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DIVISION: 32 00 00—EXTERIOR IMPROVEMENTS
Section: 32 32 00—Retaining Walls
Section: 32 32 23—Segmental Retaining Walls

REPORT HOLDER:

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EVALUATION SUBJECT:

TERRASTOP™ SEGMENTAL RETAINING WALL SYSTEM

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2009 and 2006 *International Building Code®* (IBC)
- 2009 and 2006 *International Residential Code®* (IRC)

Properties evaluated:

Physical properties

2.0 USES

The Terrastop™ segmental retaining wall system consists of modular concrete units for the construction of dry-stacked, vertical, segmental landscaping and retaining walls, with or without a mass of reinforced, retained soil stabilized by horizontal layers of geosynthetic reinforcement materials.

3.0 DESCRIPTION

3.1 Terrastop™ Segmental Retaining Wall System:

The Terrastop™ segmental retaining wall system is a vertical structure consisting of one course of either Terrastop™ System 5 or System 2 modular concrete units, followed by several courses of Terrastop™ System 2 modular concrete units dry-stacked in a running bond, with or without horizontal layers of a geosynthetic reinforcement material placed between stacked Terrastop™ System 2 concrete units and extended into compacted backfill soil, to a wall height resulting from a design as a conventional gravity wall relying solely on the weight of the dry stacked Terrastop™ System 2 modular concrete units (see Section 4.1.2); or to a wall height resulting from a design as a composite-mass gravity structure relying on both the weight of the dry stacked concrete units and the mass of the geogrid-reinforced soil (see Section 4.1.3), to resist forces associated with retained soils and surcharge loads. This evaluation report recognizes the Terrastop™ modular concrete units as compliant with standard physical property specifications; and for facing connection strength when geosynthetic reinforcement material is interlocked with vertically stacked Terrastop™ modular concrete units. The interaction of the geosynthetic reinforcement material in soil is outside the scope of this report.

3.2 Materials:

3.2.1 Terrastop™ Modular Concrete Units: The Terrastop™ System 5 and System 2 modular concrete units are compliant with the material specifications, strength requirements and absorption requirements, permissible tolerances, and finish and appearance requirements of ASTM C 1372. The Terrastop™ modular concrete units are manufactured as dry cast concrete units with normal-weight aggregates complying with ASTM C 33.

In areas where repeated freezing and thawing under saturated conditions occur, evidence of compliance with freeze-thaw durability requirements as described in ASTM C 1372, Sections 5.2 and 8.3, must be furnished to the code official, when required by the code official, for approval prior to construction.

Specified nominal dimensions of the Terrastop™ System 2 modular units are 4 inches (vertical height) by 8 inches (width, parallel to wall face) by 12 inches (depth, perpendicular to wall face); the specified nominal dimensions of the Terrastop™ System 5 modular units are 4 inches (vertical height) by 8 inches (width, parallel to wall face) by 24 inches (depth, perpendicular to wall face). Permissible variation from these specified nominal dimensions is $\pm^1/_8$ inch (3.2 mm). See Figures 1 and 2.

Each Terrastop™ System 2 modular unit has a nominal dry weight of 30 pounds (13.6 kg), and has maximum water absorption of 6 percent (percentage of dry weight of the units). Wall coverage equals 4.5 System 2 modular units per square foot of wall surface. System 5 and System 2 modular concrete units are manufactured with vertical and horizontal drainage grooves that are concealed in completed, dry-stacked segmental walls, providing a continuous network of water drainage channels within the stacked units for hydrostatic pressure relief. Each unit has an interlocking concrete shear key that ensures vertical alignment of successive courses. The units are manufactured in a variety of colors with integral pigments, and optional brick or split face appearance.

3.2.2 Base Leveling Pad Materials: Material must consist of maximum $^3/_4$-inch-diameter (19.1 mm) crushed stone or normal-weight concrete (reinforced or nonreinforced as specified by the registered design professional).

3.2.3 Drainage Material: The drainage layer behind Terrastop™ segmental retaining walls must consist of maximum 1-inch-diameter (25.4 mm) free draining, clean, crushed stone or crushed gravel.

