EB701 - ENGINEERED WRAP-FACE VEGETATED SOLUTION FOR CONSTRUCTING REINFORCED-EARTH WALLS AND STEEPENED SLOPES

INTRODUCTION

Soil reinforcement using sheets of embedded inclusions, such as steel-wire grids, woven geotextile fabrics, and polymeric geogrids, has significantly advanced geotechnical design and construction practices in the earthwork industry over the past 40 years. Installing planar, horizontal reinforcing elements in a constrained, compacted soil fill is the basis for constructing Mechanically Stabilized Earth (MSE) structures that include steepened slopes, known as Reinforced Soil Slopes (RSS), and near-vertical retaining walls.

In recent years, as site conditions allow, project designers have sought vegetated facing on these structures rather than traditional hardscape systems (i.e., concrete panels, modular blocks, shotcrete, or rock filled wire-frame units). In response, new patented technology has been developed to provide a vegetated facing option using PYRAMAT® 75, a pyramidal-woven, High-Performance Turf Reinforcement Mat (HPTRM), in conjunction with fiber-composite internal braces.

This advancement in wrap-face MSE construction eliminates the need for temporary external bracing (formwork) or for facing elements comprised of metallic wire-frame units, which traditionally have served as a bulkhead to allow mechanical compaction of backfill soil directly behind the face. In many cases, on-site soil can be used for infill, provided it contains little organic detritus and does not include fine-grained elastic soil. Vegetation can be seeded or planted during construction or post-construction, depending on the specific application and site conditions. Straight and curved alignments are possible, and this wrap-face system is especially well-suited to streambank, wetland, littoral and coastal applications, as well as for landslide remediation or as wing walls for Geosynthetic Reinforced Soil – Integrated Bridge System (GRS – IBS) construction.

COMPONENTS AND CAPABILITIES

By design, PYRAMAT 75 enhances vegetation establishment and root-system reinforcement while providing sufficient strength and durability for excellent long-term performance of PYRAWALL™ Engineered Wrap-Face Vegetated Solution. The bracing components are made of a high-strength, fiber-composite material. The bracings are woven through the PYRAMAT 75 (Figure 1) and assembled to stand-up the fabric at the face to allow soil filling and compaction for each lift.

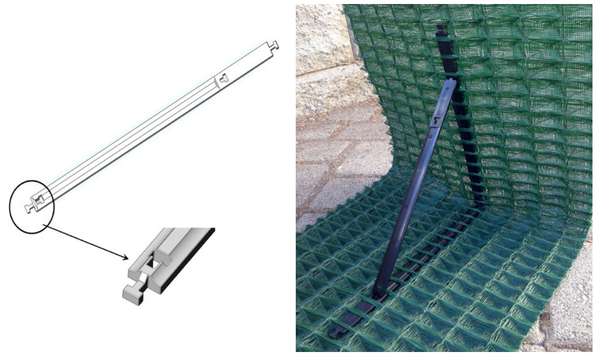

Figure 1 - Fiber-composite bars are threaded through the fabric and snapped together to form an internal brace

PYRAMAT 75 provides a typical wrap layer along the bottom, 1 foot for the near-vertical face, and the remaining material folded back over the compacted soil infill. This layered wrap-face system produces a reinforced soil mass, which is designed to resist lateral earth pressures and provides excellent erosion protection as vegetation is established (Figure 2). If additional reinforcement is required within the backfill zone, geogrids or woven geotextiles can be placed in-between successive lifts and extended back as far as needed to meet geotechnical design criteria. For a traditional RSS application, the additional geosynthetic materials serve as the primary reinforcement and the PYRAMAT 75 wraps at the face serve as secondary reinforcement.

