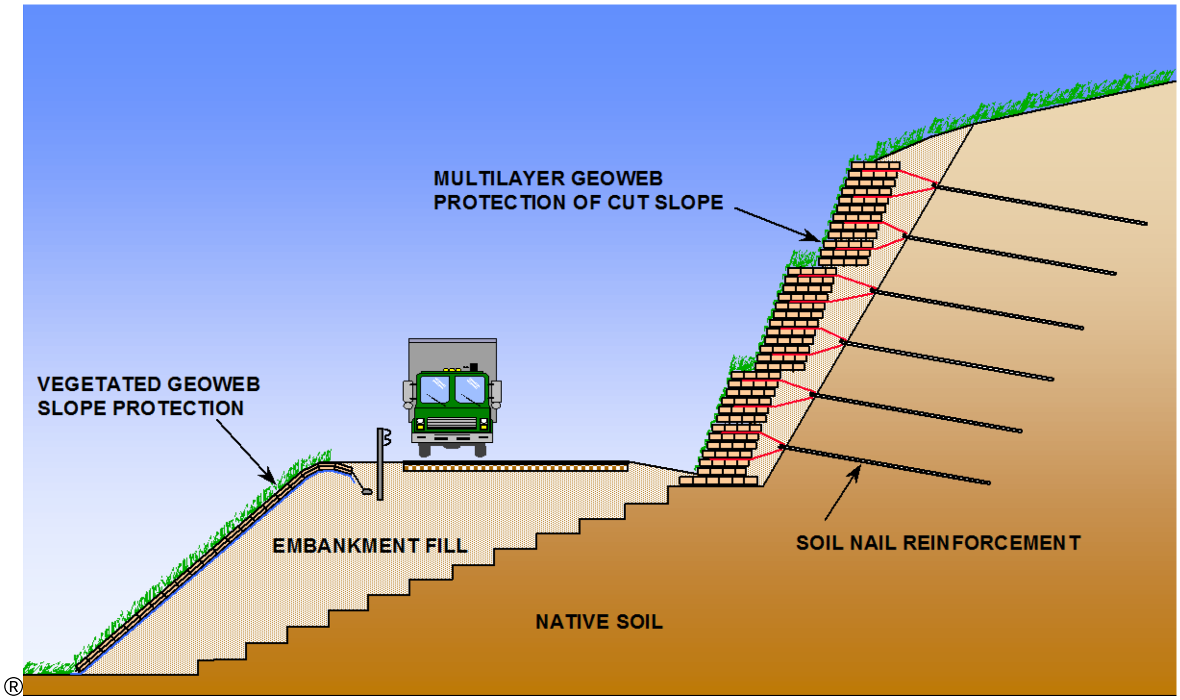
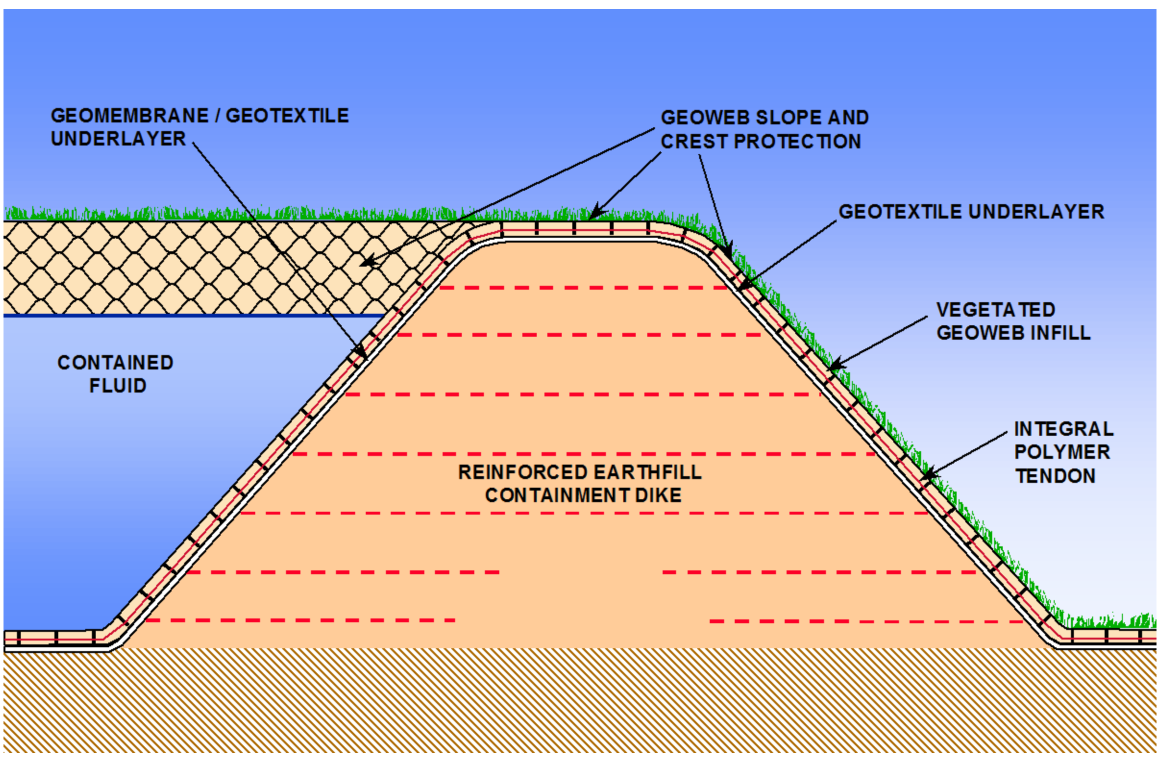
PRESTO GEOSYSTEMS