3.2.4 Backfill Material: Backfill material placed behind the segmental retaining wall must be soil that is free of organic material, construction debris, and boulders; or a controlled low-strength material; or as specified by the registered design professional. Backfill used in the reinforced fill mass must consist of suitable fine-grained or coarse-grained soil placed in lifts compacted to at least 90 percent of the maximum dry density as determined by ASTM D 1557 or 95 percent per ASTM D 698.

3.2.5 Geogrid Soil Reinforcement Material: The geogrid material for use with the Terrastop™ landscape and retaining wall systems recognized in this evaluation report is the Stratagrid® 200, manufactured by Strata Systems, Inc.

4.0 DESIGN AND INSTALLATION

4.1 Design:

4.1.1 General: Structural calculations must be submitted to the code official for each wall system installation. The system must be designed as a gravity or reinforced-soil retaining wall that depends on the weight and geometry of the Terrastop™ System 2 and System 5 modular concrete units and soil to resist lateral earth pressures and other lateral forces. Lateral active earth pressures are determined using the Coulomb earth pressure theory, except that for the case of a horizontal back slope ($\beta = 0$) and a vertical wall surface ($\omega = 0$), the coefficient of active earth pressure and the orientation of the critical failure surface reduces to classic Rankine equations. The design must include evaluation of both external and internal stability of the structure and include consideration of external loads such as surcharges and seismic forces. The minimum safety factors are 1.5 for lateral sliding and 2.0 for overturning for segmental retaining walls with a geogrid-reinforced soil mass. The minimum safety factor against lateral sliding and overturning shall be in accordance with 2009 IBC Section 1807.2.3, 2006 IBC Section 1806.1, or 2009 IRC Section R404.4 or 2006 IRC Section R404.5, as applicable, for segmental retaining walls without a reinforced soil mass. The minimum safety factor is 2.0 for bearing capacity. Seismic safety factors may be 75 percent of the minimum allowable static safety factors.

A site-specific soils investigation report in accordance with 2009 IBC Section 1803, 2006 IBC Section 1802, or 2009 or 2006 IRC Section R401.4, as applicable, is required. The soils investigation report must provide a global slope stability analysis that considers the influence of site geometry, subsoil properties, groundwater conditions, and existing (or proposed) slopes above and below the proposed retaining wall. The soils report also must specify the soil-reinforcement and interaction coefficients, including the coefficient of interaction for pullout and coefficient of direct sliding; and include derivation of the ultimate tensile strength of the geogrid material (according to ASTM D 4595), and the applicable safety factors for deriving the ultimate strength, long-term design strength and allowable tensile strength of the geogrid. The soils investigation report must also specify safety factors for tensile rupture and pullout of the geogrid. Where the wall is located in an area enforcing the 2009 IBC, in Seismic Design Categories C through F, the site-specific soils report must include the information as required by 2009 IBC Section 1803.5.11. Where the wall is located in an area enforcing the 2009 IBC, in Seismic Design Categories D through F, the site-specific soils report must include the information as required by 2009 IBC Section 1803.5.12. Where the segmental retaining wall is located in an area enforcing the 2006 IBC, in Seismic Design Category C, the site-specific soils report must include the information as required by 2006 IBC Section 1802.2.6; where the wall is located in an area enforcing the 2006 IBC, Seismic Design Category D, E, or F, the site-specific soils report must include the information as required by 2006 IBC Section 1802.2.7.

The design of Terrastop™ segmental retaining walls is based on accepted geotechnical principles for gravity and soil-reinforced structures. Specifics of design recommended by the report holder are found in their document entitled, "Design Manual—Terrastop® Interlocking Blocks," with a 2003 copyright date.

Table 1 provides equations for the shear strength between stacked Terrastop™ System 2 modular concrete units without any geogrid material placed between vertically stacked units for different loads applied normal to the segmental units and the connection interface. Table 2 provides equations for the shear strength between stacked Terrastop™ System 2 modular concrete units with a layer of Stratagrid® 200 geogrid material placed between vertically stacked units for different loads applied normal to the segmental units and the connection interface.

