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Standard Guide for the Use of Geocells in Geotechnical and Roadway Projects[1]

This standard is issued under the fixed designation D8269; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide is intended to cover basic considerations for the use of geocells in various geotechnical and roadway projects to bring a unified understanding of efficient and appropriate ways to utilize this type of ground improvement technology for a variety of geotechnical-related applications, including but not limited to: load support for pavements, subgrade improvement, slope stability, retaining walls, earth retention, and slope and channel protection. Engineers and owners interested in using this manufactured product can refer to the information in this guide to learn about key design principles, properties, mechanisms, and methodologies for applicable geotechnical applications. Geotechnical designs that incorporate geocells should take into consideration the specific attributes of each product. The engineer is encouraged to utilize design methodologies based on reliable test results and research.

1.2 This guide offers a collection of information and does not recommend a course of action. This guide cannot replace education or experience, and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances.

1.3 This guide is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this guide be applied without consideration of a project's many unique aspects.

1.4 The word "standard" in the title of this guide means only that this guide has been approved through the ASTM International consensus process.

1.5 The values given in SI units are to be regarded as standard. Values in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1693 Test Method for Environmental Stress-Cracking of Ethylene Plastics

D3895 Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry

D4355/D4355M Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture, and Heat in a Xenon Arc-Type Apparatus

D4439 Terminology for Geosynthetics

D4595 Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method

D5199 Test Method for Measuring the Nominal Thickness of Geosynthetics

D5262 Test Method for Determining the Unconfined Tension Creep and Creep Rupture Behavior of Planar Geosynthetics Used for Reinforcement Purposes

D5397 Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test

D5721 Practice for Air-Oven Aging of Polyolefin Geomembranes

D5885/D5885M Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry

D5994/D5994M Test Method for Measuring Core Thickness of Textured Geomembranes

D6392 Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods

[1] This guide is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.01 on Mechanical Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D6992 Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method
D7238 Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent UV Condensation Apparatus
E2254 Test Method for Storage Modulus Calibration of Dynamic Mechanical Analyzers

2.2 *ISO Standards:*[3]
ISO 6721-1 Plastics—Determination of Dynamic Mechanical Properties—Part 1: General Principles
ISO 10319 Geosynthetics—Wide-Width Tensile Test
ISO 13426-1 Geotextiles and Geotextile-Related Products—Strength of Internal Structural Junctions—Part 1: Geocells

2.3 *GRI Standards:*[4]
GRI GS13 Guide for Geomembrane-Related Geocell Seam Strength and Its Efficiency with Respect to the Perforated Sheet Strength
GRI GS15 Specification for Test Methods, Test Properties and Testing Frequency for Geocells Made from High Density Polyethylene (HDPE) Strips

3. Terminology

3.1 *Definitions*—For definitions of common geosynthetics terms used in this guide, refer to Terminology D4439.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *geocell, n*—a three-dimensional, compartmentalized, polymeric structure having discrete cells that are formed by expanding the structure, that is subsequently filled with soil, aggregate, concrete, pulverized debris, recycled asphalt pavement, or other infill material for geotechnical applications such as: (*1*) load support for unpaved and paved roads, railways, ports, heavy-duty pavements, container yards, and basal embankment stabilization; (*2*) retaining structures, free-standing structures, and fascia walls; and (*3*) slope, channel, and geomembrane protection.

4. Summary of Guide

4.1 This guide covers some of the major considerations associated with the design of geotechnical projects where the soil, aggregate, concrete, or other infill materials may be improved through the three-dimensional mechanical stabilization of geocells.

4.2 Common geocell applications include: (*1*) load support for unpaved and paved roads, railways, ports, heavy-duty pavements, container yards, and basal embankment stabilization; (*2*) retaining structures, free-standing structures, and fascia walls; and (*3*) slope, channel, and geomembrane protection.

5. Significance and Use

5.1 This guide covers applications, support mechanisms, and design principles associated with geocells to help designers and engineers determine when and how to appropriately use this technology.

5.2 A better understanding of the key design principles, material properties, mechanisms of improvement, and methodologies will help engineers and owners interested in using geocells understand the most efficient and appropriate ways to utilize this type of ground improvement for a variety of geotechnical-related applications.

