EB214 - ENGINEERED SOLUTION FOR SLOPE STABILITY

INTRODUCTION

This Engineering Bulletin is a summary of a more detailed paper prepared by Propex Operating Company, LLC (Propex) and Intermountain GeoEnvironmental Services, Inc. 1 The original paper, which contains a compilation of research, design methodology, and references related to slope stability may be obtained from Propex.

The stability of slopes has the ability to greatly impact the state of the surrounding infrastructure, positively by supporting that infrastructure or negatively, causing collateral damage from economic loss to loss of life. Typical means for slope stabilization can be costly and aesthetically unpleasing. An Anchor Reinforced Vegetation System (ARVS) has the ability to stabilize a slope in a cost effective and aesthetic manner. An ARVS employs the use of a High Performance Turf Reinforcement Mat (HPTRM) permanently secured with Percussion Driven Earth Anchors (PDEAs) to promote vegetation, reduce erosion, and improve slope stability.

SLOPE INSTABILITY

A slope becomes unstable causing a soil mass to mobilize when the shear stress acting on the soil becomes greater than the shear strength of the soil. There are many factors that can affect the shear strength of soil and many circumstances can place additional shear stresses on soil. Due to the large amount of variables impacting the stability of a slope it is almost impossible to find the sole cause of slope mobilization. The implementation of measures to correct one or two key failure mechanisms, however, has been effective in slope stabilization. While erosion, the detachment, transportation, and deposition of soil particles, can be a factor affecting slope stability it must be differentiated from slope failure, the mobilization and sliding of a large soil mass (Figure 1).

Figure 1 - Slope Failure

MODES OF FAILURE AND REINFORCEMENT

When a slope fails it tends to do so by one of two modes, translational or rotational failure. Translational failure is described as a sliding mass of soil along a plane of failure parallel to the surface of the slope. Typically, this is when the length of the failure is greater than 10 times the depth of failure. Rotational failure is described as a deep-seated sloughing of a larger mass of soil along a plane of failure of a circular shape. The incorporation of PDEAs can assist in remediating either type of failure by passively increasing the shear resistance of the soil (Figure 2).

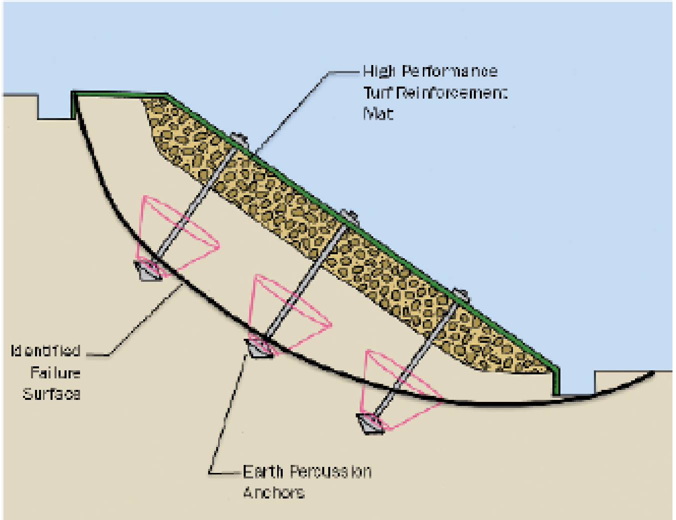

Figure 2 - ARVS Crosvs-Section Anchoring Past Failure Plane

SLOPE STABILITY ANALYSIS

While utilizing the passive force of PDEAs to resist shear and lateral forces related with soil mobilization, an ARVS also utilizes an HPTRM to help distribute these resisting forces as well as control erosion. When evaluating the stability of a slope a comparison of driving forces (those causing slope failure) and resisting forces (those preventing slope failure) must be made. This comparison, shown as a ratio of resisting forces to driving forces, is known as a Factor of Safety (FS), where a value below is a statically unstable slope.

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Generally accepted FS criteria have been developed by the United States Army Corps of Engineers (USACE) for different conditions (Table 1).

Condition	Minimum Factor of Safety
Long-term Stability (Drained)	1.5
End of Construction (Undrained)	1.3
Rapid Drawdown (Undrained)	1.1 to 1.3

Table 1 - Minimum Factors of Safety, USACE

A minimum FS should be selected by the engineer based on criteria such as project type, degree of uncertainty, and critical nature of the project. The engineer must also determine the mode of failure, or potential failure, in order to analyze the slope appropriately. The mode of failure can be qualitatively determined by visual inspection or interpretation of the slope geometry and soil information. Both existing and proposed slope geometry must also be known in order to correctly asses the slopes current and proposed stability. Along with the minimum FS, mode of failure, and slope geometry, the engineer must also determine appropriate soil properties, having the following collected at minimum:

- Soil classification
- Soil unit weight (in situ and saturated)
- Soil shear strength (drained or undrained, as applicable) from direct shear or triaxial tests
- Presence of ground water and distance from surface
- Analysis of soil-water interaction and influence on pore water pressure
- Existence of and vertical location of partially weathered rock and/or bedrock
- Computation of linear strength envelope (Mohr-Coulomb criteria)

ANCHOR REINFORCED VEGETATION SYSTEM

The engineered solution of an ARVS utilizes an HPTRM in conjunction with PDEAs at a prescribed frequency and depth to perform three main functions. The PDEAs are utilized as passive reinforcement to increase the shear stress of the soil, resisting the driving forces. The HPTRM works to distribute the load throughout the PDEAs to further resist the driving forces and acts to establish and reinforce the slope vegetation, improving the long term stability of the slope and impeding erosion.