Figure 2 - Constructed and vegetated PYRAWALL

The steepest suggested face angle for PYRAWALL is 1H:4V (76°), though vegetation establishment typically is enhanced when the angle is 1H:3V (71.5°) or less. PYRAWALL should be founded directly on native soil or approved structural fill. Because PYRAWALL is flexible, curves can be incorporated along the wall or slope alignment. This can be achieved

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for each successive lift by cutting the horizontal PYRAMAT 75 sections perpendicular to the wall face, and then spreading or overlapping the fabric accordingly (Figure 3).

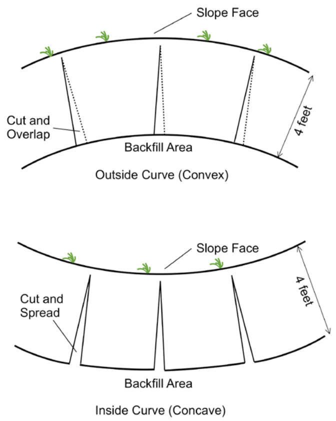

Figure 3 - PYRAWALL with curved section

DESIGN CONCEPTS

The reinforced soil mass must resist the lateral earth pressure due to the retained soil as well as any lateral contribution from surcharge loading in the backslope area. The lateral earth-pressure force, F_a, measured in force per unit length of wall face is estimated using the Coulomb active earth pressure coefficient K_a given by:

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

where: β= batter angle of wall (inclination of wall face from vertical)

Φ_w = friction angle at wall-soil interface (typically 0.67Φ)

Φ = friction angle of retained soil

u = backslope angle

Using standard geotechnical engineering practice, the lateral earth-pressure force is:

$$F_a = 0.5\ \gamma\ H^2\ K_a$$

where γ = unit weight (density) of retained soil; H = height of wall system.

Lateral force due to any surcharge loading applied in the backslope area is:

$$F_q = q\ H\ K_a$$

where H = height of wall system; q = surcharge loading.

These forces tend to overturn the geosynthetic wrap-wall system or cause it to slide horizontally outward along its base and therefore must be sufficiently resisted by the weight of the reinforced soil mass and its internal strength to provide long-term stability.

The geotechnical analysis focuses on providing adequate reinforcing length (L) to generate the required frictional resistance along the base and to have a L/H ratio high enough to resist overturning. Given the typical reinforcing length of 4 to 4.5 feet (1.2 to 1.4 meters) for PYRAWALL®, the recommended maximum wall height is 10 feet (3.0 meters) for typical site and soil conditions as shown in Table 1 (Miller, 2016a).

Table 1. Maximum recommended PYRAWALL® height for 1H:4V (76°) face and no surcharge

Backslope Angle [1]	Soil Friction Angle (°)				
	27	28	30	32	34
Flat, 0°	7 ft (2.1 m)	8 ft (2.4 m)	10 ft (3.0 m)	10 ft (3.0 m)	10 ft (3.0 m)
8H:1V, 7.1°	6 ft (1.8 m)	7 ft (2.1 m)	8 ft (2.4 m)	10 ft (3.0 m)	10 ft (3.0 m)
6H:1V, 9.5°	5 ft (1.5 m)	6 ft (1.8 m)	8 ft (2.4 m)	10 ft (3.0 m)	10 ft (3.0 m)
4H:1V, 14.0°	4 ft (1.2 m)	5 ft (1.5 m)	7 ft (2.1 m)	9 ft (2.7 m)	10 ft (3.0 m)
3H:1V, 18.4°	3 ft (0.9 m)	4 ft (1.2 m)	6 ft (1.8 m)	7 ft (2.1 m)	10 ft (3.0 m)
2.5H:1V, 21.8°	2 ft (0.6 m)	3 ft (0.9 m)	4 ft (1.2 m)	6 ft (1.8 m)	9 ft (2.7 m)
2H:1V, 26.6°	NR[2]	NR[2]	2 ft (0.6 m)	4 ft (1.2 m)	7 ft (2.1 m)

