REPORT OF REVIEW THE REDI-ROCK PRECAST MODULAR RETAINING WALL SYSTEM

August 2022

HIGHWAY INNOVATIONS, DEVELOPMENTS, ENHANCEMENTS AND ADVANCEMENTS (IDEA)

The Redi-Rock Precast Modular Retaining Wall System has been evaluated in accordance with the IDEA protocol. Key information regarding this system is presented in this final report of review. Comprehensive and important details of the system's components, design, construction and quality control measures are presented in the "Summary Table of MSEW+ Program Input Parameters for Redi-Rock Retaining Wall System" located at the end of this report and the Redi-Rock Submittal.

Applicant Information

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Review Summary

Following its initial review of the Redi-Rock Precast Modular Retaining Wall System & Concrete Modular Block Unit Paired with Extensible Reinforcement submittal, the review team provided the applicant with a series of comments, requests for clarification and additional analysis. **The applicant has been thorough in its responses and the review team finds that there are no outstanding issues that should be brought to the attention of the transportation agencies. Rather, the agencies are encouraged to rely upon the Redi-Rock Precast Modular Retaining Wall System & Concrete Modular Block Unit Paired with Extensible Reinforcement submittal for projects where the Redi-Rock Retaining Wall System is proposed.**

Submittal Checklist

The checklists used from the IDEA protocol for this evaluation are C1 – Initial Technical Evaluation Checklist for Concrete Modular Block Paired with Extensible Reinforcement and C7 – Initial Technical Evaluation Checklist for Concrete Modular Gravity Wall System. This is the first evaluation of the Redi-Rock Precast Modular Retaining Wall System by either the HITEC or IDEA evaluation program.

Confidential Information

The applicant has the option to omit information from the version of its submittal that is attached to the final report if it believes that such information is confidential. In such instances, the applicant will notify the review team. However, for the Redi-Rock Precast Modular Retaining Wall System no information has been designated by the applicant as confidential.

System Description

Components

The Redi-Rock system comprises precast modular blocks conforming to ASTM C1776 Standard Specification for Wet-Cast Precast Modular Retaining Wall Units. The system includes blocks of varying size and configuration, which are machine-set in varying site-specific configurations to construct gravity retaining walls or paired with strips of TenCate Miragrid reinforcement to construct mechanically stabilized earth (MSE) walls. The blocks used in the gravity and MSE systems are compatible; allowing a single wall to transition between gravity and MSE structures, depending on height, soils, and loading conditions. Other components include gravel core fill, and geotextile filter.

Redi-Rock block units can be categorized into four broad categories: Solid, Hollow Core, Freestanding, and Positive Connection (PC). All blocks (with the exception of half units) are 46⅛ in (1172 mm) long and are either 18 in (457 mm) or 36 in (914 mm) in height. All Redi-Rock blocks are compatible with one another.

For MSE walls, after the Redi-Rock modular units are set in the wall, 12-inch-wide strips of Miragrid reinforcement are positioned through the open unit core.

System History

The Redi-Rock Gravity Wall system was first developed in 1999. The founders of Redi-Rock owned a heavy civil construction firm and were working on a project in Northern Michigan where they were presented with a challenge to develop a new way to construct retaining walls. Owning several ready-mix plants, they were also seeking new ways to use the concrete production from their plants. In early 2000, the first producer was licensed by Redi-Rock. Since that time, Redi-Rock has grown into a network of over 120 licensed producers in 15 countries on 6 continents. Redi-Rock was the first to patent the large block retaining wall system, and currently owns over 24 patents. There are millions of square feet of Redi-Rock retaining walls all over the world, in applications ranging from residential to rail projects with E80 loading.

The original blocks that were developed were intended to be used as a gravity wall system. Not long after developing the gravity wall system, it became necessary to have a reinforced wall system so that taller walls could be achieved. The first version of the Redi-Rock reinforced wall system was called the 1AT system (AT standing for Anchor Tail). The 1AT connection utilized a fiberglass rod and anchored tail to generate pullout resistance of the geogrid from the facing units. In 2012, Redi-Rock engineers developed the current Redi-Rock modular concrete MSE wall system. It involves casting a vertical core slot in the wall facing unit, thus creating a weight independent connection for their MSE wall system. This wall system is called the Positive Connection (PC) system, which is the MSE wall system referenced in this submittal.

The oldest Redi-Rock gravity wall was installed in 1998, in Petoskey, Michigan. The oldest MSE wall with PC system was built in 2011 in Louisville, Kentucky. The tallest gravity wall is 25.5 feet in height and is located in Nashville, Tennessee. The tallest PC Redi-Rock MSE wall in the US is 51.5 feet and is located in Kittrell, North Carolina.

System Properties
The following properties are reported by the applicant for Redi-Rock Precast Modular Retaining Wall System.

Soil reinforcement ultimate tensile strengths. The ultimate tensile strengths for the TenCate Miragrid soil reinforcement are the minimum average roll values (MARV) as published by the reinforcement manufacturer, TenCate. The AASHTO NTPEP independently measured ultimate strength values (NTPEP, 2019) indicate that the sampled products have a tensile strength that exceeds the manufacturer's MARVs.
Soil reinforcement nominal tensile strengths. The nominal tensile strengths (T_{al}) for the Miragrid soil reinforcement is computed as the ultimate strength ($T_{ult\text{-}MARV}$) divided by reduction factors for creep (RF_{CR}), degradation (RF_D), and installation damage (RF_{ID}). The equation for this calculation is:

$$T_{al} = \frac{T_{ult-MARV}}{RF_{CR} x RF_D x RF_{ID}} \qquad \text{Eq. 1}$$

The AASHTO NTPEP independently measured creep reduction value (NTPEP, 2019) of 1.44 is used for a 75- and 1.45 is used for 100-year design life. The durability reduction factor is a function of wall fill specifications, particularly pH limits. A durability reduction value of 1.15 or 1.3 is typical. The installation damage reduction factor is a function of the wall fill properties (gradation, D_{50}, angularity, etc.) and placement techniques. Recommended values are presented for two wall fills with maximum gradation sizes 1 ½ -inch, and 3/8-inch sieve.

Soil reinforcement-facing unit connection capacity. The connection capacities of the Miragrid reinforcement and Redi-Rock PC units have been evaluated by short-term connection strength testing. The long-term Miragrid creep reduction factor was used to evaluate the long-term connection strength.

Reinforcement Pullout and Interface Shear. Independent pullout test results are as presented in Appendix Tab 1.2.7. Testing was performed on Miragrid reinforcement in general accordance with ASTM D 6706. The tests were performed on a range of soils (i.e., silty sand, and #57 stone base). Based on these results, an F* equal to 0.8 tanφ, and α value equal to 1.0 may be used for reinforced backfill consisting of silty sand or #57 stone and in the absence of project-specific pullout testing.

The interface shear friction angle was determined from direct shear tests in general accordance with ASTM D 5321. A copy of the interface direct shear test report is provided in Appendix Tab 1.1.10. Based on the test results the interface friction coefficient (ρ) is equal to 0.8 for silty sand (SW) and equal to 0.9 for #57 stone.

System Innovations
This IDEA evaluation concurs with Redi-Rock that their system provides the following innovations:

- Rounded interlocking shear knobs and groove. The top of each block (excluding top blocks) incorporates a pair of rounded dome-shaped knobs which interlock with the shear groove cast into the bottom of the overlying blocks. This provides robust unit-to-unit interface shear capacity, as well as easy positioning during construction, and the ability to easily create curves. The forming system allows for the size and the location of the shear knobs to be varied, resulting in various options for overall wall batter, including 0°, 1°, 5° (standard), 27.5°, and 43°.

- Positive Connection geogrid reinforcement connection. The Positive Connection (PC) system provides a geogrid reinforcement connection between geogrid soil reinforcement and precast concrete facing units that is independent of normal load and utilizes a significant proportion of the full tensile strength of the geogrid.

Reviewer Comments

Following its initial review of the Redi-Rock Precast Modular Retaining Wall System submittal, the review team provided the applicant with 34 comments and requests for clarification. The applicant has been thorough in its responses and the review team finds that there are no outstanding issues that should be brought to the attention of the transportation agencies. Rather, the agencies are encouraged to rely upon the final Redi-Rock Precast Modular Retaining Wall System submittal for projects where the Redi-Rock System is proposed.

Closing

An update technical evaluation should be performed for the Redi-Rock Precast Modular Retaining Wall System in five years (i.e., August 2027) or upon notice that a significant modification of the system has been made. For details regarding update technical evaluations and other guidance for the use of technical evaluations by transportation agencies, go to https://www.geoinstitute.org/special-projects/idea.

References

NTPEP (2019). Laboratory Evaluation of Geosynthetic Reinforcement, Final Product Qualification Report for Miragrid XT Geogrid Product Line, Submitting Manufacturer: TecCate Geosynthetics, National Transportation Product Evaluation Program (NTPEP) Report REGEO-2016-01- [TenCate-Miragrid XT], American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C.

Summary Table of MSEW+ Program Input Parameters for the REDI-ROCK Retaining Wall System						
Geogrid Soil Reinforcement						
Data / Geogrid		5XT	8XT	10XT	20XT	24XT
T_{ult} (lb/ft)		4,700	7,400	9,500	13,705	27,415
Durability Reduction Factor, RF_D	5<pH<8	1.15	1.15	1.15	1.15	1.15
	4.5≤pH≤5	1.30	1.30	1.30	1.30	1.30
	8≤pH≤9	1.30	1.30	1.30	1.30	1.30
Installation Damage Reduction Factor, RF_{ID}	100% < 1.5-in.; D_{50} = 1.12-in.	1.59	1.59	1.55	1.49	1.40
	100% < 3/8-in.; D_{50} < #4	1.10	1.10	1.10	1.10	1.10
Creep Reduction Factor, RF_{cr}	75 years	1.44	1.44	1.44	1.44	1.44
	100 years	1.45	1.45	1.45	1.45	1.45
Coverage Ratio		0.25 or 0.50	0.25 or 0.50	0.25 or 0.50	0.25 or 0.50	0.25 or 0.50
Friction Angle along geogrid-soil Interface, ρ	Fine to Medium Sands[a]	0.8 tanφ	0.8 tanφ	0.8 tanφ	0.8 tanφ	0.8 tanφ
	Well-graded sands, sand & gravel[a]	0.9 tanφ	0.9 tanφ	0.9 tanφ	0.9 tanφ	0.9 tanφ
Pullout Resistance factor, F*	Sands[a]	0.8 tanφ	0.8 tanφ	0.8 tanφ	0.8 tanφ	0.8 tanφ
	Gravels[a]	0.8 tanφ	0.8 tanφ	0.8 tanφ	0.8 tanφ	0.8 tanφ
Scale-effect correction factor, α	Sands[b]	1.0	1.0	1.0	1.0	1.0
	Gravels[b]	1.0	1.0	1.0	1.0	1.0
Facia Geometry and Unit Weight[f]:		Depth/height = 2.44 or 3.38 ft / 1.5 ft				
		Horizontal distance to center of gravity = 1.18 or 1.71 ft				
		Average unit weight of block = 143 lb/ft^3				
Connection Strengths:		CR_{cr}[d]				
	σ[c] (lb/ft^2)	5XT	8XT	10XT	20XT	24XT
75-Year Design	0	0.583	0.583	0.569	0.556	0.479
	CRult					
100-Year Design	0	0.579	0.579	0.566	0.552	0.476
Connection strength reduction factor, RF_d		1.15	1.15	1.15	1.15	1.15
Creep Reduction Factor, RF_c[e]		1.0	1.0	1.0	1.0	1.0

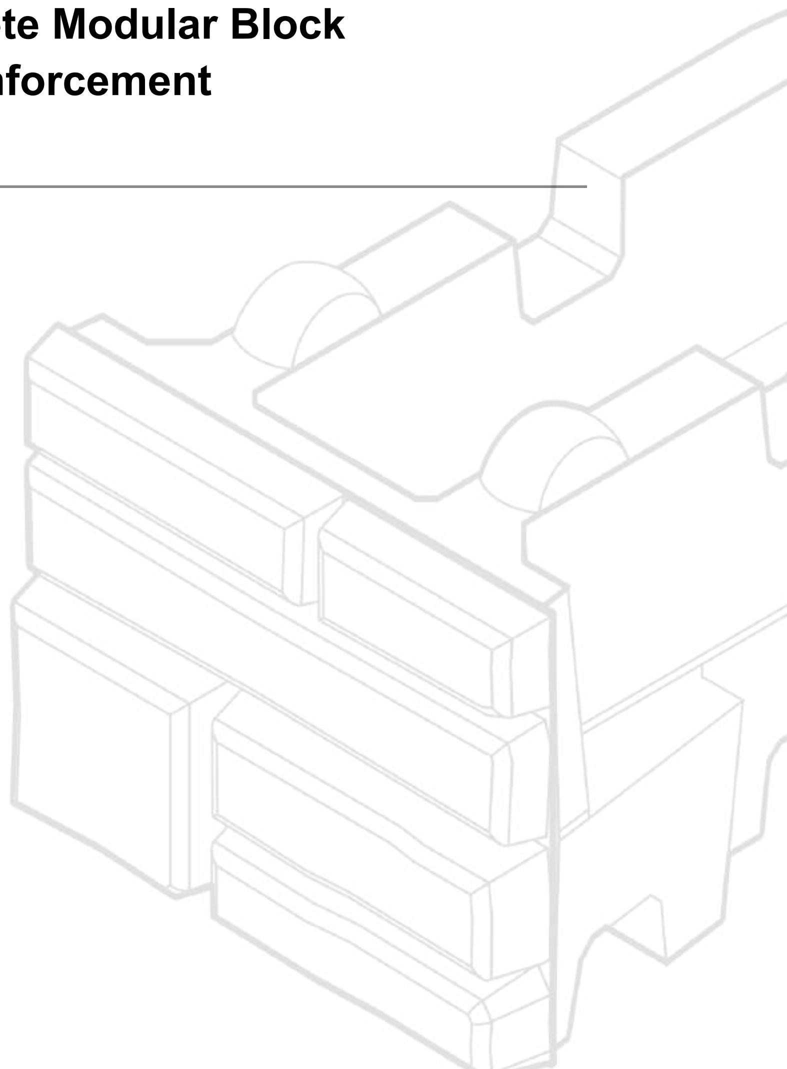
[a] Predominant material
[b] Scale-effect Correction Factor has been eliminated from the FHWA 2022 MSE Design manual
[c] Normal pressure (lb/ft^2) Redi-Rock connection is independent of normal load
[d] MSEW program term ($CR_{cr} = T_{cre}/T_{ult}$)
[e] The values for CR_{cr} for input into MSEW include a reduction factor for creep and the geogrid lot strength. RF_d is not included in the value of CR_{cr} as MSEW includes this reduction factor separately.
[f] Facia geometry and unit weight in this table are for the PC system.

Redi-Rock Precast Concrete Modular Gravity Retaining Wall System & Concrete Modular Block Unit Paired With Extensible Reinforcement

Technical Evaluation Submittal for:

Highway Innovations, Developments, Enhancements, and Advancements (IDEA)

August 3, 2022



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INTRODUCTION

This document constitutes Redi-Rock International's technical submittal document for evaluation by the Federal Highway Administration's *Highway Innovations, Developments, Enhancements, and Advancements (IDEA)* program for Redi-Rock's precast concrete modular gravity wall system and Redi-Rock's concrete modular block unit paired with extensible reinforcement.

The Redi-Rock system comprises precast modular blocks conforming to ASTM C1776 *Standard Specification for Wet-Cast Precast Modular Retaining Wall Units*. The system includes blocks of varying size and configuration, which are machine-set in varying site-specific configurations to construct gravity retaining walls, or paired with strips of geogrid reinforcement to construct mechanically stabilized earth (MSE) walls. The blocks used in the gravity and MSE systems are compatible; allowing a single wall to transition between gravity and MSE structures, depending on height, soils, and loading conditions.

Redi-Rock International, LLC is a subsidiary of Aster Brands, headquartered at 2940 Parkview Drive, Petoskey, Michigan 49770. Redi-Rock manufactures the forming system and licenses the product to independent producers.

SECTION 1: ERS COMPONENTS

1.1 Facing/Gravity Unit

1.1.1 Unit Innovation

Redi-Rock was a pioneer in the large-format, precast modular block industry. Some innovations and improvements over existing systems include:

- Rounded interlocking shear knobs and groove. The top of each block (excluding top blocks) incorporates a pair of rounded dome-shaped knobs which interlock with the shear groove cast into the bottom of the overlying blocks. This provides robust unit-to-unit interface shear capacity, as well as easy positioning during construction, and the ability to easily create curves. The forming system allows for the size and the location of the shear knobs to be varied, resulting in various options for overall wall batter, including 0°, 1°, 5° (standard), 27.5°, and 43°.
- Deep, robust face texture. Redi-Rock blocks are cast in a steel form with polyurethane face mold, which results in over 5 in (127 mm) of relief in the face texture. With multiple texture options available and several unique face molds per texture, this results in walls that are not only structurally sound and durable, but also aesthetically pleasing.
- Multiple solid and hollow core units that interlock with each other. This allows the designer to optimize gravity wall sections for design and construction purposes.
- Positive Connection geogrid reinforcement connection. The Positive Connection (PC) system provides a geogrid reinforcement connection between geogrid soil reinforcement and precast concrete facing units that is independent of normal load and utilizes a significant proportion of the full tensile strength of the geogrid.

1.1.2 Types of Units

Redi-Rock block units can be categorized into four broad categories: Solid, Hollow Core, Freestanding, and Positive Connection (PC). All blocks (with the exception of half units) are 46 ⅛ in (1172 mm) long and are either 18 in (457 mm) or 36 in (914 mm) in height. All Redi-Rock blocks are compatible with one another.

<u>Solid Blocks</u>

Solid blocks are 18 in (457 mm) in height and either 28 in (710 mm), 41 in (1030 mm), or 60 in (1520 mm) wide, having a face area of 5.75 ft^2 (0.53 m^2). The differences in depth allow for increasing width where necessary for wall stability, or optimizing when conditions allow. These blocks are generally used in gravity applications.

Figure 1 - Redi-Rock solid block

Solid blocks are available in bottom, middle, and top configurations. Bottom blocks, as the name implies, are used for the bottom row of a wall, and do not have a shear groove, so that the blocks sit in full contact with the bearing pad. Middle blocks, which are used throughout the height of the wall, except for the bottom and top rows, have both shear grooves and shear knobs, and thus engage with the blocks above and below. Top blocks are produced with a recess on the top allowing soil to extend to the face.

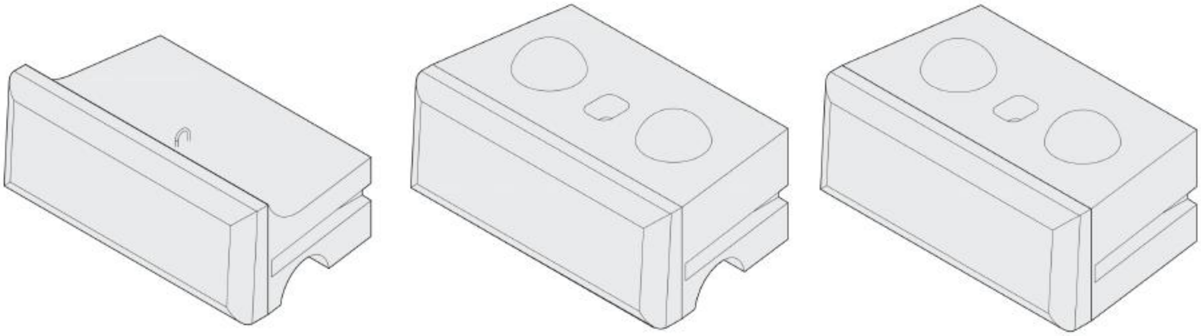


Figure 2 - (left) top block, (middle) middle block, and (right) bottom block. All blocks shown have a depth of 28 in (710 mm).

Solid blocks are available in half units, which are 22 13/16 in (579 mm) long. These are used when the end of the wall must terminate vertically, and are useful when stepping the top or bottom of the wall.

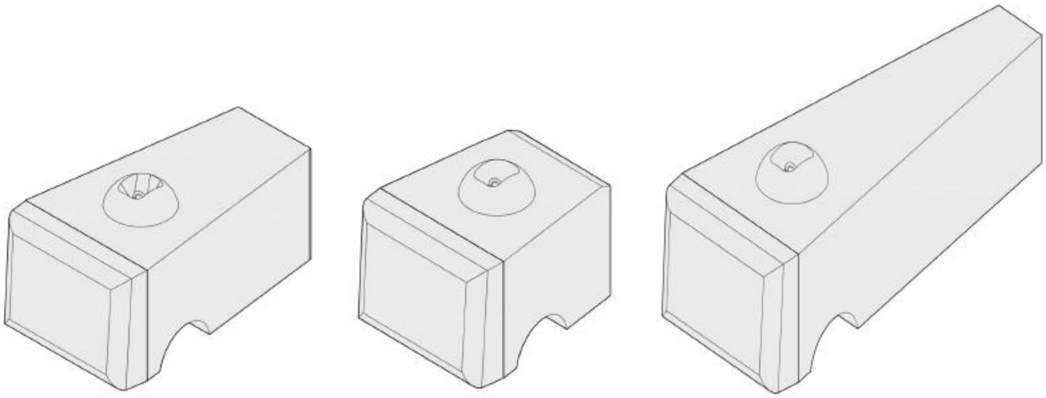


Figure 3 - (left) 28 in (710 mm), (middle) 41 in (1030 mm), and (right) 60 in (1520 mm) half blocks

Hollow-Core Retaining Blocks

Hollow-core retaining blocks are available in two types:

- 41 in (1030 mm) hollow-core units that are essentially 41 in (1030 mm) solid blocks (as described above) cast with a significant amount of concrete removed to reduce raw material usage and shipping weight;
- and XL blocks that are 36 in (914 mm) high and available in 52 (1320 mm), 72 (1830 mm), and 96 in (2440 mm) widths.

