An Introduction to Geotextiles for Soil Wall Reinforcement

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(Figures, tables and equations in this publication are at times at times a little difficult to read, but they are the best available. ***DO NOT PURCHASE THIS PUBLICATION IF THIS LIMITATION IS UNACCEPTABLE TO YOU.****)*

1. INTRODUCTION. Soil, especially granular, is relatively strong under compressive stresses. When reinforced, significant tensile stresses can be carried by the reinforcement, resulting in a composite structure which possesses wider margins of strength. This extra strength means that steeper slopes can be built. Geotextiles have been utilized in the construction of reinforced soil walls since the early 1970's. Geotextile sheets are used to wrap compacted soil in layers producing a stable composite structure. Geotextile-reinforced soil walls somewhat resemble the popular sandbag walls which have been used for some decades. However, geotextile-reinforced walls can be constructed to a significant height because of the geotextile's higher strength and a simple mechanized construction procedure.

2. ADVANTAGES OF GEOTEXTILE-REINFORCED WALLS. Some advantages of geotextile-reinforced walls over conventional concrete walls are as follows:

a. They are economical.

b. Construction usually is easy and rapid. It does not require skilled labor or specialized equipment. Many of the components are prefabricated allowing relatively quick construction.

c. Regardless of the height or length of the wall, support of the structure is not required during construction as for conventional retaining walls.

d. They are relatively flexible and can tolerate large lateral deformations and large differential vertical settlements. The flexibility of geotextile reinforced walls allows the use of a lower factor of safety for bearing capacity design than for conventional, more rigid structures.

e. They are potentially better suited for earthquake loading because of the flexibility and inherent energy absorption capacity of the coherent earth mass.

3. DISADVANTAGES OF GEOTEXTILE-REINFORCED WALLS. Some disadvantages of geotextile-reinforced walls over conventional concrete walls are as follows:

a. Some decrease in geotextile strength may occur because of possible damage during construction.

b. Some decrease in geotextile strength may occur with time at constant load and soil temperature.

c. The construction of geotextile-reinforced walls in cut regions requires a wider excavation than conventional retaining walls.

d. Excavation behind the geotextile-reinforced wall is restricted.

4. USES. Geotextile-reinforced walls can be substantially more economical to construct than conventional walls. However, since geotextile application to walls is relatively new, long term effects such as creep, aging, and durability are not known based on actual experience. Therefore, a short life, serious consequences of failure, or high repair or replacement costs could offset a lower first cost. Serious consideration should be given before utilization in critical structures. Applications of geotextile-reinforced walls range from construction of temporary road embankments to permanent structures remedying slide problems and widening highways effectively. Such walls can be constructed as noise barriers or even as abutments for secondary bridges. Because of their flexibility, these walls can be constructed in areas where poor foundation material exists or areas susceptible to earthquake activity.

5. GENERAL CONSIDERATIONS.

a. The wall face may be vertical or inclined. This can be because of structural reasons (internal stability), ease of construction, or architectural purposes. All geotextiles are equally spaced so that construction is simplified. All geotextile sheets, except perhaps for the lowest one, usually extend to the same vertical plane.

b. Geotextiles exposed to UV light may degrade quite rapidly. At the end of construction, a protective coating should be applied to the exposed face of the wall. An application of 0.25 gallon per square yard of CSS-1 emulsified asphalt or spraying with a low viscosity water-cement mixture is recommended. This cement mixture bonds well and provides satisfactory protection even for smooth geotextiles. To protect the face of the wall from vandalism, a 3-inch layer of gunnite can be applied. This can be done by projecting concrete over a reinforcing mesh manufactured from No. 12 wires, spaced 2 inches in each direction, and supported by No. 3 rebars inserted between geotextile layers to a depth of 3 feet.

c. When aesthetic appearance is important, a low-cost solution, like the facing system comprised of used railroad ties or other such materials, can be used.

d. No weepholes are specified, although after UV and vandal protection measures the wall face may be rather impermeable. To ensure the fast removal of seeping water in a permanent structure, it is recommended to replace 1 to 2 feet of the natural foundation soil (in case it is not free-draining) with a crushed-stone foundation layer to facilitate drainage from within and behind the wall. The crushed rock may be separated from the natural soil by a heavy weight geotextile.

