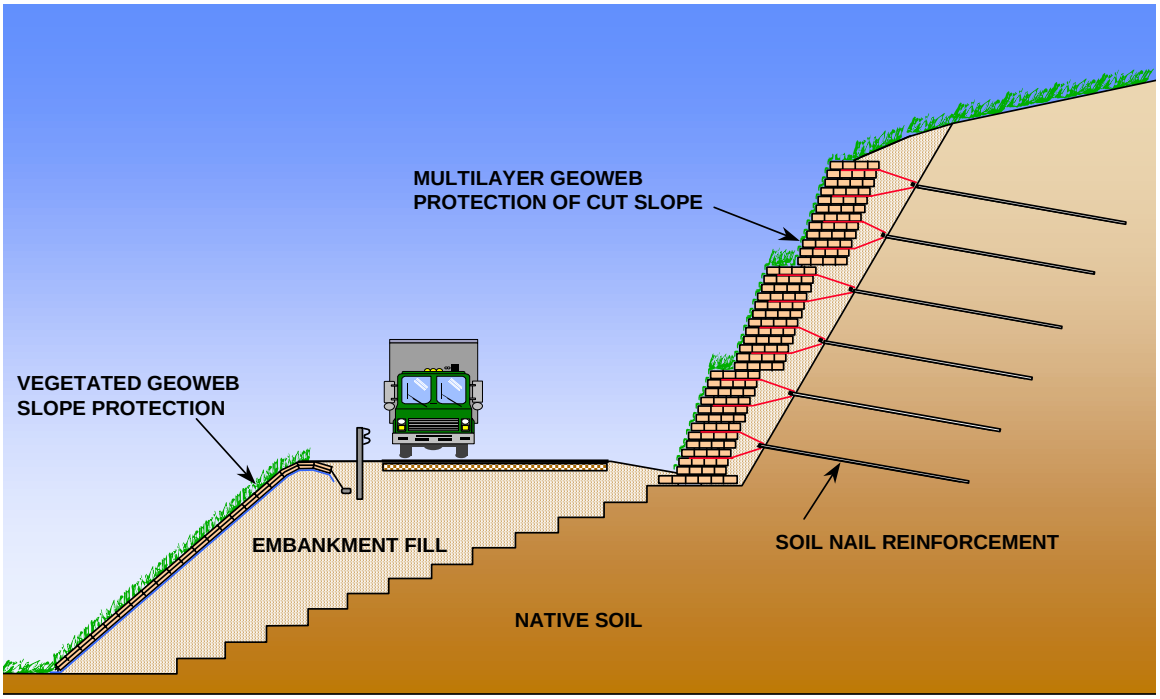
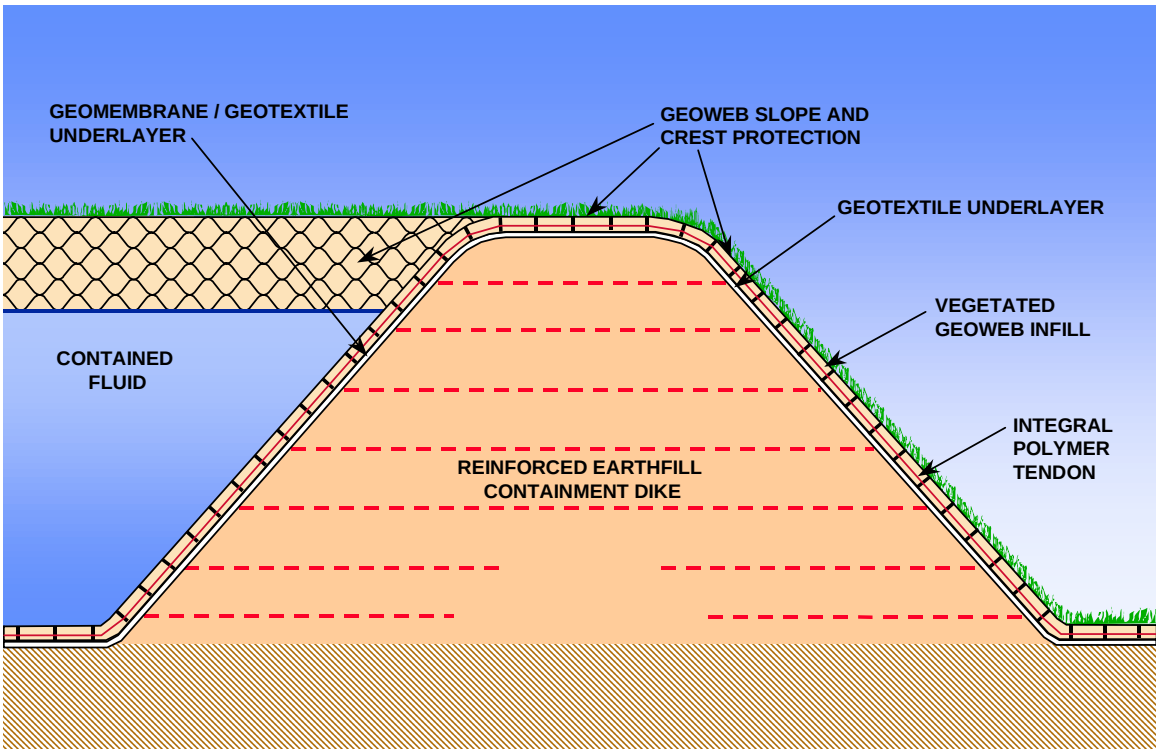
THE GEOWEB® SLOPE PROTECTION SYSTEM
TECHNICAL OVERVIEW





