Geosynthetic Stabilized Earth using Compost Filter Socks for Sustainable Vegetated Walls and Slopes

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ABSTRACT

Common applications of compost filter socks have focused on placement along perimeters of construction sites or at intervals along slopes to detain and treat stormwater runoff. These mesh tubes filled with compost or other infill materials (e.g., municipal yard trimmings, wood chips, food residuals, biosolids, manure) provide three-dimensional filters that help retain sediment and other pollutants. However, these compost socks also can be used as a “greenscape” facing for geosynthetic stabilized earth structures, such as retaining walls and oversteepened slopes/embankments. Long-term slope stability is achieved through layers of geogrid reinforcement installed within the compacted backfill, while the compost socks at the face of the earth structure provide surface protection. The compost socks can be pre-seeded with selected seed varieties mixed in with the compost during the tube-filling process (along with specified nutrients as desired), or the freshly constructed wall/slope can be hydroseeded directly on the exposed surface of the compost socks. Geotechnical design of these green stabilized earth structures is discussed, along with examples of construction methods and LEED certification credits.

Key Words: compost sock, geosynthetic stabilized earth, sustainable retaining walls, LEED points

1 Introduction

Common applications of compost filter socks have focused on placement along perimeters of construction sites or at intervals along slopes to detain, divert, and treat stormwater runoff. They also often are used as stormwater inlet protection. These mesh tubes filled with compost materials (e.g., municipal yard trimmings, wood chips, food residuals, biosolids, manure) provide three-dimensional filters that help retain sediment and other pollutants. The sock fabric is comprised of much more durable synthetic materials than that found in the outer confinement netting of fiber wattles, which often are filled with wheat, rice, or flax straw. Due to their significant weight and contact area with the ground surface, compost socks do not require trenching and ground disturbance like other sediment control devices. Compost socks are flexible and conform readily to irregularities along the ground surface, and they can be filled on-site (typically by bark blower or auger-feed system) or can be pre-filled and then moved into position. In some situations, the compost socks can be filled at a distribution center, coiled onto pallets and then shipped to the site for unpacking and installation. The length of such individual coiled socks typically ranges from 4.5 to 7.5 m (15 to 25 ft).

If the compost socks installed at a site are considered to be “permanent”, then selected seeds can be added to the organic compost infilling which will germinate and establish vegetation in, through, and around the sock. The tubes also can be slit to allow for planting or sprigging. If the socks are considered temporary sediment control measures, then as the ground is stabilized and vegetated, the socks can be coiled and reused, or they can be cut open so the organic infill can be spread at the site and the sock fabric can be recycled.

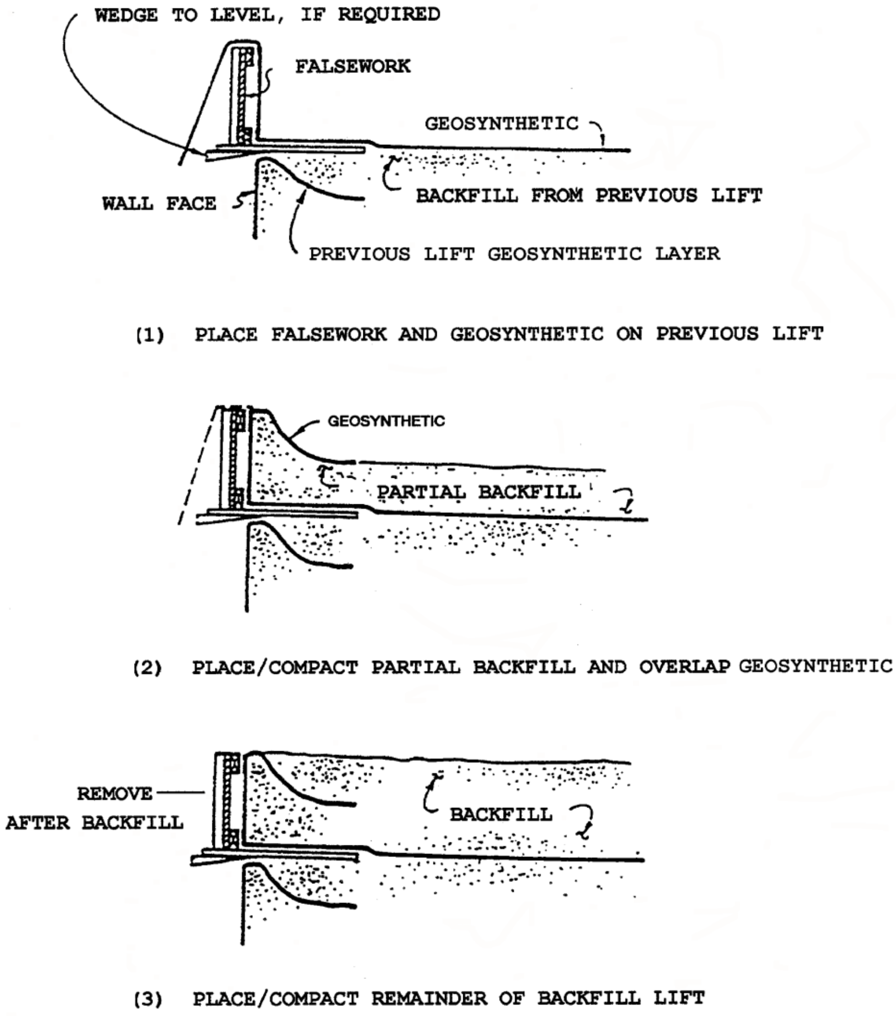
In most cases for the infilling material, it is desirable to prescribe a mature, stable compost that is compatible with the nutrient and pH requirements of current or planned vegetation at the site. Examples of recommended specifications for chemical and physical properties of compost infill are presented on the U.S. EPA website under its NPDES stormwater menu of BMPs (U.S. EPA, 2008).