4.1.2 Gravity Segmental Retaining Walls: The gravity segmental retaining wall system relies on the weight and geometry (built-in concrete shear key) of the Terrastop™ System 2 and System 5 modular concrete units to resist lateral earth pressures. Gravity wall design is based on standard engineering principles for modular (segmental) concrete retaining walls. The maximum height of retaining walls constructed by dry stacking Terrastop™ System 2 modular concrete units must be determined for each soil and back slope combination.

4.1.3 Geogrid-reinforced-soil Segmental Retaining Walls:

4.1.3.1 General: The geogrid-reinforced-soil segmental retaining walls rely on the weight and geometry of the dry, vertically stacked Terrastop™ System 2 and System 5 modular concrete units and the weight of the zone of geogrid-reinforced compacted (infill) soil to act as a composite gravity wall system with a cohesive mass to resist lateral earth pressures. The design of a reinforced soil structure must be specific to the Terrastop™ modular concrete units, soil reinforcement (geogrid material) strength and soil interaction, soil strength properties, and structure geometry.

4.1.3.2 Structural Analysis: Structural analysis must be based on accepted engineering principles, the Terrastop™ Landscape Wall System Design Manual dated 2003, and the IBC or IRC, as applicable. The analysis must include all items noted in Sections 4.1.3.2.1 and 4.1.3.2.2 of this report. All contact surfaces of the units must be maintained in compression.

4.1.3.2.1 External Stability Analysis: The minimum length of the reinforced mass is 0.6 times the height of the wall (as measured from the top of the leveling pad to the top of the wall) or as required to satisfy a safety factor of 1.5 on sliding at the base, whichever is greater. The minimum safety factor for overturning the reinforced mass is 2.0, considering the mass as a rigid body rotating about the toe of the wall. Global stability analysis must be provided for walls with slopes below the toe of the wall, walls on soft foundations, walls that will be designed for submerged conditions, or tiered walls. After completion of

the external stability analysis and determination of the geogrid layout, investigation is necessary of total and differential settlement of the soils, which may have varying soil strengths along the length and width of the segmental retaining wall with geogrid reinforced soil.

4.1.3.2.2 Internal Stability Analysis: Geogrid spacing (vertical distance between successive geogrid layers) and geogrid length (horizontal length of the geogrid material in the anchorage zone of the soil) must be based on local stability analysis of the geogrid's capacity to hold the reinforced soil mass together so that it can be assumed as a rigid body for global and overall slope stability analysis. Internal stability analysis must investigate limit states identified as geogrid pullout, geogrid tensile overstress, internal sliding (movement of Terrastop units with or without a layer of geogrid material), and facing connection. Vertical spacing of the geogrid material is typically limited to 2 times the depth of the Terrastop unit.

Tension calculations for each respective layer of geogrid material are based on the earth pressure and surcharge load calculated using a tributary volume between successive geogrid layers. Calculated tension loads must not exceed the geogrid's allowable working tensile strength. The facing connection capacity must be checked where the geogrid material is sandwiched between two courses of Terrastop System 2 modular concrete units. When serviceability of structures is deemed critical, the facing connection capacity must be limited to a load associated with a maximum $^3/_4$-inch (19.1 mm) movement of a geogrid layer relative to the two courses of Terrastop System 2 modular concrete units holding the goegrid material in place. Refer to Table 2 for facing connection peak tensile strength and allowable tensile strength based on a $^3/_4$-inch (19.1 mm) deformation serviceability limit.

A calculation check must be made on anchorage capacity of the upper layers of geogrid from the soil zone beyond the theoretical Coulomb or Rankine failure plane. The ratio of the developed anchorage capacity to the applied force in the geogrid layer must be equal to or greater than 1.5, which is the minimum applicable safety factor required for design.

4.2 Installation:

The wall system units must be assembled in a running bond pattern. The wall system units must be dry stacked (assembled without mortar or grout) using each unit's interlocking shear key for alignment, unit-to-unit shear resistance, and mechanical interlock of geogrid soil reinforcement material. General requirements for installation of the Terrastop™ segmental retaining wall system must be in accordance with the manufacturer's published installation instructions and this report. See Figure 3 for typical installation details.