PRESTO PRODUCTS COMPANY, P.O. BOX 2399, APPLETON, WISCONSIN, USA 54912-2399
Telephone: 920-738-1118 or 800-548-3424 ■ Fax: 920-738-1222
e-mail: info@prestogeo.com www.prestogeo.com/

THE 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 both vegetated and hard surfacing 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 can also provide means of fully vegetating 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 downslope in suspension as run-off flows concentrate. Rills and gullies form and expand as soil loss progresses. Rainfall intensity, soil erodibility, slope steepness, and vegetative cover condition control the rate and extent of such erosion.

Localized Surface Instability Problems

Ground-water 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 subsoils 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

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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 - The 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:

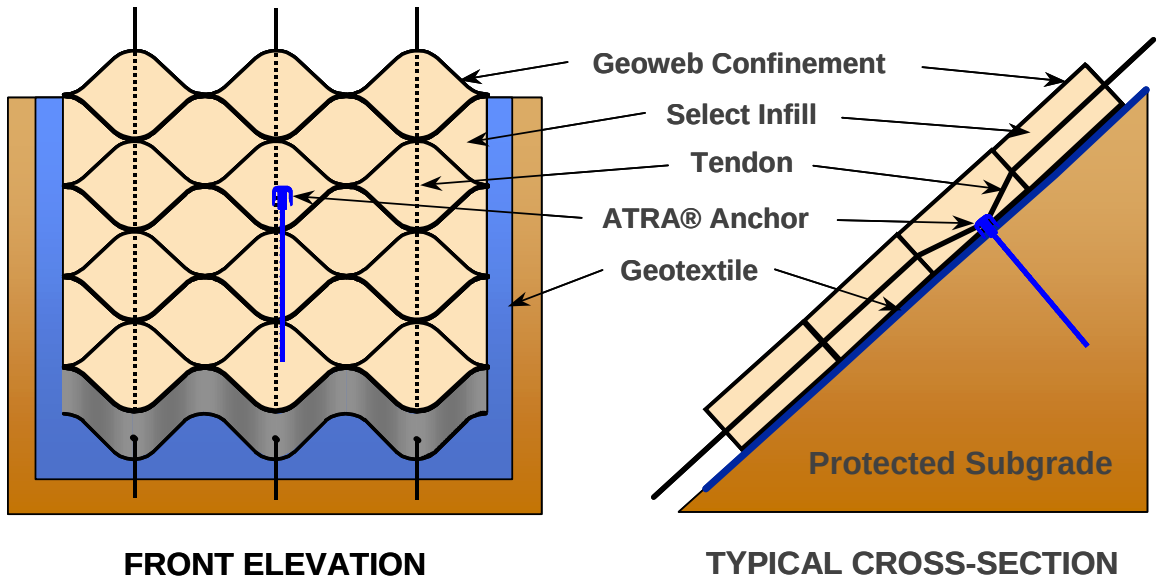

Figure 1 Key Components of the Geoweb System

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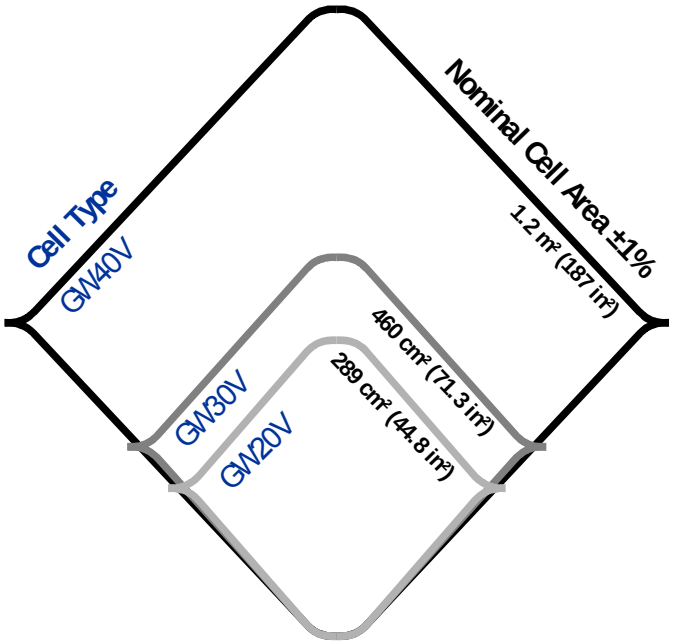
Geoweb cellular confinement sections – Cell Sizes & Depths



Nominal cell depths available are:

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

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
- Concrete of various strengths and surface finishes
- Combinations of the above to meet special conditions

Integral polymeric tendons

A variety of standard tendons (see Table 1), covering a range of tensile strengths, is available to meet specific anchorage requirements. Spacing and quantity of individual tendons within each Geoweb section is determined through static analysis methods available from Presto.

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)
TPP-44	4.40 kN (990 lbf)

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Ground anchors

Geoweb slope protection systems can be secured with an array of surface anchors or a crest anchorage system to suit design requirements and subgrade conditions. The most commonly used types of anchor are illustrated in Figure 3. Anchor details are determined through static analysis methods available from Presto.

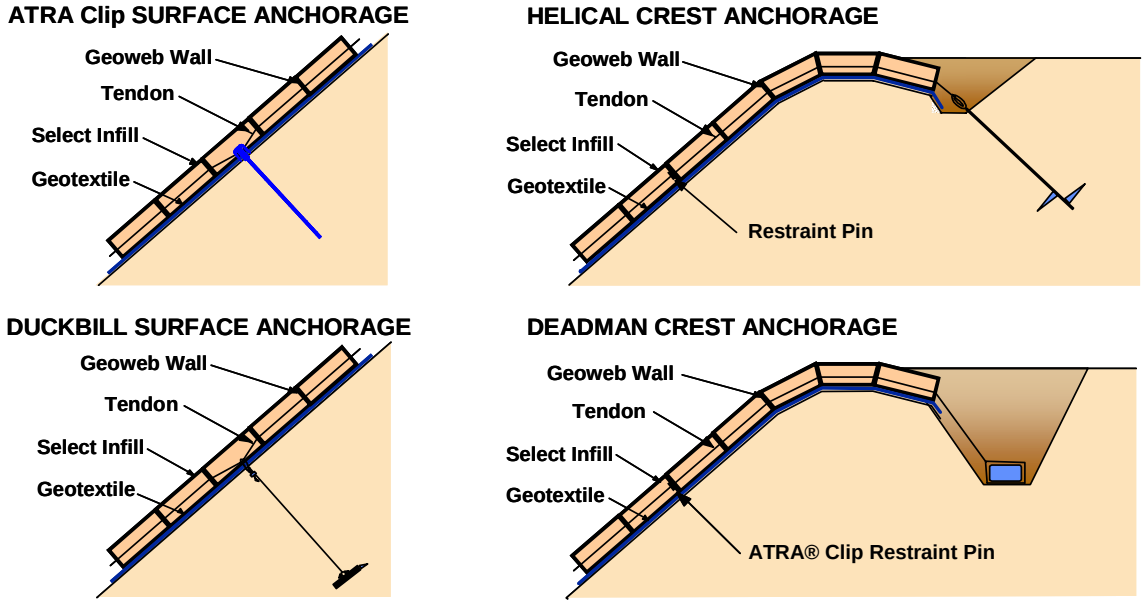

Figure 3 Typical Geoweb Anchorage Schemes

Non-woven geotextile underlayer

Installation of a suitable geotextile below the Geoweb confinement system is typical of slope protection work. The geotextile underlayer can perform a number of important functions that include:

- In-plane drainage of groundwater seepage from the slope subgrade.
- Confinement and filtration of subgrade soil particles.
- Reinforcement of root-mass with vegetated infills.
- 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
- Erosion blankets of all types
- 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 subgrade soil. The sliding resistance of composite systems, which

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incorporate geomembrane and/or geotextile underlayer, can be limited by relatively low coefficients of friction associated with such geosynthetic materials.

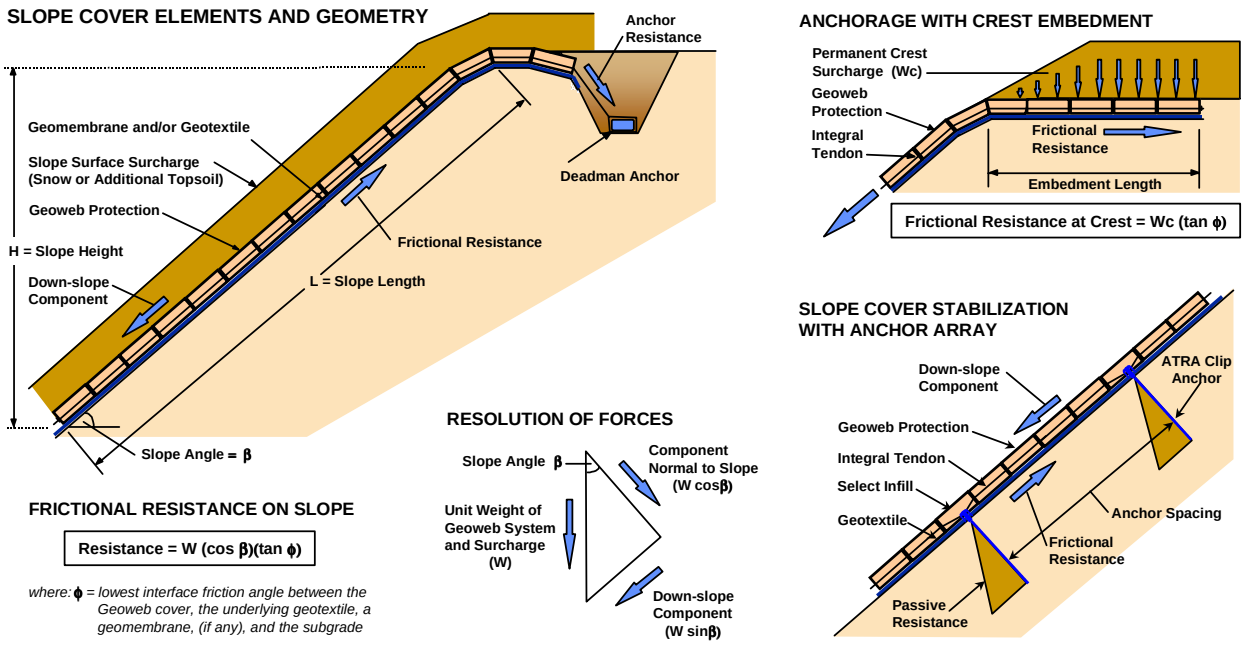

Figure 4 Stability Analysis of the Geoweb Slope Protection System

As slope inclination increases, the down-slope component of the cover's self-weight exceeds the available frictional resistance, thereby necessitating additional anchorage. The integral polymeric tendons of the Geoweb system provide an effective means of supplying the required restraint.

Surface anchor pins within the Geoweb cell (see Figure 3) and distributed along each tendon, are the most common form of slope cover anchorage. Analysis involves determination of the maximum contributory area of slope cover that can be supported by an individual anchor pin.

Crest anchorage of an entire slope cover can be incorporated when installation of surface anchors is impractical or when perforation of the underlying geosynthetic layers is unacceptable. A number of crest anchorage schemes, including deadman anchors and embedment of the tendoned 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.