5.3 This guide does not preclude the judgment and practice of those competent in geotechnical design.

6. Overview of the Geocell Technology and Basic Construction Considerations

6.1 Geocells are supplied as a group of connected strips (referred to as a "panel" or "section") that, when opened, form a network of open cells (see Fig. 1). Individual geocell sections can be connected using suitable, manufacturer-approved connection devices that provide sufficient strength to prevent panel separation during installation and throughout the entire design life. Geocells may differ in terms of their basic physical and material characteristics, including but not limited to: open cell/section dimensions, number of cells per unit area (cell density), cell depth (height), or presence/absence of perforations or texture. Geocells have been used successfully in practice since the 1980s. Selection of a geocell product should be based on a detailed evaluation of project-specific needs and circumstances as performed by a geotechnical engineer or other qualified professional, and geocell use should be consistent with the manufacturer's recommendations that are based on reliable test results and research (**1, 2**).[5]

6.2 Individual cells consist of two strips that are connected together on either end, and held open prior to filling through lateral forces applied to the cell walls from the adjacent sets of cell walls that are connected to them. In application, two types of hoops are present in any configuration that involves the installation of multiple adjoining geocell panels. These include factory-welded hoops, and mechanically joined hoops using manufacturer-recommended methods (refer to 6.5). Located within the body of individual geocell panels, factory-welded hoops consist of the cell wall material and the seams on either end. Located around the perimeter of the individual geocell panels, mechanically joined hoops are formed in the field during connection of adjoining panels. The primary mechanism by which geocells provide benefit is through lateral confinement of the infill; therefore, it is necessary that the entire hoop of material that makes up each individual cell and the connection devices remains intact during construction and throughout the life of the structure. The entire hoop, including the seams, must remain intact and be sufficiently strong to carry the applied hoop stresses without breaking, deforming excessively, relaxing, or degrading during construction and for

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[4] Available from Geosynthetic Institute (GSI), 475 Kedron Ave, Folsom, PA 19033, https://www.geosynthetic-institute.org.