Excavation must be conducted for the base leveling pad, drainage fill, and soil-reinforced fill zone until undisturbed soil of appropriate bearing capacity is exposed. Excavations must be inspected by a qualified geotechnical engineer or soils engineer for adequate bearing capacity of foundation soils and groundwater conditions.

A wall base pad of crushed stone or plain structural concrete, or both, as described in Section 3.2, must be installed. When the base pad is crushed stone, its thickness is typically from 4 inches to 6 inches (101.6 mm to 152.4 mm), and it is compacted to a minimum 90 percent modified proctor according to ASTM D 1557. An unreinforced plain concrete leveling pad compliant with 2009 IBC Section 1809.8, 2006 IBC Section 1805.4.2.3 or 2009 or 2006 IRC Section R402.2, as applicable may be used in place of, or in combination with, the crushed stone pad, except the thickness of the concrete pad may be as determined by the registered design professional. Regardless of the wall base pad material, the top surface of the pad must be sloped into the backfill area $^1/_4$ inch per foot (6.4 mm per 304.8 m) to compensate for outward wall rotation caused by differential soil settlement and geogrid soil reinforcement initial elongation.

The first course of units consists of either the 12-inch-deep (304.8 mm) Terrastop System 2 modular unit or the 24-inch-deep (609.6 mm) Terrastop System 5 modular unit, depending on soil capacity and wall height. Following courses of Terrastop System 2 modular units are placed in a running bond pattern, and loose aggregate or any debris is removed from the top surface of the units so that the male/female interlock shear keys are completely engaged at each succeeding course. For segmental retaining walls installed without any geogrid soil reinforcement, the Terrastop System 2 modular units must be stacked in two-course increments and then the gravel drain backfill and compacted soil backfill are placed.

For installations receiving rain runoff, a 3-inch-diameter (76.2 mm) perforated drain pipe encased in a filter fabric must be installed at the base of the wall and sloped a minimum of $^1/_4$ inch per foot (6.4 mm per 304.8 m), with unrestricted flow towards outlets away from the wall and its backfill. A minimum 8-inch-thick (203.2 mm) layer of drainage gravel backfill must be placed directly behind the stacked units.

For segmental retaining walls installed with geogrid soil reinforcement, the end of the geogrid material must be placed at the designated courses (elevations) of the wall in accordance with the approved design and construction documents. Geogrid reinforcement material must be cut to length, as specified in the approved construction documents, and laid on compacted soil backfill, such that the first transverse rib is positioned just on the inside surface of the front face of the Terrastop System 2 modular units so that the male/female interlock shear keys completely engage the geogrid reinforcement, ensuring a continuous mechanical anchorage along the entire length of wall bed joint. The strong direction of the geogrid reinforcement must be perpendicular to the segmental wall face, and the reinforcement must remain taut during placement of compacted soil backfill. Adjacent rolls may be placed side by side; no overlap is required. Adequate geogrid reinforcement tautness must be inspected and verified prior to installation of fill over it. Geogrid reinforcement material with slack, folds or wrinkles must be removed and re-tensioned in accordance with the registered design professional's specifications before placement proceeds of compacted soil fill. The backfill soil properties, lift thickness, and degree of compaction must be determined by the soils engineer based on site-specific conditions. The backfill soil is placed and compacted over the geogrid reinforcing layer in appropriate lift thickness to ensure compaction. Placement of the Terrastop™ System 2 modular units, geogrid reinforcement, and drainage fill layer, and compacted soil backfill, is repeated, as shown on plans, to finished grade. The reinforced backfill must be placed and compacted no lower than the top unit-elevation to which geogrid placement is required. Provisions for adequate subsurface drainage must be determined by the soils engineer.

