluated for global stability, settlement, overturning, sliding and bearing capacity. Normally, the geotextile reinforcement length is set at a minimum ratio of 1.0 times the retained height, H. For further information on evaluating global stability, see Sections 2.3.12.1 and 3.11.1 of the Bridge Manual.

2. Determine the Soil Pressure Diagram at the Failure Surface

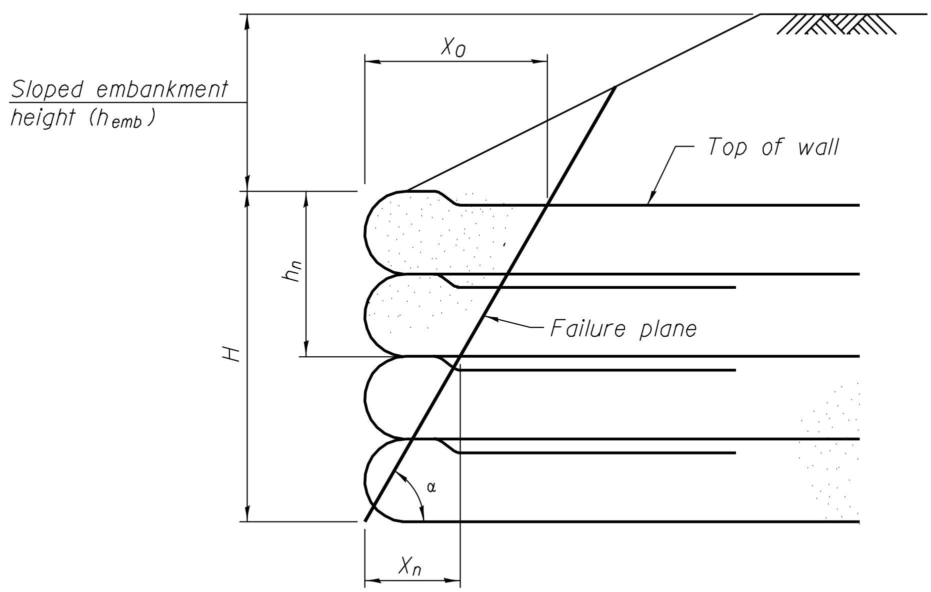
   a. The loadings for external stability analysis for a wall are determined from lateral earth pressures which are applied to the vertical plane at the rear of the geotextile reinforced mass. In contrast, the loadings for internal stability analysis are determined from lateral earth pressures which occur within the reinforced mass. The maximum stress in the geotextile soil reinforcement occurs at the internal stability failure plane This failure plane extends from the base of the wall at the front face, upward at an angle α, as shown in Figure 1 and is computed using the following relationship:

$$\alpha = 45° + \frac{\phi}{2}$$

   Where ϕ is the friction angle of the soil within the reinforced mass.

   The Guide Bridge Special Provision (GBSP) 46 allows the contractor to select between several coarse and fine aggregate gradations. The lowest quality aggregate gradation permissible can be assumed to provide at least a 30° friction angle in its compacted state. As such, this angle is recommended for design purposes.

   b. Calculate the lateral soil pressure diagram applied to the wall in order to determine the required geotextile length for resisting pullout and identify the geotextile strength requirements. The diagram should be constructed from the ground surface to the top of the wall at the offset from the face where the failure plane intersects the top of the wall. The offset distance, X_0, is shown in Figure 1 and is computed using the following relationship:



Sloped embankment
height (h_{emb})
X_0
Top of wall
h_n
H
Failure plane
α
X_n

FIGURE 1

$$X_0 = \frac{H}{\tan \alpha}$$

Where H is the total retained height of the wall.

Offsets, X_n, at intermediate layers of soil reinforcement can be found with the following equation,

$$X_n = \frac{H - h_n}{\tan \alpha}, \text{where } n = 1 \text{ to number of reinforced soil layers}$$

Below the top of the wall, the pressure diagram is applied to the rear face of the failure plane surface. For most cases (when the embankment height is relatively small compared to the wall height) the construction of the pressure diagram is straightforwardly computed by multiplying the total vertical overburden pressures (traffic surcharge, total embankment height above wall, and wall select fill to each geotextile reinforcement) by Rankine's K_a for level backslope conditions. This K_a can be calculated using the following relationship:

$$K_a^{level} = \left[\tan\left(45^o - \frac{\phi}{2}\right)\right]^2$$

However, in cases where the backslope angle and embankment height are substantial, using the total embankment height/level K_a may be too conservative. In these cases, the actual overburden pressure (prorated traffic surcharge, embankment height at offset of failure plane/geotextile intersection, and wall select fill to each geotextile reinforcement) should be computed and multiplied by Rankine's K_a for sloping conditions. This K_a can be calculated using the following relationship:

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

Where β is the backslope angle of embankment relative to horizontal.

c. Since it is often not apparent which K_a assumption will provide the most appropriate lateral earth pressure, it is recommended both cases be calculated at each soil reinforcement level and the lower pressure be selected for design. As can be seen in Figure 2, both assumptions err on the conservative side. Thus, the smaller value is recommended since it is assumed to be closer to correct while still being conservative. The following equation can be used to calculate the level surcharge lateral soil pressure case:

$$\sigma_n^{level} = K_a^{level}\left[(h_{emb} + h_n)(\gamma_s) + S\right]$$

Where S is the full traffic surcharge (normally taken as 0.25 ksf), γ_s is unit weight of soil (conservatively assumed to be 0.125 ksf), h_{emb} is the full height of the embankment, and h_n is the distance from the top of the wall to where lateral pressure is being calculated (see Figure 3).

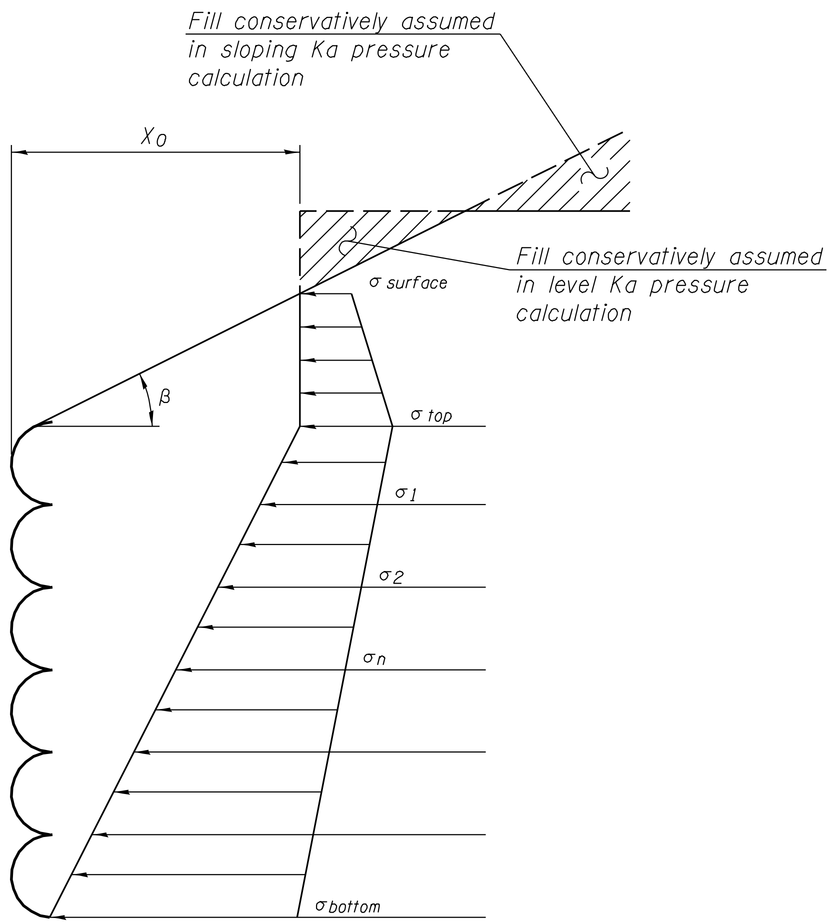
The sloped surcharge lateral soil pressure case can be computed using the following equation:

$$\sigma_n^{Sloped} = K_a^{Sloped}\left[(h_{sn} + h_n)\gamma_s + S\left\{\frac{\frac{1}{2}(h_f + h_{sn})}{h_{emb}}\right\}\right]$$

$$h_{sn} = X_n \tan\beta \le h_{emb}\text{, where } n = 0 \text{ to number of reinforced soil layers}$$