[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

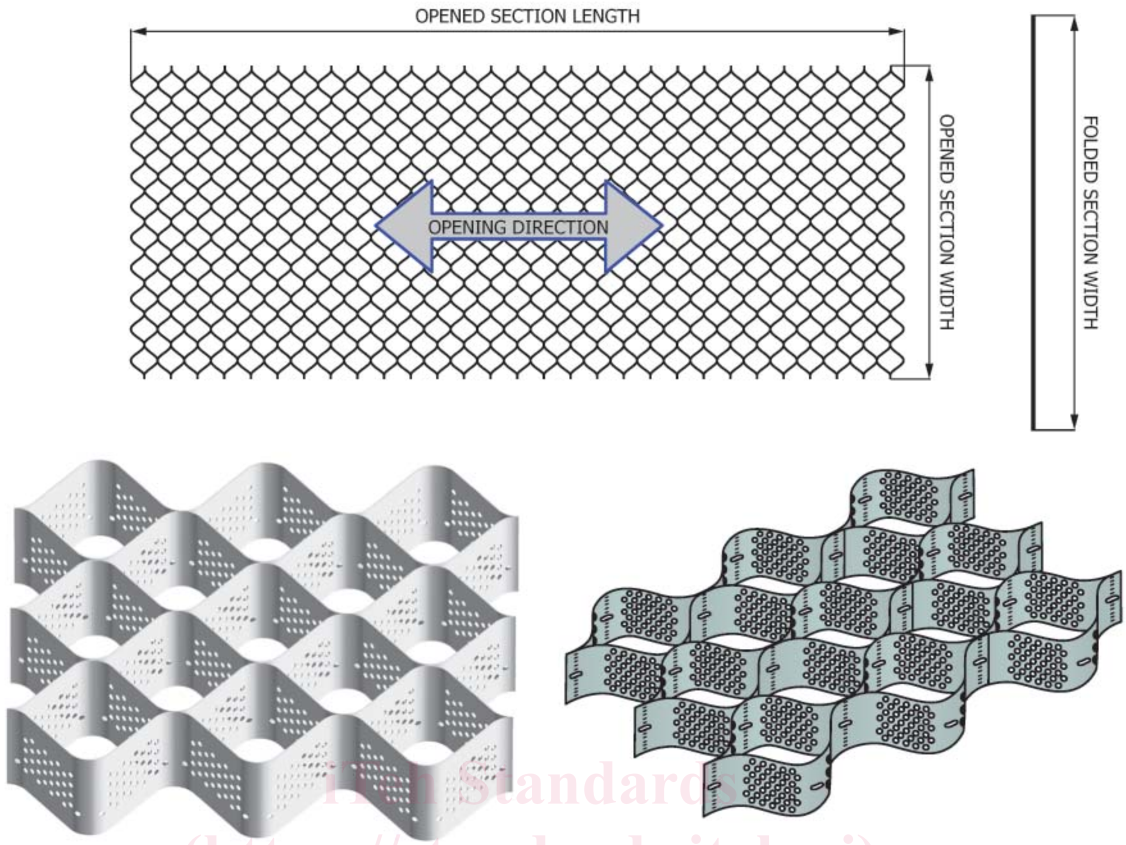

FIG. 1 Plan View and 3D View of Geocells
(layout of perforations in 3D view may vary between different manufacturers)

the entire design life of the structure. Any of these failure modes in either the cell wall, seams, or connectors will allow the infill to expand laterally, rendering individual cells or the entire geocell layer ineffective.

6.3 Lateral restraint (or confinement) of the infill material is provided by the hoop of material that forms the cell wall, and the improved lateral support of adjacent cells (that is, the slab/mattress effect), as reported in Refs (**3-6**). The suitability of the geocell in specific design cases and the magnitude of confinement provided by the geocell are directly dependent on the key material properties outlined in 6.8, the geometry of the individual cells, and the position of the geocell layer within the geotechnical structure.

6.4 The mattress effect mentioned in 6.3 relies on the composite behavior of an integrated infill-geocell system in which lateral earth pressures are mobilized and transferred across a three-dimensional network of interconnected cells. In this regard, the properties of the infill material (that is, particle size/distribution, angle of internal friction, relative density, etc.) act in conjunction with the discrete elements/characteristics of the geocell material (comprised of cell walls, seams/joints, connection devices, perforations/texture, and in some cases, earth anchoring devices) to facilitate the desired ground improvement effect. The infill materials, along with each of the above-referenced discrete elements of the geocell system, will each impart some level of influence over system performance. Accordingly, the behavior of the composite system is similarly influenced by these factors, along with the geometry of the machine-welded geocells (which are not exactly circular shaped, as shown in Fig. 1); the number of adjacent geocells acting in response to an applied load; and the stiffness of system components. In general, with increasing numbers of adjacent cells (cell density) surrounding the location of an applied load, the resulting horizontal pressure is distributed over a wider area. Emersleben and Meyer (**7**) observed that the horizontal pressure in a single cell was distributed to the 24 closest surrounding cells, exemplifying the mattress effect of the composite behavior. Individual cells limit lateral movement of the infill, which reduces vertical settlement and increases stiffness within the reinforced layer. As these individual cells work in concert with other adjacent cells (that is, the mattress effect), applied loads are more widely spread, resulting in a more uniform distribution of applied stresses as well as a reduction in the magnitude of these stresses to underlying layers, the result of which is a decrease in the overall settlement and a reduction in differential settlement.

6.5 A single group of geocells has a finite length and width depending on how it was manufactured. As mentioned in 6.1, a larger continuous area can be covered by attaching single groups of geocells to one another from end to end, side to side, or both. Common methods of attachment include stapling and locking devices, as well as the use of specialized manufacturer-specific connection devices. Manufacturer's recommendations for attachment should be followed as long as they are durable and provide sufficient connection strength, pullout/separation resistance, resistance to lateral and vertical movement, and resistance to node rotation between subsequent geocell groups.

6.6 Geocell section opening size in the field is determined by the distance that the geocell is stretched from side to side. For typical load support projects, geocells are temporarily held open by staking the edges in a manner that ensures that all geocell openings can be filled. Stakes can be left in place or removed and reused as the construction advances. Slope and channel protection applications typically require that permanent stakes, tendons, or both, be installed to hold the geocells in place. Temporary staking, bent frames, or both are typically used to hold geocells open for retaining wall applications.