4.3 Special Inspection:

Special inspection must be provided in accordance with IBC Section 1704.5 (IBC and IRC). The inspector's responsibilities include verifying the following:

1. The modular concrete unit dimensions.
2. Terrastop™ unit compliance with ASTM C 1372, including compressive strength and water absorption, as described in Section 3.1 of this report.
3. Foundation preparation.
4. Terrastop™ unit placement, including alignment and inclination.
5. Geosynthetic reinforcement type (manufacture and model number) and placement.
6. Backfill placement and compaction.
7. Drainage provisions.

For existing site soil conditions, backfill placement and load-bearing requirements, special inspection must be provided in accordance with IBC Section 1704.7 (IBC and IRC). The approved soils report and the documents used to determine compliance with the code must be prepared by the registered design professional. During placement, the special inspector must determine that approved materials and procedures are used in accordance with the provisions of the approved soils report.

5.0 CONDITIONS OF USE

The Terrastop™ segmental retaining wall system described in this report complies with, or is a suitable alternative to what is specified in, those codes listed in Section 1.0 of this report, subject to the following conditions:

5.1 The systems are designed and installed in accordance with this report, the manufacturer's published installation instructions, and accepted engineering principles. If there is a conflict between this report and the manufacturer's published installation instructions, this report governs.

5.2 The Terrastop™ Landscape Wall System Design Manual, dated 2003, must be submitted to the code official upon request.

5.3 The wall design calculations are submitted to, and approved by, the code official. The calculations must be prepared by a registered design professional where required by the statutes of the jurisdiction in which the project is to be constructed.

5.4 A site-specific soils investigation in accordance with 2009 IBC Section 1803, 2006 IBC Section 1802, or 2009 or 2006 IRC Section R401.4, as applicable, as noted in Section 4.1.1 of this report, must be provided for each project site.

5.5 In areas where repeated freezing and thawing under saturated conditions occur, evidence of the units' compliance with freeze-thaw durability requirements of ASTM C 1372, Sections 5.2 and 8.3, must be furnished to the code official for approval prior to construction.

5.6 Special inspection must be provided for backfill placement and compaction, geogrid placement (when applicable), and block unit installation, in accordance with Section 4.3 of this report.

5.7 Details in this report are limited to areas outside of groundwater. For applications where free-flowing groundwater is encountered, or where wall systems are submerged, the installation and design of systems must comply with the recommendations of the soils engineer, and must be approved by the code official.

5.8 Project specifications or soil and water conditions that indicate sulfate concentrations identified in ACI 318-08 Table 4.2.1 as moderate (S1), severe (S2) or very severe (S3) shall include mix designs for the concrete masonry and grout that comply with ACI 318-08 Table 4.3.1. See 2009 IBC Section 1904.5.

5.9 Project specifications or soil and water conditions that indicate sulfate concentrations identified in ACI 318-05 Table 4.3.1 as moderate, severe or very severe shall include mix designs for the concrete masonry and grout that comply with ACI 318-05 Table 4.3.1. See 2006 IBC Section 1904.3.

5.10 This report evaluates only the connection strength of the geogrid material when attached to the block units as described in Section 4.2. Physical properties of the geogrid material and its interaction with the soil have not been evaluated.

6.0 EVIDENCE SUBMITTED

Data in accordance with the ICC-ES Acceptance Criteria for Segmental Retaining Walls (AC276), dated October 2004 (editorially revised May 2011).

7.0 IDENTIFICATION

Each pallet of Terrastop™ modular concrete units is identified with the report holder's name (Rapid Building Systems); manufacturer's name (Betco Supreme, an Oldcastle Company) and address (Gainesville, Virginia); the name of the product (Terrastop™ System 2 or System 5); and the evaluation report number (ESR-2513).

TABLE 1—UNIT-TO-UNIT INTERFACE PEAK SHEAR AND SERVICEABILITY SHEAR STRENGTHS

TERRASTOP™ MODULAR CONCRETE UNITS	UNIT-TO-UNIT INTERFACE SHEAR CAPACITIES (lbs/linear ft)			
	Peak (Ultimate) Shear Strength, S_p		Serviceability Shear Strength, S_{ss}	
	Equation[1]	Maximum	Equation[1]	Maximum
System 2–to–System 2	S_p = 1015 + 2.49 N	S_p = 9250	S_{ss} = 82 + 0.50 N	S_{ss} = 1420
System 2–to–System 5				

For **SI:** 1 in. = 25.4 mm, 1 plf = 14.6 N/m.