GEOWEB®

SLOPE PROTECTION SYSTEM

TECHNICAL OVERVIEW





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Introduction

The Geoweb Cellular Confinement System offers a broad range of surface protection treatments for slopes that are subjected to erosive forces. The inherent flexibility of the system, combined with a variety of simple, yet positive anchoring techniques, permits the application of vegetated, aggregate and hard surface materials to steep slopes.

By ensuring the long-term stability and effectiveness of slope cover materials, the integrity of underlying soils can be guaranteed and appropriate aesthetic standards maintained. The Geoweb system provides the ability to fully vegetate slope surfaces that could not otherwise support plant life.

Outlined are common causes of slope surface instability, and recommended design procedures and construction details which relate to specific structures and conditions.

Examples of Geoweb Slope Surface Stabilization

Embankment slopes	Cut slopes	Shoreline revetments
Containment dikes and levees	Dam faces and spillways	Landfill caps
Abutment protection	Earth covered structures	

Surface Instability - Identifying Problems and Defining Causes

General Surface Erosion Problems

Rainfall Impact and Run-Off Detachment and transportation of soil particles down slope in suspension as run-off flows concentrate. Rills and gullies form and expand as soil loss progresses. Rainfall intensity, potential soil erosion, slope steepness, and type of cover condition control the rate and extent of such erosion.

Localized Surface Instability Problems

Groundwater Seepage Drainage of ground-water from the slope can create high localized seepage pressures that result in soil piping as particles are washed out from the slope cover layer. This action undermines adjacent material leading to progressive degradation of the slope surface.

Freeze-Thaw Conditions Cyclic freezing and thawing of slope soils can trap lenses of free water or soil slurry between frozen cover materials and subsoil producing zones of low shear resistance. This condition can result in the down-slope movement of sections of the cover material that would otherwise be stable.

Wave Impact and Run-Up Hydrodynamic impingement, combined with high velocity up-rush and back-flow, imposes high stress on the slope cover materials. Cyclic hydraulic-uplift-forces further destabilize cover materials and allow displacement and loss of both armoring and underlying soils.

Ice Action Shoreline and dam face revetments can be subjected to severe abrasion and uplift stresses due to movement of adjacent ice fields. Wind-generated impact and the flotation of adhered ice formations during water level fluctuations can be particularly damaging.

General Slope Cover Instability Problems

Steep Slope Cover Addition of vegetated topsoil or hard armoring to existing or reinforced steep slopes requires special slope cover anchorage methods. Examples include (1) slopes that are steeper than the natural angle of repose of the cover material and (2) slope inclinations that exceed the interface friction angle of the cover material and subsoil.

Geomembrane Protection Geomembrane and geotextile slope covers can render a protective soil cover unstable due to the relatively low coefficient-of-friction of many geosynthetics. Stability can be further reduced if the cover is saturated, subjected to wave impact and uplift forces, or surcharged with additional fill or snow loads.

Absence or Loss of Toe Support The stability of a slope cover layer may depend on the end-bearing support at the toe of slope. Scour in the lower sections of the slope can destabilize the entire protective cover. Similarly, crest anchorage in place of toe support can cause protection of the upper part of a long submerged slope.

Inadequate Crest Anchorage Integrated, flexible slope protection can be secured with crest anchors in place of conventional toe support. This is particularly advantageous when protecting only the upper part of a long submerged slope. Inadequate crest anchorage can result in general slope cover instability.

Geoweb Slope Stabilization Systems - Key Components

Key components of the Geoweb System are indicated in Figure 1. A discussion of the interdependence of these components and sub-components, where appropriate, follows:

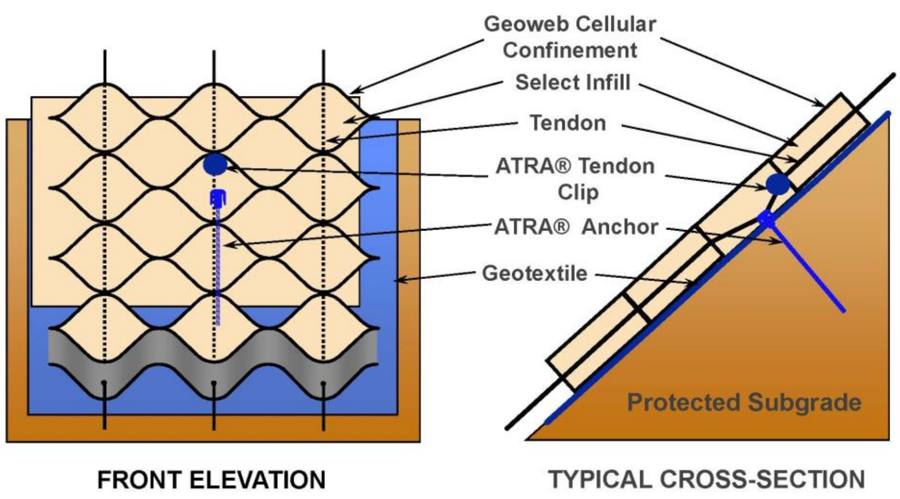
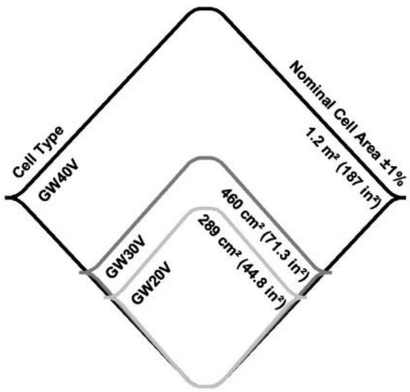


Figure 1 Key Components of the Geoweb Slope Protection System

Geoweb Cellular Confinement Sections – Cell Sizes & Depths



Nominal cell depths available are:

75 mm (3 in)
100 mm (4 in)
150 mm (6 in)
200 mm (8 in)
300 mm (12 in)

Figure 2 Geoweb Cell Sizes

Select Infill Materials

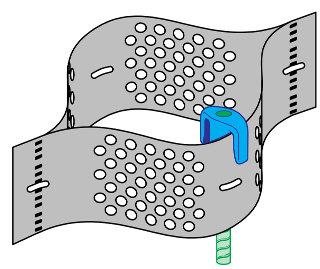
Specific solutions to given problems require a range of infill materials including:

- Topsoil with various selected vegetation
- Aggregates including sand, gravel and rock
- Engineering infill consisting of topsoil and aggregate
- Concrete of various strengths and surface finishes
- Combinations of the above to meet special conditions

ATRA® Anchors

ATRA Anchors consist of a standard 0.5 inch (13 mm) steel reinforcing rod with an ATRA Stake Clip attached as an end cap. ATRA Anchors are driven into the sub grade so the arm of the ATRA Stake Clip engages with the top of the cell wall.

Spacing and quantity of individual ATRA Anchors with each Geoweb section is determined through static analysis methods available from Presto Geosystems.



Integral Tendons

A variety of standard tendons (TP = woven polyester, TK = woven Kevlar®), covering a range of tensile strengths are available to meet specific anchorage requirements. Refer to Table 1 for tendon descriptions.

Spacing and quantity of individual tendons within each Geoweb section is determined through static analysis methods available from Presto Geosystems.

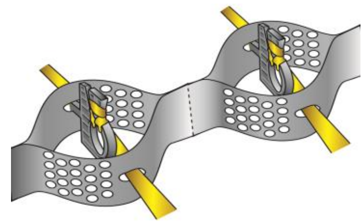
Table 1 Typical Tendons

Reference Name	Minimum Break Strength
TP-31	3.11 kN (700 lbf)
TP-67	6.70 kN (1500 lbf)
TP-93	9.30 kN (2090 lbf)
TK-89	8.90 kN (2000 lbf)
TK-133	13.34 kN (3000 lbf)
TK-178	17.7 kN (4000 lbf)

ATRA® Tendon Clips

The ATRA Tendon Clip is a molded, high strength polyethylene device with a locking member and post to transfer weight from the tendons to the cell walls.

Spacing and quantity of the ATRA Tendon Clips with each Geoweb section is determined through static analysis methods available from Presto Geosystems.



Ground Anchors

Geoweb slope protection systems can be secured with an array of surface anchors or crest anchorage systems to meet design requirements and sub grade conditions. Typical anchorage methods include ATRA Anchors or Tendons/ATRA Tendon Clips/Deadman. Special high capacity anchors (Duckbill® and Helical) can be included in situations where high uplift forces and extreme slope angles are involved.

The most commonly used types of anchors are illustrated in Figure 3. Anchor details are determined through static analysis methods available from Presto Geosystems.