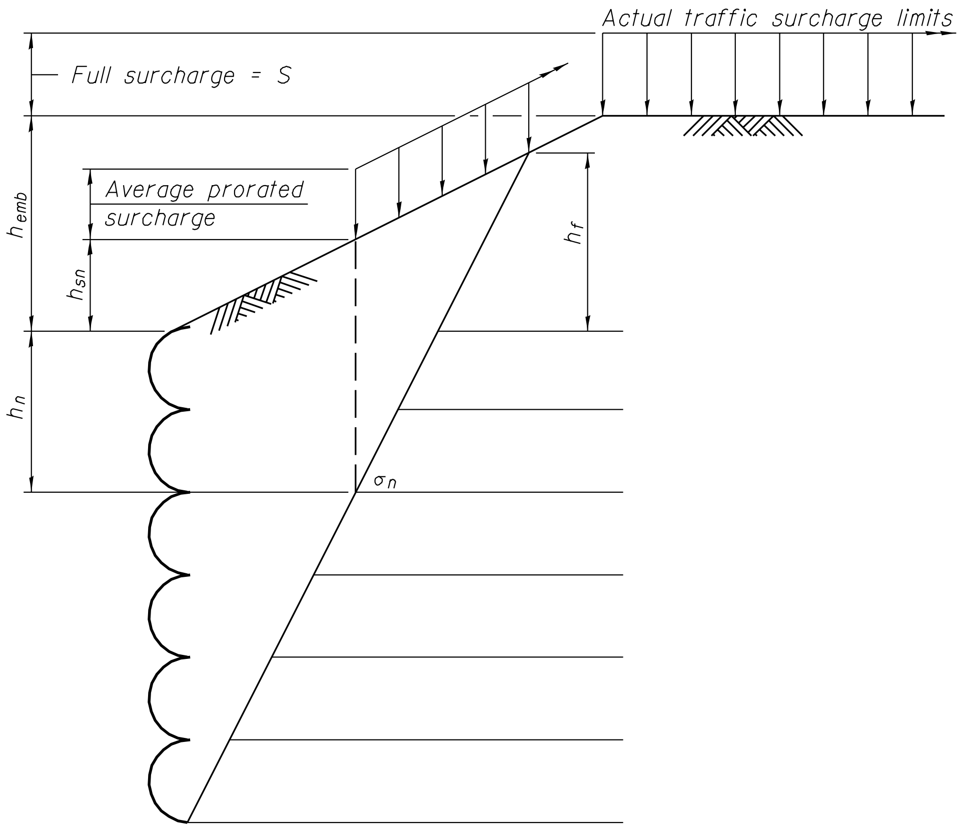
$$h_f = \frac{X_0}{\sin(\alpha - \beta)}\sin\beta\sin\alpha \le h_{emb}$$

Where h_{sn} is the height of embankment above the wall a distance from the face to the failure plane intersection with the soil reinforcement at the point where the lateral pressure is being calculated. h_f is the vertical height of the failure plane above the wall. Note that only a prorated average of the full traffic surcharge is included in the sloped embankment case when h_{sn} is less than h_{emb}. It is assumed that the actual traffic surcharge only occurs on the level portion of the embankment. As a result, the effects of the traffic surcharge on the wall design dissipate as the distance from the surcharge increase (see Figure 3).



Fill conservatively assumed in sloping Ka pressure calculation
X_0
Fill conservatively assumed in level Ka pressure calculation
σ surface
β
σ top
σ_1
σ_2
σ_n
σ bottom

FIGURE 2



σ_n = Location of lateral soil pressure calculation

FIGURE 3

3. Establish the Required Geotextile Service Strength and Internal Stability Length

   a. In order to ensure stability, each geotextile layer shall have adequate strength to resist the applied force generated by the design lateral soil pressures. The applied force (per horizontal foot of wall face) to be restrained by the soil reinforcement layers within the center portion of the wall can be calculated by multiplying the design soil pressure at the geotextile depth by the soil reinforcement vertical spacing as shown below.

$$P_n = \sigma_n (Sv_n)$$

When the vertical spacing above and below the geotextile is not the same, the average spacing can be used to approximate the tributary pressure diagram surface area. The applied force on the lowest level of geotextile is assumed to only carry ½ the vertical spacing since the geotextile layer immediately above carries the remainder.

$$P_{Bottom} = \frac{1}{2}\sigma_{Bottom}(Sv_{Bottom})$$

The top layer of soil reinforcement carries ½ the soil pressure from the vertical spacing below but also must carry the total soil pressure calculated above the wall. The following equation can be used to calculate the force on the top layer of geotextile reinforcement:

$$P_{Top} = \frac{1}{2}(\sigma_{Top} + \sigma_{Surface})(h_{s0}) + \frac{1}{2}\sigma_{Top}(Sv_{Top})$$

See Figure 4 for a graphical representation of these soil pressure tributary areas.