[1]N = superimposed normal (applied) load (lbs/linear foot of unit).

TABLE 2—UNIT-TO-GEOGRID-TO-UNIT INTERFACE PEAK SHEAR AND SERVICEABILITY SHEAR STRENGTHS

TERRASTOP™ MODULAR CONCRETE UNITS	UNIT-TO-GEOGRID-TO-UNIT INTERFACE SHEAR CAPACITIES[2] (lbs/linear ft)			
	Peak (Ultimate) Shear Strength, V_u		Serviceability Shear Strength, V'_u	
	Equation[1]	Maximum	Equation[1]	Maximum
System 2–to-Geogrid-to–System 2	V_u = 3054 + 1.08 N	V_u = 6545	V'_u = 563 + 0.22 N	V'_u = 1050

For **SI:** 1 in. = 25.4 mm, 1 plf = 14.6 N/m.

[1]N = superimposed normal (applied) load (lbs/linear foot of unit).
[2]Geogrid must be installed such that the first rib is positioned just to the inside surface of the front face of the Terrastop™ System 2 concrete units.

TABLE 3—GEOGRID MATERIAL FACING CONNECTION STRENGTH
(Facing Connection Strength at Peak Load and Facing Connection Strength at Serviceability Limit of $^3/_4$ inch)

GEOGRID MATERIAL	GEOGRID FACING CONNECTION STRENGTH[1,2] (lbs/linear ft)					
	Peak (Ultimate) Connection Strength			Serviceability Connection Strength		
	Applied Load, N (plf)	Peak Connection Strength, T_{cp}	Maximum Peak Connection Strength, T_{cp}	Applied Load, N (plf)	Serviceability Connection Strength, T_{sc}	Maximum Serviceability Connection Strength, T_{sc}
Stratagrid® 200	N ≤ 386	T_{cp} = 138 + 1.36 N	—	N ≤ 364	T_{sc} = 136 + 1.15 N	—
	N > 386	T_{cp} = 555 + 0.28 N	917	N > 364	T_{sc} = 431 + 0.34 N	894

For **SI:** 1 in. = 25.4 mm, 1 plf = 14.6 N/m.

[1]N = superimposed normal (applied) load (lbs/linear foot of geogrid).
[2]Geogrid must be installed such that the first rib is positioned just on the inside surface of the front face of the Terrastop™ System 2 concrete units.