For an entirely different application, these compost socks also can be used as a “greenscape” facing for geosynthetic stabilized earth structures, such as retaining walls and oversteepened slopes/embankments. Long-term slope stability is achieved through layers of geogrid reinforcement installed within the compacted backfill, while the compost socks at the face of the earth structure provide surface protection and organic growing media for establishing vegetation.

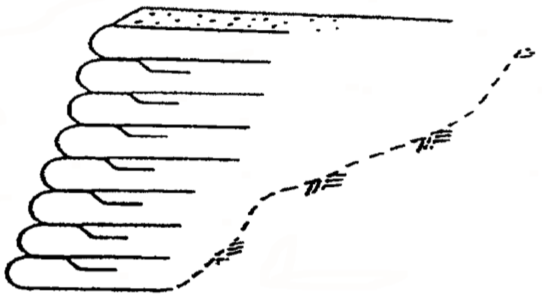
2 Engineering Concepts of Geosynthetic Stabilized Earth Structures

Soil reinforcement with layers or sheets of man-made inclusions, including geotextile fabrics and polymeric geogrids, has been used by geotechnical engineers for over 30 years. The use of such horizontal reinforcing elements in a compacted soil backfill allows for the construction of mechanically stabilized earth (MSE) structures that include steepened slopes (known as reinforced soil slopes, or RSS) and near-vertical walls (MSEW). The engineering concept behind these structures is that the geosynthetic sheets tie together the compacted backfill within the reinforced zone to form a large, coherent gravity mass that sufficiently resists the overturning and sliding forces that result from the active earth pressure applied by the retained soil in the slope. Though it is common to use pre-cast concrete panels or modular concrete blocks as a facing system for MSE structures, geosynthetic-wrapped facings also can be used (Figure 1). These often require a secondary, more permanent facing treatment, such as sprayed-on shotcrete or gunite on near-vertical faces and special seeding and erosion control treatments for reinforced slopes.

Geotechnical engineering design methods for MSE structures have been well documented (for example, see Koerner, 1998; U.S. DOT, 2001; and NCMA, 2009). Physical properties of the soils that comprise the reinforced zone, additional backfill areas, and the undisturbed zone in the retained slope must be described through field studies and laboratory testing to provide input for the design calculations. This requires that some site-specific field investigation and soil sampling be accomplished to describe the soils and collect representative specimens for subsequent laboratory testing. Though



(a) Lift construction sequence for geosynthetic-faced MSE walls and reinforced slopes.



(b) Finished MSE structure ready for facing protection of shotcrete or vegetation.

Figure 1. Example of geosynthetic-wrapped MSE structure (U.S. DOT, 2001).

various relevant tests may be prescribed by the responsible engineer at specific construction sites, a typical suite of tests might include some or all of the following:

1. Standard Practice for Classification of Soils for Engineering Purposes (ASTM D2487), or Standard Practice for Description and Identification of Soils (ASTM D2488)
2. Standard Test Methods for Atterberg Limits (ASTM D4813);
3. Standard Test Method for Particle-Size Analysis of Soils (ASTM D422);
4. Standard Test Method for Laboratory Compaction Characteristics of Soil (ASTM D698 or ASTM D1557);
5. Standard Test Method for In-Place Density and Water Content of Soil (ASTM D6938);
6. Standard Test Method for Direct Shear Test of Soils (if needed) (ASTM D3080);
7. Standard Test Method for pH of Soils (if needed) (ASTM D4972).