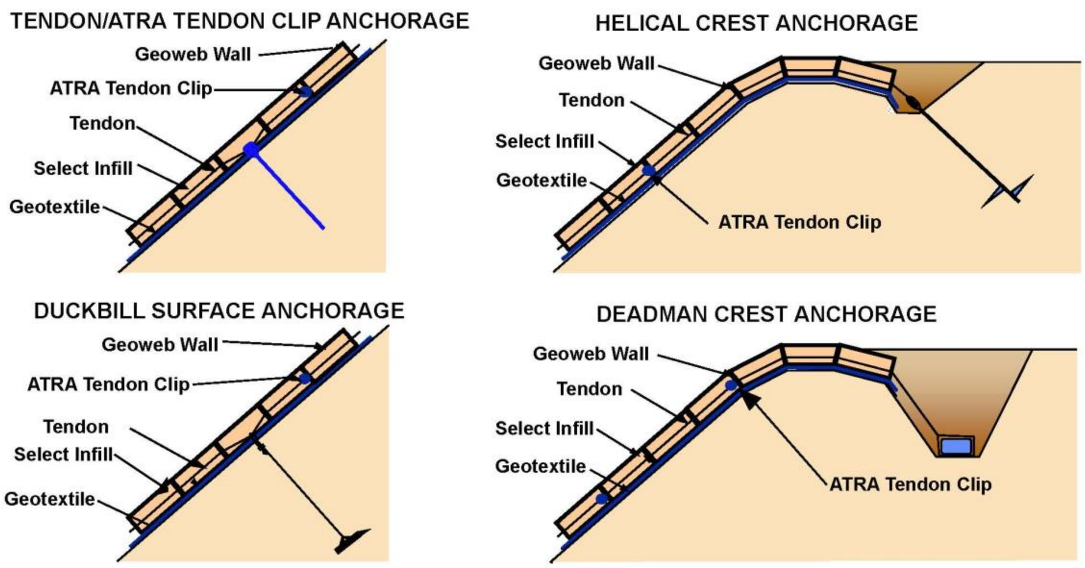


Figure 3 Typical Geoweb Anchorage Schemes

Woven and Non-Woven Geotextile Separation Layer

Installation of a suitable geotextile below the Geoweb confinement system may be required in some slope protection installations. The geotextile separation layer can perform a number of important functions that include:

- In-plane drainage of groundwater seepage from the slope sub grade.
- Confinement and filtration of sub grade soil particles.
- Reinforcement of root-mass with vegetated infill.
- Mechanical protection of underlying geomembranes.
- Tensile reinforcement of slope protection system.

Surface Treatments

Specific solutions to given problems may also require a range of surface treatment materials including:

- Spray applied polymeric and natural binders
- Hydro seeding
- Erosion control blankets
- Turf reinforcement mats
- Concrete grouts

Geoweb Slope Stabilization Systems - Design Considerations

Analysis of Slope Cover Stability

The natural tendency of a protective cover layer to slide down-slope is resisted by the frictional resistance at the interface of the system and the sub grade soil. The sliding resistance of composite systems, which incorporate geomembrane and/or geotextile separation layer, can be limited by relatively low coefficients of friction associated with such geosynthetic materials.

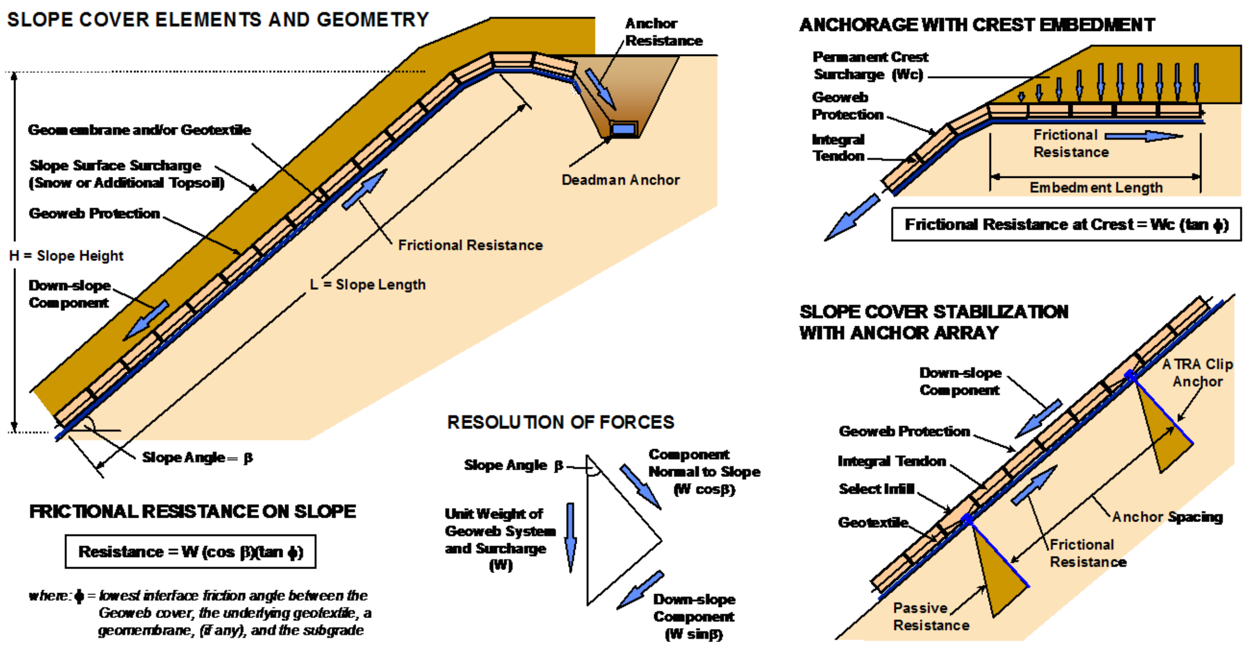


Figure 4 Stability Analysis of the Geoweb Slope Protection System

As slope angle increases, the down-slope component of the covers self-weight exceeds the available frictional resistance, thereby necessitating additional anchorage. ATRA Anchors and/or tendons provide effective means of supplying the required restraint.