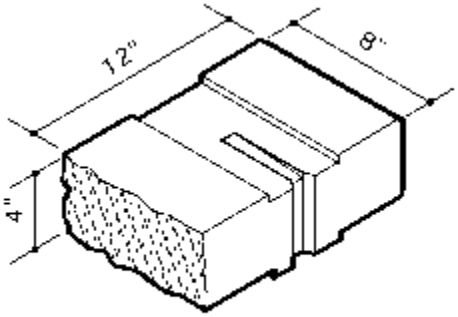

FIGURE 1—TERRASTOP™ SYSTEM 2 MODULAR CONCRETE UNITS FOR SEGMENTAL RETAINING WALLS

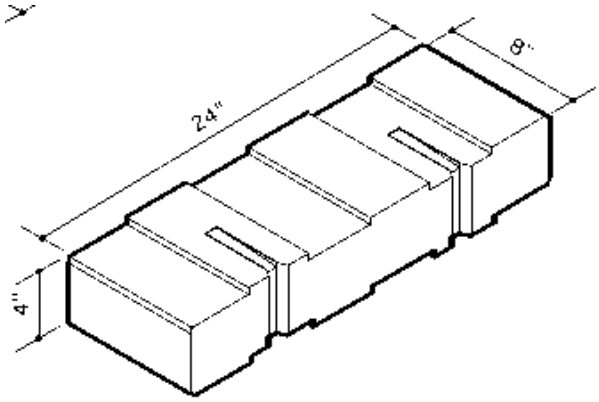

FIGURE 2—TERRASTOP™ SYSTEM 5 MODULAR CONCRETE UNITS FOR FOUNDATION LAYER OF SEGMENTAL RETAINING WALLS

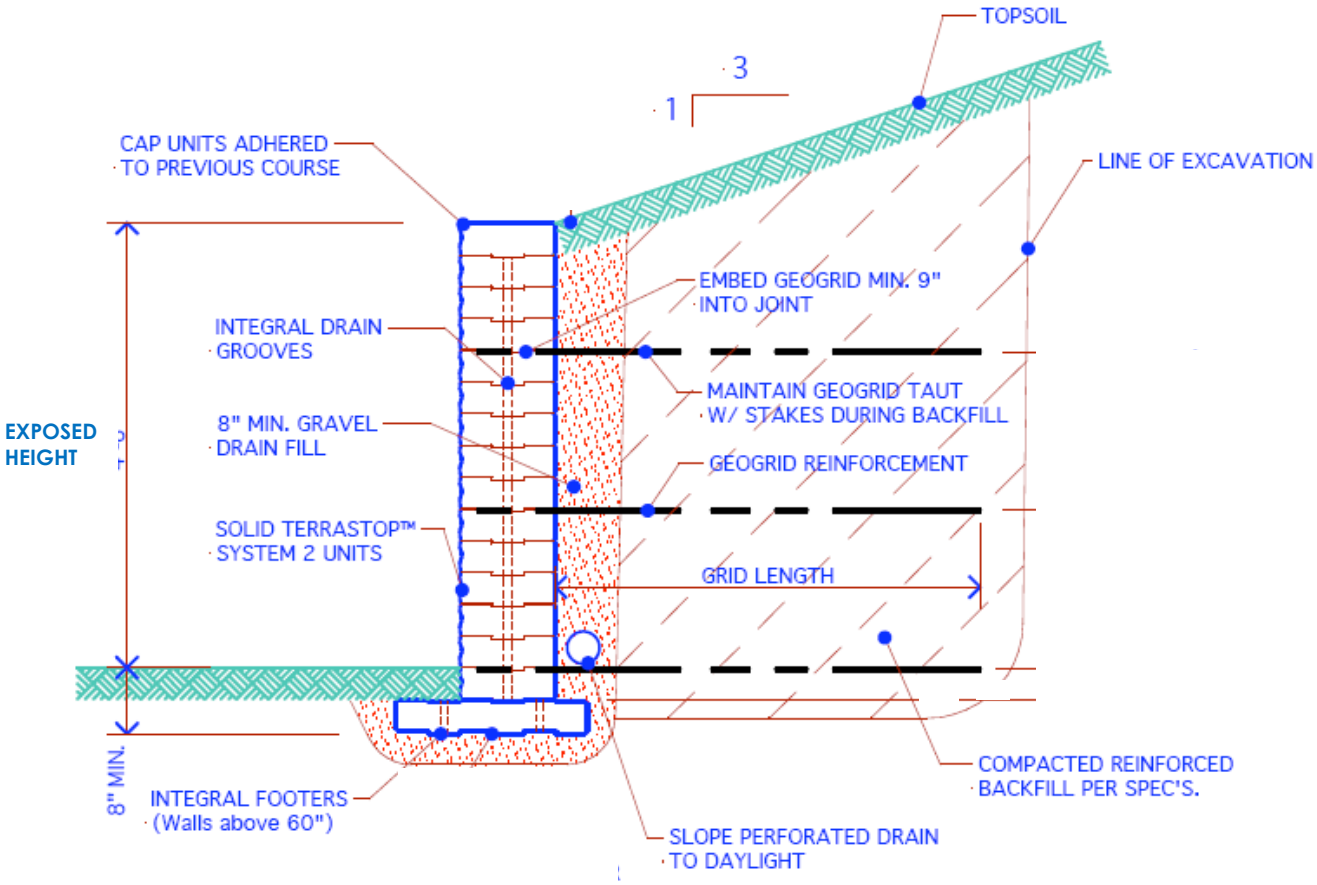

FIGURE 3—TYPICAL INSTALLATION DETAILS