The 41 in (1030 mm) hollow-core blocks can be used where 41 in (1030 mm) solid blocks would otherwise be used (with the slightly reduced design unit weight accounted for in the design). XL blocks are 36 in (914 mm) high and are used where the additional block width is required to construct taller gravity walls. Each block provides 11.5 ft^2 (1.07 m^2) of face area. Hollow-core blocks are not differentiated into bottom, middle, or top units.

Figure 4 - (left) 41 in (1030 mm) hollow-core block and (right) 72 in (1830 mm) XL hollow-core block

Freestanding Blocks

Freestanding blocks are textured on two sides (three sides for corner units) and are nominally 24 in (610 mm) wide. They are used where blocks will be exposed on both sides, such as a parapet-type application, where a cap is used to finish the top of the wall, or in conjunction with retaining blocks to construct corners. Freestanding blocks are available in bottom, middle, and top configurations, as well as half blocks.

Figure 5 - Freestanding block

Positive Connection (PC) Blocks

Positive Connection (PC) blocks are used to construct MSE walls. They are produced by casting a 13 in (330 mm) wide slot into 28 in (710 mm) or 41 in (1030 mm) solid blocks. PC blocks are available in bottom, middle, and top configurations. They are not available as half blocks.

Figure 6 - 28 in (710 mm) PC block with 12 in (300 mm) geogrid strip

1.1.3 Unit Specifications

Blocks are manufactured conforming to ASTM C1776, *Standard Specification for Wet-Cast Precast Modular Retaining Wall Units.*

Blocks are manufactured of fresh, first-purpose, air-entrained, wet-cast concrete conforming to the requirements of ASTM C94 and to the specifications listed in Table 1. Concrete used for the manufacture of Redi-Rock blocks is normal weight and has a minimum 28-day compressive strength of 4,000 psi (27.6 MPa).

Table 1 - Concrete Mix Properties

Freeze Thaw Exposure Class[1]	Minimum 28-Day Compressive Strength[2]	Maximum Water Cement Ratio	Nominal Maximum Aggregate Size	Aggregate Class Designation[3]	Air Content[4]
Moderate	4,000 psi (27.6 MPa)	0.45	1 in (25 mm)	3M	4.5% +/- 1.5%
Severe	4,000 psi (27.6 MPa)	0.45	1 in (25 mm)	3S	6.0% +/- 1.5%
Very Severe	4,500 psi (30.0 MPa)	0.40	1 in (25 mm)	4S	6.0% +/- 1.5%
Maximum Water-Soluble Chloride Ion (Cl^-) Content in Concrete, Percent by Weight of Cement[5,6]					0.15
Maximum Chloride as Cl^- Concentration in Mixing Water, Parts Per Million					1000
Maximum Percentage of Total Cementitious Materials By Weight [7,9] (Very Severe Exposure Class Only):					
Fly Ash or Other Pozzolans Conforming to ASTM C618					25
Slag Conforming to ASTM C989					50
Silica Fume Conforming to ASTM C1240					10
Total of Fly Ash or Other Pozzolans, Slag, and Silica Fume[8]					50
Total of Fly Ash or Other Pozzolans and Silica Fume[8]					35
Alkali-Aggregate Reactivity Mitigation per ACI 201					
Slump (Conventional Concrete) per ASTM C143[10]			5 in +/- 1½ in (125 mm +/- 40 mm)		
Slump Flow (Self-Consolidating Concrete) per ASTM C1611			18 in – 32 in (450 mm – 800 mm)		

(1)Exposure class is as described in ACI 318. “Moderate” describes concrete that is exposed to freezing and thawing cycles and occasional exposure to moisture. “Severe” describes concrete that is exposed to freezing and thawing cycles and in continuous contact with moisture. “Very Severe” describes concrete that is exposed to freezing and thawing cycles and in continuous contact with moisture and exposed to deicing chemicals. Exposure class should be specified by the owner/purchaser prior to order placement.

(2)Test method ASTM C39.

(3)Defined in ASTM C33 Table 3 *Limits for Deleterious Substances and Physical Property Requirements of Coarse Aggregates for Concrete*.

(4)Test method ASTM C231.

(5)Test method ASTM C1218 at age between 28 and 42 days.

(6)Where used in high sulfate environments or where alkali-silica reactivity is an issue, water soluble chloride shall be limited to no more than trace amounts (from impurities in concrete-making components, not intended constituents.)

(7)The total cementitious material also includes ASTM C150, C595, C845, C1157 cement. The maximum percentages shall include:
- (a) Fly ash or other pozzolans in type IP, blended cement, ASTM C595, or ASTM C1157.
- (b) Slag used in the manufacture of an IS blended cement, ASTM C595, or ASTM C1157.
- (c) Silica fume, ASTM C1240, present in a blended cement.

(8)Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of the total weight of the cementitious materials.

(9)Prescriptive limits shown may be waived for concrete mixes that demonstrate excellent freeze/thaw durability in a detailed and current testing program.

(10)Slump may be increased by a high-range water-reducing admixture.

1.1.4 Unit-Unit Connection Details

Facing units are dry stacked in a running bond configuration. Unit to unit load distribution is accomplished via the knobs and grooves cast into the tops and bottoms of the blocks, respectively. This connection is discussed in more detail in Section 1.1.11.

Connection between the facing unit and reinforcement is discussed in Section 1.2.5.

1.1.5 Unit Dimensions, Tolerances, and Reinforcement

Nominal block dimensions are listed in the following table, along with acceptable manufacturing tolerances. These are illustrated in the our block library in Appendix 1.1.5A.

Table 2 - Block Dimensions and Tolerances

Block Type	Dimension	Nominal Value	Tolerance
28 in (710 mm) Block (solid and PC)	Height	18 in (457 mm)	+/- 3/16 in (5 mm)
	Length	46 ⅛ in (1172 mm)	+/- 1/2 in (13 mm)
	Width*	28 in (710 mm)	+/- 1/2 in (13 mm)
41 in (1030 mm) Block (solid, hollow core, and PC)	Height	18 in (457 mm)	+/- 3/16 in (5 mm)
	Length	46 ⅛ in (1172 mm)	+/- 1/2 in (13 mm)
	Width*	40 ½ in (1030 mm)	+/- 1/2 in (13 mm)
60 in (1520 mm) Block	Height	18 in (457 mm)	+/- 3/16 in (5 mm)
	Length	46 ⅛ in (1172 mm)	+/- 1/2 in (13 mm)
	Width*	60 in (1520 mm)	+/- 1/2 in (13 mm)
52 in (1320 mm) XL Block	Height	36 in (914 mm)	+/- 3/16 in (5 mm)
	Length	52 in (1320 mm)	+/- 1/2 in (13 mm)

	Width*	60 in (1520 mm)	+/- 1/2 in (13 mm)
72 in (1830 mm) XL Block	Height	36 in (914 mm)	+/- 3/16 in (5 mm)
	Length	46 ⅛ in (1172 mm)	+/- 1/2 in (13 mm)
	Width*	72 in (1830 mm)	+/- 1/2 in (13 mm)
96 in (2440 mm) XL Block	Height	36 in (914 mm)	+/- 3/16 in (5 mm)
	Length	46 ⅛ in (1172 mm)	+/- 1/2 in (13 mm)
	Width*	96 in (2440 mm)	+/- 1/2 in (13 mm)
Freestanding Block	Height	18 in (457 mm)	+/- 3/16 in (5 mm)
	Length	46 ⅛ in (1172 mm)	+/- 1/2 in (13 mm)
	Width*	23 in (584 mm) - 24 in (610 mm)	+/- 1/2 in (13 mm)

* Block tolerance measurements shall exclude variable face texture.

For freestanding blocks, depth varies between 23 in (584 mm) for Limestone and Cobblestone texture and 24 in (610 mm) for Ledgestone texture.

Note that the block depths provided in the above table include the highly-textured block face, which constitutes approximately 5 ⅜ in (137 mm) of the total block depth. Block lengths are provided for whole blocks. Half block length is 22 13/16 inches (579 mm).

Retaining blocks are tapered by 7.7° on each side to allow the blocks to form an outside (convex) curve.

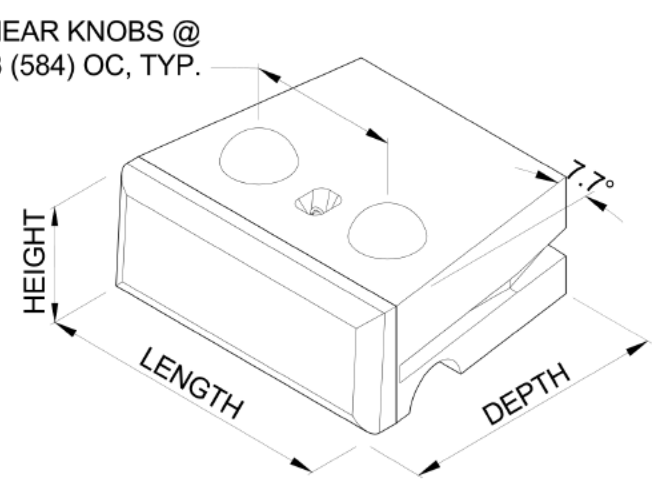


Figure 7 - Block dimensions

Redi-Rock 18 in (457 mm) tall blocks and freestanding blocks are produced from plain (unreinforced) concrete. Redi-Rock 36 in (914 mm) tall XL blocks contain steel bar reinforcement. The reinforcement consists of a cage constructed from ASTM A615 No. 4, Grade

60 bars. The basic concept is illustrated in Figure 8 and further detail is provided in Appendix 1.1.5B. Note that, if required, galvanized or epoxy-coated bars can be used. Centralizers are used during production to maintain bar position. A minimum of 1 in (25 mm) of concrete cover over all steel bars is required. Reinforcement calculations for XL block reinforcement are included in Appendix 1.1.5B.

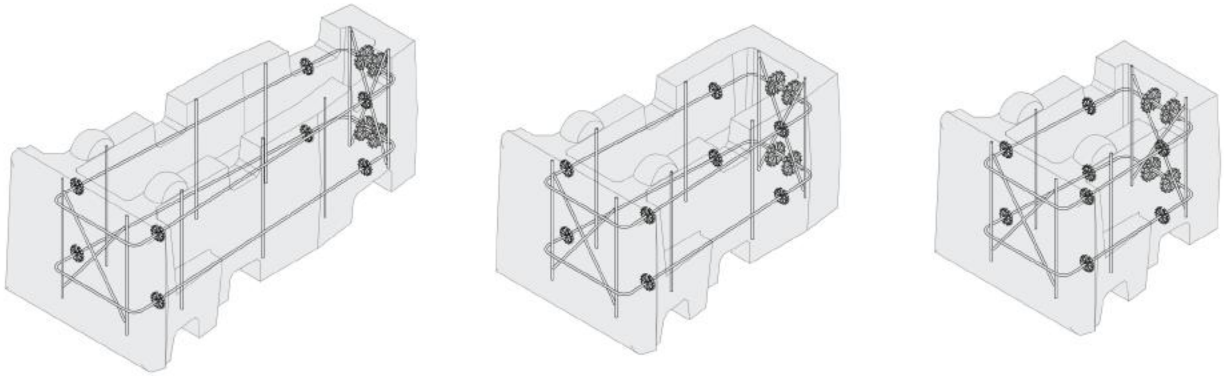


Figure 8 - XL (left) 96 in (2440 mm), (middle) 72 in (1830 mm), and (right) 52 in (1320 mm) XL block reinforcing

Beside the reinforcing bars utilized in the XL blocks, the only other steel used in Redi-Rock blocks are the lift hooks. These are utilized within the manufacturing plant for removing the block from the form and moving it around the plant. They are also used at the project site for lifting the blocks into position. They have no long-term use in the function of the completed retaining wall.

1.1.6 Unit Fabrication

Redi-Rock precast modular block units are produced using first purpose wet-cast concrete. Units are generally produced within enclosed environments at precast and ready-mix facilities.

All retaining units are cast face down in steel forms with interchangeable polyurethane liners cast from natural stone. Once the units have been set, for the 18 in (457 mm) high category, the spring-loaded doors can be released and rotated to the open position.

In the case of 36 in (914 mm) high XL blocks, a series of jacks are used to eject the two sides of the forms which then slide along a rail system to provide working space.

Once all doors are opened, the blocks are lifted from the forms vertically and rotated 90° before being placed in curing/storage.

1.1.7 Unit Compressive Strength

Concrete used in the production of Redi-Rock facing units must exhibit a compressive strength of at least 4,000 psi (27.6 MPa) at 28 days, as measured on cylinder specimens in accordance with ASTM C39. For sites that are classified as Very Severe Exposure Class in per ACI 318, minimum 28-day concrete compressive strength is 4,500 psi (30.0 MPa).

1.1.8 Unit Density and Absorption

Target unit density and absorption requirements are intended for dry-cast units and are thus not applicable for wet-cast Redi-Rock blocks.

1.1.9 Unit Air Content

Concrete used in the production of Redi-Rock blocks is air-entrained to provide resistance to freeze-thaw effects. Required air content range is dependent on exposure class as defined by ACI 318. For moderate exposure, air content in the range of 4.5% +/- 1.5% is required. Where exposure is severe or very severe, air content shall be 6.0% +/- 1.5%.

1.1.10 Unit-Unit Shear

Original interface shear testing was carried out in October 2011 to evaluate the mechanical/frictional performance of the shear capacity for the 18 in (457 mm) high category using Redi-Rock 28 in (710 mm) PC modular concrete blocks.

Two test series were run to establish the shear capacity of blocks using the standard 10 in (254 mm) dome and the reduced 6 ¾ in (171 mm) dome, intended for use with the reinforced earth system to achieve reduced batter walls.

For the 10 in (254 mm) dome, all tests were stopped prior to failure of the dome to reduce risk of damage to laboratory equipment. In the case of the 6 ¾ in (171 mm) dome tests, 4 shear failures were recorded while the other 6 tests were stopped prior to failure of the dome to reduce risk of damage to laboratory equipment. Original complete combined reports are located in Appendix 1.1.10.

<u>Design values for blocks using the 10 in (254 mm) dome are as as follow:</u>

Peak Shear: S_p = 6,061 + N tan 44° ≤ 11,276 lb/ft (S_p = 88.45 + N tan 44° ≤ 164.56 kN/m) Service State Shear: S_{ss} = 3,390 + N tan 51° ≤ 11,276 lb/ft (S_{ss} = 49.47 + N tan 51° ≤ 164.56 kN/m)

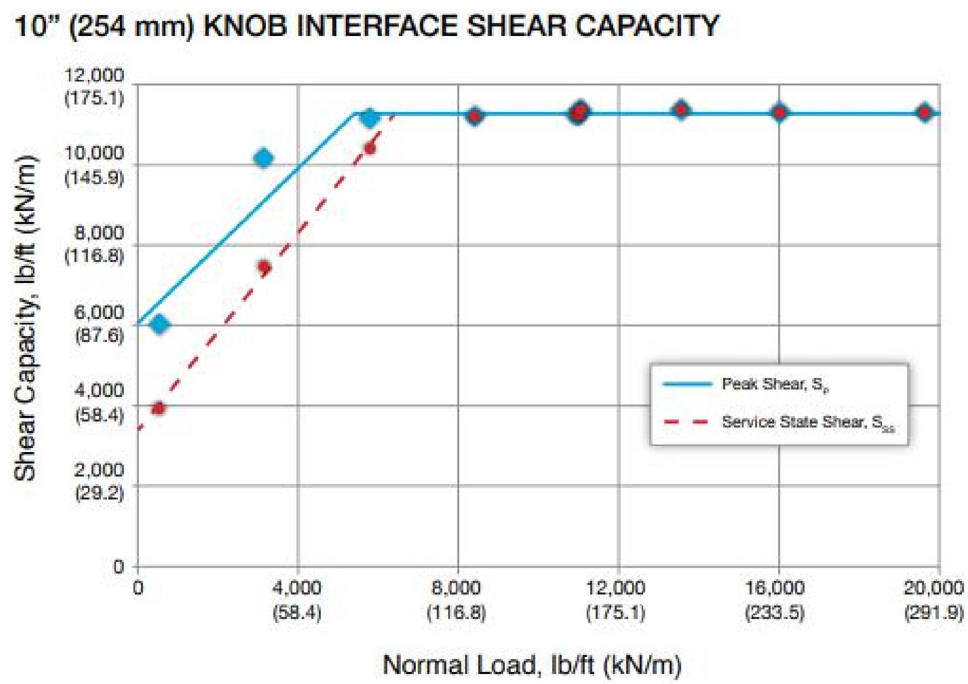


Figure 9 - Peak envelope for 10 in (254 mm) knob interface shear capacity

<u>Design values for blocks using the 6 ¾ in (171 mm) dome are as as follow:</u>

Peak Shear(d): S_p = 1,178 + N tan 54° ≤ 10,970 lb/ft (S_p = 17.19 + N tan 54° ≤ 160.1 kN/m)
Service State Shear(d): S_{ss} = 616 + N tan 52° ≤ 10,970 lb/ft (S_{ss} = 8.99 + N tan 52° ≤ 160.1 kN/m)

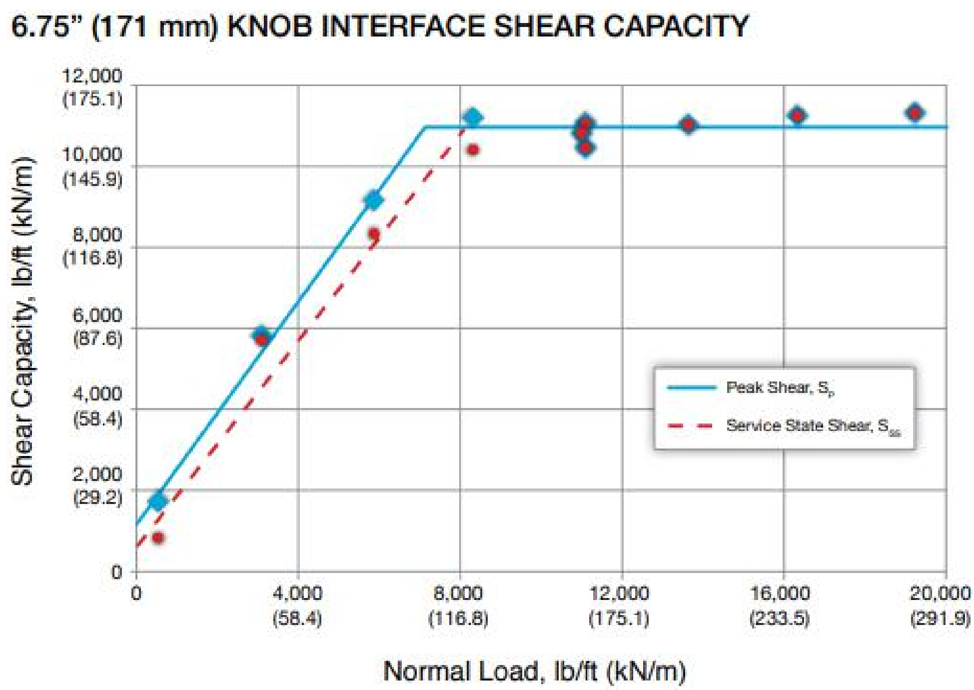


Figure 10 - Peak envelope for 6 ¾ in (171 mm) knob interface shear capacity

In preparation for the launch of the Redi-Rock 36 in (914 mm) high XL block range in 2018, third party tests were carried out to determine the mechanical/frictional performance of the shear capacity for the 36 in (914 mm) high category, using Redi-Rock 52 in (1320 mm) hollow-core concrete block units.

The third party testing was performed by TRI Environmental, Inc. Austin, Texas 78733 in December of 2017. See Test Report (TRI Log # 28156) in Appendix 1.1.10.

Subsequent tests were performed at the Redi-Rock test facility in Charlevoix, MI. The original internal test report is included in Appendix 1.1.10 for reference.