ATRA Anchors within the Geoweb cell (see Figure 3) is a common form of slope cover anchorage for shallow slopes. Analysis involves determination of the maximum contributory area of slope cover that can be supported by an individual ATRA Anchor.

Tendons and crest anchorage of an entire slope cover can be incorporated for steeper slopes or when installation of surface anchors is impractical and perforation of the underlying geosynthetic layer is unacceptable. A number of crest anchorage schemes, including deadman anchors and embedment of the tendon Geoweb system at the crest of slope, can be employed. See Figure 3 and Figure 4.

Concentrated Surface Flow

Geoweb protected slopes that are subjected to concentrated surface flows require evaluation of maximum potential flow velocities, depths of flow and hydraulic shear stresses. The limiting hydraulic shear resistance of the specified Geoweb infill materials and the total tractive force applied to the cover, as a whole, must also be determined. Additional system anchorage may be required in some situations.

Wave Attack

Slopes that are exposed to wave attack must be designed to resist hydraulic uplift forces generated by wave impact and rapid water-level fluctuations. Empirical data relating to concrete revetments of varying weight, geometry and flexibility are generally employed in the design of these structures. Anchoring schemes, which resist uplift forces, can be incorporated to increase system stability.

Geoweb System with Vegetated Topsoil infill

General

Well-established vegetation is recognized as an effective and attractive form of protection for slopes that are exposed to mild or moderate surface erosion. However, the overall effectiveness of vegetated covers can be compromised if persistent or concentrated surface run-off occurs. Such flows can progressively remove soil particles from the root zone, creating rills and gullies that ultimately destroy the protection.

Benefits of Cellular Confinement

- The Geoweb cell walls, which contain the topsoil infill, form a series of *check-dams* extending throughout the protected slope. Normal rill development, produced when concentrated flow cuts into the soil, is prevented since flow is continuously redirected to the surface. This mechanism also disrupts flow velocity and hence the erosive force of run-off.
- A predetermined depth of topsoil and the developing vegetative root mass is contained and protected within the individual cells. Roots readily penetrate through the non-woven geotextile separation layer into the subsoil, thereby creating an integrated, blanket reinforcement throughout the slope surface.
- In arid regions, it has been observed that Geoweb cells can enhance the development of indigenous vegetation by retaining a higher proportion of available moisture in the near-surface soil zone.

Design Guidelines - General

- Partial emptying of cells can be expected when infill materials naturally consolidate or become saturated prior to establishment of vegetation.
- Un-vegetated installations should be protected with an erosion control blanket or turf reinforcement mat to protect exposed topsoil if precipitation is expected before vegetation is established.
- Degradable erosion blankets can be used in areas where rapid development of the turf is expected.
- Vegetated topsoil infill is recommended in situations where surface flows are intermittent, and of relatively short duration (< 48 hours). A peak velocity of 8.1 m/s (26.5 ft/s) and a peak shear stress of 77 kg/m² (15.9 lbf/ft°) can be sustained for intermittent flows when the vegetated cover is well established.
- All surface treatments (degradable blankets, erosion control blankets, turf reinforcement mats, etc) shall be selected and installed in accordance with Manufacturer's guidelines.

Cell Size Selection

- Slope steepness, intensity of surface run-off, and the minimum expected angle of repose of the infill material are the most important factors when selecting cell size. The following cell size recommendations assume that full vegetative cover will be established prior to exposure to design run-off conditions. GW40V cell Geoweb is normally suitable with vegetated topsoil infill when slope angles are below 22° (2.5H:1V) and moderate run-off intensities are anticipated. Slopes steeper than 22° (2.5H:1V) or exposure to severe or concentrated flow conditions, require GW30V and sometimes GW20V cell Geoweb. See Figure 2 for Geoweb cell size details.

- Cell depth required for vegetated protection is 75 mm (3 in), provided the subsoil will support root development and slope angles are below 22° (2.5H:1V). Slopes steeper than 22° require a cell depth of at least 100 mm (4 in). Situations that could require greater cell depths include; re-vegetation of rock slopes, applications with highly erodible soils and support of vegetated slopes in arid regions.
- Hydraulic action prior to full development of vegetation within the cells can result in loss, settlement or reshaping of infill soils as shown in Figure 5. The relationship between geometrical variables can be expressed as:

$$\phi = \beta - \arctan\left(\frac{d - d_e}{L}\right) \text{ or}$$

$$d = L \tan(\beta - \phi) + d_e \text{ where:}$$

ϕ = minimum angle of repose of the infill material,
β = slope angle,
d = depth of the cell (mm),
L = length of the cell (mm),
d_e = minimum acceptable depth (mm) of infill material.

The recommended minimum d_e is ½ d. The appropriate Geoweb cell size and depth based on a d_e of ½ d can be determined using Figure 6.