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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 retards 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 underlayer 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.
- Vegetated topsoil infill is recommended in situations where surface flows are intermittent, of moderate intensity, and of relatively short duration (< 24 hours). Peak velocities of 6 m/s (20 ft/s) can be sustained for short periods when the vegetated cover is well established.
- Degradable erosion blankets should be applied to protect exposed topsoil and seed and to promote rapid establishment of vegetation. Erosion blankets should be selected and installed in accordance with their manufacturer's guidelines.
- For better overall performance, a lightweight, 150 - 200 g/m^2 (4 - 6 oz/yd^2), needle-punched, non-woven geotextile underlayer is a recommended component of the vegetated system.

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 infills when slope angles are below 30° and moderate run-off intensities are anticipated. Slopes steeper than 30° (1.75H:1V) or exposure to severe or concentrated flow conditions, require GW30V cell Geoweb. See Figure 2 for Geoweb details.
- Normal cell depth for vegetated protection is 75 mm (3 in), provided the subsoil will support root development and slope angles are below 30°. Slopes steeper than 30° require a cell depth of at least 100 mm (4 in). Situations that could require greater cell depths include; revegetation of rock slopes, applications with highly erodible soils and support of vegetated slopes in arid regions.

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- Hydraulic action prior to full development of vegetation within the cells can result in loss or settlement or reshaping of infill soils as shown in Figure 5. The relationship between geometrical variables can be expressed as:

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

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

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.

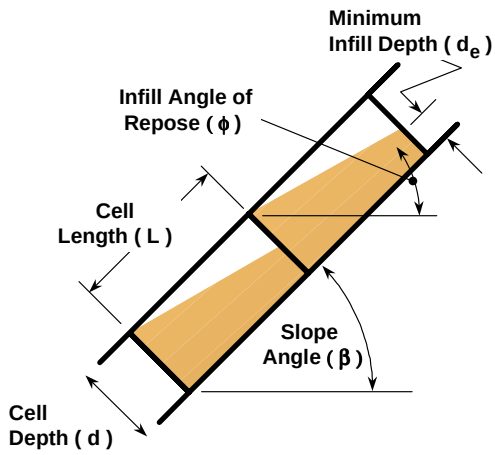

Figure 5 Determination of Minimum Cell Depth

Surface Anchorage

- Typical surface anchorage for re-vegetation of earth slopes includes 3 or 5 tendons per 2.44 m (8 ft) wide Geoweb section, running down the slope, with 460 mm (18 in) ATRA® Anchors spaced at 1000 mm (3 ft) intervals along each tendon. Complete anchor details are determined through static analysis methods available from Presto.
- Special slope anchorage requirements should be determined in accordance with guidelines presented in the section on Special Anchorage Methods.

System Installation

- On steep slopes, topsoil infilling should generally proceed from top to toe of slope. Excessive over filling and placement of large clumps of soil in the cells should be avoided. Tamping of infill is recommended to remove excessive air voids from the topsoil. Ensure that all cells are completely filled after lightly tamping the infill. Over tamping (compacting) of infill may retard establishment of vegetation.
- Seeding and installation of erosion blankets should immediately follow placement of infill.

Geoweb System with Aggregate Infill

General

Gravel and crushed stone can provide effective slope protection provided the slope angle is less than the angle of repose of the cover 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.

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Benefits of Cellular Confinement

- Confinement of loose aggregate within Geoweb cells permits their 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 below.
- 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.