6.7 The bulk of the background and research information used to develop this guide is based on geocells made of extruded plastic strips. Geocells are also made of nonwoven geotextiles (as shown in Fig. 2) and, where appropriate, specific guidelines for these materials are also included in the guide. It is important to note that geocells made from different types of materials, sizes, strengths, etc. may behave or perform differently from one another; therefore, it is important to understand and utilize proper material properties that relate to its performance for each of the applications outlined below. Manufacturer's recommendations for each material type should be based on reliable test results and research for their specific material.

6.8 The polymeric properties of the geocell are directly related to its performance throughout the entire project design life (**3**). These properties include tensile strength, tensile stiffness, resistance to plastic deformation or creep, hoop strength, and environmental durability (as outlined in 6.9). Because geocells act cooperatively due to the proximity of surrounding cells (that is, mattress effect, see 6.4), it is also important to assess the performance benefits imparted to the entire layer in which the geocell is employed. Accelerated methods are available to evaluate and verify long-term performance of the geocell system itself and as part of a complete solution (for example, rolling wheel load tests, cyclic plate load tests, and full-scale laboratory test sections) (**7-9**). Triaxial tests have also been used to evaluate and understand the strength properties of the composite geocell-soil system (**10**). The entire

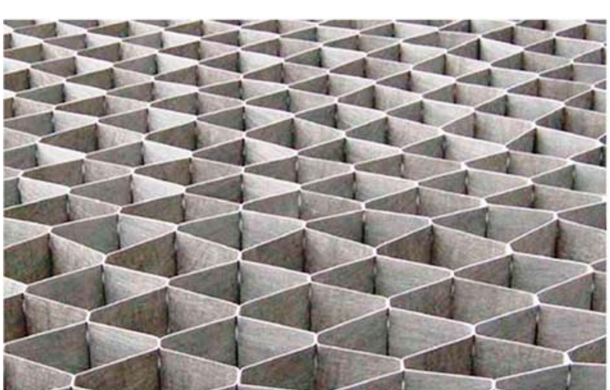

FIG. 2 Nonwoven Geotextile-Based Geocell

hoop of material forming the cellular structure must remain intact to ensure adequate performance throughout the design life, including both factory-welded hoops and hoops formed as a result of connections between adjacent panels.

6.9 Consideration should be given to the environmental conditions associated with the design. These conditions include temperature, chemical or environmental contamination, submerged conditions, prolonged exposure to sunlight, seismic activity, etc. The material properties of the geocell should be evaluated under the expected conditions to ensure proper performance throughout the design life. Tests are available to evaluate environmental stress cracking resistance (ESCR), corrosion resistance (particularly for staples or other types of metal connectors), and resistance to ultraviolet and oxidation degradation.

6.10 Infill material can include most types of non-plastic soils and sand, granular fills, concrete, and recycled materials. In pavement and retaining wall applications a free-draining granular fill is typically used, having a wide range of quality, including uniformly graded aggregates and recycled materials. Reinforced slope applications may require a graded, free-draining granular fill. Topsoil can be used in the outer cell if a vegetated fascia is desired. Topsoil, aggregate, and concrete can be used as infill for channel protection. The type of infill should be based on the slope angle and channel hydraulic conditions. Vegetated topsoil is often used in slope protection applications. Generally, geocells provide higher benefit when lower quality infill is used because the level of improvement compared to fill alone is greater. Nevertheless, the use of geocells with high-quality granular layers (in particular for surface transportation applications) may also lead to significant improvement of surface support with lower deflections, extended life in terms of increased traffic, or both. Greater load-carrying capacity, reduced thicknesses of the structural layers, extended life, or combinations thereof can be realized in roadway applications through the use of geocells with a wide range of infill quality including inferior materials, which may reduce overall project cost and reduce construction time (**5**).

6.11 Filling should be done without driving directly on the unfilled geocells to avoid damage. Construction equipment can advance onto the geocells once the infill material is deep enough to prevent equipment from directly contacting the top of the geocell. The drop height of infill material into the cells should be limited to prevent panel distortion. Overfill material thickness should be determined based on the design or experience, or both, and should be compacted together with geocell infill material.