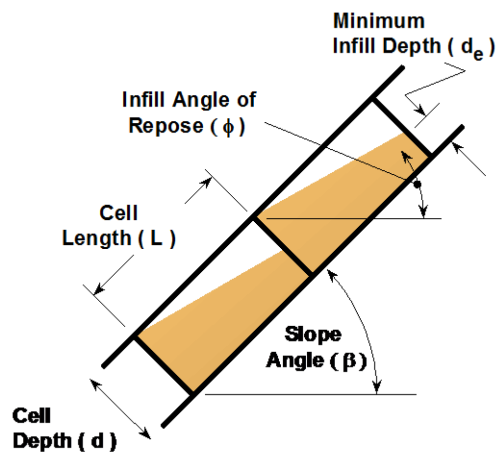


Figure 5 Determination of Minimum Cell Depth

Surface Anchorage

- Typical surface anchorage for re-vegetation of earth slopes includes ATRA Anchors and/or tendons based on the slope angle, geotextile separation layer and sub grade soils. Complete anchorage recommendations are determined through static analysis methods available from Presto Geosystems.
- Special slope anchorage requirements should be determined in accordance with guidelines presented in the section on Special Anchorage Methods

Geoweb System with Aggregate Infill

General

Crushed aggregate can provide effective slope protection provided the slope angle is less than the angle of repose of the aggregate infill material. It is important to ensure that adequate toe support is provided to prevent undermining of the loose aggregate further up the slope. Concentrated runoff can erode channels within the cover material if hydrodynamic forces are excessive. It is very important that the aggregate is crushed and not rounded to enhance cell lock-up.

Benefits of Cellular Confinement

- Confinement of aggregate within Geoweb cells allow for the use of smaller aggregate to resist velocities typically associated with larger, more costly rip rap. Typical reduction in rip rap size is at least 30% smaller than rip-rip as sized by the Abt and Johnson (1991) and at least 50% smaller than the size recommended by USACE (1994) method. This is especially important in areas where larger rock is not locally available.
- Confinement of aggregate within Geoweb cells permits use on steeper slopes than would otherwise be possible. The slope angle may exceed the angle of repose of the infill material when completely full cells are not essential. A wide range of aggregate infill/slope geometry combinations can be accommodated by selecting the appropriate cell size and cell depth for the aggregate in question. Refer to Figure 6.

- Aggregate-filled Geoweb slope protection can tolerate more intense sheet-flow conditions than unconfined aggregate cover layers. The cell walls prevent channeling that could otherwise develop within the cover layer by limiting localized flow concentrations and increasing hydraulic shear stresses.
- The erosion resistance of aggregate-filled Geoweb sections can be increased without losing the inherent flexibility of the system by the application of a concrete surface grout.