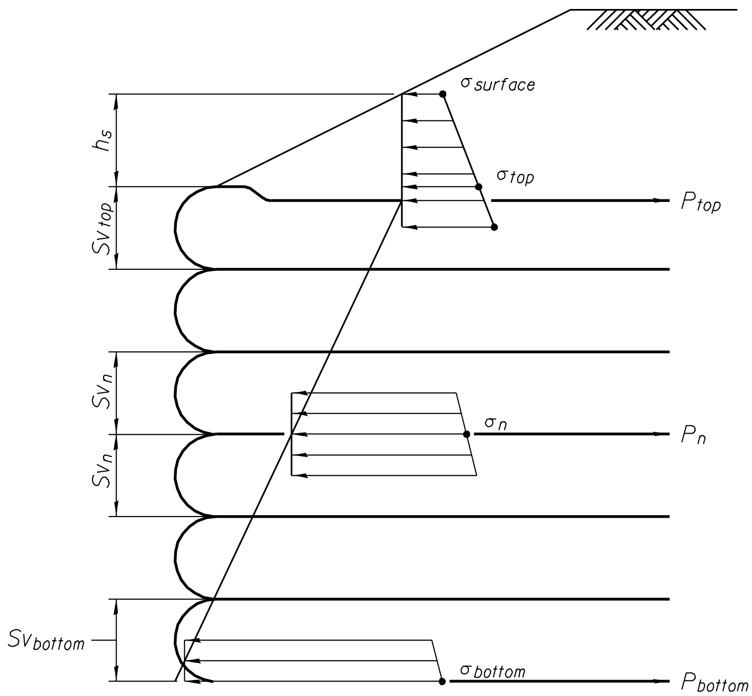

σ surface
hs
σ top
Ptop
Svtop
Svn
σn
Pn
Svn
Svbottom
σ bottom
Pbottom

FIGURE 4

Once the strength demand (kips/ft.) of the geotextile is determined at each level, the maximum value is used as the controlling design value for the wall and placed on the Contract plans as T_{min}. The contractor is required to submit computations to the Department demonstrating that the selected geotextile has an allowable design strength larger than T_{min}. The computation of the allowable design strength of the geotextile involves starting with the ultimate strength of the fabric and reducing it by several partial factors of safety (see the GBSP 46 for more detail on the contractor's calculation of allowable fabric strength).

b. In addition to strength, each geotextile layer shall have adequate pull out resistance to withstand the applied force generated by the design lateral soil pressures with a minimum factor of safety of 1.5. The total fabric length, $L_n^{Internal}$, required for internal stability consists of the portion from the face to the failure plane, L_n^{fail}, and the portion beyond the failure plane, $L_n^{pullout}$ (See Figure 5). The required soil reinforcement length beyond the failure plane can be calculated using the following equation:

$$L_n^{pullout} = \frac{1.5P_n}{2(\tan\phi)(0.6)(2/3)[(1/2)(h_{sn}+h_f)+h_n]\gamma_s} \geq 3 \text{ ft.}$$

Where P_n is the applied force (per horizontal foot of wall face) determined from the geotextile strength calculation. The required length to the failure plane can be calculated using the following equation:

$$L_n^{fail} = \frac{H-h_n}{(\tan\alpha)} \text{ (also equal to } X_n\text{)}$$

The two reinforcement lengths are added together to determine $L_n^{Internal}$ at each layer and compared the geotextile reinforcement width required for external stability $L_n^{External}$. The maximum of these lengths is selected and used at each level such that a consistent soil reinforcement length will act as a semi-ridge mass which satisfies both external and internal stability requirements.