6.12 Compaction should be done in a manner that prevents damage to the geocell but thoroughly densifies the infill material with sufficient energy to ensure that further densification during the life of the structure is minimized and that hoop stresses in the geocell walls are engaged. Vibratory compaction is generally preferred in load support applications to ensure the geocell infill is adequately densified. Sheepsfoot rollers should not be used to compact materials within the geocell-stabilized layer. Compaction requirements may vary depending on the specific application, and manufacturer's instructions should be consulted.

6.13 The primary benefit of geocells used in load support and roadway projects is through increased stiffness of the stabilized layer achieved by a reduction in volumetric changes of the infill during loading by means of lateral confinement provided by the geocell. The geocell-enhanced layers are improved through the addition of tensile strength at low strain levels provided by the geocell hoop. The cellular structure limits the vertical settlements of the stabilized infill by laterally restricting movement of the individual particles (that is, lateral confinement). The ability to maintain low permanent deformation levels from applied loads and provide long-term, stable (that is, elastic) confinement of the infill material is directly dependent on the ability of the geocell to retain its key material properties (refer to 6.8) and dimensions throughout the design life. The mattress effect (described in 6.4) allows for improved load transfer and distribution to underlying layers. The ability of the reinforced layer to maintain low permanent deformation levels from applied loads and provide long-term, stable (that is, elastic) confinement of the infill material is also dependent on the ability of the composite system to effectively translate applied loads into lateral earth pressures, which are then distributed across a three-dimensional network of interconnected cells. An elastic response of the improved layer can be achieved by limiting loads in the cell walls or seams (or both) below a predetermined threshold, because excessive permanent plastic deformation over the design life or rupture of the seams or cell walls, or both, will limit the benefit of the geocell or cause the structure to fail.

6.14 The volume of infill material that can be accommodated within individual cells is directly related to the length of hoop of material that forms the cell wall (that is, the cell size) and its height. Changes in the height of the geocell are negligible, so settlement of the infill over time is primarily a factor of the length of the wall perimeter or geocell hoop. Performance of the geocell depends on the ability of individual hoops (formed either by mechanical welding or mechanical joining) to remain intact and to resist stretching during construction and throughout the life of the structure. Limiting strain in the geocell hoop is the primary mechanism that restrains particle movement within each cell in the lateral direction (that is, lateral confinement), and results in a direct reduction of the vertical displacement of the infill (**11**), as explained in Note 1. A second and important mechanism that helps restrict lateral movements within the geocell layer is the increased lateral support provided by adjacent cells (that is, the slab/mattress effect), as reported in Refs (**3-6**) and further discussed in 6.4.

NOTE 1—The vertical strain of the reinforced layer is directly related to the strain in the geocell hoop. Considering a single cell opening, the relationship between the vertical settlement of the infill (or vertical strain, ε_v) and the expansion of the geocell hoop (or hoop strain, ε_h) is as follows:

$$\varepsilon_v = (1 + \varepsilon_h)^2 - 1 \quad (1)$$

which results in vertical settlements that are approximately double the hoop strain. This concept is especially important for load-bearing applications where reduction of settlement or vertical strain is of primary concern. In this case, restricting the accumulated permanent strain in the geocell will ensure that the geocell layer limits settlement, which will minimize distortion and maintain acceptable performance of the stabilized system throughout the design life.

6.15 Whether or not geocells are used, depending on the gradation of the support materials beneath the granular/geocell layer, it may be necessary to include a geosynthetic separation layer to prevent the migration of fines into the stabilized layer or punching of the infill material into softer layers beneath, or both.

6.16 Geocells made of extruded plastic strips are typically perforated and textured, while geocells made from geotextiles are oftentimes not perforated. Water flow through geocells made from nonwoven materials depends on their permittivity. The configuration of perforations or hole diameters, or combinations thereof, in the geocell should ensure adequate confinement of the infill. Having a distribution of perforations enhances the friction and interlocking of the infill soil and reduces stress concentrations, leading to better confinement and improved effectiveness of lateral drainage.