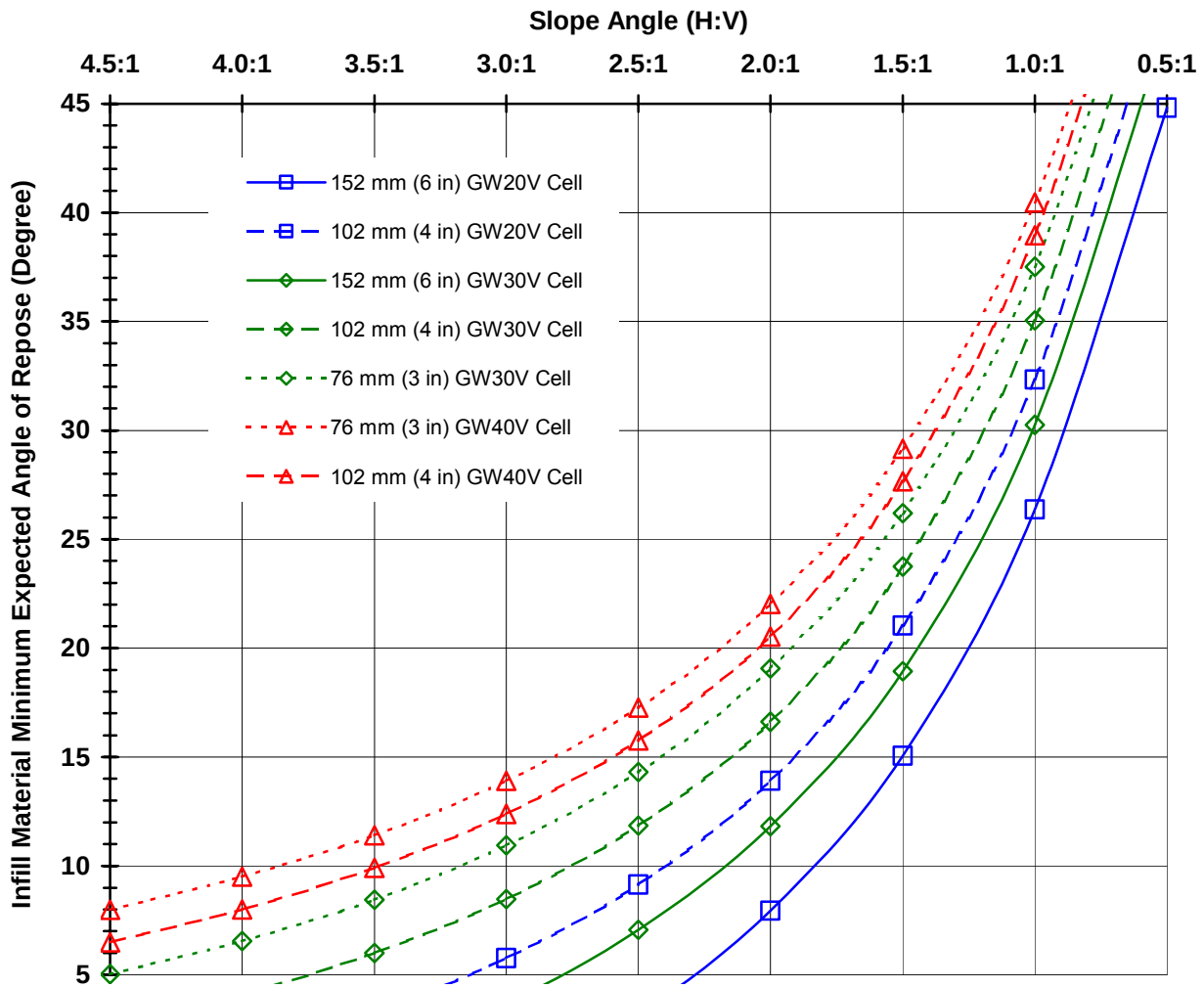

Figure 6 Geoweb Type Selection for Various Slopes and Infills

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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 grouts are applied to the surface of aggregate infills to increase erosion resistance, a minimum grout penetration depth of 25 mm (1 in) is recommended.
- A non-woven geotextile underlayer, 200 - 300 g/m^2 (6 - 8 oz/yd²) 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	76 mm (3 in)	102 mm (4 in)	152 mm (6 in)	203 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 3 or 5 tendons per Geoweb section, running down the slope, with 460 mm (18 in) ATRA® Anchors spaced at 1000 mm (3 ft) intervals along each tendon. Complete anchor details are determined through static analysis methods available from Presto.
- If ATRA® Anchors cannot be used, tendons should be placed through every cell to increase the superimposed weight of aggregate infill bearing directly on the tendon system.
- Special slope anchorage requirements should be determined in accordance with guidelines presented in the section on Special Anchorage Methods.

System Installation

- Infilling operations on slopes should avoid end dumping or dropping small aggregate from heights greater than 1000 mm (3 ft) and large aggregate from heights greater than 500 mm (1.5 ft). Ensure that all cells are full but not excessively over-filled.
- Aggregate can be compacted into the Geoweb cells with a plate tamper or using the back of a smooth bucket on the placement equipment.