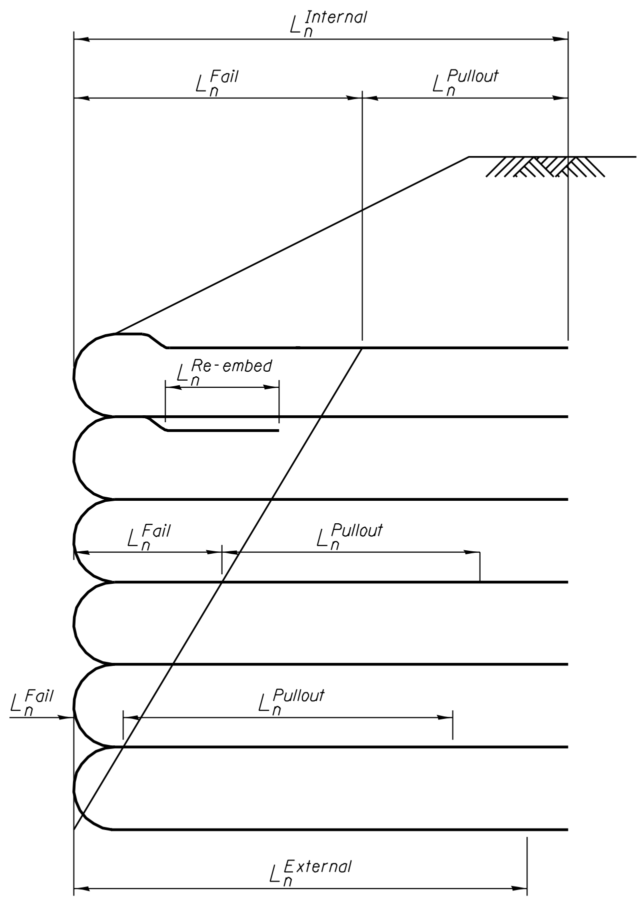

$L_n^{Internal}$
L_n^{Fail}
$L_n^{Pullout}$
$L_n^{Re\text{-}embed}$
L_n^{Fail}
$L_n^{Pullout}$
L_n^{Fail}
$L_n^{Pullout}$
$L_n^{External}$

FIGURE 5

4. Calculate the Required Re-Embedment Length

The re-embedment length for soil reinforcement layers 1 to n-1 is determined such that adequate pullout resistance is developed behind the geotextile face to retain the corresponding lateral soil pressures. The soil pressures at the wall face will generally be less than at the global failure plane described above. At the face, there is a failure plane for each individual layer which is parallel to the global failure plane and begins at the bottom of each soil layer. The earth pressure diagram at the wall face for each layer should be calculated in a similar manner as at the global failure surface, checking the level and sloped soil pressure cases. The set of equations given below have been modified from those presented above for the case of calculating required re-embedment lengths.

$$\sigma_n^{level} = K_a^{level}\left[(h_{emb} + h_n)(\gamma_s) + S\right]$$

$$\sigma_n^{Sloped} = K_a^{Sloped}\left[(h_n)\gamma_s + S\left\{\frac{\frac{1}{2}(h_{fn})}{h_{emb}}\right\}\right]$$

$$h_{fn} = \frac{h_n / \tan\alpha}{\sin(\alpha - \beta)} \sin\beta \sin\alpha \le h_{emb}$$

$$P_n = \sigma_n (Sv_n)$$

$$L_n^{re-embed} = \frac{1.5P_n}{2(\tan\phi)(0.6)(\frac{2}{3})\left[(\frac{1}{2})(h_{fn}) + h_n\right]\gamma_s}$$

Unlike the pressures along the global failure surface, h_{sn} will always be zero when determining the pressure along the face, but h_f should now be calculated for the failure surface at each level. As such, h_{sn} has been removed from the equations above and h_{fn} has been substituted for h_f. As with the pullout length, the re-embedment length should not be less than 3.0 ft., starting from 1.0 ft. behind the face where a minimum of 3 in. of select granular fill separates the re-embedment length from the geotextile reinforcement above (see Figure 5). The re-embedment length at the top of the wall is analyzed as soil reinforcement and should extend beyond the failure plane as required by design.

Geotextile Wall Design Example: Box Culvert- Stage Construction with 8.0 ft. Fill

Top of Culvert Elevation	= 397.50 ft.
Roadway Profile Grade	= Level Profile Grade, Elevation 405.50 ft.
Angle of Internal Soil Friction ϕ	= 30^o
Unit Weight of Soil γ_s	= 0.125 k/ft.^{3}
Live Load Surcharge S	= 0.250 k/ft.^{2}
Wall Face Offset	= 4 ft. from Stage Construction Line

1. <u>Establish Wall Retention Geometry</u>

Determine Bottom of Wall Elevation

Assuming the bottom of wall rests on the top of the culvert:

Bottom of Wall Elevation = 397.50 ft.