Design values for the 10 in (254 mm) shear knob for the 36 in (914 mm) high XL block range are as as follow:

Peak Shear Envelope:[c]

$S_{p(1)}$ = 4547 + N tan 44° **(N < 7,017 lb/ft)**
$S_{p(2)}$ = 8488 + N tan 22° **(7017 lb/ft ≤ N < 16,118 lb/ft)**
$S_{p(max)}$=15,000 lb/ft **(N ≥ 16,118 lb/ft)**

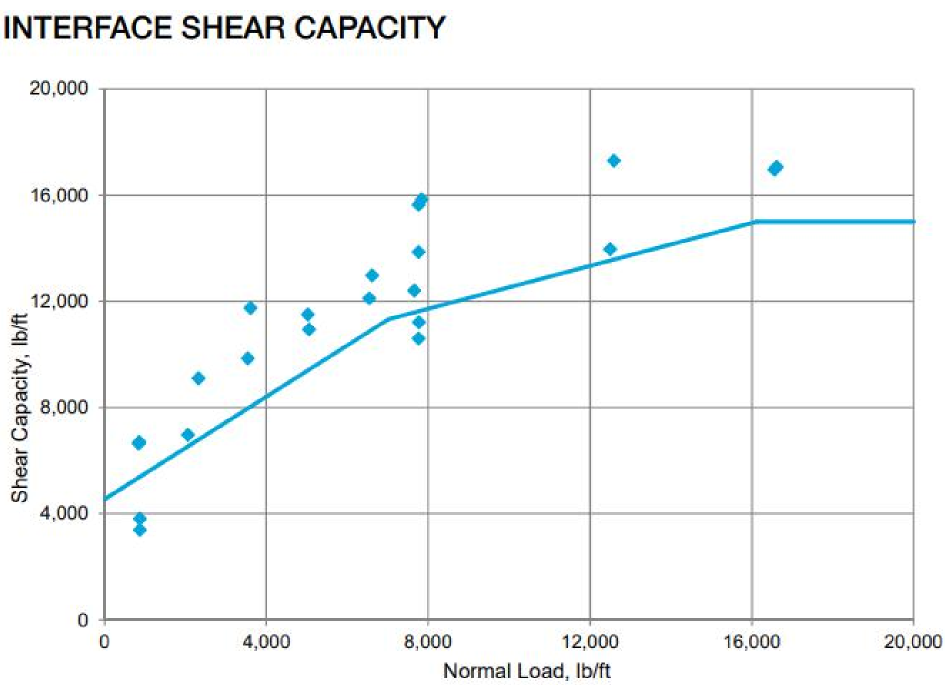


Figure 11- Peak envelope for 36 in (914 mm) high XL block range knob interface shear capacity

A subsequent hollow core product was launched in 2020 to complement the 18 in (457 mm) high category, the 41 in (1030 mm) hollow-core retaining block. The blocks were tested by ASTER BRANDS at the internal testing facility in Charlevoix, MI in accordance with ASTM D6916 & NCMA SRWU-2. The full report is included in Appendix 1.1.10 for reference.

Design values for the 10 in (254 mm) shear knob for the 18 in (457 mm) high hollow-core block are as follow:

Peak Shear Envelope:[b]

S_p=5358 lb/ft + N tan 37° ≤ 12,906 lb/ft
(S_p = 78.2 kN/m + N tan 37° ≤ 188.3kN/m)

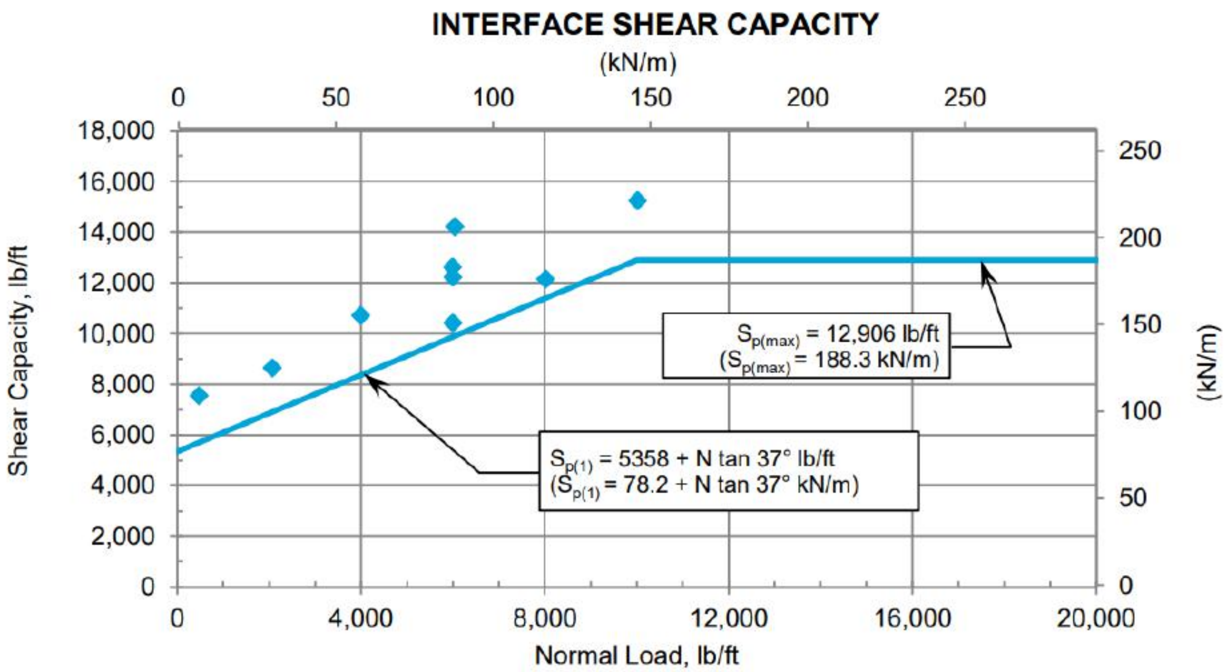


Figure 12 - Peak envelope for 18 in (457 mm) high 41 in (1030 mm) hollow-core block knob interface shear capacity

The shear capacity results for each block/knob configuration are different. For stability calculations it's important to utilize the specific results for the respective block/knob configuration.

1.1.11 Unit Shear, Alignment, and Bearing Devices

Redi-Rock blocks are cast with lifting hooks on the top of the blocks and to the rear to provide control while maneuvering the blocks on site. The blocks also incorporate forklift slots on the sides to allow for movement and placement with skid-steer or forklift.

The blocks comprise a knob (dome) and groove (trough) system, with a groove on the underside of the blocks that engages with the spherical domes on the top of the blocks to provide lateral resistance.

The blocks are dry stacked, with the knobs on the top of the units engaging with the groove on the bottom of the next course of units. The block-to-block setback available with Redi-Rock is controlled by the size and location of the shear knobs. While the 10 in (254 mm) diameter knob and the 1 ⅝ in (41 mm) setback position is the most common configuration, Redi-Rock has three different knob sizes and three different locations available.

- Five degree (5°) setback, the standard offered in the Redi-Rock range, is achieved using the 10 in (254 mm) knobs.

- One degree (1°) setback, the standard offered in the Redi-Rock range, is achieved using the 7 ½ in (190 mm) knobs.

- Zero degree (0°) setback, the standard offered in the Redi-Rock range, is achieved using the 6 ¾ in (171 mm) knobs.

The above mentioned setback options are available with the 28 in (710 mm), 41 in (1030 mm), and 60 in (1520 mm) blocks and the 28 in (710 mm) (Shown in Figure 13) and 41 in (1030 mm) PC blocks.

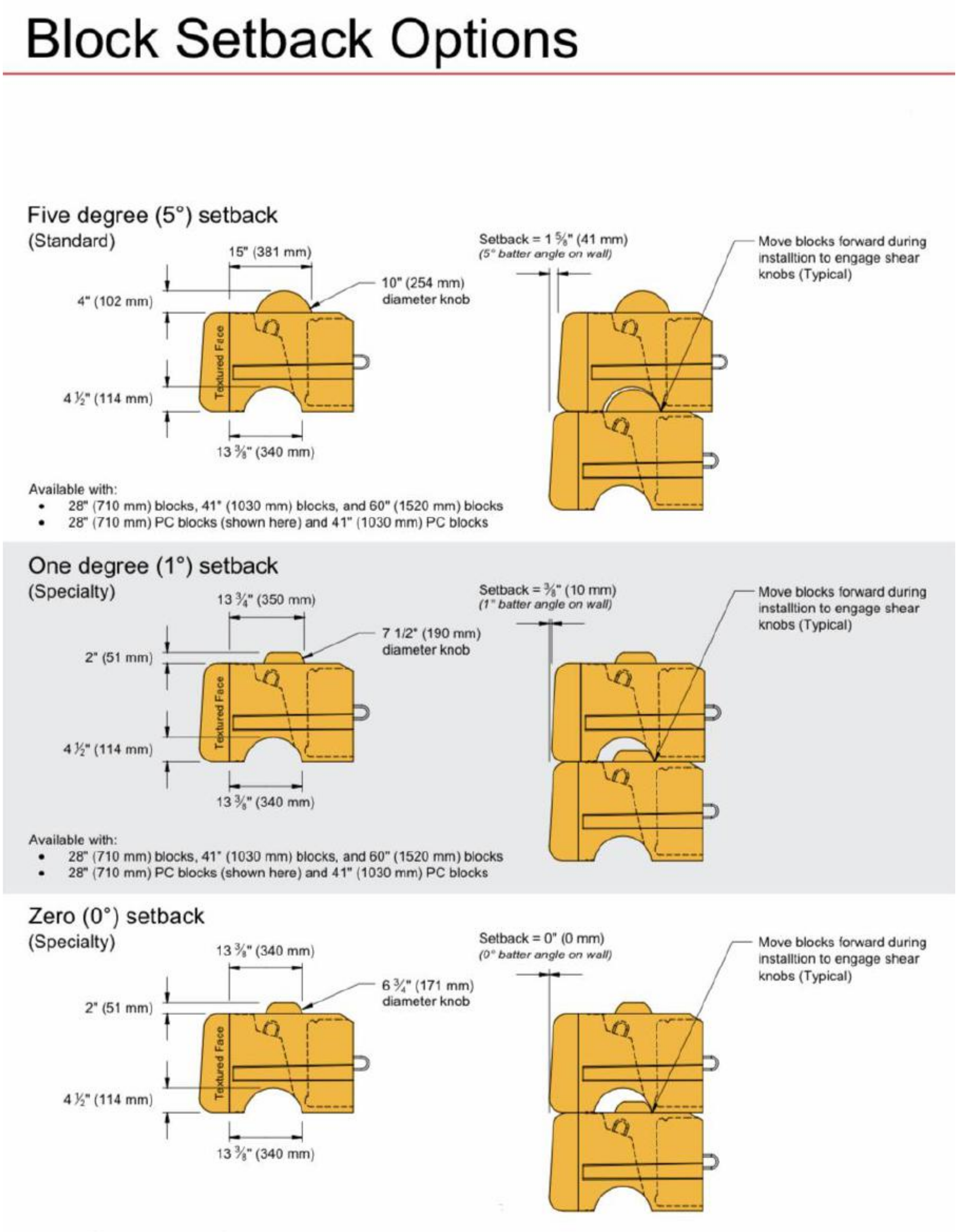


Figure 13 - Standard block face batter options

Redi-Rock has two options for large batter retaining walls; both created by relocating the knob further back on the blocks compared to our smaller batter walls (5° and less). There are two knob locations further back on the block that create the 9 in (230 mm) setback block and the planter block. Blocks made with knobs in either of these locations almost exclusively use 10 in (254 mm) diameter knobs.

These options can be used to achieve taller gravity walls when the use of geosynthetic reinforcement is:

- undesirable
- not feasible (will not fit within the required project retaining wall geometry)
- not economical
- not permitted

Block Setback Options

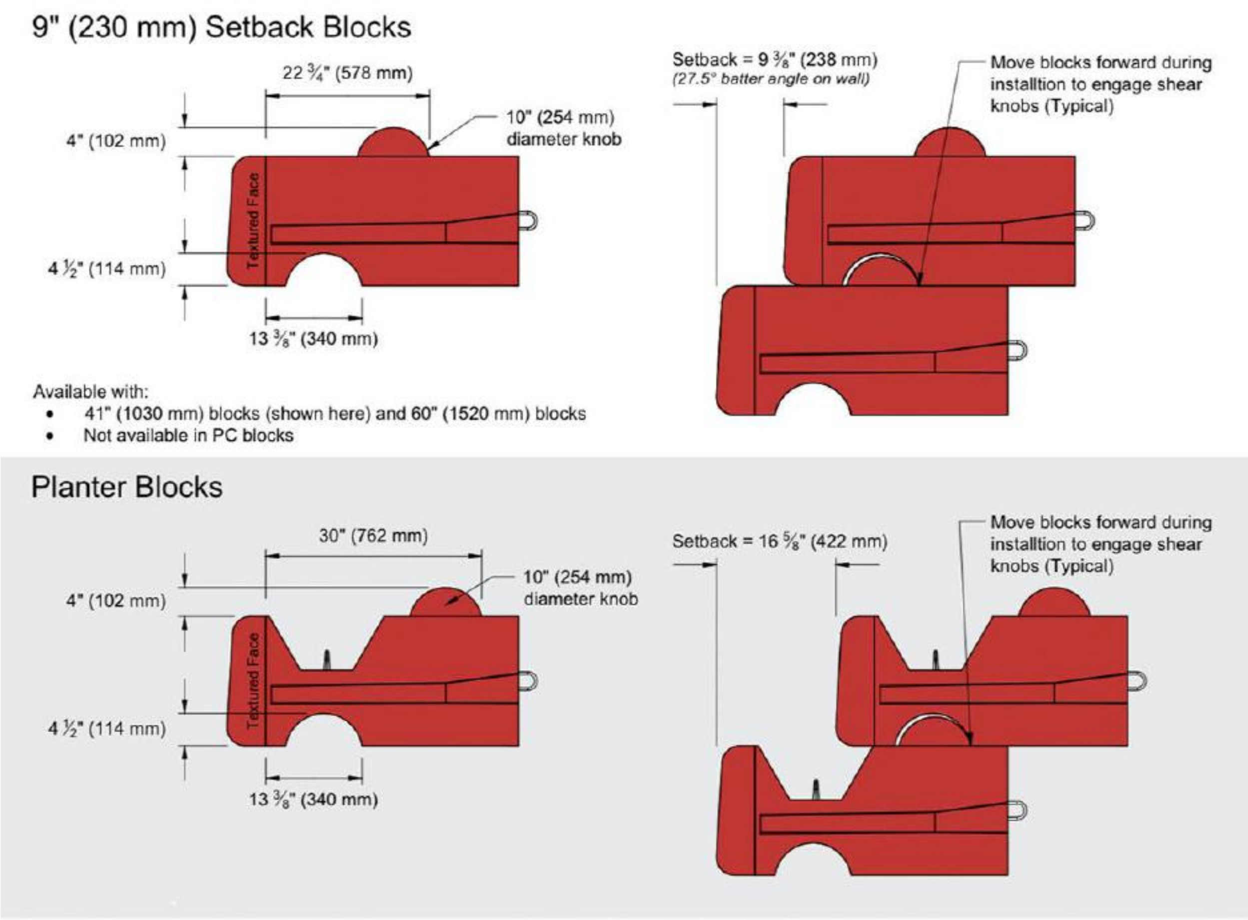


Figure 14 - Increased setback options

The block-to-block setback available with 36 in (914 mm) high Redi-Rock XL hollow-core retaining blocks and the 18 in (457 mm) tall 41 in (1030 mm) hollow-core block, is controlled by the location of the shear knobs cast into the blocks. The 3 ¼ in (83 mm) setback for the 36 in (914 mm) tall range, and 1 ⅝ in (41 mm) setback for the 18 in (457 mm) hollow-core range, creates a 5° batter angle on the back of the wall which is consistent with the batter angle created by the standard 18 in (457 mm) high Redi-Rock blocks with 10 in (254 mm) shear knobs.

The alignment for the hollow-core range is indicated in Figure 15, portraying the 36 in (914 mm) high Redi-Rock XL hollow-core retaining blocks.

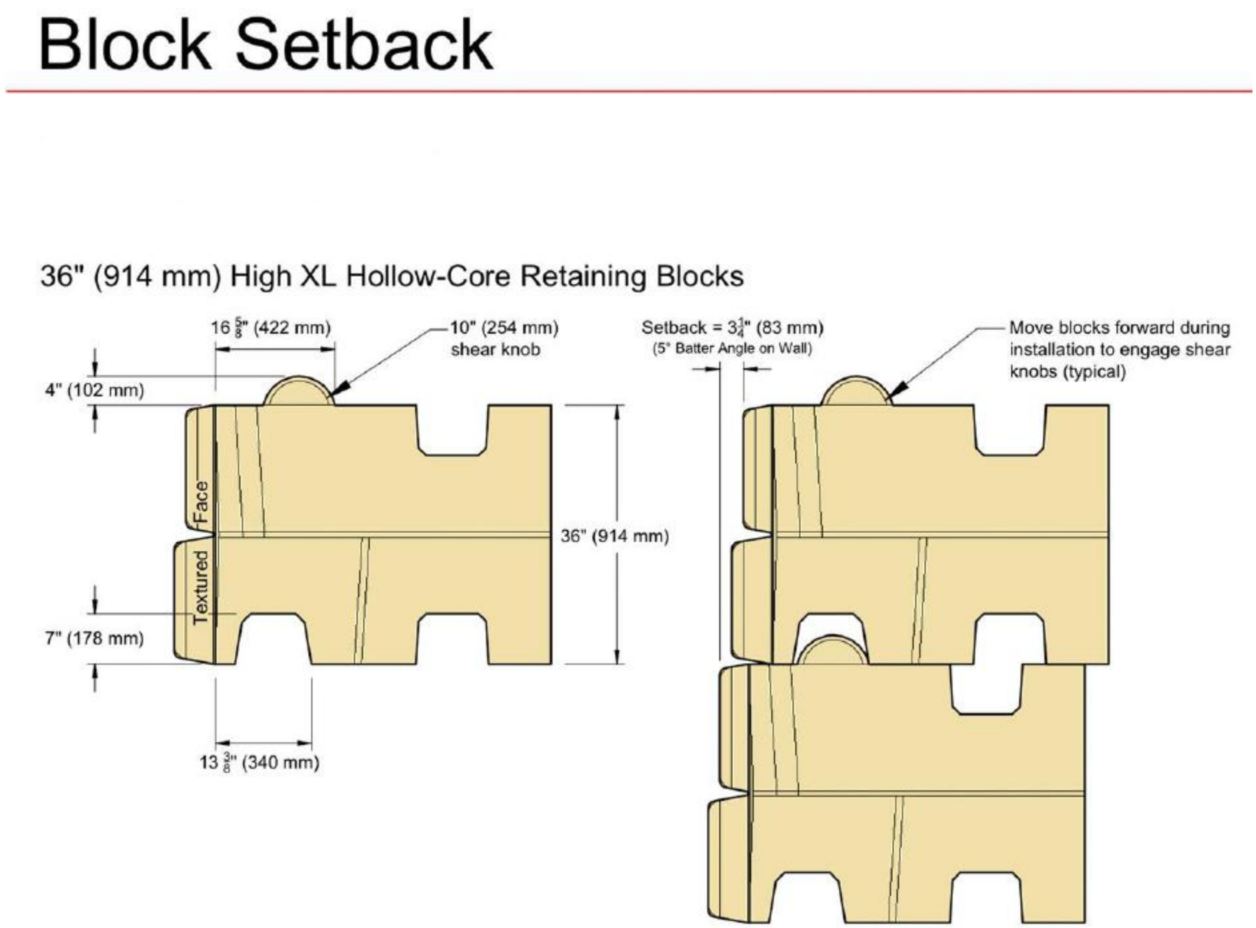


Figure 15 - Hollow-core range setback

1.1.12 Filter Considerations

A minimum 12 in (300 mm) drainage column should be considered in most applications, directly behind the PMBs. Redi-Rock recommends the use of a non-woven geotextile separator to prevent migration of fines into the free draining aggregate materials. For MSE applications (PC system) the filters should be applied between geogrid layers. In the case of a granular wedge installed behind the PMBs, it is also recommended to line the cut with a geotextile separator to prevent native material migrating into the imported granular backfill. Figures 16 and 17 illustrate the application of geotextile separators in gravity and MSE (PC system) applications.