6. PROPERTIES OF MATERIALS.

6.1 RETAINED SOIL. The soil wrapped by the geotextile sheets is termed “retained soil.” This soil must be free-draining and nonplastic. The ranking (most desirable to less desirable) of various retained soils for permanent walls using the Unified Soil Classification System is as follows: SW, SP, GW, GP, and any of these with a borderline classification is dual designated with GM or SM. The amount of fines in the soil is limited to 12 percent passing sieve No. 200. This restriction is imposed because of possible migration of fines being washed by seeping water. The fines may be trapped by geotextile sheets; thus, eventually creating low permeability liners. Generally, the permeability of the retained soil must be more than 10-3 centimeters per second. The ranking order indicates that gravels are not at the top. Although they posses high permeability and, possibly, high strength, their utilization requires special attention. Gravel, especially if it contains angular grains, can puncture the geotextile sheets during construction. Consequently, consideration must be given to geotextile selection so as to resist possible damage. If a geotextile possessing high puncture resistance is available, then GP and GW should replace SP and SW, respectively, in their ranking order. The retained soil unit weight should be specified based on conventional laboratory compaction tests. A minimum of 95 percent of the maximum dry unit weight, as determined by ASTM D 698 should be attained during construction. Since the retained soil will probably be further densified as additional layers are placed and compacted, and may be subjected to transitional external sources of water, such as rainfall, it is recommended for design purposes that the saturated unit weight be used.

6.2 BACKFILL SOIL. The soil supported by the reinforced wall (the soil to the right of L in Figure 1) is termed “backfill soil.” This soil has a direct effect on the external stability of the wall. Therefore, it should be carefully selected. Generally, backfill specifications used for conventional retaining walls should be employed here as well. Clay, silt, or any other material with low permeability should be avoided next to a permanent wall.