For MSE walls, backfill material in the reinforced zone should be reasonably free from organics and other deleterious materials, should have a PI (Plasticity Index, per ASTM D4813) of no more than 6, and should conform to the following gradation guidelines: 100 percent passing the ¾-inch sieve (19 mm), 0-60 percent passing the No. 40 sieve (0.425 mm), and 0-15 percent passing the No. 200 sieve (0.075 mm). For lesser quality backfill, soil properties must be evaluated thoroughly with respect to their influence on soil shear strength, soil interaction with geogrid, and drainage properties. In the case of RSS structures, lesser quality backfill that contains more fines (i.e., particles passing the No. 200 sieve) may be used, but a minimum soil frictional strength of 28^o is recommended (U.S. DOT, 2001).

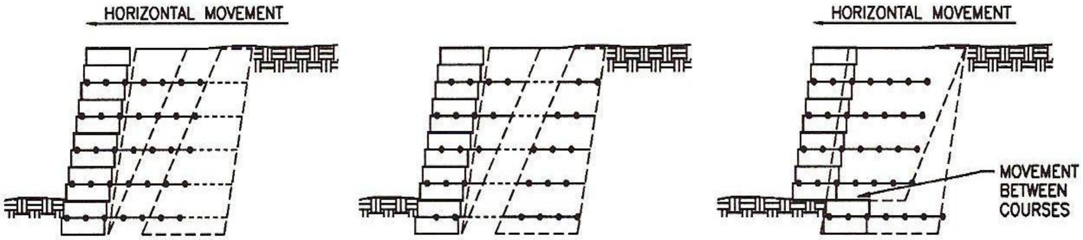
The measured or estimated soil properties (particularly the soil unit weight and shear strength) then can be used along with the geometry of the proposed MSE wall to conduct engineering stability analyses to design the structure. These calculations focus on internal stability (Figure 2), external stability (Figure 3), and compound stability, which involves a combination of one of the modes in Fig. 2 with a rotational failure surface similar to that shown in Fig. 3d (U.S. DOT, 2001; NCMA, 2009). Final design recommendations include backfill compaction specifications, the length of the geogrid-reinforced zone, the spacing layout of the geogrids, and the minimum LTDS (long-term design strength, in units of tensile force per linear width) required for the geogrids. Recommended vertical spacing intervals for the geogrids rarely exceed 0.4 to 0.6 m (16 – 24 inches) due to internal stability concerns. The design protocol for RSS structures is somewhat simpler and focuses primarily on potential rotational failure surfaces through and around the geogrid-reinforced zone. Due to the geogrid wrapping at the face, the layout typically includes primary and secondary reinforcement layers (Figure 4).

Compaction control during construction is critical to the long-term performance of these earth structures. For most projects, a nuclear moisture-density gage (per ASTM D6938) is used to confirm that the contractor is achieving the specified soil density via mechanical compaction of the granular backfill. That specified density value often is based on 95-percent of the maximum dry density according to ASTM D698 (standard compaction) or 90-percent of the maximum dry density according to ASTM D1557 (modified compaction).

3 Compost Socks Used as a Facing System

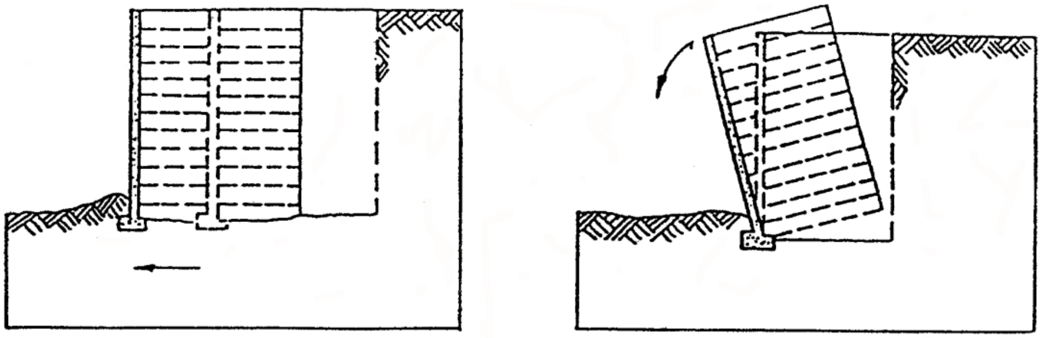
Geosynthetic-wrapped MSE and RSS structures also can be built using compost socks at the face, which often eliminates the need for temporary bracing and which expedites the construction process. As needed, stakes or cable anchors can be used for restraining the socks to prevent any displacement due to compaction activity behind them. Construction of such earth structures relies on wrapping the compost socks with geosynthetic fabric, preferably geogrid, and incorporating these wraps into the compacted backfill zone with a system similar to that shown in Figure 4. Geotechnical design methods are similar to those previously described, with the only major exception being the lighter weight of the facing units (say, 6.3 kN/m^3, or 40 lb/ft^3) as compared to modular concrete blocks (22.8 kN/m^3, or 145 lb/ft^3). Example calculations using Mathcad® (PTC, 2009) for external sliding and overturning, and for internal geogrid strength, are summarized in the Appendix.