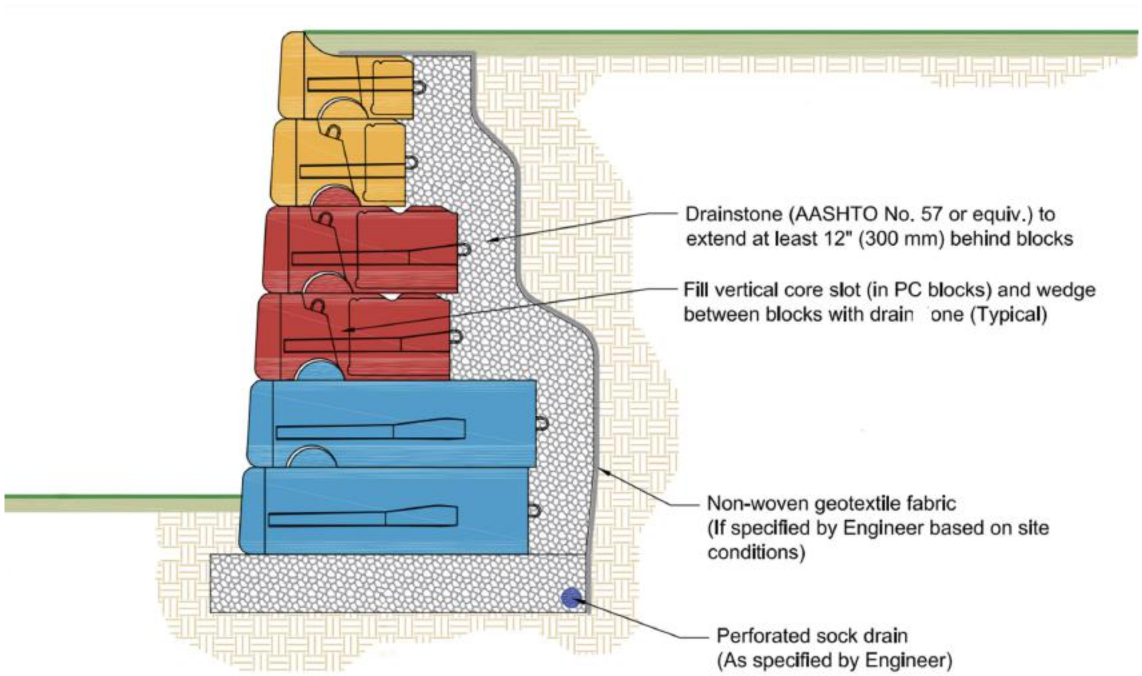


Figure 16 - Use of non-woven geotextile separator for drainage column - 18 in (457 mm) high blocks

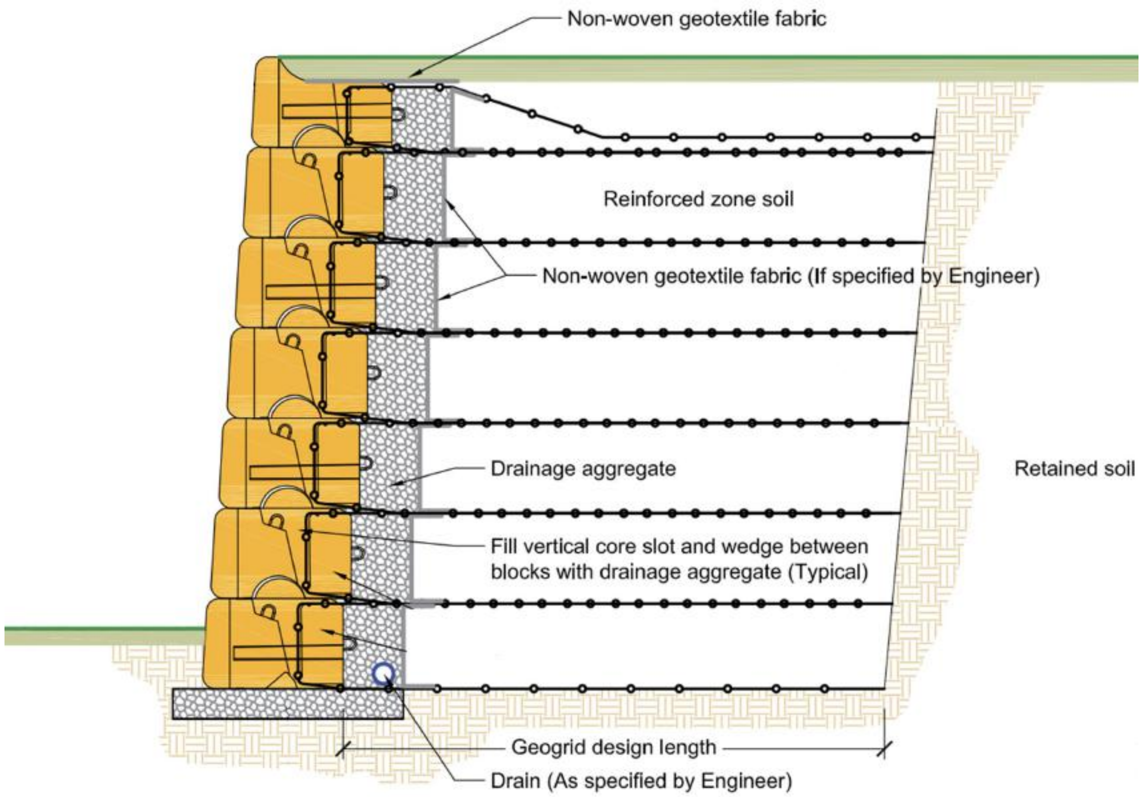


Figure 17 - Use of non-woven geotextile separator for drainage column - PC system

As the 36 in (914 mm) high XL range is a hollow-core system, the voids in the blocks should be filled with drainstone such as AASHTO No. 57 or equivalent. A non-woven geotextile fabric should be placed at the back of the 36 in (914 mm) high XL blocks and between drainstone and retained soil (If specified by Engineer based on site soil conditions). Figure 18 illustrates how this should be installed and incorporates a standard drainage column in the upper rows which are composed of 18 in (457 mm) high Redi-Rock blocks.

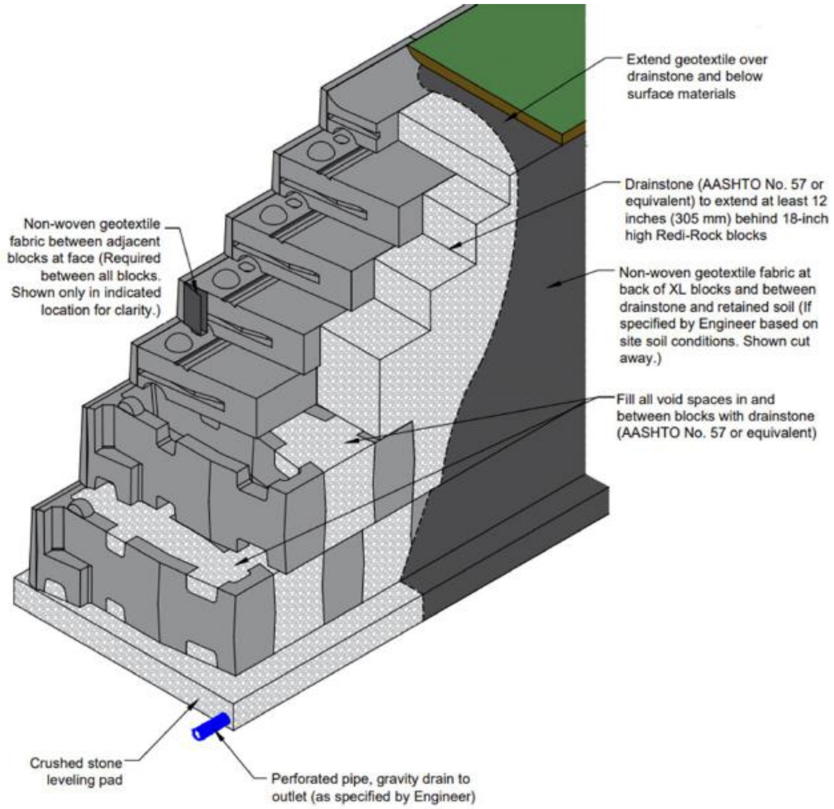


Figure 18 - Isometric view of non-woven geotextile separator for 36 in (914 mm) high XL blocks

Place a piece of 18 in (457 mm) by 18 in (457 mm) non-woven geotextile fabric in each vertical joint between blocks. In the case of 36 in (914 mm) XL blocks, two pieces should be considered – one on the upper half of the joint and one in the lower, wedge-shaped portion of the joint - to prevent the drainage aggregate and backfill material from migrating through the vertical joints between adjacent units at the block face.

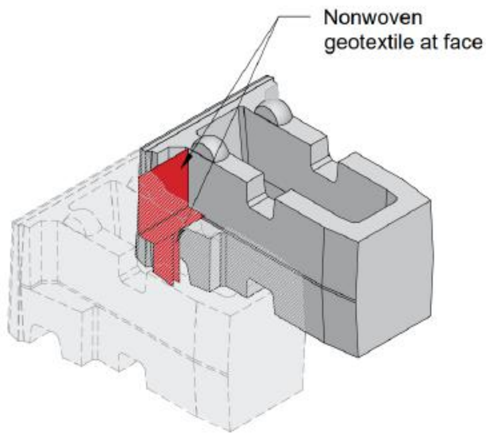


Figure 19 - Non-woven geotextile separator between blocks to prevent loss of drainage stone

1.1.13 Aesthetic Facing Options

Redi-Rock facing units are available in four standard facing textures with a nearly limitless number of custom color blends as well as various stock color blends that vary from manufacturer to manufacturer.

The first standard facing texture is “Limestone”, the most widely manufactured face texture. Limestone is made up of 4 unique facing panel inserts that can be rotated 180° in the form cell to create 8 different block faces that are randomly mixed within the constructed retaining wall face to approximate the appearance of natural rock. A wall with Limestone texture is shown in Figure 20.

Figure 20 – Limestone face texture

The second standard facing texture with Redi-Rock blocks is “Cobblestone”. Cobblestone is made up of 2 unique facing panel inserts that can also be rotated 180° in the form cell to create 4 different block faces for random installation. The Cobblestone face offers a deep texture face with nearly 3 in (76 mm) of relief. A wall with Cobblestone texture is shown in Figure 21.

Figure 21 – Cobblestone face texture

The third facing texture is “Ledgestone”. Ledgestone is the combination of 8 unique facing panel inserts that can be rotated to create the inverted version of the original resulting in a highly randomized texture in the constructed wall face. Ledgestone texture provides up to 5 in (127 mm) of relief. Ledgestone is manufactured with a standard requirement for the application of multiple colors (base color + highlight color) to each facing unit. A wall with Ledgestone texture is shown in Figure 22.

Figure 22 – Ledgestone face texture

The fourth facing texture is “Kingstone”. Kingstone consists of 8 unique facing panel inserts that can be rotated to create the inverted version of the original resulting in a highly randomized texture in the constructed wall face. A wall with Kingstone texture is shown in Figure 23.

Figure 23 – Kingstone face texture

Most standard stock colors are offered by Redi-Rock licensed manufacturers in variations of gray and brown tones. However, custom color combinations using integral color additives to the concrete batch mix, shake-on color hardener, masonry stains and translucent sealers can all be employed to achieve virtually any design, color or finish. The Nevada Department of Transportation (DOT), for example, selected a post-construction applied stain to achieve a custom dark-red color for Redi-Rock freestanding units used on a US Highway 95 Interchange Improvement project near Las Vegas, Nevada. The custom color Nevada DOT walls are shown in Figure 24.

Figure 24 – Custom color by Nevada DOT

1.1.14 Limits Due to Curves and Corners

Convex curves can easily be incorporated into a Redi-Rock wall. The 18 in (457 mm) high Redi-Rock blocks are tapered 7.7° on each side, as shown in Figure 25 and Figure 26. The smallest radius that can be made with Redi-Rock blocks (without cutting the blocks) occurs when the blocks are placed together with their sides touching. This minimum radius for full size blocks is 14 ft, 6 in (4.42 m) from the face of the blocks.

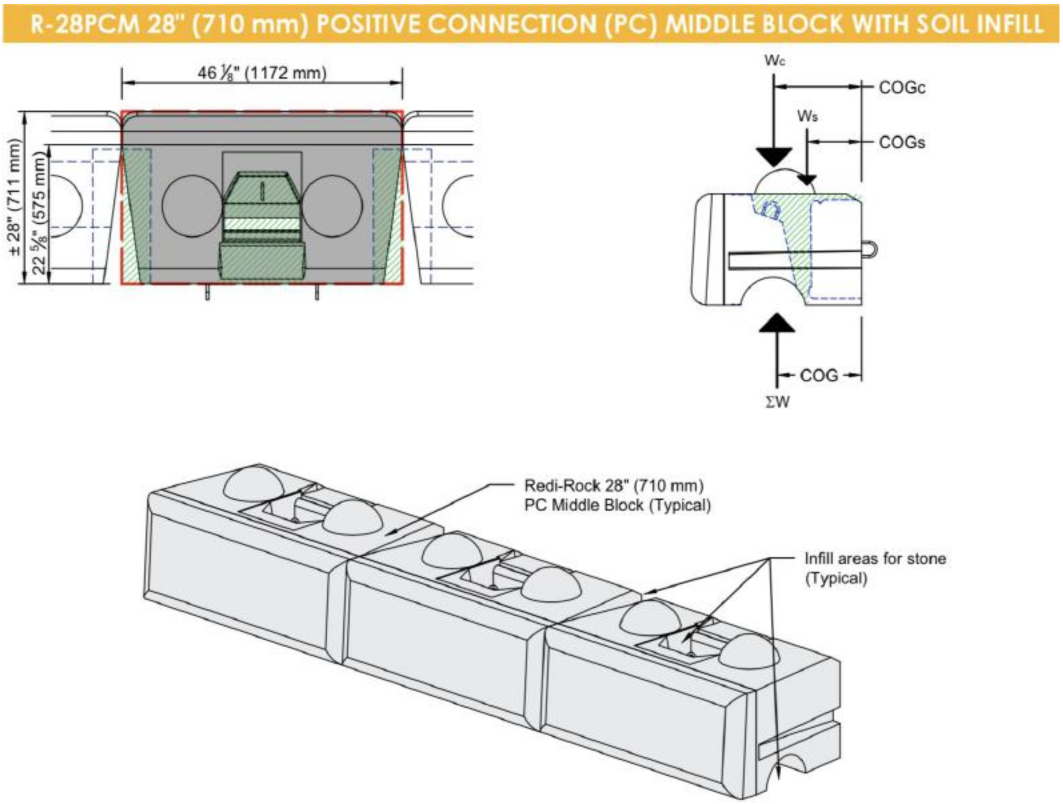


Figure 25 – 28 in (710 mm) Redi-Rock PC block with 7.7° taper

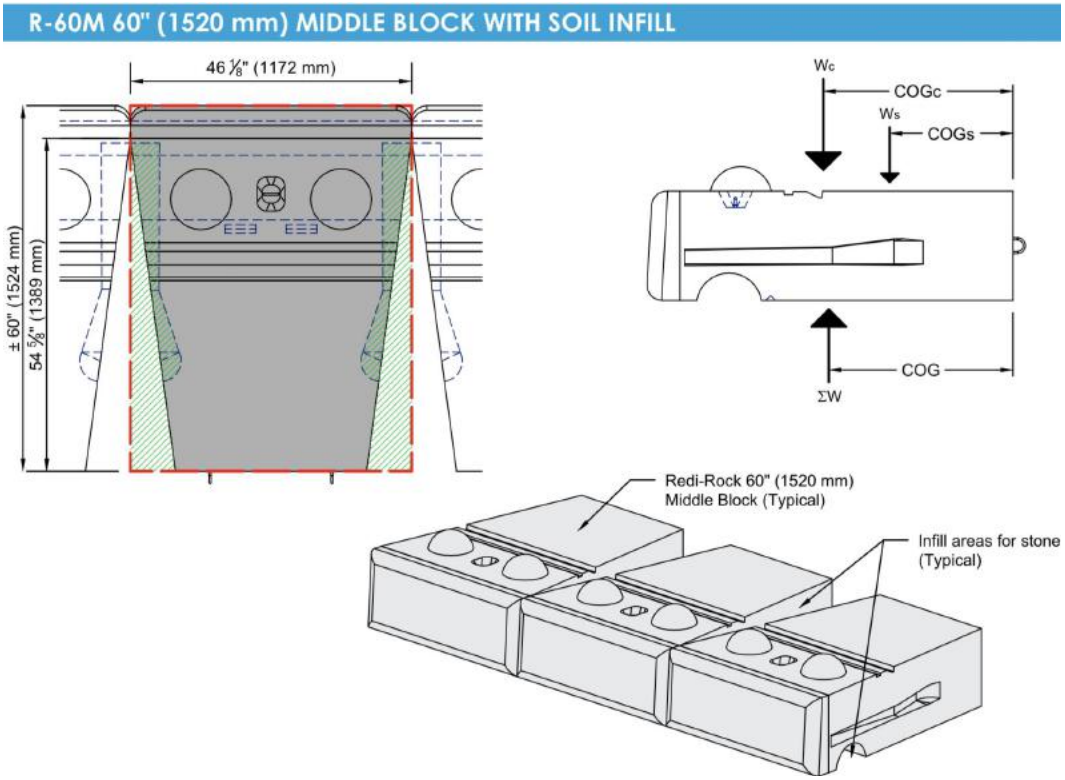
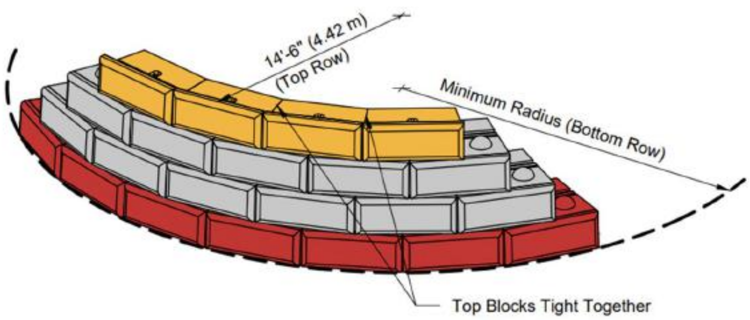


Figure 26 – 60 in (1520 mm) Redi-Rock block with 7.7° taper

Block-to-block setback will cause the radius for each succeeding row to be smaller than the row below. To ensure the minimum radius for the top row of blocks in a wall, start with the minimum radius and then add 2 in (51 mm) per course for each standard setback, 18-in (457 mm) high block; 10 in (254 mm) per course for each 9 in (230 mm) setback block, and 17 in (432 mm) per course for each planter block in the wall below the top row of blocks. For 36 in (914 mm) high XL blocks, add 4 in (101 mm) per row.

MINIMUM RADIUS FOR BOTTOM ROW OF BLOCKS

	18-INCH (457 mm) HIGH BLOCKS	36-INCH (914 mm) HIGH XL BLOCKS
Height of Wall	Radius From Face of Block	Radius From Face of Block
1'-6" (0.46 m)	14'-6" (4.42 m)	
3'-0" (0.91 m)	14'-8" (4.47 m)	
4'-6" (1.37 m)	14'-10" (4.52 m)	
6'-0" (1.83 m)	15'-0" (4.57 m)	15'-0" (4.57 m)
7'-6" (2.29 m)	15'-2" (4.62 m)	15'-2" (4.62 m)
9'-0" (2.74 m)	15'-4" (4.67 m)	15'-4" (4.67 m)
10'-6" (3.20 m)	15'-6" (4.72 m)	15'-6" (4.72 m)
12'-0" (3.66 m)	15'-8" (4.78 m)	15'-8" (4.78 m)
13'-6" (4.11 m)	15'-10" (4.83 m)	15'-10" (4.83 m)
15'-0" (4.57 m)	16'-0" (4.88 m)	16'-0" (4.88 m)
16'-6" (5.03 m)		16'-2" (*.** m)
18'-0" (5.49 m)		6'-4" (4.98 m)
19'-6" (5.94 m)		16'-6" (5.03 m)
21'-0" (6.4 m)		16'-8" (95.08 m)



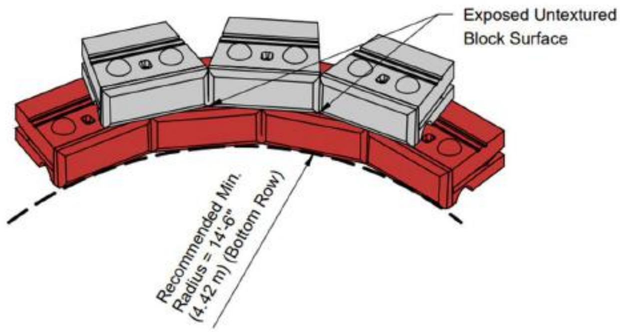


Figure 27 – Minimum radii

Concave curves may be installed at varying radii. The blocks should be placed tight together to make a smooth curve. Although there is no fixed minimum radius, smaller radii lengths of less than 14.5 ft (4.42 m) will result in exposing more of the untextured top face of the blocks in the underlying layer.

Standard 90° corners, both internal and external, can be easily achieved with Redi-Rock and have several standardised construction details.

Internal corners are generally achieved by butting one wall against another, treating each as an individual structure. This reduces the need to knit blocks on site which would involve cutting and manipulating the blocks as shown in Figure 28.