7. Design Applications

7.1 *Geocells Used as Load Support for Unpaved and Paved Roads, Railways, Ports, Heavy-Duty Pavements, and Basal Embankment Stabilization:*

7.1.1 Geocells used in this application are commonly deployed on a horizontal surface using one or more layers to strengthen, stabilize, or enhance the load-carrying capability of the trafficked surface, or to enable the use of inferior infill materials (typically granular and non-plastic materials such as sand, poorly graded aggregates, local weak and marginal non-plastic soils, recycled asphalt pavement, and other waste products including pond ash, etc.) (**12**). Load support improvement is provided through a three-dimensional matrix of interconnected cell walls that provide tensile strength (pseudo-cohesion) to unbound materials used as infill, resulting in a stiffer stabilized layer. Other key improvements provided by the geocell are the reduction of vertical settlements, deformation, or both by limiting volumetric changes within the infill material and added flexural strength of the geocell/infill composite system (**7**).

7.1.2 The primary support mechanism of geocells in load support applications (for example, roads, railroads, port loading platforms, etc.) is accomplished through durable lateral restraint of soil particles submitted to vertical loads from vehicles, as described in 6.3, 6.4, and 6.13. This support mechanism provides a reduction in vertical stress transfer to layers beneath and increased support to layers above throughout the entire design life of the structure.

7.1.2.1 In this application, the cell wall perimeter should be designed to limit the permanent (that is, plastic) hoop strain over the entire design life in order to limit vertical settlement (**3**). It is necessary to evaluate the resistance to accumulated permanent deformation of the entire width of the cell wall (or a representative sample of the entire structural configuration including perforations, if any) in order to characterize its long-term behavioral properties.

7.1.2.2 The geometry of the individual cells should provide sufficient confinement of the infill material. The primary geometric attributes that affect its ability to provide mechanical stability are cell height and the effective diameter of the cell opening (**13**).

7.1.3 Design of load support (for example, roads, railways, load platforms) modified by geocells depends on many factors that should be evaluated through performance testing.

7.1.3.1 *Improved Stiffness*—Geocells used directly above a weak subgrade/surface primarily provide benefit by improving the stiffness/strength of the soils within the geocell layer, which more widely distributes the applied load, thereby protecting soils subject to high deformation levels (**14**). Geocells used in the subbase and base layers primarily improve the modulus of the infill material (**15**). The magnitude of this improvement is dependent on the properties of the geocell material, its dimensions, the strength and depth of the infill, and the strength of underlying support layers. For all locations, the geocell material should maintain its key material properties for significantly low levels of accumulated permanent deformation for the entire design life when subjected to the applied design load (see Note 1).

7.1.3.2 *Limited Permanent Deformation*—Refer to 6.2, 6.8, and 6.14.

7.1.3.3 *Decreased Vertical Stresses to Lower Layers*—Vertical stresses to the subgrade are reduced through increased load spread angle of applied traffic loads (**16**). The increased magnitude and maintenance of this angle under working loads is dependent on the stiffness of the material making up the geocell hoop, and the maintenance of this angle is dependent upon the ability of the geocell to resist accumulated permanent deformation over the design life.

7.1.3.4 *Increased Confinement*—Lateral confinement of the infill materials limits lateral movement and, therefore, limits vertical deformations and settlements. In general, the magnitude of confinement increases as cell density increases (that is, smaller cell diameters) (**3**). Manufacturers' recommendations, based on reliable test results and research, should be followed to ensure confinement.

7.1.3.5 *Greater Zone of Vertical Influence in the Improved Layer*—The zone of influence of the geocell is extended above and below the geocell system where the stabilization mechanism is active. The extent of the zone of influence should be evaluated to quantify its effect on the design.

7.1.3.6 *Improved Infill Shear Resistance*—Improved confinement increases the shear resistance of infill through transfer of applied vertical loads into geocell hoop stresses.

7.1.3.7 *Reduced Particle Abrasion*—Aggregate movement and particle abrasion are minimized through lateral confinement and the improved lateral support from adjacent cells due to the improvement of the infill materials within adjacent cells (that is, the slab/mattress effect).

7.1.4 Optional solutions may include the use of geotextiles or geogrids together with a geocell to provide enhanced load support capabilities in areas with expansive soils or very weak ground (**17**).