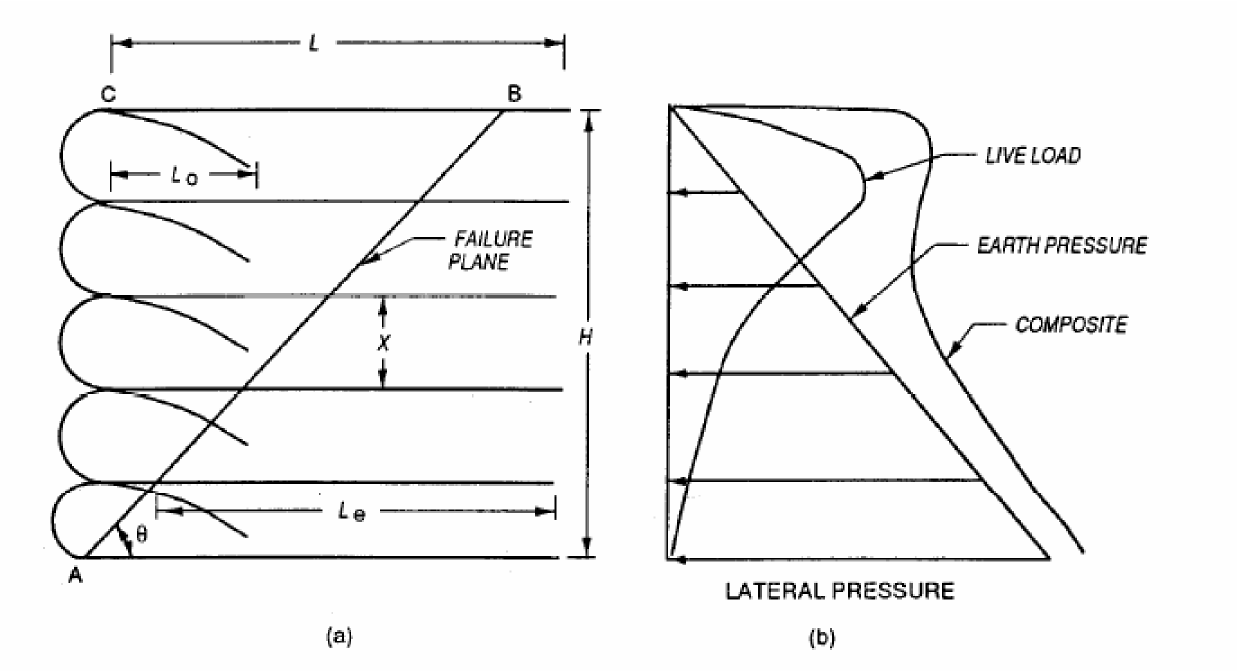

Figure 1
General Configuration of a Geotextile Retained Soil Wall
and Typical Pressure Diagrams

If low quality materials are used, then a geotextile filter meeting filtration requirements should be placed to separate the fines from the free draining backfills, thus preventing fouling of the higher quality material. Since the retained soil and backfill may have an effect on the external stability of the reinforced wall, the properties of both materials are needed. The unit weight should be estimated for the retained soil; use the maximum density at zero air voids. The strength parameters should be determined using drained direct shear tests (ASTM D 3080) for the permeable backfill. The backfill and the retained soil must have similar gradation at their interface so as to minimize the potential for lateral migration of soil particles. If such requirement is not practical, then a conventional soil filter should be designed, or a geotextile filter should be used along the interface.

7. DESIGN METHOD. The design method recommended for retaining walls reinforced with geotextiles is basically the U.S. Forest Service method as developed by Steward, Williamson, and Mahoney (1977) using the Rankine approach. The method considers the earth pressure, line load pressure, fabric tension, and pullout resistance as the primary design parameters.

7.1 EARTH PRESSURE. Lateral earth pressure at any depth below the top of the wall is shown in Figure 1a, and is given by:

$$\sigma_{ho} = K_o \gamma d$$

where

σ_{ho} = lateral earth pressure acting on the wall

K^o = at rest pressure coefficient

γ = soil unit weight

d = depth below the top of the wall

(Eq. 1)

A typical earth pressure distribution is shown in Figure 1b. Use of the "at rest" pressure coefficient, K^o , is recommended and is determined by the following equation:

$$k_o = 1 - \sin \phi$$

(Eq. 2)

where ϕ is the angle of internal friction of the soil. The failure surface, AB in figure 1a, slopes upward at an angle of $\Theta = 45 + \Theta/2$.

7.2 LIVE LOAD PRESSURE. Lateral pressures from live loads are calculated for a point load acting on the surface of the backfill using the following equation:

$$\sigma_{hl} = Px^2z/R^5$$

where

P = vertical load

x = horizontal distance from load to wall and perpendicular to the wall

(Eq. 3)

z = vertical distance from load to point where stress is being calculated

$\mathbf{R} = \sqrt{\mathbf{x}^2 + \mathbf{y}^2 + \mathbf{z}^2}$

y = horizontal distance from load to wall, and parallel to the wall

A typical live load pressure distribution is shown in Figure 1b. Figure 2 illustrates live load stress calculations.

7.3 FABRIC TENSION. Tension in any fabric layer is equal to the lateral stress at the depth of the layer times the face area that the fabric must support. For a vertical fabric spacing of X, a unit width of fabric at depth d must support a force of $\sigma_h X$, where $\sigma_h X$ is the average total lateral pressure (composite of dead plus live load) over the vertical interval X .