Notes:
1. General results based on external stability analysis for base sliding and overturning; designer also must consider local conditions and global stability for these wall geometries
2. Not Recommended

For internal stability, the geosynthetic reinforcement must have sufficient embedment length behind the line of maximum tensile force to resist horizontal forces F_{ah} and F_{qh}. The geosynthetic reinforcement must also have proper vertical spacing and have adequate tensile strength to resist lateral earth forces expected. The restraining force due to the embedded geosynthetic (i.e., anchorage capacity) is (NCMA, 1996):

$$F_{gr} = 2\ (L_e)\ (C_i)\ (d)\ (\gamma)\ \tan(\Phi)$$

where F_{gr} = restraining force of the geosynthetic per unit width;

L_e = embedment length behind line of maximum tensile force (refer to Figure 3);

d = depth to the geosynthetic from the ground surface;

γ= moist unit weight of the infill soil;

Φ= friction angle of the infill soil;

C_i = unitless coefficient of interaction between backfill soil and the geosynthetic, typically 0.75 for clay/silt, 0.85 for sand, 0.90 for gravel and coarse sand.

The reinforcements of PYRAWALL are uniformly spaced

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vertically at 1-foot (0.3-meter) intervals. Internal stability is then realized with L_e = 1 foot (0.3 meters) for typical PYRAWALL conditions up to a maximum recommended height of 10 feet (3 meters) per Table 2.

Table 2. Calculated factor of safety (FOS) against geosynthetic pullout for PYRAWALL 10-feet high with 76° face angle and flat backslope

Depth (ft)	Soil Friction Angle 30°			Soil Friction Angle 27°		
	P_{ah} (lb/ft)	F_{gr} (lb/ft)[1]	FOS[2]	P_{ah} (lb/ft)	F_{gr} (lb/ft)[1]	FOS[2]
5	124	554	4.47	146	489	3.35
6	149	665	4.46	175	587	3.35
7	174	776	4.46	205	685	3.34
8	198	887	4.48	234	783	3.35
9	344	998	2.90	405	882	2.18

Notes:
1. Assuming L_e = 1 foot and coefficient of interaction C_i = 0.80
2. Minimum FOS for accepted design criteria is 1.5

For PYRAWALL applications of height greater than 10 feet (3.0 meters) (Figure 4), the PYRAMAT 75 serves as secondary reinforcement near the face, reducing the load on the primary reinforcement and the facing, as well as redistributing potential high facing loads due to seismic loads or high surcharge loads (Frankenberger, et al., 2017; Leshchinsky, et al. 2016; Leshchinsky, et al. 2017). PYRAWALL provides geotechnically-sound, vegetated alternatives to traditional hardscape-faced structures

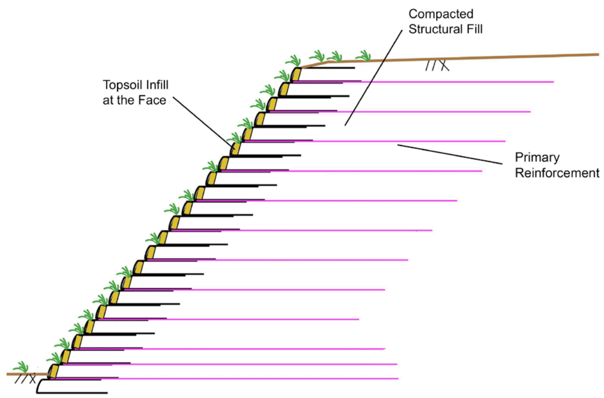

Figure 4 - PYRAWALL reinforced soil slope with additional geosynthetic layers

Global stability analysis must consider potential failure surfaces external to the reinforced-soil zone, as well as those passing through the reinforced zone (i.e., internal compound stability). Depending on face angle, backslope angle, soil strength, and reinforcement strength, the critical failure path (the one having the minimum computed FOS value) may or may not pass through the reinforced zone.