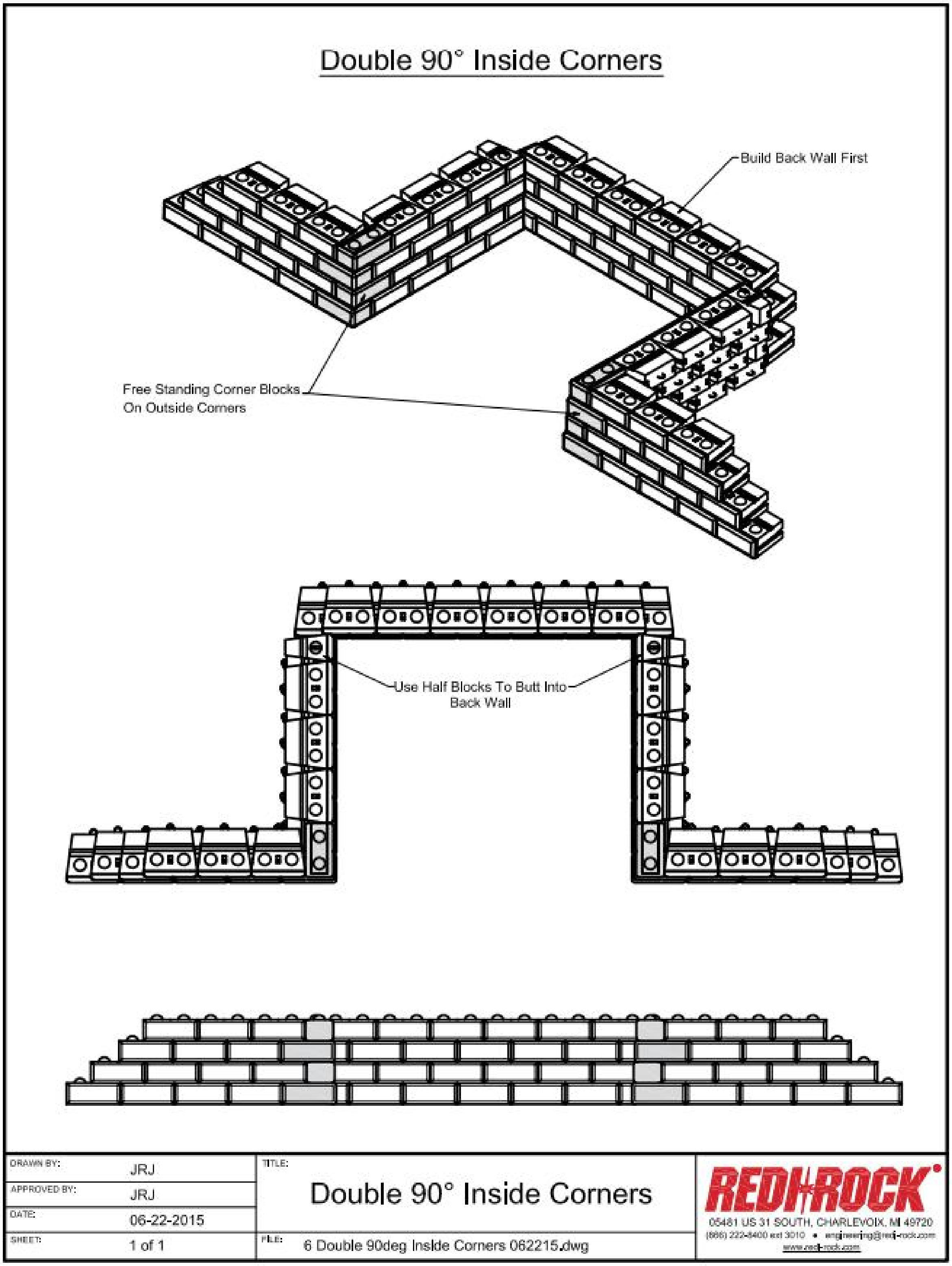


Figure 28 - Double inside corners

External corners are achieved by incorporating freestanding corner blocks with trimmed shear knobs or specialty F-90C (Freestanding 90° corner blocks) with modified shear knob size and alignment to allow for corners with modifying the blocks on site.

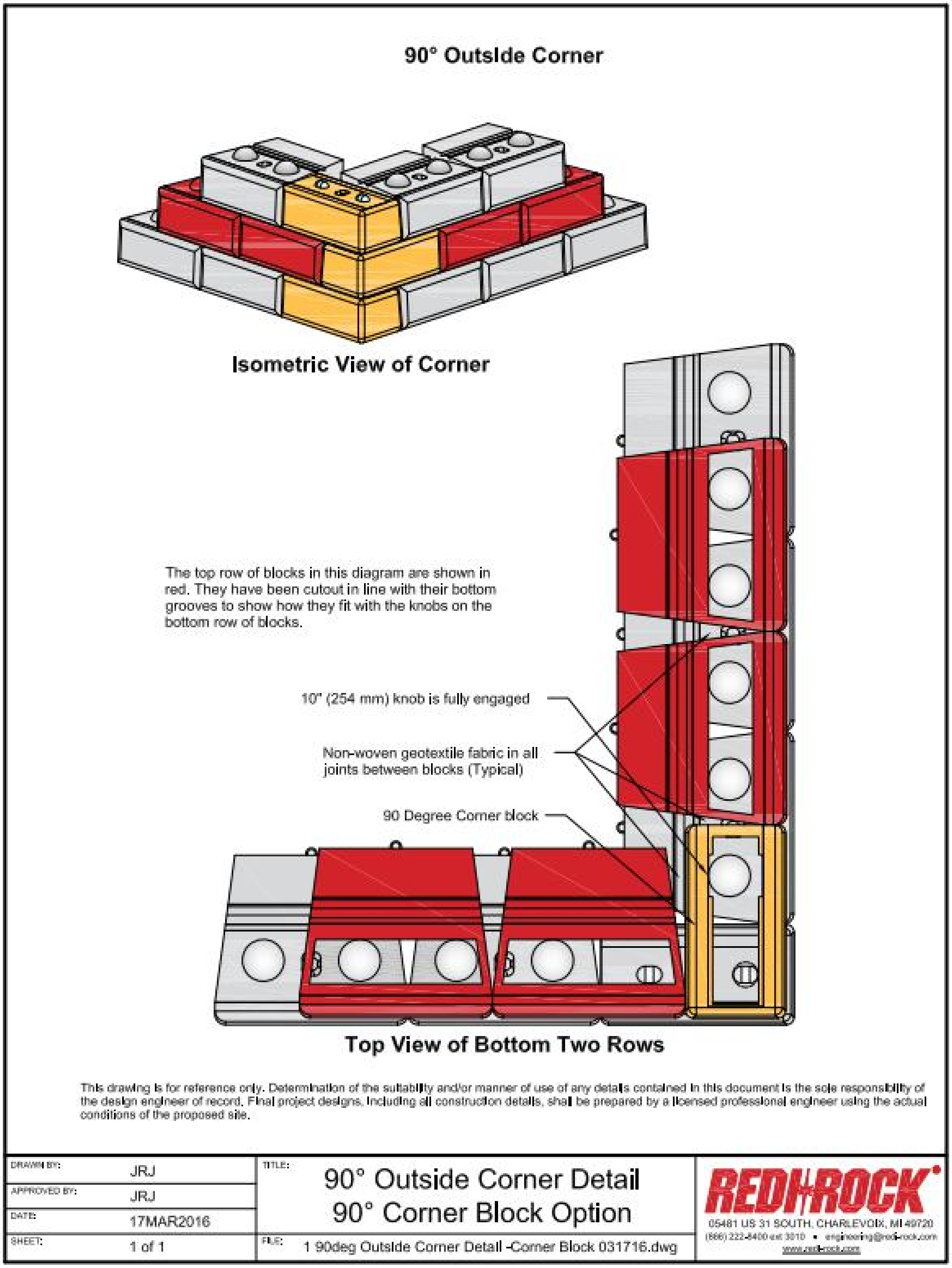


Figure 29 - Outside corner detail

Standard corners can also be achieved using the modified blocks for increased setback as discussed in *1.1.11 Shear, Alignment, and Bearing Devices.*

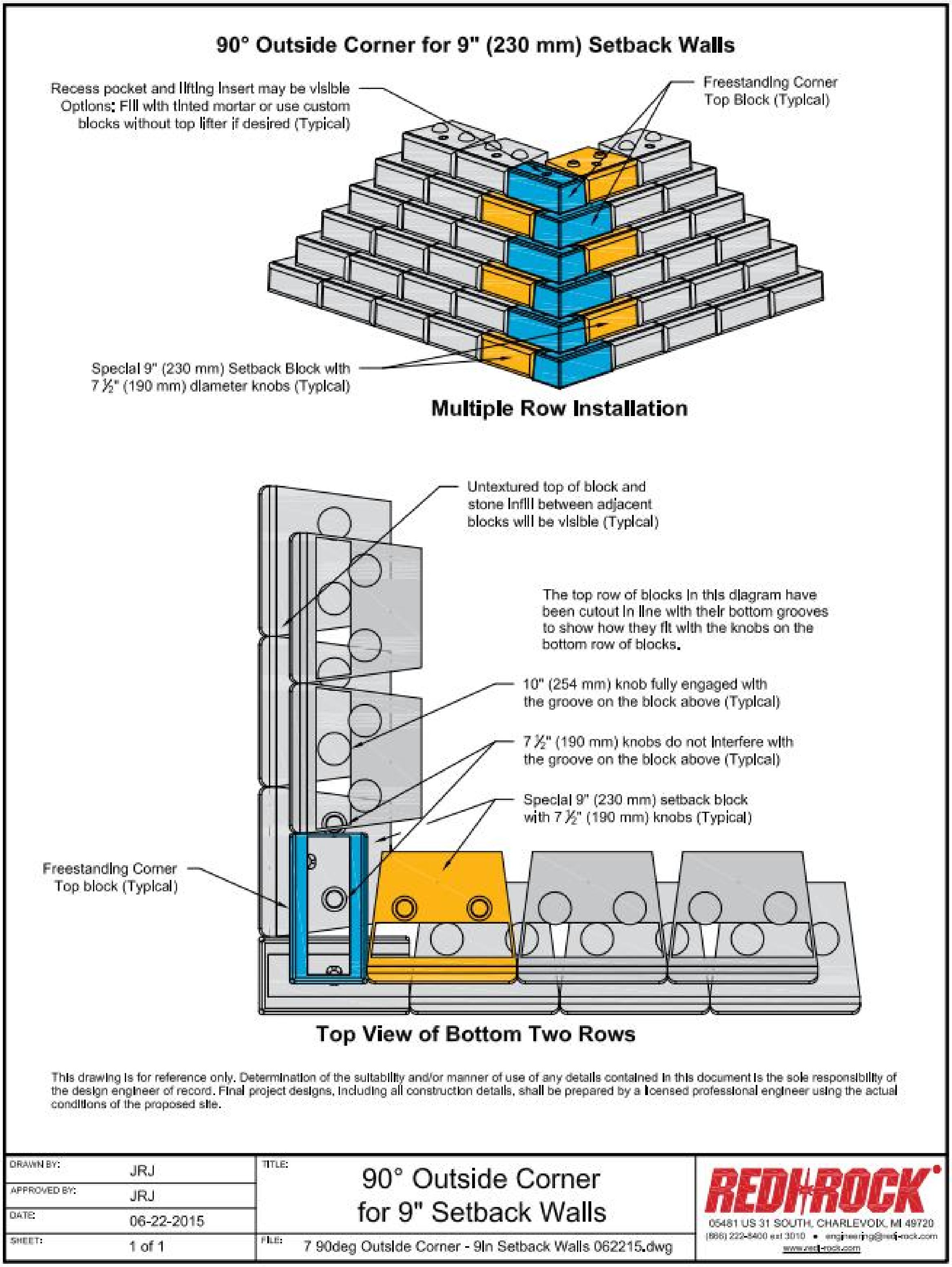


Figure 30 - Outside corners for 9-in setback walls

The 36 in (914 mm) high Redi-Rock XL hollow-core retaining blocks can also be configured to match the standard 18 in (457 mm) high range corner details.

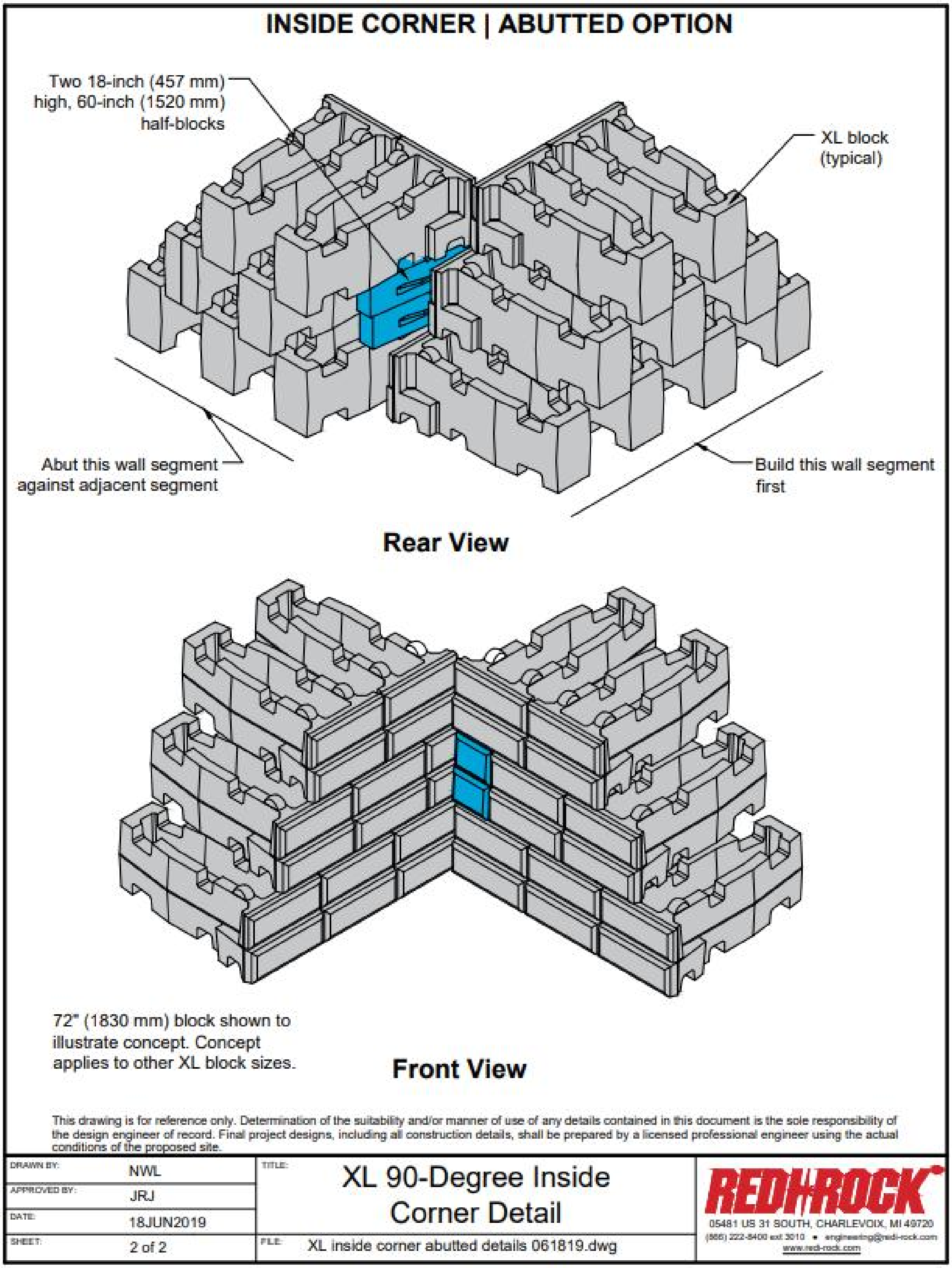


Figure 31 - XL inside corner

1.2 Extensible Reinforcement

1.2.1 Reinforcement Innovation

Redi-Rock's Positive Connection (PC) system utilizes 12 in (300 mm) wide strips of geogrid reinforcement that wrap through a vertical slot that is cast into the precast facing unit. This connection (discussed in more detail below) provides a connection between the geogrid and facing unit that is normal-load independent and utilizes a significant proportion of the full tensile strength of the geogrid.

1.2.2 Types of Reinforcement

The TenCate Miragrid XT products are the only geogrids currently recommended for use with the PC system. The Miragrid XT products are manufactured in Pendergrass, Georgia and have been evaluated in accordance with AASHTO's *National Transportation Product Evaluation Program* (NTPEP). Miragrid XT is a PVC-coated PET geogrid. For use with Redi-Rock, the geogrid is factory-cut in 12-in (300 mm) wide strips. The Miragrid XT types used with the Redi-Rock system are: 5XT, 8XT, 10XT, 20XT, and 24XT.

1.2.3 Reinforcement Specifications

Miragrid geogrid is composed of high molecular weight, high tenacity polyester multifilament yarns woven in tension and finished with a PVC coating. Table 3 summarizes the ultimate tensile strength and long-term reduction factors of the Miragrid XT products recommended for use with the PC System (based on the 2019 NTPEP report).

Table 3 - Miragrid® XT PET Geogrid Design Strength Properties

Properties		**5XT**	**8XT**	**10XT**	**20XT**	**24XT**
Ultimate Tensile Strength, T_{ult} (lb / ft)		4,700	7,400	9,500	13,705	27,415
Creep Reduction Factor, RF_{CR}						
Reference Temperature 20°C (68°F)	75-year design	1.44	1.44	1.44	1.44	1.44
	100-year design	1.45	1.45	1.45	1.45	1.45
Installation Damage Reduction Factor, RF_{ID}						
Soil Type 1: Coarse Aggregate (GP, φ=34°) 19 mm (3/4") < D_{50} ≤ 38 mm (1-1/2")		1.59	1.59	1.55	1.49	1.40
Soil Type 2: Sandy Gravel/Coarse Sand (GP or SP, φ=34°) D_{50} ≤ 19 mm (3/4")		1.10	1.10	1.10	1.10	1.10
Durability Reduction Factor, RF_D						
5.0 < pH < 8		1.15	1.15	1.15	1.15	1.15
4.5 ≤ pH ≤ 5 and 8 ≤ pH ≤ 9		1.30	1.30	1.30	1.30	1.30

The minimum average roll values (MARV) from NTPEP (2019) are used for ultimate tensile strength, T_{ult} and listed in Table 3.

The creep reduction factors from NTPEP (2019) are used for the standard reference temperature of 20° C (68° F) and shown in Table 3.

The recommended installation damage reduction factors in Table 3 are based on NTPEP (2019). Testing was completed for Miragrid 2XT, 3XT, 7XT, 8XT, and 24XT. Installation damage testing resulted in values of RF_{ID} that ranged from 1.01 to 2.01. In general, there was a trend of decreasing RF_{ID} as product unit weight/tensile strength increases, and increasing RF_{ID} with increasing grain size. The values in Table 3 were chosen to conservatively interpolate or bracket the measured data. Where the test data suggest RF_{ID} values less than 1.1, a minimum value of 1.10 was selected.

Reduction factors for durability RF_D recommended in FHWA-NHI-10-024 (2009) Table 3-11 have been adopted by Redi-Rock and are included in Table 3.

1.2.4 Reinforcement NTPEP Report

The Miragrid XT products used with the Redi-Rock system have been evaluated in accordance with AASHTO's National Transportation Product Evaluation Program (NTPEP). The NTPEP report is included in Appendix 1.2.4.

1.2.5 Facing-Reinforcement Connection

The block to geogrid connection for walls constructed with the Redi-Rock Positive Connection (PC) system is created by looping a 12 in (300 mm) wide factory-cut strip of Mirafi Miragrid XT geogrid through a 13 in (330 mm) wide vertical core slot cast into the Redi-Rock facing unit. Both legs of the geogrid strip are extended full length into the reinforced zone behind the wall providing tensile reinforcement at both the top and bottom elevations of each block. No pins, fasteners, or other devices are required. Geogrid reinforcement strips are typically installed through each and every block facing unit and are normally installed perpendicular to the alignment of the retaining wall block facing units. When a geogrid reinforcement strip is installed in every block unit, the top and bottom layers of geogrid reinforcement in the wall consist of a 12 in width of geogrid placed at 46 in (1168 mm) on-center, developing roughly 25 percent coverage. When subsequent block courses are installed in a running bond configuration, the intermediate layers of geogrid reinforcement in the wall consist of a 12 in width of geogrid placed at 23 in (584 mm) on-center for roughly 50 percent coverage. Geogrid reinforcement strips may also be designed for installation in every other block or in every block on every other block course yielding 25 percent reinforcement coverage throughout the entire wall.

Due to the nature of the connection, the connection capacity is independent of the normal load acting at each geogrid elevation. Due to the shape of the core slot, the connection capacity ranges from almost 70% to almost 100% of the geogrid tensile strength.

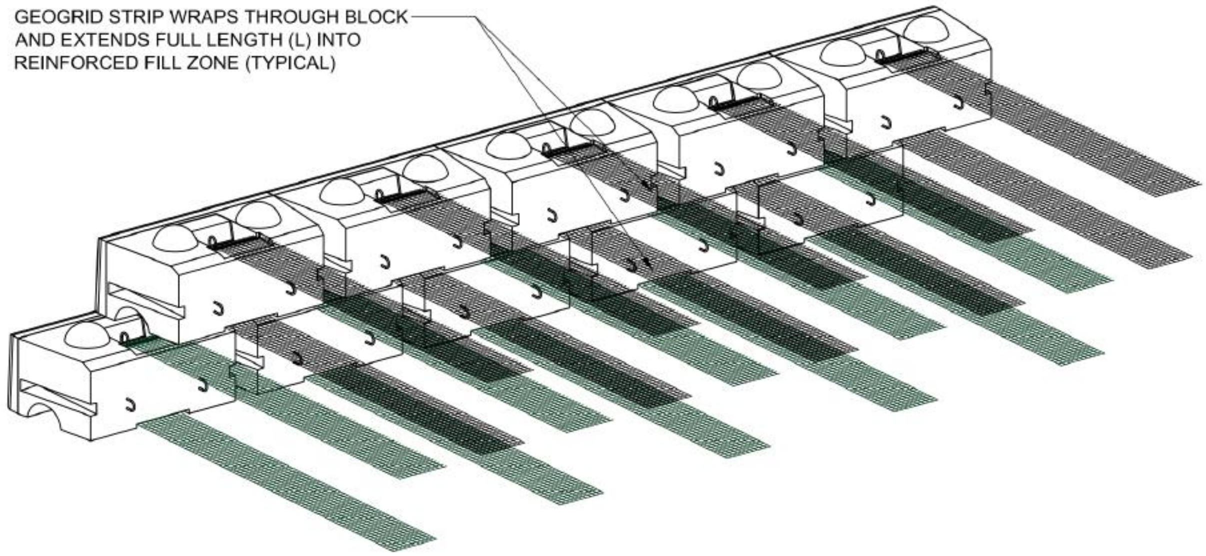


Figure 32 - 3D view of back of wall illustrating geogrid connection and resulting reinforcement configuration

1.2.6 Connection Strength Testing

Connection strength, or capacity, between 12 in (300 mm) wide strips of Mirafi geogrid and the PC block facing units was tested in full-scale connection tests conducted per ASTM D6638. Two complete sets of connection tests for five different types of Mirafi geogrids were conducted. In the first series of tests, the connection was tested without crushed stone core fill in the vertical core slots. In the second series of tests, the vertical core slots were filled with crushed limestone meeting the size requirements of No. 57 per AASHTO M43. The actual particle size distribution curve for the core fill used in the test is included in the individual test reports. The compaction used to consolidate the crushed stone in the tests was consistent with Redi-Rock's installation recommendations. Ultimate wide-width tensile strength values of the geosynthetic reinforcement sample lot utilized for the tests are included in the test reports. Copies of the laboratory test results for connection testing with and without crushed stone infill in the vertical core slot are provided in Appendix 1.2.6A.