This type of design tool is flexible and fast, allowing for the analysis of various slope configurations and soil conditions. Essentially, in addition to providing basic parameter inputs, the user also designates a value for a trial length of the geogrid-reinforced zone behind the wall facing. If this trial length turns out to be too short, then one or both of the design factor of safety values for sliding ($FS_{sliding}$ = 1.5) and for overturning (FS_{over} = 2.0) will not be attained in the analysis. The user then must increase the geogrid length until **both** computed factors meet or exceed the design values. The analysis also considers a regularly spaced geogrid interval to compute the minimum LTDS of the geogrid to prevent rupture. The example in the Appendix is based on a regular interval of 0.2 m (8 in.), which typically occurs in actual construction using a 0.23-m (9-in.) diameter compost sock (which compresses slightly) with geogrid installed at each construction lift. Incidentally, for efficient backfill compaction, the thickness for each compaction lift typically should not exceed 0.2 m (8 in.) for hand-operated compaction equipment.

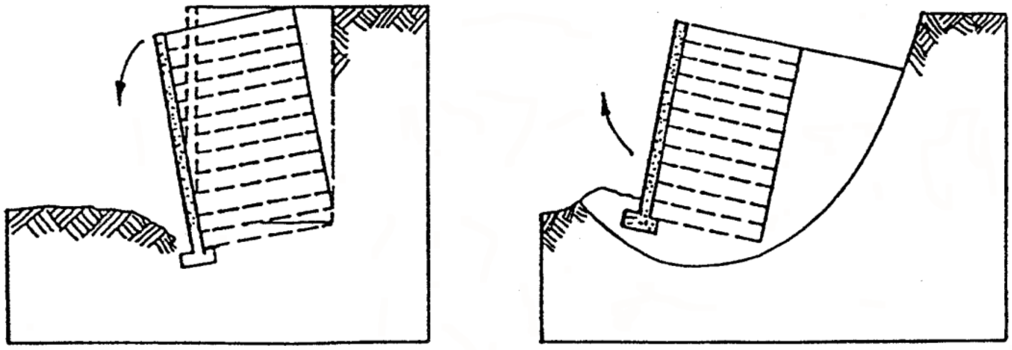


(a) Geogrid pullout (b) Geogrid rupture (c) Internal slip

Figure 2. Potential internal failure modes within the reinforced zone (adapted from NCMA, 1993).



(a) Sliding **(b) Overturning (eccentricity)**



(c) Bearing capacity **(d) Deep seated stability (Rotational)**

Figure 3. Potential external failure modes for MSE walls (U.S. DOT, 2001).

Figure 5 illustrates an example of a geosynthetic-wrapped MSE wall with compost socks at the face, depicting a project where a stabilized-earth structure provided an economical repair for a road embankment failure. Note that the length of the geogrid-reinforced zone behind the wall face is approximately 60 percent of the final wall height, which can be appropriate for MSE walls with a face angle of about 1H:3V (71^{o}) for good-quality, granular backfill and with a flat backslope above the wall. For steeper angles, a longer reinforced zone is required; for flatter angles, the structure would be considered a RSS and the geotechnical analysis and design would be somewhat different. To establish permanent grass vegetation on the slope face, like that shown in Figure 5b, grass seed can be included with the organic infill of the socks at the time of filling or it can be applied to the wall face via hydroseeding. In the latter case, specialized mulches and tackifiers are needed to successfully retain the mix on the slope face.