Determine Top of Wall Elevation

The top of wall elevation is taken as the profile grade, less h_{emb}, which is assumed to be 2.0 ft.

$$\text{Top of Wall Elevation} = 405.50 \text{ ft.} - 2.0 \text{ ft.} = 403.50 \text{ ft.}$$

Determine Backslope Angle β

$$\text{Backslope Angle } \beta = \tan^{-1}\left(\frac{405.50 \text{ ft.} - 403.50 \text{ ft.}}{4}\right) = 26.57°$$

Select Geotextile Reinforcement Vertical Spacing

Use 6 - 1 ft. thick layers of geotextile reinforcement.

Find Minimum Soil Reinforcement Length $L_n^{External}$ *Required to Satisfy External Stability*

Try minimum reinforcement length of 1.0H:

$L_n^{External}$ = 1.0H = 1.0(403.50 – 397.50) = 6.0 ft.

Detailed analysis of bearing capacity, sliding, overturning and settlement (not included in this example) indicates this length is adequate.

2. Determine the Soil Pressure Diagram at the Failure Surface

Find Angle of Internal Soil Failure α

$$\alpha = 45^\circ + \frac{\phi}{2}$$

$$= 45^\circ + \frac{30^o}{2}$$

$$= 60^\circ$$

Find Pressure Diagram Offset Distance X_0

$$X_0 = \frac{H}{\tan\alpha}$$

$$= \frac{6.0 \text{ ft.}}{\tan 60^o}$$

$$= 3.46 \text{ ft.}$$

Find K_a^{level} *and* K_a^{sloped}

$$K_a^{level} = \left[\tan\left(45^o - \frac{\phi}{2}\right)\right]^2$$

$$= \left[\tan\left(45^o - \frac{30^o}{2}\right)\right]^2$$

$$= 0.33$$

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

$$= (\cos 26.57^o)\left[\frac{\cos 26.57^o - \sqrt{\cos^2 26.57^o - \cos^2 30^o}}{\cos 26.57^o + \sqrt{\cos^2 26.57^o - \cos^2 30^o}}\right]$$

$$= 0.54$$

Find σ_n^{level} *and* σ_n^{Sloped} *at Embankment Surface, Top of Wall, Bottom of Wall, and Each Intermediate Fabric Depth*

$$\sigma_n^{level} = K_a^{level}\left[(h_{emb} + h_n)(\gamma_s) + S\right]$$

$$\sigma_n^{Sloped} = K_a^{Sloped}\left[(h_{sn} + h_n)\gamma_s + S\left\{\frac{\frac{1}{2}(h_f + h_{sn})}{h_{emb}}\right\}\right]$$

Where:

$$h_f = \frac{X_0}{\sin(\alpha - \beta)}\sin\beta\sin\alpha \leq h_{emb}\ ;\ h_f = \frac{3.46}{\sin(60 - 26.57)}\sin 26.57 \sin 60 \leq 2.0$$

$$h_f = 2.43 \leq 2.0\ \therefore h_f = 2.0 \text{ ft.}$$

$$h_{sn} = X_n \tan\beta \leq h_{emb}, \text{ where } n = 0 \text{ to number of reinforced soil layers}$$

N	h_n (ft.)	h_{sn} (ft.)	σ_n^{level} (ksf)	σ_n^{Sloped} (ksf)	Controlling Case
Surface	N/A	1.73	0.083	0.126	Level
Top of Wall (0)	0.00	1.73	0.165	0.243	Level
1	1.00	1.44	0.206	0.281	Level
2	2.00	1.15	0.248	0.319	Level
3	3.00	0.87	0.289	0.358	Level
4	4.00	0.58	0.330	0.396	Level
5	5.00	0.29	0.371	0.434	Level
Bot. of Wall (6)	6.00	0.00	0.413	0.473	Level