The full-scale connection tests measured ultimate connection load at rupture at a minimum of six normal loads with two additional normal load repeats for a total of eight connection tests for each of the five Miragrid product styles. The results for the tests with crushed limestone core fill in the vertical core slot are shown in Figure 33.

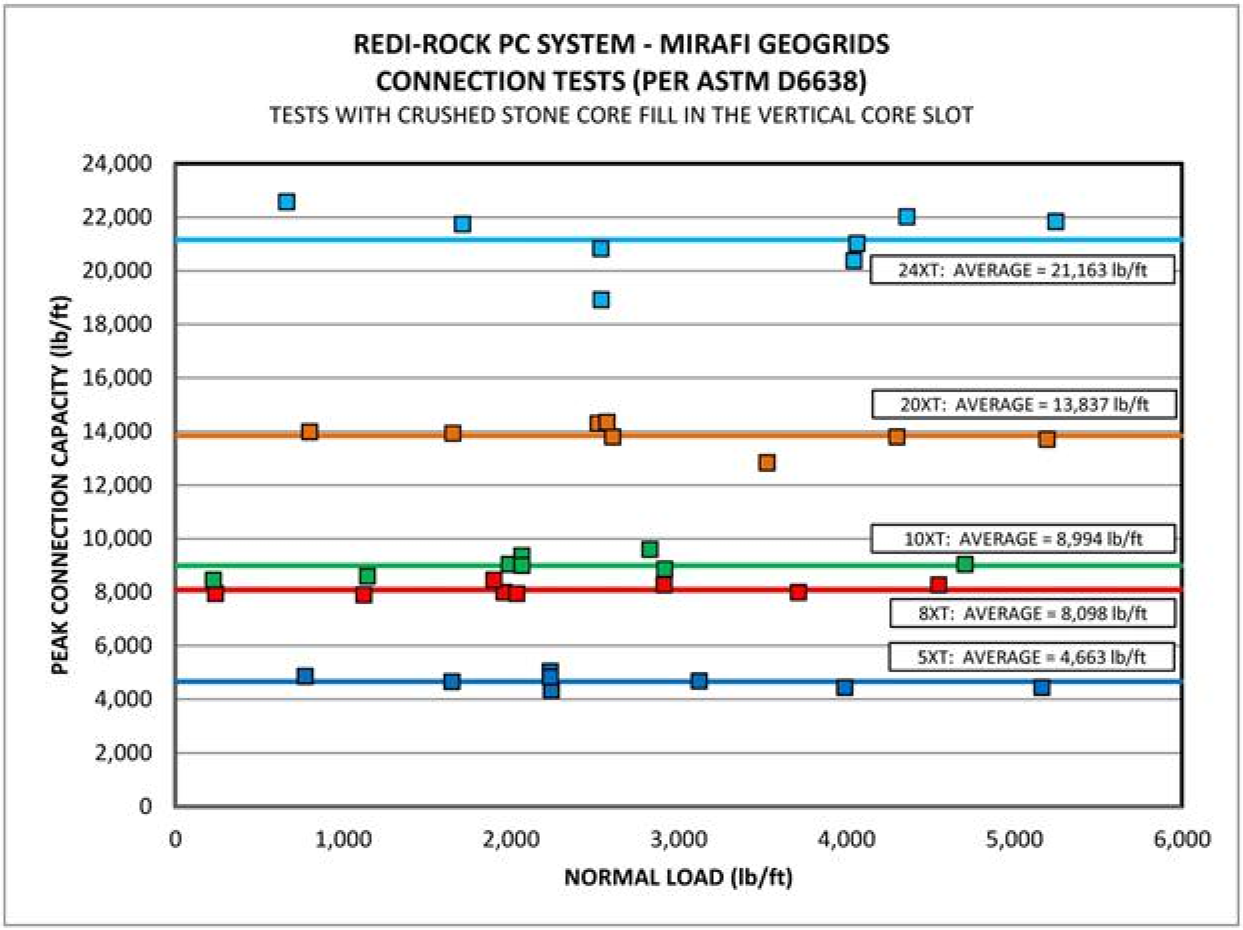


Figure 33 - Connection test results for Redi-Rock PC system facing units and Mirafi geogrids with crushed limestone core fill in the vertical core slot

The ultimate connection strength data generated for the PC system was evaluated to determine its dependence upon the normal load. A linear regression statistical best fit line was established and the coefficient of determination, R^2, for the best fit line was calculated for each Miragrid product style test series. These R^2 values ranged between 0.008 and 0.307 with an average of 0.163. Given that a value of 1.0 for R^2 indicates perfect dependence between the dependent and independent variables and a value of 0.0 indicates complete independence, a minimum value of R^2 of 0.70 was selected as the limit to determine if the best fit line is statistically valid. Based upon this criterion, connection strength of the PC system is not dependent on normal load and linear regression is not a valid approach for the recommendation of an ultimate connection capacity envelope. Since a typical linear regression between connection strength and normal load does not apply to the PC system, another approach to determine connection strength was required.

The method employed to determine the connection strength of the PC system is completed in multiple steps. First, each individual connection test was treated as a continuous random variable. The values from Miragrid test series were evaluated to determine if the sample data could be considered to be representative of a normally distributed population. Once the expectation of normality of the test series was established, a 95% confidence interval was calculated from the data by evaluating each test series with the Student's T-test at the 95% confidence level for n-1 degrees of freedom. The confidence interval was calculated as the mean test value plus or minus the test statistic (t value) times the standard error of the mean.

After determining the confidence interval for each test series, the lower 95% confidence values were normalized to the minimum average roll value (MARV) for the geosynthetic material by multiplying them by MARV over lot strengths of the tested material ($T_{ult\text{-}conn\ 95}$ * $MARV/T_{lot}$). The normalized 95% confidence values were plotted against strength of the geosynthetic material. The results are shown in Figure 34. Best fit curves for the tests with and without the inclusion of crushed stone fill in the vertical core slot were established through the normalized lower 95% confidence values. The coefficients of determination, R^2, for the best fit curves are greater than 0.99 and show an extremely high dependence between strength of the geosynthetic material and the connection strength.

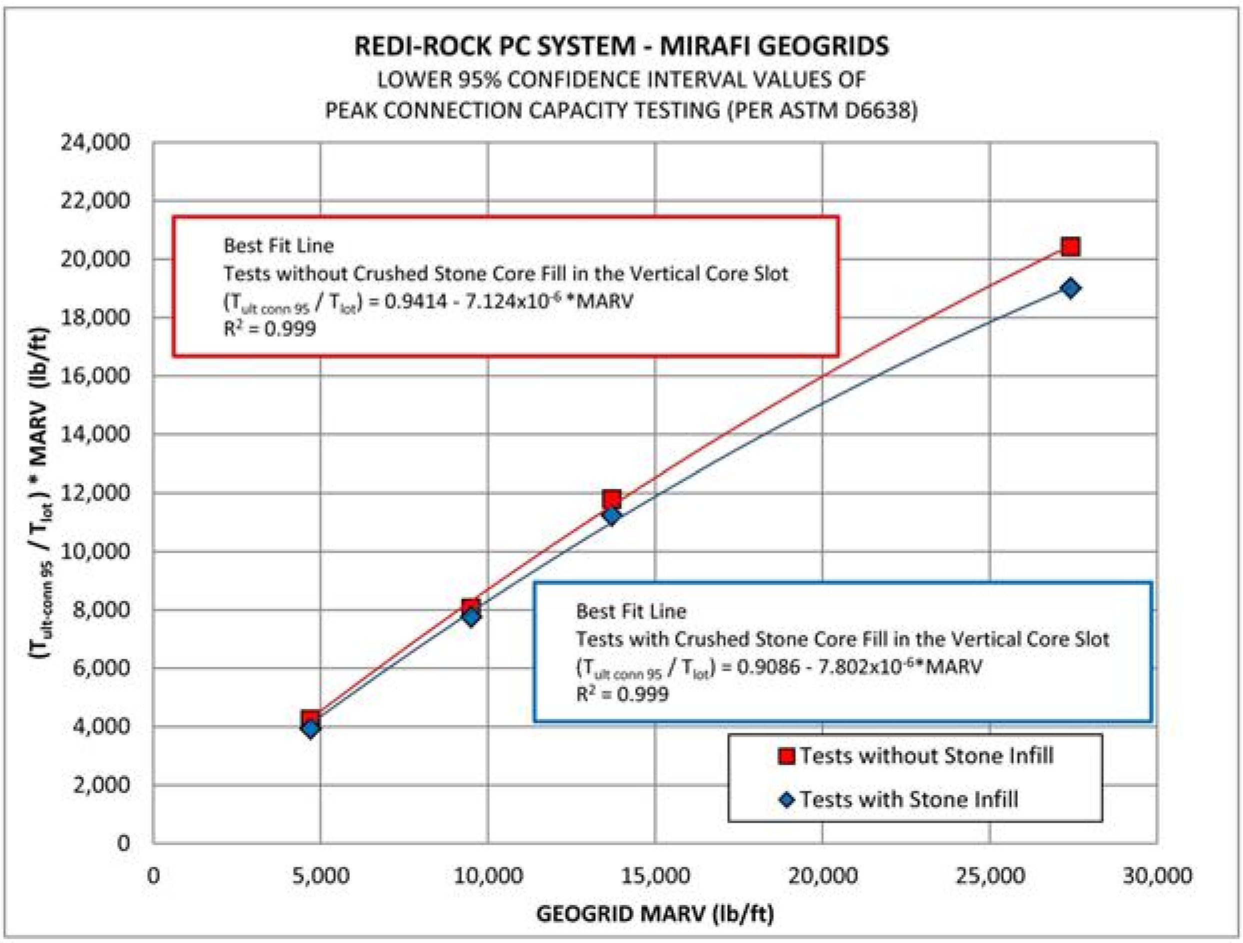


Figure 34 - Best fit curves for the lower 95% confidence values of Peak Connection tests normalized to the Minimum Average Roll Value (MARV) for Mirafi geogrids

The best fit curves in Figure 34 can also be used to determine the installation damage to the geosynthetic material caused by the placement and compaction of the crushed stone core fill in the vertical core slot of the PC block facing units. The two best fit curves show a reduction in connection strength of 4% to 7%, depending on the geosynthetic material.

A series of in-block installation damage tests was performed to validate the strength reduction shown in the connection tests as summarized in Figure 34. A report of the tests is included in Appendix 1.2.6B. A comparison of the reduction in strength of geosynthetic material measured during the in-block installation damage tests and the reduction in connection strength calculated from the best fit curves is shown in Table 4.

Table 4 – Strength Reduction Factor for Miragrid Geogrid Installed in the Redi-Rock PC Block Facing Unit with Crushed Limestone Core Fill in the Vertical Core Slot

Miragrid	5XT	10XT	20XT
Ultimate Tensile Strength (MARV), T_{ult} (lb/ft)	4,700	9,500	13,705
In-Block Installation Damage Reduction Factor Calculated from Best Fit Curves of Full-Scale Connection Tests, $RF_{ID\ BEST\ FIT}$	1.04	1.05	1.05
In-Block Installation Damage Reduction Factor Calculated from In-Block Installation Damage Tests, $RF_{ID\ IN\text{-}BLOCK}$	1.01	1.04	1.06

The data summarized in Table 4 indicates that approximately the same reduction in strength of the geosynthetic material can be obtained using either the best fit curves or in-block installation damage testing. This close correlation provides an opportunity to evaluate the connection strength of the PC system for walls constructed with a stone core fill material that differs from the crushed limestone used in the full scale connection tests. To evaluate alternate stone core fill material, an in-block installation damage test can be performed using the geosynthetic material, stone core fill, and compaction requirements proposed for the actual field installation. Then the strength reduction factor for installation damage, RF_{ID}, determined from the in-block testing can be applied to full scale connection tests performed without the inclusion of crushed stone fill in the vertical core slot to determine appropriate design values for the Redi-Rock PC system connection with the alternative stone core fill material desired.

Table 5 summarizes the connection information necessary for the design of the PC system.

Table 5 – Miragrid® Long-term Connection Design Parameters

Connection Design Parameter	5XT	8XT	10XT	20XT	24XT
Ultimate Tensile Strength (MARV), T_{ult} (lb / ft)	4,700	7,400	9,500	13,705	27,415
Short-term Ultimate Connection Strength Reduction Factor, CR_u (1)	0.84	0.84	0.82	0.80	0.69
Creep Reduction Factor (20°C)					
75-Year Design, $RF_{CR(75)}$	1.44	1.44	1.44	1.44	1.44
100-Year Design, $RF_{CR(100)}$	1.45	1.45	1.45	1.45	1.45
Durability Reduction Factor, RF_D (2)	1.15	1.15	1.15	1.15	1.15
Long-term Connection Strength Reduction Factor (CR_u / RF_{CR})					
75-Year Design, CR_{cr}	0.58	0.58	0.57	0.56	0.48
100-Year Design, CR_{cr}	0.58	0.58	0.57	0.55	0.48
Nominal Long-term Geosynthetic Connection Strength [(MARV * CR_u) / (RF_{CR} * RF_D)]					
75-Year Design, $T_{ac(75)}$ (lb / ft)	2,384	3,754	4,704	6,621	11,423
100-Year Design, $T_{ac(100)}$ (lb / ft)	2,368	3,728	4,672	6,575	11,344

1. Values given for CR_u are those recommended by Redi-Rock International for design based upon a detailed analysis. The lower value of the 95% confidence level of the ultimate connection strength was determined from test results. These values were compared to a statistical best fit line of connection strength across the entire range of geogrid products tested. The lower value of the 95% confidence level test results, the statistical best fit line, and the CR_u value for lighter weight geogrids was selected and listed in Table 5 to account for any testing anomalies and provide a lower bound for CR_u.

2. Recommended value for 5 < pH < 8. RF_D value of 1.3 recommended for 4.5 ≤ pH ≤ 5 and 8 ≤ pH ≤ 9. Use outside of 3 < pH < 9 range is not recommended per FHWA-NHI-10-024 (2009).

The nominal long-term connection strength has been determined according to the protocol defined in Appendix 1.1.5B.4 "Connection Resistance Defined with Short-Term Testing" of FHWA-NHI-10-025 (2009). Section 11.10.6.4.4b of the AASHTO (2012) follows the same method for calculation of long-term connection design capacity.

The following limitations exist for the application of these connection strength parameters:

- These connection strength values are based on installation of crushed limestone core fill meeting the requirements of AASHTO 57 per M43 in the vertical core slot using compaction effort to consolidate the crushed stone consistent with Redi-Rock's installation recommendations. Other core fill material or level of compaction should be evaluated with an in-block installation damage test.
- Splayed installation of the reinforcement strips. Occasionally, it will be necessary to splay the reinforcement strips to accommodate obstructions in the reinforced zone. Any vertical or horizontal splay angle in excess of 15° or an approximate 4:1 ratio with respect to true level or perpendicular placement should not be permitted.
- Incorrect installation of the Miragrid strip in the vertical core slot or failure to secure the Miragrid strip in a taut condition prior to placement and compaction of the reinforced backfill. Installation procedures published by Redi-Rock International are attached in Appendix 3.1.2. These instructions should be explicitly followed to ensure proper performance of the PC system.
- Substitution of a weaker geogrid style than that required (e.g., substitution of a 5XT strip in place of a required 10XT strip). Although, substitution of a stronger geogrid style than that required is generally acceptable. No substitution of any Miragrid style should be made without the written consent of the wall design engineer of record.
- Because there is no steel reinforcement in the PC block facing units, extremely high connection loads may cause the facing unit to crack. This failure mechanism of the connection was observed in the laboratory testing in test examples 6 and 8 of the 24XT test series at load levels well beyond those allowed in actual design. Since the load required to cause the cracking is much greater than the allowable connection strength, this phenomenon is not a concern for wall design and performance.

1.2.7 Reinforcement Pullout Testing

Geogrid pullout tests were conducted for four Miragrid geogrids in two soils in accordance with ASTM D6706. The test report is included in Appendix 1.2.7.

Measured Coefficient of Interaction (C_i) values were reported within the range of 0.85 to 1.08 with a linearly decreasing relationship between normal load and C_i. Friction factor, F*, and coefficient, α, were not reported. F* can be computed as $F^* = C_i \tan\varphi / \alpha$. A default value of α can be taken as 0.8 for extensible geogrid reinforcement, as recommended by FHWA-NHI-10-024. Our recommended values, based on the pullout tests, are as shown below:

Table 6 - Pullout Capacity Design Parameters

Geogrid	C_i (SM, SP)	C_i (SW, GP, GW)	α
Miragrid 5XT	0.8	0.9	1.0
Miragrid 8XT	0.8	0.9	1.0
Miragrid 10XT	0.8	0.9	1.0
Miragrid 20XT	0.8	0.9	1.0
Miragrid 24XT	0.8	0.9	1.0

1.2.8 Soil-Geosynthetic Interface Shear Testing

Soil-geogrid pullout tests were conducted for four Miragrid geogrids in two soils in accordance with ASTM D5321. The test report is included in Appendix 1.2.8.

The soil-geosynthetic interface friction angle, ρ, was found to be 29 to 30 degrees for test soil with a peak internal angle of friction, φ, of 32 degrees, and 47 to 50 degrees for soil with a peak friction angle of 50 degrees. Measured Coefficient of Direct Sliding (C_{ds}) values were reported within the range of 0.88 to 0.99, depending on normal stress. Our recommended values are as shown below:

Table 7 - Soil-Geosynthetic Interface Shear Design Parameters

Geogrid	C_{ds} (SM, SP)	C_{ds} (SW, GP, GW)
Miragrid 5XT	0.8	0.9
Miragrid 8XT	0.8	0.9
Miragrid 10XT	0.8	0.9
Miragrid 20XT	0.8	0.9
Miragrid 24XT	0.8	0.9

1.3 Other Components

1.3.1 Component Innovation

Redi-Rock blocks are one part of the system that comprises a gravity or MSE retaining wall. With proper engineering design (following conventional design methodologies, discussed in a later section), walls can be adapted for a variety of site conditions and components.

1.3.2 Reinforced & Retained Fill Soil

Redi-Rock International recommends the requirements for reinforced fill soil listed in FHWA NHI-10-024/025 as amended by AASHTO LRFD Bridge Construction Specifications, Customary U.S. Units, 2012. They are restated in Table 8 for convenience.

Table 8 - FHWA Recommended MSE Wall Select Granular Reinforced Backfill Requirements

US Sieve	Sieve Size (mm)	Percent Passing by Weight
4-inch	102	100
No. 40	0.425	0-60
No. 200	0.075	0-15
Plasticity Index	PI ≤ 6	
Soundness	The materials shall be substantially free of shale or other soft, poor durability particles. The material shall have a magnesium sulfate soundness loss of less than 30 percent after four cycles (or a sodium sulfate value less than 15 percent after five cycles).	
Notes: (a) To apply default F* values, Cu, should be greater than or equal to 4. (b) As a result of recent research on construction survivability of geosynthetics, it is recommended that the maximum particle size for these materials be reduced to ¾-in. (19 mm)(1) unless construction damage assessment tests are or have been performed on the reinforcement combination with the specific or similarly graded large size granular fill.		

These requirements are reflected in Section 7.3.6.3 of the AASHTO Bridge Construction Specifications (2010) with the following additional requirements:

- Minimum effective internal angle of friction, φ = 34°
- pH of 5 to 10
- Resistivity of not less than 30 Ω • m
- Chlorides not greater than 100 ppm
- Sulfates not greater than 200 ppm

We recommend limiting pH to no more than 9 when using polyester geogrids. It's important to note that the limits for resistivity and chlorides/sulfates ion content do not apply for soils interacting with geosynthetic reinforcements such as PVC coated polyester such as the one presented in this document.

Gravel infill material utilized for unit fill (between adjacent block facing units), vertical core slot and hollow core fill, and drain stone is a durable crushed stone meeting the particle size distribution requirements provided in Table 9.

Table 9 – Gravel Infill Gradation Requirements

Sieve Size	Percent Passing
1-½ inch	100
1 inch	95 - 100
¾ inch	90 - 100
½ inch	20 - 100
3/8 inch	0 - 70
No. 4	0 - 25
No. 8	0 - 10
No. 16	0 - 5

Material meeting the size requirements of no. 57, 6, 67, 68, or 7 per AASHTO M 43 will meet the Redi-Rock gradation requirements for gravel infill. It is intended that an equivalent material conforming to specific state Department of Transportation (DOT) designations be used.