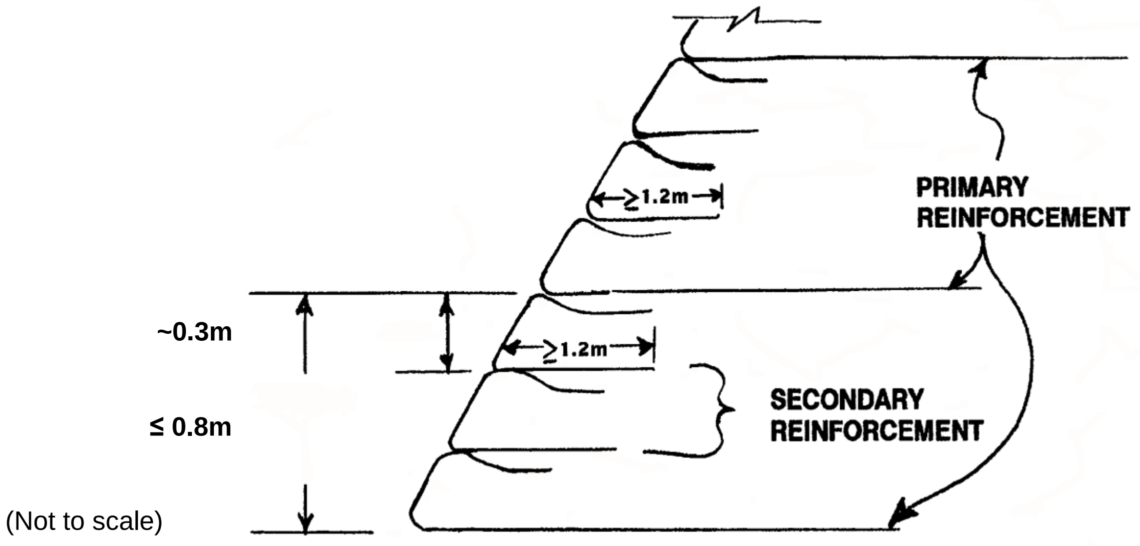


Figure 4. Typical geosynthetic reinforcement spacing layout for high RSS structures.

(a) Compost socks at the face are wrapped with geogrids incorporated into a compacted, reinforced zone of granular backfill.

(b) Completed MSE structure with new vegetation growth on the compost-sock facing.

Figure 5. Compost-sock facing used for a geosynthetic-wrapped MSE structure (photos courtesy of RST Environmental Solutions Ltd., Palmerston North, NZ).

For some projects, there may not be adequate space available behind the proposed final wall face to provide adequate length of the geogrid-reinforced zone to meet the design safety factor requirements. A hybrid approach that combines MSE and ground-anchor technology is well suited to this situation, and often provides a “green” solution that is more economical than relying solely on a comprehensive ground-anchor program to stabilize the slope. Depending on the geologic conditions, ground anchors may consists of grouted soil nails, pneumatically-shot soil nails, helical anchors, driven shoe-type anchors, grouted tie-back anchors, or rock bolts/dowels. A critical component of this hybrid wall system is the manner in which the geogrid sheets are attached to the ground anchors. One option is to use a high-strength steel mesh attached to the temporary exposed face using the extended heads of the anchors (Figure 6). The short geogrid wraps then are tied (using steel wire, clamps, or rings) to this wire mesh as needed. The engineering analysis for this system involves using the effective tensile load that could be transferred from the geogrid to the anchors, a force that resists both sliding and overturning of the sock-faced, shortened geogrid-reinforced zone.

(a) Due to inadequate space for a wide enough reinforced backfill zone, short geogrid wraps are attached to a slope-anchoring system based on soil nails installed in the backslope.

(b) Completed sock-faced structure built up to the desired grade.

(c) Permanent vegetation established on the compost-sock facing of the slope.

Figure 6. Compost-sock facing used for a geosynthetic-wrapped, hybrid MSE and anchored structure (photos courtesy of RST Environmental Solutions Ltd., Palmerston North, NZ).

A potentially more flexible and construction-friendly compost sock option for facing MSE and RSS structures is a tubular sock module with integrated geogrid extensions, known as the BioSock-SSE™ (U.S. Patent Pending). This module consists of a 1.4-m long, double-walled compost sock with a geogrid wrap pre-attached during the manufacturing process using two high-strength, multiple-stitched seams, one along the top and one along the bottom when referenced to the module's installed horizontal position. The geogrid extensions typically are 1-m long, but can be longer if needed. Within the granular backfill zone immediately behind each row of modules, the geogrid extensions are interlocked within the backfill to provide a coherent, stabilized-earth structure that can be built 2 to 2.5 meters high. For taller walls and slopes, supplemental geogrid layers can be added during compaction of the backfill to extend the length of the reinforced zone by sandwiching them between consecutive module geogrid extensions within the granular interlock zone (Figure 7).