7.4 PULLOUT RESISTANCE. A sufficient length of geotextile must be embedded behind the failure plane to resist pullout. Thus, in Figure 1a, only the length, Le, of fabric behind the failure plane AB would be used to resist pullout. Pullout resistance can be calculated from:

$$P_A = 2d\gamma \text{ TAN } 2/3\ \phi$$

where

P_A = pullout resistance

d = depth of retained soil below top of retaining wall

γ = unit weight of retained soil

ϕ = angle of internal friction of retained soil

L_e = length of embedment behind the failure plane

(Eq. 4)

It can be seen from this expression that pullout resistance is the product of the overburden pressure, γd, and the coefficient of friction between retained soil and fabric which is assumed to be TAN 2/3 Φ. This resistance is in pounds per square foot which is multiplied by the surface area of $2L_e$ for a unit width. Where different soils are used above and below the fabric layer, the expression is modified to account for different coefficients of friction for each soil:

$$P_A = d\ \gamma\ (\text{TAN } 2/3\ \phi_1 + \text{TAN } 2/3\ \gamma_2)$$

(Eq. 5)

8. DESIGN PROCEDURE. The recommended design procedure is discussed in the following steps. The calculations for the fabric dimensions for overlap, embedment length and vertical spacing should include a safety factor of 1.5 to 1.75 depending upon the confidence level in the strength parameters.

8.1 RETAINED SOIL PROPERTIES Φ AND γ. Only freedraining granular materials should be used as retained soil. The friction angle, Φ, will be determined using the direct shear (ASTM D 3080)

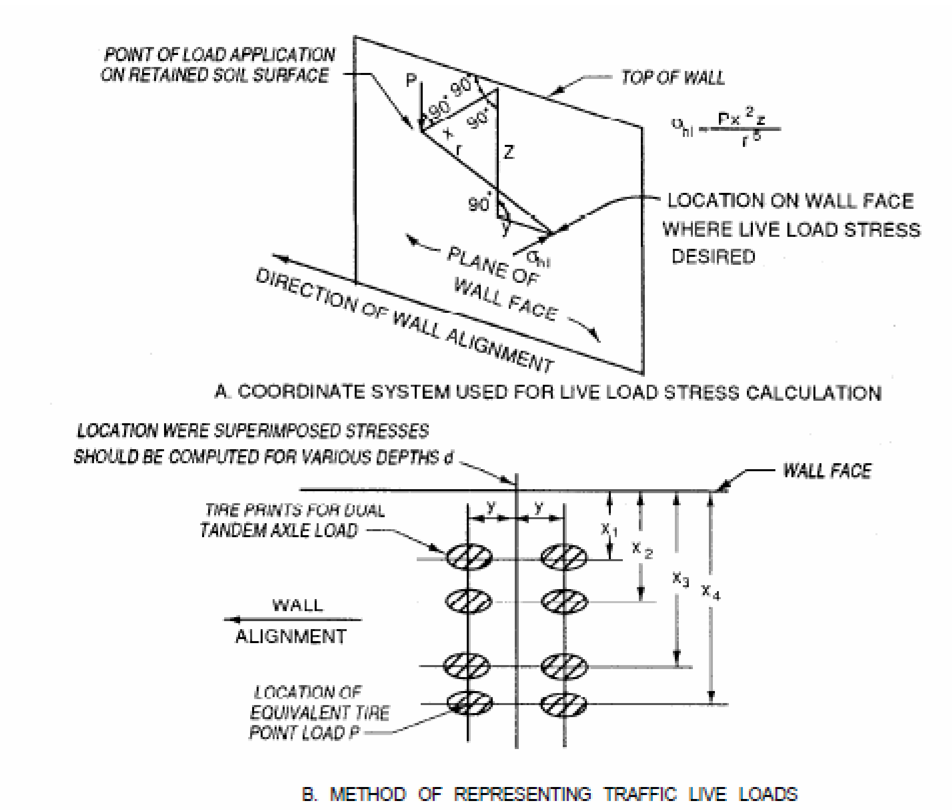

Figure 2

Procedures for Computing Live Load Stresses on

Geotextile Reinforced Retaining Walls

or triaxial tests (ASTM D 2850). The unit weight, γ, will be determined in a moisture density test (ASTM D 698). Generally, 95 percent of ASTM D 698 maximum density can be easily attained with granular materials. However, other densities can be specified so long as the friction angle used is consistent with that density. The saturated unit weight is used in lateral pressure calculations.