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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 ready-mixed concrete produces 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 underlayer, combined if necessary with custom outlet ports, assures effective subgrade 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 wall surface of the Geoweb system. The cell wall can be either surface textured perforated or textured non-perforated. The amplitude of the texture is greater than potential concrete shrinkage, thereby locking the concrete infill into the individual cells of the system. Selection of perforated Geoweb sections provides additional anchorage due to concrete flow between cells through the 10mm (3/8 in) diameter 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.
- Lean-mix and gap-graded concrete can be used as low-cost infills where surface stresses are moderate.
- 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 underlayer 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.

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Cell Size Selection

- GW30V cell Geoweb is generally recommended on slopes steeper than 20° (2.75H: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

- Special slope anchorage requirements should be determined in accordance with guidelines presented in the section on Special Anchorage Methods.

System Installation

- Concrete infilling should proceed from top to toe of slope. Over-filling of cells is generally not recommended.

Special Anchorage Methods

Determining Anchorage Requirements for Sliding Resistance

- The analysis of slope cover stability involves a comparison of the downslope 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, stakes, J-pins, 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 anchors that protrude into the slope. Examples include construction of fluid containment structures and landfill caps where protective covers are placed over impermeable membranes. Use of the tendoned Geoweb system allows the entire protective cover to be suspended from suitable crest anchors.
- When installation of an 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 anchors can not be readily or effectively installed.

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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 is based on the particular slope geometry, subsoil, protection type and possible surcharge loads. The ATRA® Anchor is generally recommended.
- It is generally recommended that ATRA® Clip Stake (or other anchor method) be secured to the integral tendons by forming an appropriate knot in the tendon at each anchor location. The anchor is then driven into the ground so the bottom of the ATRA® Clip is flush with underside of the Geoweb section. This ensures that anchors do not project above the surface of the protection after the cells are infilled.
- The maximum allowable down-slope spacing of individual surface anchors is governed by the tensile resistance of the tendoned Geoweb system. The size and shear capacity of each anchor dictates the density of the overall anchor array. Complete anchor details are determined through static analysis methods available from Presto Products Company.

Rock Anchors

- An array of rock anchors can be used to secure the tendoned, 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 downslope as a mass is an indication of this problem. The combination of anchors and tendoned Geoweb sections create a tensioned surface membrane system that confines and restrains potentially unstable subsoil. Design is based on an assessment of the maximum potential thickness of the unstable soil zone. This can be evaluated by carefully surveying previously failed slopes.

Uplift Restraint Anchors

- Uplift resistance of tendoned, 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 subgrade 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.

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Available Tools & Services

Presto Geosystems and its authorized distributors 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 920-738-1118. In addition to working directly with you, the following information has been specifically developed and available for your use with the **Geoweb Slope Protection System**.

General Overview	Product data, basic engineering concepts and theory for general application of the Geoweb system.
Application Overview	How the system works, specific to the application area.
Case Histories	Specific project information on the design, construction and performance of the Geoweb system for all application areas.
SPECMaker® Specification Development Tool	A software tool available to develop complete material and construction specifications specific both to the application area and to details controlling the specific project.
Design Package	
System Component Guideline	A set of tables relating system components to application areas.
Request for Project Evaluation	An application-specific project checklist to ensure all relevant data is collected for detailed engineering design of the Geoweb system.
Material Specification	An inclusive specification for most variations of the Geoweb material, anchoring materials, tendons, etc. See SPECMaker® Tool.
CSI Format Specifications	Comprehensive guide specification & product description of the Geoweb cellular confinement system in the standard CSI format.
Construction Specifications	Available through SPECMaker® Tool.
AutoCAD® Drawings	Drawings in DWG format and paper copy providing all the engineering details needed for plans with the Geoweb system.
Technical Overview	An application-specific, in-depth discourse centered on the theory and application of theory to solving problems with the Geoweb system.
Construction Package	
Installation Guideline	An illustrated, application-specific, guideline for installation of the Geoweb system.
Other Resources	
Videos	***Advancing Geotechnology*** ***Construction Techniques – Load, Slope & Channel*** ***Construction Techniques – Earth Retention*** Available in Multiple Languages
Technical Resources Library CD	All of the above and more. Requires Microsoft® Internet Explorer 4.0 and Windows® 95 minimum.
Project Evaluation Service	Available through authorized distributors and representatives for all applications of the Geoweb cellular confinement system.

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