1.3.3 Drainage

With the exception of the Redi-Rock XL blocks, Redi-Rock requires that a 12 in (300 mm) wide drainage course consisting of open-graded crushed aggregate be placed behind the facing units within a wall. The aggregate should meet the size requirements described above for gravel infill.

Redi-Rock XL hollow-core blocks are installed with a large relative volume of free-draining aggregate infill and significant connectivity between the retained zone and the infill; therefore, a drainage course behind the blocks is not required.

Depending on the relative gradation between the retained backfill and drainage course and/or infill, a needle-punched, nonwoven geotextile may be necessary to separate the backfill material from the open-graded aggregate. The nonwoven geotextile fabric should meet the requirements for Class 3 construction survivability in accordance with AASHTO M 288. If the open-graded aggregate meets the filter criteria for the backfill material, the geotextile is not required.

A 4 in (100 mm) minimum diameter perforated drain pipe should be incorporated in the bottom of the drainage course or heel of the leveling pad to collect and discharge any water collected from the drainage course or infill material. Gravity outlets should be provided for this pipe, either through or under the facing or around the ends of the wall.

1.3.4 Coping

Redi-Rock offers multiple coping options for walls. In the first coping option, the top of the wall can be finished with a cast-in-place coping. The cast-in-place coping spans multiple Redi-Rock block facing units and can be installed on a constant slope, eliminating the steps in the top of the wall which occur at the end of each course of 18 in (457 mm) high facing units.

The second coping option uses one or more courses of Redi-Rock freestanding units at the top of the wall. A course of cap units are placed on top of the freestanding units to provide a finished look to the top of the wall. The freestanding blocks have finished texture on 2 or 3 sides. Freestanding units are used when part or all of the back and end of the block is exposed. The coping option with freestanding and cap blocks is often used when pedestrian traffic must be accommodated at the top of the retaining wall.

The third coping option utilizes 28 in (710 mm) wide top block facing units. The top 5 in (127 mm) of the top block facing unit is recessed to allow the site to be graded flush with the top of the wall. Topsoil can be placed to the back of the face texture on the top block facing unit and grass or ground cover vegetation can be established at the top of the wall.

Drawings illustrating coping options, including their method of attachment, are included in Appendix 1.3.4.

1.3.5 Traffic Barriers

Traffic barriers can be incorporated into the wall in two general methods: post and beam guardrail or moment slabs. Details depicting these can be found in Appendix 1.3.5. Guidance for loading that can be considered in wall design to account for traffic impact loads can be found in FHWA-NHI-10-024.

1.3.6 Slip Joints

A vertical slip joint can be made by incorporating half block facing units at the desired joint location in every other course of facing units. The half block facing units offset the standard running bond installation. When used in this application, one side of the half block facing units aligns with the vertical joint between the two facing units immediately below. This results in a vertical joint which runs the entire height of the wall and provides a slip joint. Figure 35 shows a PC system retaining wall which incorporates 2 vertical slip joints on either side of a cast-in-place headwall/collar for a large pipe penetration through the wall.

Figure 35 – Vertical Slip Joint

Drawings depicting a vertical slip joint are included in Appendix 1.3.6.

SECTION 2: ERS DESIGN

2.1 Design Methodology

2.1.1 Design Innovation

The Redi-Rock precast modular block system does not contain innovations related to design methodology.

2.1.2 Design Methodology

Retaining wall design using Redi-Rock units follows standard retaining wall design theory and methodology. Essentially, the design process for gravity walls involves selecting a trial wall configuration, determining the earth pressures acting on the wall, and comparing the resisting forces and moments of the trial wall - due to the wall's self-weight - to the loading. Failure modes that must be considered are:

- Sliding of the entire wall
- Overturning of the entire wall
- Sliding at block-to-block interface
- Overturning at block to block interface
- Bearing capacity
- Global stability

For reinforced walls, the above failure modes are considered for the combined facing and reinforced soil mass, with the addition of internal stability checks for:

- Geogrid tensile strength
- Geogrid pullout strength
- Geogrid-block connection strength
- Sliding at geogrid layer

Gravity walls can be designed in accordance with AASHTO LRFD Bridge Design Specifications (9th Edition) Section 11.11 and MSE walls can be designed following Section 11.10.

The design methodology used for the design examples is in accordance with AASHTO's LRFD Bridge Design Specifications.

The gravity example calculations were performed mainly using Excel and MathCAD programs. MSEW from ADAMA Engineering was used for the analysis of the MSE wall example calculations using the simplified method.

2.1.3 Addressing Obstructions

Obstructions in the reinforced zone of a Redi-Rock MSE wall can be addressed in a few different ways depending on the type and size of the obstruction as well as it's proximity to the wall's facing. In some cases, it might be appropriate to design the section of wall directly in front of the obstruction as a gravity wall without geogrid reinforcement. Some of these cases may include large diameter vertical piles or manholes which can assume the active pressure that otherwise would act on the wall facing. In this case, the wall facing can be designed as a gravity wall with narrow backfill.

Another way to address obstructions in the reinforced zone is to use a waler beam attached to the back of each row of blocks. The waler beam would have horizontal extensions that extend into the reinforced zone on either side of the obstruction. These extensions would then have a structural element such as a pipe where the geogrid reinforcement would wrap around and extend into the embankment creating the reinforced zone for the section of wall with the obstruction.

If the obstruction is smaller, such as a sonotube or guardrail fence post, they can be installed in between the 12 in (300 mm) wide geogrid reinforcement strips. The strips are also flexible and can be splayed around these types of obstructions.

Examples of these solutions can be found in Appendix 2.1.3.

2.2 Design Examples

2.2.1 Gravity Example Calculations

Gravity wall example calculations are included in Appendix 2.2.1.

2.2.2 MSEW Example Calculations

Mechanically stabilized earth wall example calculations are included in Appendix 2.2.2.

SECTION 3: CONSTRUCTION

3.1 Construction Procedures

3.1.1 Construction Innovation

The Redi-Rock system provides innovations to the retaining wall construction process. The blocks' large per-unit area saves time during construction and the innovative knob and groove design adds to the efficiency and ease of construction.

For MSE walls, the Redi-Rock Positive Connection (PC) system provides a vertical core slot cast into each PC block through which a 12-in (300 mm) wide strip of geogrid is threaded. This eliminates the need for special connection parts such as clips, bars, or mechanical fasteners, simplifying the wall construction sequence and resulting in faster safer installation.

Redi-Rock XL blocks are 36 in (914 mm) tall, which is twice the height of regular Redi-Rock blocks. With double the per-unit area, the speed of installation during construction is further increased while allowing for taller gravity structures in a narrower footprint.

3.1.2 Construction Manual

The construction manual (installation guide) for the Redi-Rock system is included in Appendix 3.1.2.

3.1.3 Unit Installation

The installation of Redi-Rock blocks for both straight and curved sections of the structure and at corners is provided in the installation guide. In general, no modifications are required to be made to blocks during installation.

3.1.4 Facing and Reinforcement Installation at Curves and Corners

Convex (outside) and concave (inside) curves can easily be constructed as part of a Redi-Rock wall. As previously mentioned, Redi-Rock blocks are tapered by 7.7° on each side. Therefore, the smallest outside radius that can be constructed (without cutting the blocks) occurs when the blocks are placed together with their sides touching. This minimum radius for full size blocks is 14 ft, 6 in (4.42 m), as measured from the face of the blocks.

Geogrid layout at curves and corners is as shown in the following illustrations:

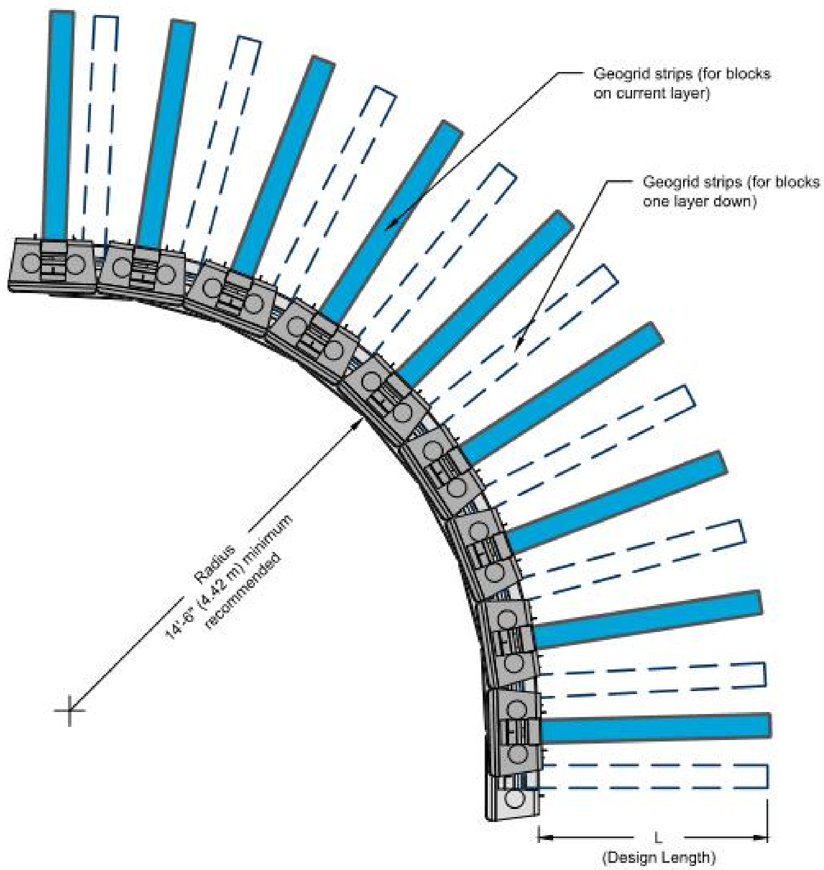


Figure 36 – Geogrid layout for concave curves

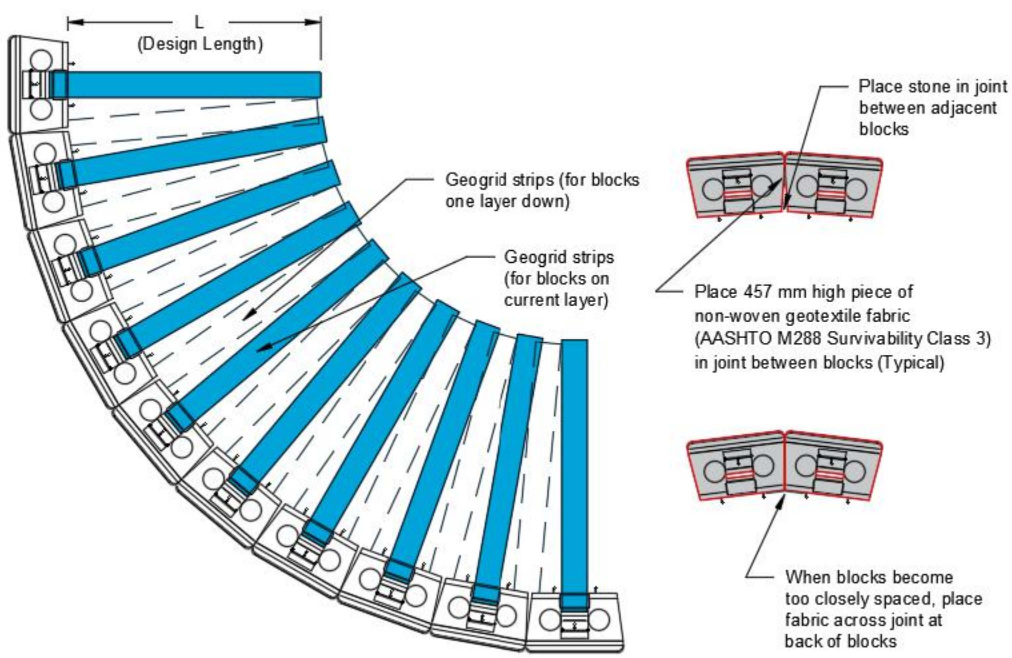


Figure 37 – Geogrid layout for convex curves

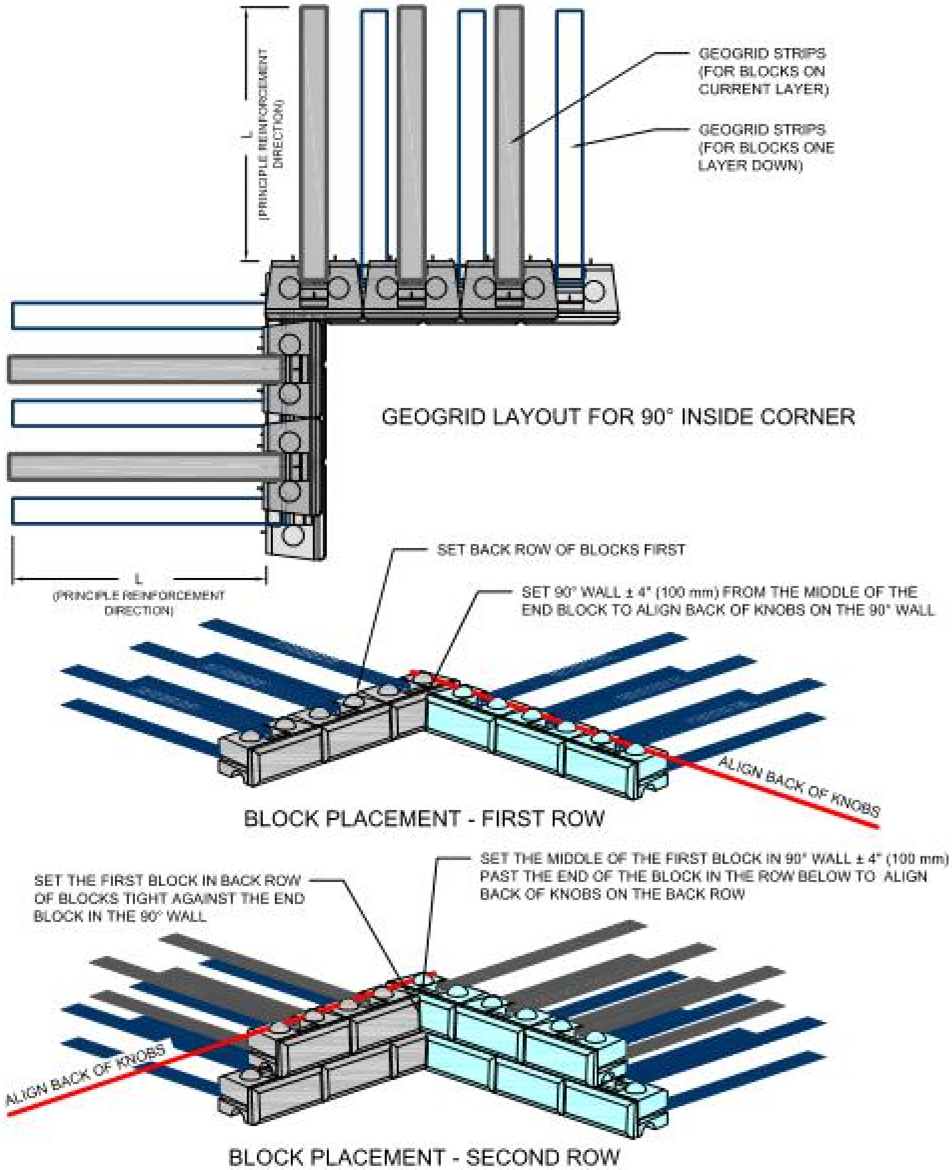


Figure 38 – Geogrid layout for 90° inside corner

3.1.5 Maintaining Alignment

Wall construction should start at a fixed point such as a building wall, 90° corner, or at the lowest elevation of the wall. The blocks shall be placed in full contact with the leveling pad and other immediately adjacent block units. Block alignment should be established by lining up the “form line” where the face texture meets the steel form finished area at the top of the block, approximately 5 in (127 mm) back from the front face.

All blocks shall be checked for level and alignment as they are placed. Small adjustments to the block location can be made with a large pry bar. Proper installation of the bottom block course is critical to maintaining the proper installation of all subsequent block courses within acceptable construction tolerance. It also makes installation of the upper rows of blocks much easier and more efficient.

Backfill shall be placed and compacted in front of the bottom block course prior to placement of subsequent block courses or backfill. This will keep the blocks in place as drainage aggregate and backfill are placed and compacted.

The vertical alignment (and wall batter) will be maintained by sliding each block forward to engage the bottom channel with the shear knobs of the block(s) in the row below.

3.1.6 Placing Reinforced and Retained Fill

Redi-Rock blocks are designed to allow for the design and construction of relatively tall non-reinforced (or gravity) walls, which use the weight of the blocks to provide stability. However, for some projects, taller walls are required. In these cases, mechanically stabilized earth (MSE) retaining walls can be built with the Redi-Rock Positive Connection (PC) system.

The geogrid used in Redi-Rock PC system walls consists of 12 in (300 mm) wide strips of PVC-coated polyester geogrid that wrap through a vertical core slot cast into the block and extend full length into the reinforced soil zone on both the top and bottom of the block.

Drainage aggregate is to be placed between and behind the blocks. The stone is placed in uniform loose lifts as required in the project plans and specifications. Consolidation of the stone between the blocks is completed by hand tamping. Care must be taken to tamp stone into the ends of the groove on the bottom of the Redi-Rock PC blocks. Behind the blocks, compaction of the stone is accomplished with a minimum of three passes with a 24 in (610 mm) wide walk-behind vibrating plate compactor capable of delivering at least 2000 lb (8.9 kN) of centrifugal force. Further compaction is to be provided, if needed to meet the density specified in the contract documents, but not less than 85% relative density of the stone determined in accordance with ASTM D-4253 and D-4254.

Only hand-operated compaction equipment is to be used within 3 ft (1 m) of the back of the PC blocks. Heavier equipment can be used beyond 3 ft (1 m) away from the PC blocks. Tracked construction equipment must not be operated directly on the geogrid strip reinforcement. A minimum fill thickness of 6 in (150 mm) is required for the operation of tracked vehicles over the geogrid strips. Turning of tracked vehicles should be kept to a minimum to prevent displacement of the fill and the geogrid strips. Rubber-tired vehicles may pass over the geogrid strips at a slow speed of less than 5 mph (8 km/hr). Sudden breaking and sharp turning should be avoided.

After placing and properly compacting the backfill to the elevation of the geogrid strip at the top of the block, the top leg of the geogrid strip is extended to the required design length. The geogrid strip is to be pulled tight to remove any slack, wrinkles, or folds. Staples, stakes, or other appropriate methods are to be used to hold it in place and keep the geogrid strip taut. Reinforced fill shall be placed first at the back of the block and moving to the terminal end of the reinforcement. This results in removing any slack in the geogrid and essentially pre-tension the reinforcement.

The center slot in the PC blocks is to be filled with drainage aggregate. Care must be taken to ensure the grid is flat against the back of the slot in the PC block to prevent any stone from lodging between the geogrid and the concrete block. The vertical core slot is to be filled completely with drainage aggregate. Consolidation of the drainage aggregate is to be achieved by hand tamping. A broom shall be used to sweep clean the top of the blocks immediately before the placement of each subsequent course of blocks. No walk-behind vibratory plate compactor is to be used on top of the Redi-Rock PC blocks.

Retained soil is to be placed immediately between the end of the reinforced soil zone (identified as the embedded end of the geogrid reinforcement strips) and the back of the excavation. Compaction of the retained soil is to be to a density as specified in the contract documents, plans, and specifications, but not less than 90% maximum density at ± 2% optimum moisture content as determined by a modified proctor test (ASTM D1557). Maximum differential elevation between the reinforced fill and the retained soil fill should never exceed 18 in (457 mm).

Backfill material shall be installed in lifts that do not exceed a thickness of 9-12 in (230-330 mm), as specified by project documents. At the end of each work day, the contractor shall grade the surface of the last lift of the granular wall infill to a 3% ± 1% slope away from the precast modular block wall face and compact it.

Construction in a similar fashion continues to the top of the wall.

3.1.7 Erosion Control During Construction

Best practice dictates that wall construction should continue without interruption or delays. This will help expedite construction and minimize the time the excavation is open.

The construction site should be graded and maintained to direct surface water runoff away from the retaining wall throughout the entire construction process. The contractor shall be responsible for protecting the precast modular block wall structure against surface water runoff at all times through the use of berms, diversion ditches, silt fence, temporary drains and/or any other necessary measures to prevent soil staining of the wall face, scour of the retaining wall foundation, or erosion of the reinforced backfill or wall infill.

For retaining walls with crest slopes and/or toe slopes, appropriate soil erosion/sedimentation control measures shall be installed along the wall immediately following construction and grading of the slope. The slope shall be immediately seeded and protected to establish vegetation. The contractor shall ensure that the seeded slope receives adequate irrigation and erosion protection to support germination and growth.

3.1.8 Installer Qualifications

In order to demonstrate basic competence in the construction of precast modular block walls, the installer shall document compliance with the following:

1. Experience.
    a. Construction experience with a minimum of 3,000 ft^2 (280 m^2) of the proposed precast modular block retaining wall system.
    b. Construction of at least three (3) precast modular block (large block) retaining wall structures within the past three (3) years.
    c. Construction of at least 5,000 ft^2 (465 m^2) of precast modular block (large block) retaining walls within the past five (5) years.