A typical construction sequence for a modular sock wall is illustrated in Figure 8. Like traditional compost socks, these smaller modules can be filled on-site or also pre-filled and then palletized and shipped to the construction site. If the infill material includes seeds, then modules need to be installed in the field immediately to prevent undesirable germination during storage. Distinct advantages of the modules include: 1) they are self-contained, "all-in-one" units that include the growing media contained within the sock and the attached geogrid extensions ready for installation; 2) their light weight (compared to concrete blocks) and portability make them easy to transport and install, especially in remote areas or sites with difficult access; 3) they can form fairly tight curves in the wall face by cutting the geogrid extensions normal to the sock and spreading them to form a concave curve or overlapping them to form a convex curve; 4) they can be plumbed with drip-irrigation tubing for controlled delivery of water if needed.

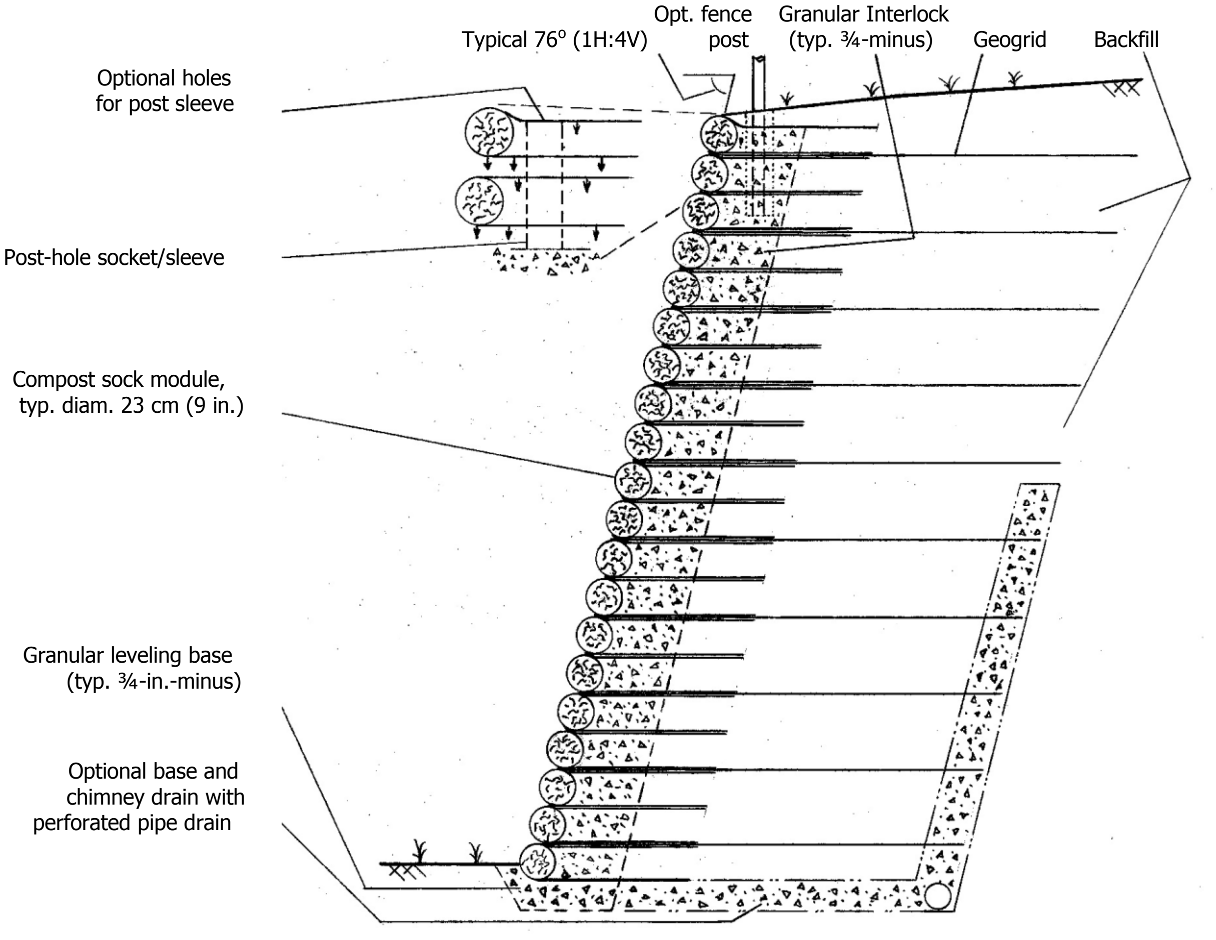


Figure 7. Example of sock-module earth retaining system with supplemental geogrids to extend the length of the reinforced zone (not to scale).