7.2 *Geocells Used in Retaining Structures, Free-Standing Structures, and Fascia Walls:*

7.2.1 Geocells used in this application are commonly deployed on a horizontal surface using two or more layers in order to create a stabilized earthen mass or retaining structure. The four general types of earthen structures using geocells are: (*1*) retaining structures such as gravity walls or steep slopes (geocell stabilization only, Fig. 3(a)); (*2*) reinforced slopes (geocells used in combination with geogrids or geotextiles or both, Fig. 3(b)); (*3*) free-standing structures such as acoustic barriers, dams, or levees; and (*4*) fascia walls (a relatively narrow band of geocells used to protect the slope face or enable vegetation, or both). Layers are built directly on top of one another and can be positioned to establish a nearly vertical exposed facing angle. Vegetative infill materials can be used in the exposed cells on the outside of the finished structure to establish face vegetation.

7.2.2 The primary support mechanism of geocells in unstable slopes is accomplished through durable, multi-layer,

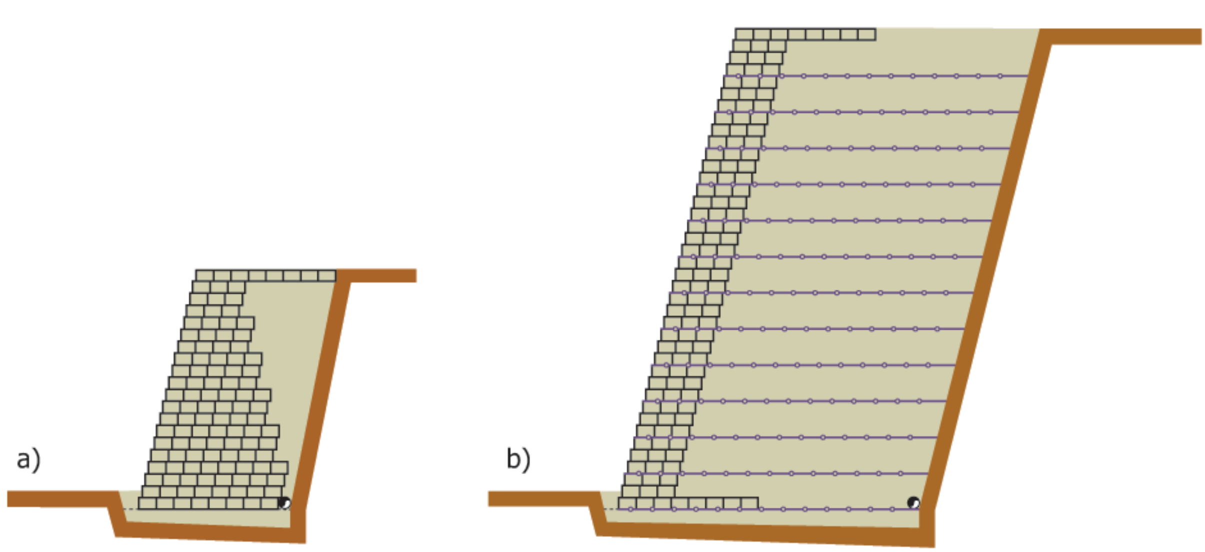

FIG. 3 General Types of Earthen Retaining Structures Using Geocells—(a) Gravity Structure; (b) Geocell-Faced Reinforced Soil Structure

mechanical soil stabilization. The geocell creates a stable mass of soil that resists active earth pressure, surcharge loads, and seismic forces. Constant stresses are realized in the geocell layers due to the vertical soil pressure of the layers above. The geocells resist these constant loads through tensile forces developed in the material forming the geocell hoops. The stabilization mechanism is outlined in 6.2. The material attributes directly related to performance in this application are outlined in 6.8. Consideration should also be given to the environmental conditions associated with the design, as outlined in 6.9.

7.2.2.1 The ability of the geocell to provide long-term stabilization of earthen retaining structures directly depends on its ability to resist accumulated permanent deformation over time (that is, creep resistance). Each individual geocell hoop should provide adequate resistance to long-term strain accumulation over the entire design life in order to maintain sufficient stability, which is highly important in engineered structures such as retaining walls. It is necessary to evaluate the resistance to long-term deformation of the entire width of the material forming the geocell hoop (or a representative sample of the entire structural configuration including perforations), as well as the anticipated hoop loads, in order to characterize its behavioral properties. Accelerated methods are available to evaluate long-term performance (**18-20**).