The material composition of the HPTRM incorporated in the ARVS is crucial for successful slope stabilization. This HPTRM should be a homogeneous, lofty, three-dimensional matrix of tightly woven polypropylene fibers. The engineer should avoid specifying a non-homogeneous HPTRM composed of various materials stitched or glued together and should require an engineered design report incorporating the entire ARVS showing the improved FS. Much consideration should be made into the tensile strength, ultraviolet (UV) stability, flexibility, and light penetration of the HPTRM. Minimum requirements should include tensile strength of 3,000 lb/ft (ASTM D-6818), UV stability of 90% strength retained at 6,000 hours (ASTM D-4355), and a light penetration of 20% maximum(ASTM D-6567) in order to demonstrate a 50 year design life. HPTRMs having polypropylene fibers of a trilobal (clover-shaped) cross-section provide additional means of capturing sediment, seeds, and moisture, ultimately offer superior vegetative establishment, and should therefore be utilized.

The PDEA utilized in an ARVS can vary in size ranging from 3.5 inches to 10 inches, in length ranging from 3 feet to 12 feet, and in strength ranging from 300 lbs to 5,000 lbs. The strength is quantified as a value known as "pull out" resistance and is completely dependent upon the anchor size and soil characteristics. This pull out resistance is utilized in the slope stability analysis and can be estimated based on geotechnical data but should be validated by in situ anchor load testing. The engineer should require that the corrosion resistance of the entire PDEA assembly exceed a 50 year design life.

ARVS INSTALLATION AND VEGETATION CONSIDERATIONS

The installation frequency or spacing of PDEAs is a result of the slope stability analysis. PDEAs are typically installed in a staggered pattern, creating a checkerboard effect. HPTRM roll edge overlaps should be a minimum of 3 inches, secured with PDEAs according to the prescribed pattern accompanied by securing pins on 12 inch centers (Figure 3) Figure 1.

The installation of PDEAs involve the use of a percussion hammer and PDEA specific drive steel to install the PDEA through the HPTRM and into the soil to the appropriate embedment depth. Once driven, the PDEA can then be tensioned to set the anchor. This process turns the anchor head to be parallel to the slope face and locks the anchor in place. The setting of the anchor creates a cone of compressive resistance above the anchor head, known as a frustum cone. For more information on installation and testing of PDEAs please see the "Anchor Load Test Manual" from Propex.

The vegetation establishment of the ARVS is critical to long term performance, providing a matrix of woven HPTRM trilobal fibers, roots, stems, and soil to serve as a securing mechanism for the ARVS to the slope face. The vegetation establishment method should be carefully considered as a critical component of the design of the ARVS. When an ARVS is installed on a slope of 3H:1V or flatter the HPTRM can be soil filled with a maximum of 1.5 inches of organic topsoil to provide an additional growth medium for the vegetation.

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However, for slopes steeper than 3H:1V soil filling should not be considered. Instead, vegetation approaches such as broadcast or hydraulically applied seed under the HPTRM or secured sod above the HPTRM should be considered. If the ARVS is to be installed where vegetation establishment is not feasible it is recommended that a light weight nonwoven geotextile with substantial UV resistance be installed below the HPTRM to mitigate the movement of fine soil particles through the ARVS while still providing a porous medium to facilitate proper drainage.

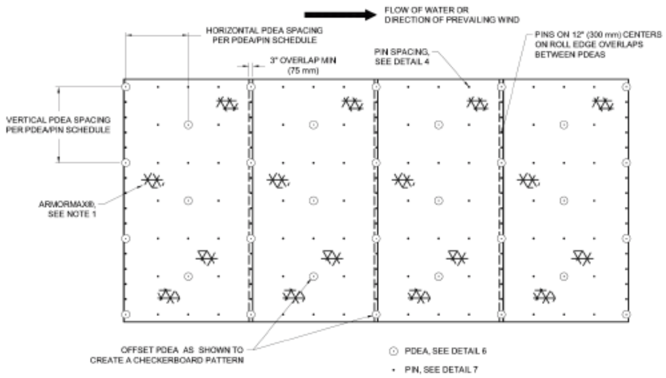

Figure 3 - Typical Anchor / Pin Pattern

SUMMARY

The use of an ARVS for slope stabilization can be an aesthetic and cost effective solution to a real problem in our infrastructure. Utilizing an HPTRM to promote vegetation and control erosion and utilizing PDEAs to improve slope stability as an ARVS is a truly engineered solution. For additional design support and installation consideration please contact Propex's Engineering Services at (423) 553-2450 or at InfrastructureSolutions@propexglobal.com

References

1. Durham, Andy. Hartley, Kent A. Glass, David A. 2012. The Anchor Reinforced Vegetation System (ARVS) as an Engineered Solution for Slope Stability: Design Methodology with a Practical Case Study Example.

2. U.S. Army Corps of Engineers. 2003. Slope Stability. Engineer Manual 1110-2-1902, U.S. Army Corps of Engineers, Washington, D.C. Print.