(a) Granular fill applied on top of the lower geogrid extension of first module row.

(d) After adding a thin layer of granular fill, the next row of modules is placed, and so on.

(b) Compaction of layer/lift of granular backfill behind module (no bracing form needed).

(e) Hydromulch and seed are applied to the final sock-module MSE wall.

(c) Upper geogrid extension of module is laid back over the backfill and smoothed.

(f) Vegetated, sock-module MSE wall several weeks after completion.

Figure 8. Typical MSE construction sequence using sock modules with integrated geogrid extensions.

4 Stabilization and Vegetation Options

As previously noted, compost socks used as a facing system provide a growth medium at the slope surface to support and sustain vegetation germinated from seeds or stolons mixed in with the organic infill material or applied to the wall face by hydromulching and hydroseeding. In addition, live cuttings/sprigs from shrubs and small trees (e.g., willow, osier, poplar) or from vines and creepers can be incorporated into the face by inserting them directly into the socks through cut slits or between subsequent vertical construction lifts as the earth structure is built. Thus, such seeds and/or cuttings will establish a vegetative community that provides long-term surface stability as the compost socks gradually degrade. The sock facing not only provides nutrients and grow media, but it also provides an immediate barrier of protection against soil erosion at the face of the wall or slope without any additional treatments or applications required (such as shotcrete/gunite or erosion control blankets). Thus, soil erosion and rilling are totally eliminated as new vegetation becomes established.

Such stabilized earth structures can be especially effective for stream-bank stabilization systems, because the compost sock facing provides initial comprehensive protection against erosion and scour while serving as a stable growth medium to establish vegetation. For socks to be submerged and installed below seasonal or permanent water levels along streams, lake shorelines, and coastal areas, the infill material can be primarily coarse sand or gravel to provide sufficient density and longevity. In areas that may be environmentally sensitive, it may be preferable to use a biodegradable, organic fabric for the sock portion of the module. This would allow the exposed portion of the sock to slowly and naturally biodegrade, while the geogrid wrap/extensions would have much greater longevity to protect new vegetation established on the face and to maintain the required earth-support elements within the reinforced soil mass behind the face.

Another potential "stabilization" issue with these sock-faced walls is their susceptibility to combustion and fire damage during wildfires. Because these slope components are geosynthetic materials, they can be severely damaged or destroyed by fire. If the threat of wildfires is a concern at a given installation site, then fire retardant treatments can be applied to the geosynthetics during the manufacturing process and/or added as a surface coating after they have been produced.

5 LEED Credits and Points

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System$^{\text{TM}}$ is a third-party certification program and serves as the nationally accepted benchmark for the design, construction, and operation of high-performance green buildings. LEED points that comprise the certification system can be earned by the use of compost socks to construct green walls and steep slopes to preserve or increase useable area at a site, to form shorelines or banks along natural or man-made water bodies (e.g., for stormwater management), and to help reduce the carbon footprint of landscape systems by establishing vegetation on earth-retention structures that normally would be hardscaped. For new construction and major renovations, a minimum of 40 points is required to achieve LEED certification for "green" building projects.

Potential LEED categories for credits and points that may be awarded for the application of compost filter socks as a vegetative facing for geosynthetic stabilized earth structures include:

Category: Sustainable Sites

Credit 5.1	Site Development – Protect or Restore Habitat	Points: 1
Credit 5.2	Site Development – Maximize Open Space	Points: 1
Credit 6.1	Stormwater Design – Quantity Control	Points: 1
Credit 6.2	Stormwater Design – Quality Control	Points: 1

Category: Water Efficiency

Credit 1	Water Efficient Landscaping *(drip irrigation in modules)*	Points: 2-4
Credit 2	Water Use Reduction *(irrigate modules with wastewater)*	Points: 2-4

Category: Materials and Resources

Credit 4	Recycled Content *(both the sock fabric and the infill)*	Points: 1-2
Credit 5	Regional Materials *(use of local compost in socks)*	Points: 1-2

Category: Innovation in Design

Credit 1	Innovation in Design	Points: 1-5

Thus, with careful planning and coordinated design efforts between the engineer and landscape architect, 8 to 12 LEED points easily could be awarded for sock-faced MSE structures, and up to 21 points could be realized if the water efficiency credits are applicable.