8.2 LATERAL EARTH PRESSURE DIAGRAM. Using the properties of the retained soil, calculate the pressure coefficient K_o = I x SIN Φ. The lateral earth pressure expression: $\sigma_{ho} = K_o\gamma h$, is used to calculate the triangular shaped pressure distribution curve for the height of the retaining wall desired.

8.3 LIVE LOAD LATERAL PRESSURE DIAGRAM. It is first necessary to determine the design load. Lateral pressure diagrams must be developed for each vehicle or other equipment expected to apply loads to the retaining wall using Equation 3. The equation is solved for each wheel and the results added to obtain the lateral pressure. This pressure is calculated at 2-foot vertical intervals over the height of the retaining wall. Normally, from one to three locations along the wall are checked to determine the most critical.

8.4 COMPOSITE PRESSURE DIAGRAM. The earth pressure and live load pressure diagrams are combined to develop the composite diagram used for design as shown in Figure 1b.

8.5 VERTICAL SPACING OF THE FABRIC LAYER. To determine the vertical strength of the fabric layer, the fabric allowable tensile strength, S, is set equal to the lateral force calculated from $\sigma_h X$, where σ_h is the lateral pressure at the middle of the layer. Thus, knowing the fabric tensile strength, the value of the fabric vertical spacing, X, can be calculated. The fabric strength should be divided by the appropriate safety factor. The equation for fabric spacing is:

$$X = \frac{S}{(F.S.)\sigma_h}$$ (Eq. 6)

8.6 LENGTH OF FABRIC REQUIRED TO DEVELOP PULLOUT RESISTANCE. The formula for pullout resistance, P_A = 2dγTAN 2/3Φ L_e, is used to solve for the pullout resistance which can be developed at a given depth geotextile length combination, or to solve for; the depth required to develop P_a. The usual case for walls is to set P_a equal to the geotextile strength and solve for, L_e, the length of the geotextile required. Thus, the expression would be:

$$L_e = \frac{P_A\,(F.S.)}{(2\ d\ \gamma\ TAN\ 2/3\ \phi)}$$

where

P_A = fabric tensile strength

F.S. = safety factor of 1.5 to 1.75

(Eq. 7)

The minimum length of the fabric required is 3 feet.

8.7 LENGTH OF FABRIC OVERLAP FOR THE FOLDED PORTION OF FABRIC AT THE FACE. The overlap, L_o , must be long enough to transfer the stress from the lower section of geotextile to the longer layer above. The pullout resistance of the geotextile is given by:

$$f = d_F\ \gamma\ TAN\ 2/3\ \phi\ L_o\ 2$$ (Eq. 8)

Where d_f = depth to overlap. Tension in the geotextile is:

$$T = \sigma_h\left(\frac{X}{2}\right)$$ (Eq. 9)

Since the factor of safety can be expressed as:

$$F.S. = \frac{f}{T} = \frac{d_F \gamma \tan 2/3 \phi L_o}{\sigma_h \left(\frac{x}{2}\right)} \qquad \text{(Eq. 10)}$$

This can be solved for the length of overlap required:

$$L_o = \frac{\sigma_h X \text{ (F.S.)}}{2 d_F \gamma \tan 2/3 \phi}$$

The minimum length of overlap should be 3 feet to ensure adequate contact between layers.

8.8 EXTERNAL WALL STABILITY. Once the internal stability of the structure is satisfied, the external stability against overturning, sliding and foundation bearing capacity should be checked. This is accomplished in the same manner as for a retaining wall without a geotextile. Overturning loads are developed from the lateral pressure diagram for the back of the wall. This may be different from the lateral pressure diagram used in checking internal stability, particularly due to placement of live loads. Overturning is checked by summing moments of external forces about the bottom at the face of the wall. Sliding along the base is checked by summing external horizontal forces. Bearing capacity is checked using standard foundation bearing capacity analysis. Theoretically, the fabric layers at the base could be shorter than at the top. However, because of external stability considerations, particularly sliding and bearing capacity, all fabric layers are normally of uniform width.

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