7.2.2.2 The geometry of the individual cells should provide sufficient confinement of the infill material. The primary geometric attributes necessary to ensure adequate mechanical stability for this application are outlined in 6.14 and 6.16.

7.2.3 Design of retaining structures using geocells depends on several factors that should be evaluated through performance testing and common engineering methods. Typically, the minimum width of a geocell wall should include at least three cells, depending on the wall height (**21**). The actual width of the retaining structure is determined from the design.

7.2.3.1 When properly designed, gravity retaining walls made from geocell-stabilized layers are typically suitable for several feet (meters) of slope height (based on design and economic considerations) when no additional reinforcement elements are used. The stabilized soil mass will retain its stability if it is properly compacted and the creep resistance of the geocell wall material is limited to low strains. The deformation properties of the entire system of geocell-enhanced layers should be evaluated to ensure long-term stability of the structure. Biaxial and uniaxial geogrids and geotextiles can be used to further reinforce geocell retaining walls to achieve greater heights based on design and economic considerations. The length and strength of each planar geosynthetic layer should be selected to accommodate the magnitude of the active pressure applied at specific elevations.

7.2.3.2 Direct sliding, overturning, rotational failures, bearing capacity, and seismic stability need to be evaluated to ensure global and internal stability of the stabilized earth mass (**22, 23**).

7.3 *Geocells Used as Erosion Control and Channel Protection:*

7.3.1 Geocells used in this application are commonly deployed on horizontal or sloped surfaces using a single layer in order to ensure the stability of vegetative, granular, or concrete infill, or to resist erosive tractive forces from flowing water, or both. The geocell is typically deployed by anchoring the upper portion and extending the material downslope. The upper portion of the geocell can be embedded in the upper embankment to better protect the subsoil beneath the geocell from undermining. An anchoring system along the crest and along the slope (stakes, tendons, or both, depending on the specific application) is typically used to hold the geocell in place for the entire design life. The contribution of the anchoring system to the overall factor of safety against panel movement is an important consideration. Stakes should not be used when geocells are used directly above a membrane. Geocells made of extruded plastic strips are perforated to provide lateral drainage, to improve the interaction of infill materials with the cell wall, and to allow root establishment between adjacent cells.

7.3.2 The primary mechanism of geocells used as erosion control and channel protection is accomplished by providing a durable, mechanical, three-dimensional barrier to hold the infill in place against sliding down the slope or to resist water tractive forces on the infill and the entire geocell protection system for the entire design life, or both (**24**). The geocell is continuously loaded in tension due to infill sliding forces, and can also experience tractive forces (parallel to the direction of flow) in the case of water flow in channels. It is important to note that the anchoring systems are a designed element used to hold the geocell in place to resist downslope sliding forces or tractive water forces due to flowing water, or both.

7.3.3 Downslope infill retention against movement is accomplished through tensile hoop strength provided by the cell walls and seams and properly designed anchoring and connection systems. The suitability of the geocell in a specific design case is directly dependent on the key attributes of the geocell as outlined in 6.8 and the geometry of the individual cells. Consideration should also be given to the environmental conditions associated with the design, as outlined in 6.9.

7.3.3.1 The dynamic tensile properties of the polymer used to form the geocell hoop (cell wall and welds) are primarily used to ensure adequate fatigue resistance for applications involving water flow. Adequate tensile modulus also ensures that elastic deformations downslope are limited.

7.3.3.2 The ability of the geocell to provide long-term stabilization in this application directly depends on its ability to resist accumulated permanent deformation. Geocells that expand, distort, or experience seam failures over time may lose their ability to provide adequate erosion control by allowing the stabilized soil layer to move down the slope (that is, erosion). Settlement and erosion of the infill also exposes the geocell, which can be aesthetically displeasing, and subjects it to additional environmental degradation. The cell walls should limit the accumulated permanent strain over the entire design life in order to maintain proper cell dimensions and keep infill material stationary. It is necessary to evaluate its tensile properties and its resistance to long-term strain accumulation for the entire width of the geocell wall (or a representative sample of the entire structural configuration including perforations, if any) in order to properly characterize its