6 Summary

Compost filter socks can provide an economic “greenscape” facing for geosynthetic stabilized earth structures in the form of stable, vegetated retaining walls and over-steepened slopes. The socks provide a contained growth medium for new vegetation while serving as a protective slope facing that prevents soil erosion. Stability of the earth structure is achieved by geogrid sheets wrapped around the socks and embedded within a granular, compacted backfill soil. Small, portable sock modules with integrated geogrid extensions provide an alternative to the wrapped-face system and can speed up the construction process, especially for remote sites or for those sites with difficult access.

Engineering experience with these types of sock-faced MSE walls has shown that the critical element in the geotechnical design typically is the factor of safety against sliding ($FS_{sliding}$) when external stability controls the design (for example, see the sample calculations in the Appendix). Thus, the practical remedy for marginally stable MSE walls during the design process is to increase the frictional resistance along the base of the reinforced structure by increasing the length of the reinforced zone by using longer geogrids and/or by adding a base layer of compacted, high-strength granular fill (e.g., ¾-in.-minus crushed rock) as shown in Figure 7. Also, these green MSE walls and RSS structures (e.g., per Figs. 5-8) are engineered structures and must be designed and built by capable and qualified personnel.

Sock-faced MSE structures provide green, sustainable options for owners and designers. With proper planning and design, such structures also are eligible for LEED points in four different categories when incorporated into new construction or major renovations.

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Appendix: Analysis of Modular Sock Wall with Granular Interlock Zone

Wall 2.13 m fin. ht. (7.0 ft), Face angle 76, 11 rows of modules, 5H:1V backslope

Wall batter angle: $\beta := 14$

Backslope angle: $b := 11$

Vert. wall face ht.: $h := 7.3$ ft

Wall sock thickness/depth: $t_b := 0.75$ ft

Thickness of granular-lock zone: $t_c := 2.0$ ft

Length of geogrid reinf. zone behind wall: $L := 3.2$ ft

Soil friction angle: $\phi := 26$

Gravel friction angle: $\phi_g := 38$

Total unit wt. of soil: $\gamma := 125$ pcf

Reinf. soil unit weight: $\gamma_r := 125$ pcf

Total unit wt. of gravel: $\gamma_c := 138$ pcf

Wall sock unit wt.: $\gamma_f := 42$ pcf

Optional surcharge: $q := 0$ psf

Number of rows: $N := 11$

Foundation base friction angle $\phi_b := 0.75 \cdot \phi_g = 28.5$

Soil/wall interface friction angle $\phi_w := .667 \cdot \phi = 17.3$

$° := \mathrm{deg}$

Effective height (with reinf. zone): $H := h + L \cdot \tan(b \cdot °) = 7.92$ ft

Reinf. soil dist. (horz.) excl. gravel zone: $t := L - t_c = 1.20$ ft

Active Earth Pressure Coef.

$$K_a := \frac{\cos[(\phi + \beta) \cdot °]^2}{\cos(\beta \cdot °)^2 \cdot \mathrm{COSB} \cdot \left[1 + \sqrt{\dfrac{\sin\left[\left|\phi + \phi_w\right| \cdot °\right] \cdot \sin[(\phi - b) \cdot °]}{\mathrm{COSB} \cdot \cos[(\beta + b) \cdot °]}}\right]^2}$$

$\boxed{K_a = 0.2998}$

Earth-Pressure Force $F_a := 0.5H^2 \cdot \gamma \cdot K_a$ $F_a = 1175.97$ lb/ft

FOS design criteria: Sliding > 1.5 Overturning > 2.0 $\boxed{FS_s = 1.634}$ $\boxed{FS_o = 3.660}$

Min. LTDS for reg.-spaced geogrid:

Enter vert. thickness of grid support zone: $t_z := 1.333$ ft

Req. Grid Force starting with lowest grid and next 3 layers:

$$F_g := \left|F_h + F_{qg}\right| \qquad F_g = \begin{pmatrix} 352.0 \\ 285.6 \\ 219.1 \\ 152.6 \end{pmatrix} \text{ lb/ft}$$

$$\text{Req. Grid } \mathrm{LTDS} := 1.5 \cdot F_g \qquad \mathrm{LTDS} = \begin{pmatrix} 528 \\ 428 \\ 329 \\ 229 \end{pmatrix} \text{ lb/ft}$$

Notes: Req. burial of first row of modules is 0.3 ft. Thickness of interlock zone is 2 ft.
Geogrid reinforcement zone is 3.0 wide behind modules (lowest geogrid needs min. LTDS of 530 lb/ft), with no supplemental (extended) geogid needed.
Gravel foundation should be 3.0-ft wide and 0.5-ft thick.
If needed, a perforated drain pipe is installed at base of gravel zone to provide lateral drainage of ground water to exit at lowest point of wall foundation.