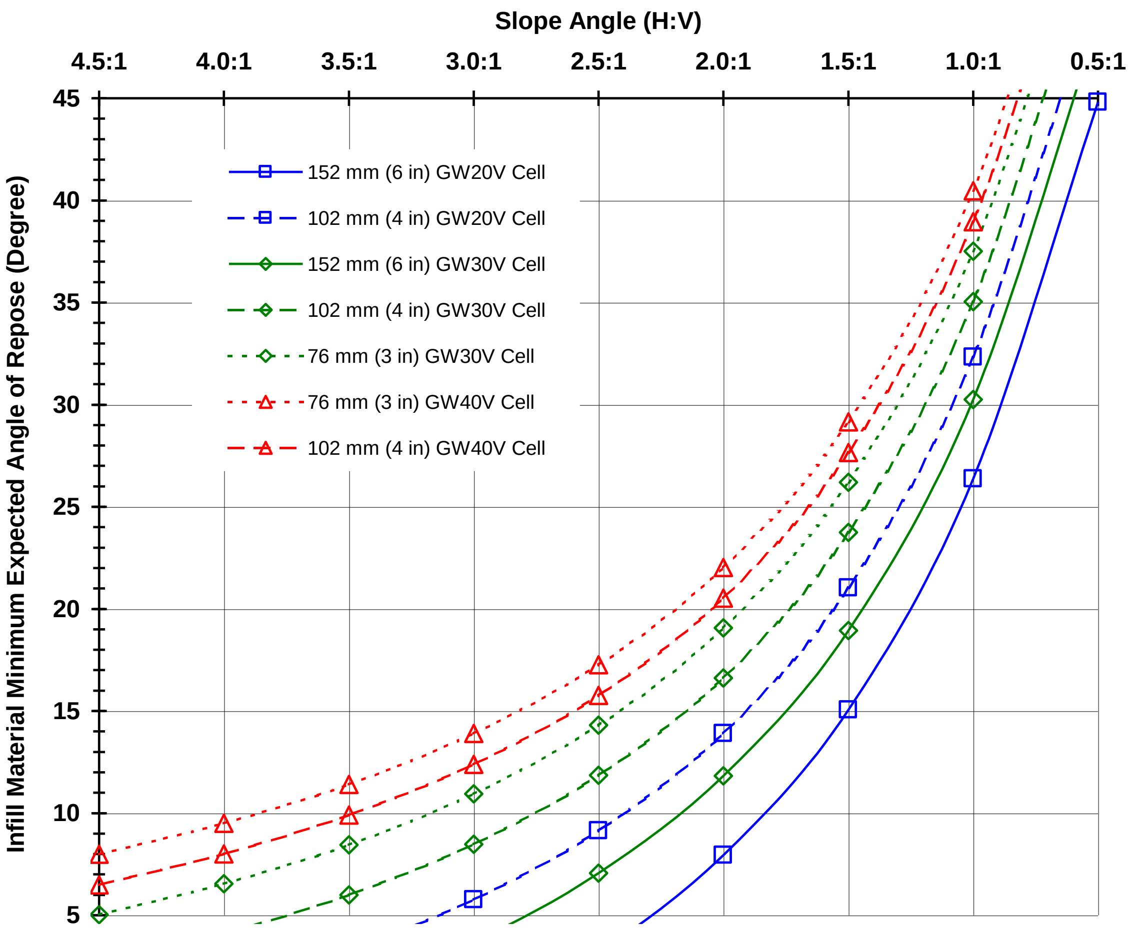


Figure 6 Geoweb Type Selection for Various Slopes and Infills

Design Guidelines

- Loose aggregate infill materials are effective as slope covers however, they should not be exposed to severe surface flows or wave action. Maximum aggregate sizes that are recommended for each Geoweb cell size and depth are shown in Table 2.
- When concrete grout is applied to the surface of aggregate infill to increase erosion resistance, a minimum grout penetration depth of 25 mm (1 in) is recommended. The fines should be limited to enhance grout penetration.
- A non-woven geotextile separation layer 200 - 300 g/m^2 (6 - 8 oz/yd^2) is recommended to prevent loss of fine-grained subsoil particles. The pore opening size of the geotextile should not exceed the d_{85} of the protected subsoil.

Cell Size Selection

- Choice of Geoweb cell size is directly related to the maximum particle size of the aggregate infill:

Table 2 Maximum Recommended Aggregate Size

Geoweb Cell Depth	75 mm (3 in)	100 mm (4 in)	150 mm (6 in)	200 mm (8 in)
GW20V Cell	50 mm (2 in)	75 mm (3 in)	75 mm (3 in)	75 mm (3 in)
GW30V Cell	50 mm (2 in)	75 mm (3 in)	100 mm (4 in)	100 mm (4 in)
GW40V Cell	50 mm (2 in)	75 mm (3 in)	150 mm (6 in)	150 mm (6 in)

- The required cell depth for aggregate infill on steep slopes relates to the natural angle of repose of the aggregate and the slope angle. Minimum recommended cell size and depth, for a range of aggregate types relative to angle of repose and slope angles, are shown in Figure 6.

Surface Anchorage

- Typical surface anchorage for aggregate filled Geoweb includes ATRA Anchors and/or tendons. Complete anchor details are determined through static analysis methods available from Presto Geosystems.
- Special slope anchorage requirements should be determined in accordance with guidelines presented in the section on Special Anchorage Methods

Geoweb System with Concrete infill

General

Poured concrete provides hard, durable protection for slopes that are exposed to severe hydraulic or mechanical stresses. The characteristics of concrete require that large poured slabs normally be steel reinforced and formed in discrete isolated sections to prevent structural cracking. The potential for damage is increased if permanent or seasonal subgrade deformations occur. Special construction joints must be provided to accommodate shrinkage from drying and thermal expansion/contraction. These factors can greatly increase installed costs.

Benefits of Cellular Confinement

- Infilling the cells of Geoweb with concrete provides a durable, erosion-resistant slope cover of uniform thickness which retains flexibility and an ability to conform to potential subgrade movement. Special compacted granular bedding layers, necessary with conventional poured concrete slabs, can be omitted.
- The quality, surface finish and thickness of the concrete can be selected to meet specific design needs. A non-woven geotextile separation layer, combined with hydraulic relief, assures effective sub grade drainage and subsoil filter protection.
- Normal drying shrinkage of the concrete infill gives the entire slope surface an ability to drain groundwater from the subgrade. The uniformly distributed shrinkage also imparts a degree of flexibility to the system.
- A mechanical bond is maintained between the concrete infill and the interior of each cell by the unique texture and perforation of the Geoweb cell wall. The amplitude of the texture is greater than potential concrete shrinkage, thereby locking the concrete infill into the individual cells of the system. Additional anchorage is provided due to concrete flowing between cells through the 10mm (3/8 in) diameter cell wall perforations.
- Installation rates can be high. Concrete can be placed by pumps, boom-mounted skips or direct discharge from ready-mix trucks. The flexible concrete forming technique is especially suitable for complex slope geometry.