3. Establish the Required Geotextile Service Strength and Internal Stability Length

Find T_{min}

T_{min} is the maximum of P_{top}, P_{bottom}, or P_n

$$P_{top} = \frac{1}{2}\left(\sigma_{top}^{level} + \sigma_{Surface}^{level}\right)\left(h_{s0}\right) + \frac{1}{2}\left(\sigma_{top}^{level}\right)\left(S_{v_{top}}\right)$$

$$= \frac{1}{2}(0.165 \text{ ksf} + 0.083 \text{ ksf})(1.73 \text{ ft.}) + \frac{1}{2}(0.165 \text{ ksf})(1.00 \text{ ft.})$$

$$= 0.30 \text{ k/ft.}$$

$$P_{bottom} = \frac{1}{2}\sigma_{bottom}^{level}\left(S_{v_{bottom}}\right)$$

$$= \frac{1}{2}(0.413 \text{ ksf})(1.00 \text{ ft.})$$

$$= 0.21 \text{ k/ft.}$$

$$P_n = \sigma_n^{level}\left(S_{v_n}\right)$$

$P_1 = (0.206 \text{ ksf})(1 \text{ ft.}) = 0.21 \text{ k/ft.}$

$P_2 = (0.248 \text{ ksf})(1 \text{ ft.}) = 0.25 \text{ k/ft.}$

$P_3 = (0.289 \text{ ksf})(1 \text{ ft.}) = 0.29 \text{ k/ft.}$

$P_4 = (0.330 \text{ ksf})(1 \text{ ft.}) = 0.33 \text{ k/ft.}$

$P_5 = (0.371 \text{ ksf})(1 \text{ ft.}) = 0.37 \text{ k/ft.}$

$T_{min} = 0.37$ k/ft.

Find $L_n^{Internal}$

$$L_n^{Internal} = L_n^{pullout} + L_n^{fail}$$

$$L_n^{pullout} = \frac{1.5P_n}{2(\tan\phi)(0.6)(2/3)[(1/2)(h_{sn} + h_f) + h_n]\gamma_s} \geq 3 \text{ ft.}$$

$$L_n^{fail} = \frac{H - h_n}{(\tan\alpha)}$$

n	h_n (ft.)	$L_n^{pullout}$ (ft.) (Calculated)	$L_n^{pullout}$ (ft.) (Governing)	L_n^{fail} (ft.)	$L_n^{Internal}$ (ft.)
Top of Wall (0)	0.00	4.18	4.18	3.46	7.64
1	1.00	2.00	3.00	2.89	5.89
2	2.00	1.82	3.00	2.31	5.31
3	3.00	1.70	3.00	1.73	4.73
4	4.00	1.62	3.00	1.15	4.15
5	5.00	1.56	3.00	0.58	3.58
Bot. of Wall (6)	6.00	0.78	3.00	0.00	3.00

Find Controlling Value of L_n

n	$L_n^{Internal}$ (ft.)	$L_n^{External}$ (ft.)	L_n (ft.)
Top of Wall (0)	7.64	6.00	7.64
1	5.89	6.00	7.64
2	5.31	6.00	7.64
3	4.73	6.00	7.64
4	4.15	6.00	7.64
5	3.58	6.00	7.64
Bot. of Wall (6)	3.00	6.00	7.64

4. <u>Calculate the Required Re-Embedment Length</u>

Using a procedure similar to above and the equations below, find the length of re-embedment required for soil reinforcement layers 1 to 5.

$$\sigma_n^{level} = K_a^{level}\left[(h_{emb} + h_n)(\gamma_s) + S\right]$$

$$\sigma_n^{Sloped} = K_a^{Sloped}\left[(h_n)\gamma_s + S\left\{\frac{\frac{1}{2}(h_{fn})}{h_{emb}}\right\}\right]$$

$$h_{fn} = \frac{h_n / \tan\alpha}{\sin(\alpha - \beta)} \sin\beta \sin\alpha \le h_{emb}$$

$$P_n = \sigma_n (Sv_n)$$

$$L_n^{re-embed} = \frac{1.5P_n}{2(\tan\phi)(0.6)(2/3)\left[(1/2)(h_{fn}) + h_n\right]\gamma_s}$$

N	h_n (ft.)	h_{fn} (ft.)	σ_n^{level} (ksf)	σ_n^{Sloped} (ksf)	Controlling Case
1	1.00	0.41	0.206	0.081	Sloped
2	2.00	0.81	0.248	0.162	Sloped
3	3.00	1.22	0.289	0.244	Sloped
4	4.00	1.62	0.330	0.325	Sloped
5	5.00	2.00	0.371	0.405	Level

n	h_n (ft.)	P_n (k/ft.)	$L_n^{re-embed}$ (ft.) (Calculated)	$L_n^{re-embed}$ (ft.) (Governing)
1	1.00	0.081	1.75	3.00
2	2.00	0.162	1.75	3.00
3	3.00	0.244	1.75	3.00
4	4.00	0.325	1.75	3.00
5	5.00	0.371	1.61	3.00