ADDITIONAL APPLICATIONS

PYRAWALL provides an economical, green alternative for wing walls on GRS-IBS projects. Abutment slopes/walls directly beneath the bridge generally comprise modular block walls or gabion walls to protect against stream scour, and because lack of sunlight and moisture often preclude a vegetated alternative. However, such hardscape facings easily can transition to a green option for the wing walls.

If a steep slope is required for new construction or for a slope remediation project involving soil nails or anchors (Miller, 2017), then PYRAWALL can serve as a vegetated "veneer" covering (Figure 5). PYRAWALL can provide a durable, permeable, and vegetated face rather than a more typical hardscape, such as shotcrete. Such projects proceed with top-down construction to install the soil nails or anchors to the desired elevation, where a narrow working bench is established. PYRAWALL then is constructed from the working bench upward, with the back end of the material attached to soil nails or anchors. In many cases, on-site soil may be acceptable for the wrap-face infill, and thus, native soil excavated to install the soil nails or anchors and form the working bench can be re-used for wall backfill.

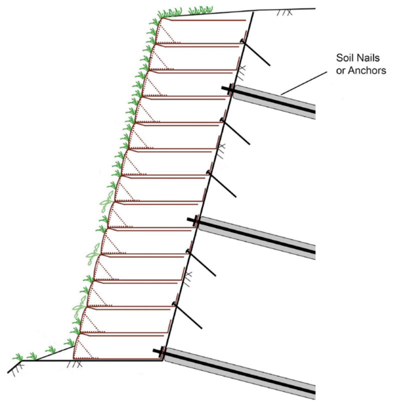

Figure 5 - PYRAWALL as vegetated facing for a steep anchored slope

For riverbank or shoreline applications, often the lower wrap lifts that are planned to be below average water level are filled with coarse granular backfill to allow free movement of water. Overlying lifts transition to finer-grained infill soil above the waterline to support wetland vegetation. PYRAWALL also is ideal for saltwater applications because the geosynthetic components are essentially environmentally inert and immune to corrosion.

VEGETATION ESTABLISHMENT

During infilling of each wrap lift, seeds or stolons can be added to the soil directly behind the fabric at the face. This process results in excellent growth media at the face where it is needed, and structural fill soil (organic and detritus free) within the reinforced zone. If desired, additional seeding can be achieved post-construction by hydroseeding the completed PYRAWALL. Besides seeded grass, other vegetation comprising bare-root stock of vines or small shrubs, or cuttings from meristem-rich plants can be inserted between wrap layers during construction with their leafy tops protruding out of the face. If needed, temporary irrigation can be used to help new plantings get established.

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SUMMARY

Potential projects for PYRAWALL range from small landscaping enhancements for residential and commercial properties to large-scale earthwork grading needed for transportation, land-development, and landfill projects, as well as for GRS-IBS bridge projects and landslide repairs. No external temporary formwork is needed to place, fill, and compact the PYRAWALL lifts. In many cases, the on-site soil can be used for the infill, provided it contains little organic detritus and does not include fine-grained elastic soil. Vegetation can be seeded or planted during construction or post-construction, depending on the specific application and site conditions. Straight and curved alignments are possible, and PYRAWALL is especially well-suited to streambank, wetland, shoreline, and coastal applications.

For remote project areas or those heavily wooded or steep sites with difficult equipment access, the ability to easily transport or carry geosynthetic materials to the site is an advantage over heavier conventional solutions. Once the site is prepared PYRAWALL can be installed. If the planned PYRAWALL is no higher than 7 feet, then over-excavation is limited and the PYRAWALL serves both as the primary reinforcement and the facing.

Note that site investigation and characterization of geotechnical soil properties always are required to provide reasonable confidence in the wall/slope design. Construction oversight and monitoring is strongly recommended to confirm the site conditions concur with those assumed in the design analysis and to verify that construction practices follow the engineering design and specifications.

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