Design Guidelines

- Concrete infill is recommended for slopes that may be exposed to severe surface flows, wave impact or ice action. Concrete quality in terms of compressive strength, aggregate/cement ratio, water/cement ratio and air entrainment should be selected in accordance with normal engineering practice relative to site conditions.
- Concrete can be used as low-cost infill where surface stresses are moderate or extra protection is desired.
- Various surface finishes (trowel, broom or rake) are possible, in order to meet specific aesthetic or surface friction requirements. Aggregates or gravel can also be embedded into the surface of wet concrete infill to produce a variety of textures, colors, and surface finishes.
- Selection of a geotextile or geocomposite separation layers is governed by the ground-water and external hydraulic conditions to which the slope protection may be subjected. Evaluation of subsoil permeability and the potential for rapid drawdown on submerged slopes is especially important relative to overall slope stability.

Cell Size Selection

- GW30V cell Geoweb is generally recommended on slopes steeper than 22° (2.5H:1V), unless the concrete infill has a very low slump.
- Cell depth selection is normally based on the potential tractive or uplift forces to which the slope protection could be exposed. In addition to increasing the unit weight of the system, greater cell depth significantly increases the flexural stiffness and uplift resistance of the system.

Surface Anchorage

- Typical surface anchorage for concrete filled Geoweb includes ATRA Anchors and/or tendons based on the slope angle, geotextile separation layer and sub grade soils. Complete anchorage recommendations are determined through static analysis methods available from Presto Geosystems.
- Special slope anchorage requirements should be determined in accordance with guidelines presented in the section on Special Anchorage Methods

Special Anchorage Methods

Determining Anchorage Requirements for Sliding Resistance

- The analysis of slope cover stability involves a comparison of the down slope force components, both static and dynamic, and the total resisting forces due to interface friction, in-plane tensile anchorage, and the in-plane resistance of anchor components (e.g. ATRA® Anchors, ATRA Tendon Clips, tendons, earth anchors, etc.).
- Input parameters and analysis methodology are summarized in the design section of this brochure. An analysis design tool is available from Presto Geosystems.

Crest Anchorage

- Crest anchorage can be used in situations that preclude the use of ATRA anchors that protrude into the slope. Examples include steep slopes, construction of fluid containment structures and landfill covers where protective impermeable geomembranes are provided. Use of Geoweb, ATRA Tendon Clips and tendons allows the entire protective cover to be suspended from suitable deadman or crest anchors.
- Typical crest anchorage system consists of a pipe deadman, concrete deadman and earth anchors.
- When installation of an ATRA anchor array is impractical, crest anchorage can be used. Examples include applications where the protection is placed on a submerged slope or where the underlying slope surface consists of random rubble fill into which ATRA anchors cannot be readily or effectively installed.

Slope Surface Anchor Arrays

- A common method of securing Geoweb protection on steep slopes involves installation of structural anchors in a uniform grid-pattern throughout the cover layer. The size, material type and distribution of the anchors are based on the slope angle, subsoil, protection type and possible surcharge loads. The ATRA® Anchor is generally recommended.

- For tendon Geoweb, the ATRA Tendon Clip is used to secure the Geoweb sections and transfer the driving forces to the cell wall. ATRA Tendon Clips are secured to the tendon using the method referenced in the Geoweb® Slope Protection Installation Guideline.
- The maximum allowable down-slope ATRA Tendon Clip spacing is governed by the tensile resistance of the tendon Geoweb section. Complete details are determined through static analysis methods available from Presto Geosystems.

Rock Anchors

- An array of rock anchors can be used to secure the tendon, topsoil-infilled Geoweb system to steep rock slopes as an effective means of re-vegetation. Friction clips attached in series along the integral tendons transfer cover loads from the cell walls to the tendon and then to the anchorage system.

Tensioned Surface Cover

- Slopes that are prone to instability during spring thaw conditions can be repaired with an array of high-capacity earth anchors extending into the slope beyond the critical failure plane. Sections of near-surface sub-soils suddenly sliding down slope as a mass are an indication of this problem. The combination of ATRA Tendon Clips and tendon Geoweb sections create a tensioned surface membrane system that confines and restrains potentially unstable surface soil. Design is based on an assessment of the maximum potential thickness of the unstable soil zone.

Uplift Restraint Anchors

- Uplift resistance of tendon, concrete-infilled Geoweb shoreline revetments, when exposed to severe wave impact, can be significantly increased by installing earth anchors in a tight grid pattern. Determining the type, distribution and capacity of the anchors requires site-specific information on the revetment geometry and prevailing wave climate. Provided sub grade soils are consistent and suitable for anchor installation, the Geoweb system is generally more cost-effective than the alternative of significantly increasing the thickness and unit weight of the revetment.

Available Tools & Services

Presto and Presto's authorized distributors and representatives offer assistance to anyone interested in evaluating, designing, building or purchasing a **Geoweb Slope Protection System.** You may access these services by calling 800-548-3424 or 1-920-738-1328. In addition to working directly with you, the following design and construction resources are available for your use with the **Geoweb Slope Protection System**.

Design	Material and CSI-format Specifications, System Components Guideline, Request for Project Evaluation, AutoCAD® Drawings, SpecMaker® Specification Development Tool, videos
Construction	Installation Guidelines, Anchor Spacing Guidelines, SpecMaker® Specification Development Tool, videos

Disclaimer

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