2. Installer experience documentation for each qualifying project shall include:
    a. Project name and location
    b. Date (month and year) of construction completion
    c. Contact information of owner or general contractor
    d. Type (trade name) of precast modular block system used
    e. Maximum height of the wall constructed
    f. Face area of the wall constructed

3. In lieu of the requirements set forth in Items 1 and 2 above, the installer must submit documentation demonstrating competency in precast modular block retaining wall construction through a training program that is deemed acceptable by the owner.

SECTION 4: QUALITY CONTROL

4.1 Manufacturing

4.1.1 Unit Manufacturing Quality Control

The Redi-Rock units are to be manufactured in accordance with the quality control process and procedures described in the Redi-Rock User Manual. A section of the User Manual is included in Appendix 4.1.1.

4.1.2 Reinforcement Quality Control

Quality Control measures that are required for the manufacturing of earth reinforcement components are to be followed in accordance with Tencate's Mirafi XT Miragrid's requirements. Tencate's Quality Control Plan for Miragrid is included in Appendix 4.1.2.

4.1.3 Alignment Device Quality Control

No alignment, shear, connection, or other type devices are required for the Redi-Rock system.

4.2 Construction

4.2.1 Construction Quality Control

Redi-Rock supports a Total Quality Management approach to Quality Assurance and Quality Control (QA/QC) in the planning, design, manufacture, installation, and final acceptance of a Redi-Rock wall. This approach requires the responsible party at each stage of the project to ensure that proper procedures are followed for their portion of the work. The responsible parties during the construction phase of a Redi-Rock wall include the contractor, engineer or owner's representative, and Redi-Rock licensed manufacturer.

The contractor is responsible for providing construction in accordance with the contract documents, plans, and specifications for the project. The contractor shall ensure that employees engaged in the construction of a Redi-Rock wall understand and follow the project plans and specifications, are familiar with the construction methods required, and have adequate safety training.

As referenced previously, the construction manual (installation guide) for the Redi-Rock system is included in Appendix 3.1.2. Construction Quality Control measures required during construction are provided throughout the various sections of the installation guide.

SECTION 5: PERFORMANCE

5.1 Performance History

5.1.1 Product History

The Redi-Rock Gravity Wall system was first developed in 1999. The founders of Redi-Rock owned a heavy civil construction firm and were working on a project in Northern Michigan where they were presented with a challenge to develop a new way to construct retaining walls. Owning several ready mix plants, they were also seeking ways to use the concrete production from their plants. Soon after their first blocks were developed, they realized that they had a great idea. In early 2000, the first licensed producer came on board. Since that time, Redi-Rock has grown into a network of over 120 licensed producers in 15 countries on 6 continents. Redi-Rock was the first to patent the large block retaining wall system, and currently owns over 24 patents. There are millions of square feet of Redi-Rock retaining walls all over the world, in applications ranging from residential to rail projects with E80 loading.

The original blocks that were developed were intended to be used as a gravity wall system. Not long after developing the gravity wall system, it became necessary to have a reinforced wall system so that taller walls could be achieved. The first version of the Redi-Rock reinforced wall system was called the 1 AT system (AT standing for Anchor Tail). The 1AT connection utilized a fiberglass rod and anchored tail to generate pullout resistance of the geogrid from the facing units. In 2012, Redi-Rock engineers developed a breakthrough MSE wall system. It involved casting a vertical core slot in the wall facing unit, creating a weight independent MSE wall system. This wall system is called the Positive Connection (PC) system, which is the MSE wall system referenced in this submittal.

5.1.2 Oldest Redi-Rock Structures (Gravity and MSE)

- The oldest gravity Redi-Rock wall was built in 1998 in Petoskey, Michigan.
- The oldest MSE Redi-Rock wall using the PC system was built in Louisville, Kentucky in August of 2011.
- These walls are still in service today.

5.1.3 Tallest Redi-Rock Structures (Gravity and MSE)

- The tallest gravity Redi-Rock wall was built in Nashville, Tennessee in 2018. This wall is 25.5 ft (7.8 m) tall
- The tallest MSE Redi-Rock wall using the PC system was built in Kittrell, North Carolina in 2016. This wall is 51.5 ft (15.7 m) tall

5.1.4 Approvals

The Redi-Rock retaining wall system has been widely used on public and private projects all over the world for over 20 years. Current approvals from state Departments of Transportation (DOT) are shown below:

Redi-Rock International - DOT & MOT Approvals				
State	**Gravity**	**Reinforced**	**Agency Contact if available**	**Comments**
Alabama	No	Yes		Application is in for Gravity
Alaska	No	No		
Arizona	No	No		
Arkansas	No	No		Allowed under special provision
California	No	No		
Colorado	Yes	Yes		No QPL. Handled through special provisions
Connecticut	Yes	No		
Delaware	No	No		
Florida	No	No		In progress; need drawings and calcs
Georgia	Yes	Yes	Stephen Wyche 404.631.1847	No QPL; Bridge office will eventually make a new special provision that lists all approved products
Hawaii	No	No		
Idaho	Yes	Yes	Dave Richards 208.334.8448	
Illinois	Yes	Yes	Matt Muller 217.782.7200	
Indiana	Yes	No	Malek Smadi 317.610.7251	
Iowa	Yes	No		
Kansas	No	No		Requires IDEA
Kentucky	Yes	No	Bart Asher	
Louisiana	No	No		Needs drawings and calcs; IDEA would help
Maine	Yes	Yes	George MacDougall 207.287.2181	
Maryland	No	No		
Massachusetts	Yes	Yes	Richard Carpenito 617.951.1348	
Michigan	Yes	Yes	Richard Endres 517.322.1207	
Minnesota	Yes	Yes	Joe Black (joe.black@state.mn.us)	
Mississippi	Yes	Yes		No QPL but we are approved
Missouri	Yes	No		
Montana	Yes	Yes		No QPL, but we are approved
Nebraska	Yes	Yes	Doug Churchwell 402.479.4678	
Nevada	Yes	Yes	Roma Clewell 775.888.7894	

New Hampshire	Yes	No	Mark Richardson 603.271.2731	
New Jersey	No	No		
New Mexico	No	Yes	Michelle Mann (michelle.mann@state.nm.us)	
New York	Yes	Yes	John Rondinaro, Gary Frederick, James Reidy	
North Carolina	No	No		
North Dakota	Yes	Yes		No QPL. Handled through special provisions
Ohio	Yes	Yes	Christopher Merklin 614.275.1361	
Oklahoma	Yes	Yes	Steve Jacobi	
Oregon	No	No		
Pennsylvania	Yes	Yes	Guozhou Li 724.321.1031	
Rhode Island	No	No		
South Carolina	No	No		No approved list; submittal in progress
South Dakota	Yes	No		
Tennessee	Yes	Yes	Wayne Seger 615.741.3351	
Texas	Yes	No	Marcus Galvan 512.416.2224	Needs calcs for PC and other items
Utah	Yes	No		
Vermont	Yes	Yes	Chris Benda 802.828.2561	
Virginia	No	Yes	Kevin Lee 804.371.9862	In progress for Gravity
Washington	No	Yes	Thomas Baker 360.705.7200	
West Virginia	Yes	Yes	Thomas White 304.558.9718	
Wisconsin	Yes	Yes	Lee Schuchardt 608.266.8494	
Wyoming	No	No		
Alberta	Yes	Yes		
British Columbia	Yes	Yes		
Manitoba	No	No		
New Brunswick	No	No		
Newfoundland and Labrador	No	No		
Nova Scotia	No	No		
Ontario	Yes	Yes		
Prince Edward Island	No	No		
Quebec	Yes	Yes		
Saskatchewan	No	No		

APPENDICES

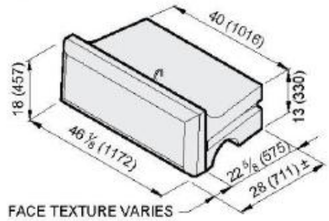
APPENDIX: 1.1.5A BLOCK LIBRARY

RETAINING BLOCKS

Block Library

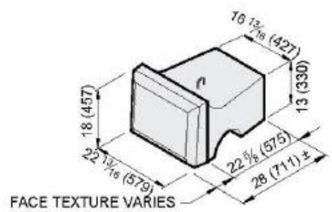
R-28T 28" (710mm) TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1230 lb (557 kg)	1160 lb (530 kg)
Block Volume:	8.57 ft^3 (0.243 m^3)	8.07 ft^3 (0.229 m^3)
Center of Gravity:	14.9" (378mm)	14.2" (362mm)



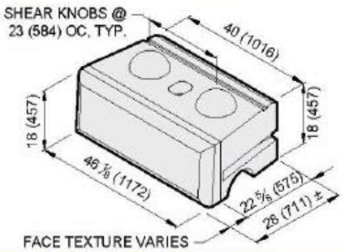
R-28HT 28" (710mm) HALF TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	570 lb (260 kg)	540 lb (240 kg)
Block Volume:	4.01 ft^3 (0.113 m^3)	3.76 ft^3 (0.106 m^3)
Center of Gravity:	15.3" (389 mm)	14.7" (373 mm)



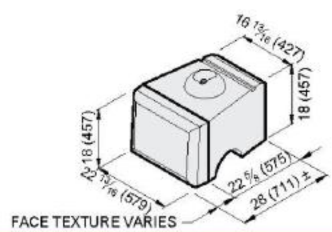
R-28M 28" (710mm) MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1610 lb (730 kg)	1540 lb (700 kg)
Block Volume:	11.28 ft^3 (0.319 m^3)	10.78 ft^3 (0.305 m^3)
Center of Gravity:	13.9" (354 mm)	13.4" (340 mm)



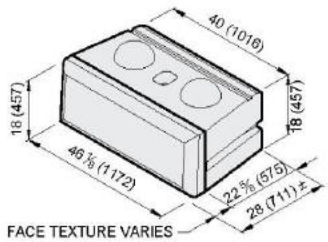
R-28HM 28" (710mm) HALF MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	750 lb (340 kg)	710 lb (320 kg)
Block Volume:	5.23 ft^3 (0.148 m^3)	4.98 ft^3 (0.141 m^3)
Center of Gravity:	14.3" (364 mm)	13.8" (350 mm)



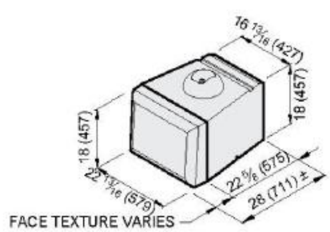
R-28B 28" (710mm) BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1740 lb (790 kg)	1670 lb (760 kg)
Block Volume:	12.19 ft^3 (0.345 m^3)	11.70 ft^3 (0.331 m^3)
Center of Gravity:	14.0" (355 mm)	13.5" (343 mm)



R-28HB 28" (710mm) HALF BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	810 lb (370 kg)	770 lb (350 kg)
Block Volume:	5.66 ft^3 (0.160 m^3)	5.41 ft^3 (0.153 m^3)
Center of Gravity:	14.3" (364 mm)	13.8" (352 mm)



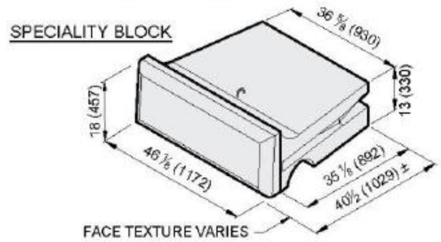
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. Half blocks contain a fork slot on only one side of the block.
7. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102mm) tall. Smaller knob diameters are available.

RETAINING BLOCKS

Block Library

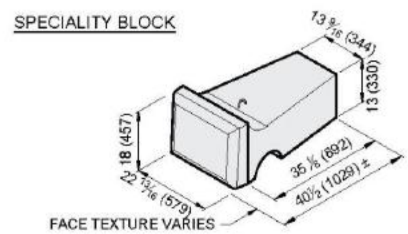
R-41T 41" (1030mm) TOP *

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1750 lb (790 kg)	1680 lb (760 kg)
Block Volume:	12.22 ft^3 (0.346 m^3)	11.73 ft^3 (0.332 m^3)
Center of Gravity:	21.3" (540 mm)	20.6" (522 mm)



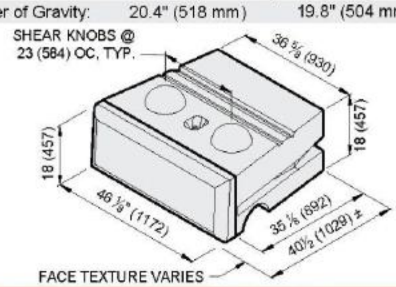
R-41HT 41" (1030mm) HALF TOP *

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	770 lb (350 kg)	740 lb (330 kg)
Block Volume:	5.38 ft^3 (0.15 m^3)	5.14 ft^3 (0.15 m^3)
Center of Gravity:	22.4" (568 mm)	21.6" (550 mm)



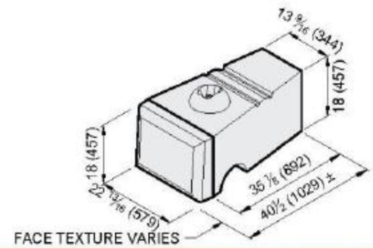
R-41M 41" (1030mm) MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2310 lb (1050 kg)	2240 lb (1020 kg)
Block Volume:	16.14 ft^3 (0.457 m^3)	15.65 ft^3 (0.443 m^3)
Center of Gravity:	20.4" (518 mm)	19.8" (504 mm)



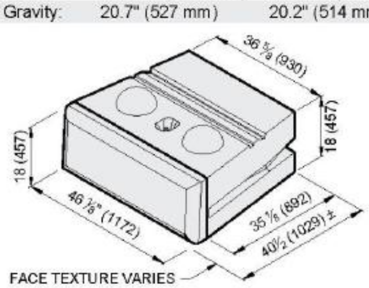
R-41HM 41" (1030mm) HALF MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1020 lb (460 kg)	990 lb (450 kg)
Block Volume:	7.14 ft^3 (0.20 m^3)	6.90 ft^3 (0.20 m^3)
Center of Gravity:	21.4" (543 mm)	20.8" (528 mm)



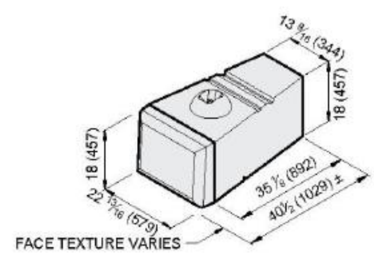
R-41B 41" (1030mm) BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2440 lb (1110 kg)	2370 lb (1070 kg)
Block Volume:	17.06 ft^3 (0.483 m^3)	16.56 ft^3 (0.469 m^3)
Center of Gravity:	20.7" (527 mm)	20.2" (514 mm)



R-41HB 41" (1030mm) HALF BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1080 lb (490 kg)	1050 lb (480 kg)
Block Volume:	7.58 ft^3 (0.21 m^3)	7.33 ft^3 (0.21 m^3)
Center of Gravity:	21.7" (551 mm)	21.2" (538 mm)



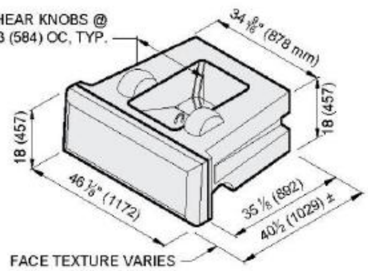
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. Half blocks contain a fork slot on only one side of the block.
7. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102mm) tall. Smaller knob diameters are available.
8. * 41" (1030mm) Top blocks are not typical and used in limited applications.

RETAINING BLOCKS

Block Library

R-41HC 41" (1030mm) HOLLOW-CORE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1,690 lb (780 kg)	1,620 lb (735 kg)
Block Volume:	11.83 ft^3 (0.33 m^3)	11.33 ft^3 (0.32 m^3)
Center of Gravity:	22.0" (558 mm)	21.3" (540 mm)
Infill Volume	6.53 ft^3 (0.18 m^3)	



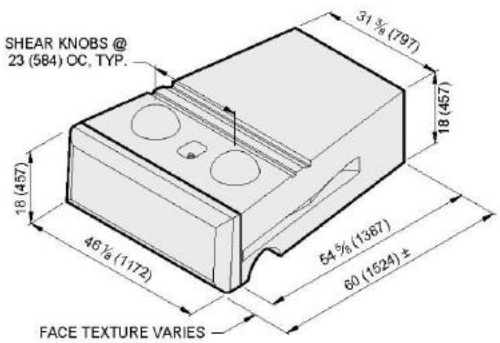
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. Half blocks contain a fork slot on only one side of the block.
7. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102mm) tall. Smaller knob diameters are available.

RETAINING BLOCKS

Block Library

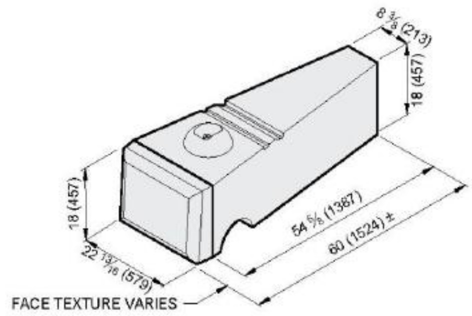
R-60M 60" (1520mm) MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	3290 lb (1490 kg)	3220 lb (1460 kg)
Block Volume:	23.00 ft^3 (0.651 m^3)	22.49 ft^3 (0.637 m^3)
Center of Gravity:	31.0" (786 mm)	30.4" (772 mm)



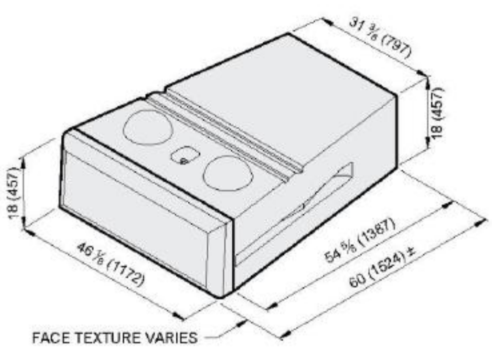
R-60HM 60" (1520mm) HALF MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1340 lb (610 kg)	1300 lb (590 kg)
Block Volume:	9.34 ft^3 (0.264 m^3)	9.09 ft^3 (0.258 m^3)
Center of Gravity:	33.7" (856 mm)	33.1" (840 mm)



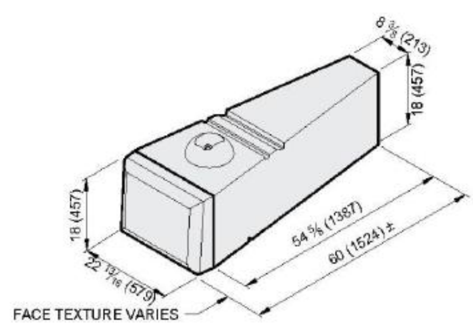
R-60B 60" (1520mm) BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	3420 lb (1550 kg)	3350 lb (1520 kg)
Block Volume:	23.90 ft^3 (0.677 m^3)	23.40 ft^3 (0.663 m^3)
Center of Gravity:	31.6" (802 mm)	31.0" (788 mm)



R-60HB 60" (1520mm) HALF BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1400 lb (630 kg)	1360 lb (620 kg)
Block Volume:	9.77 ft^3 (0.277 m^3)	9.52 ft^3 (0.270 m^3)
Center of Gravity:	34.3" (871 mm)	33.7" (856 mm)



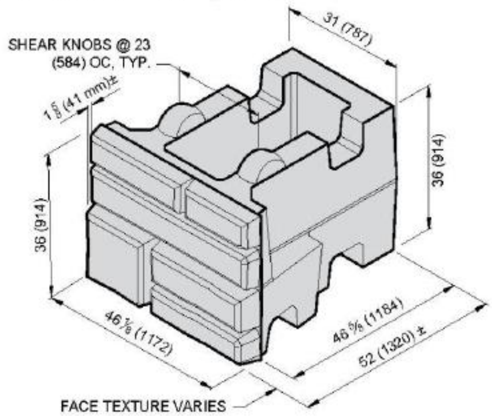
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. 60" (1520 mm) are typically used at the bottom of taller walls.
7. Half blocks contain a fork slot on only one side of the block.
8. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102mm) tall. Smaller knob diameters are available.

RETAINING BLOCKS

Block Library

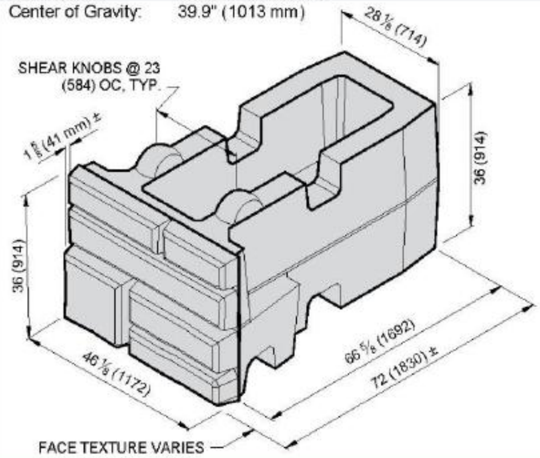
R-5236HC 52" (1320 mm) XL Hollow-Core

Face Texture:	Ledgestone
Block Weight:	3330 lb (1510 kg)
Block Volume:	23.29 ft^3 (0.660 m^3)
Infill Volume:	22.88 ft^3 (0.648 m^3)
Center of Gravity:	29.0" (737 mm)



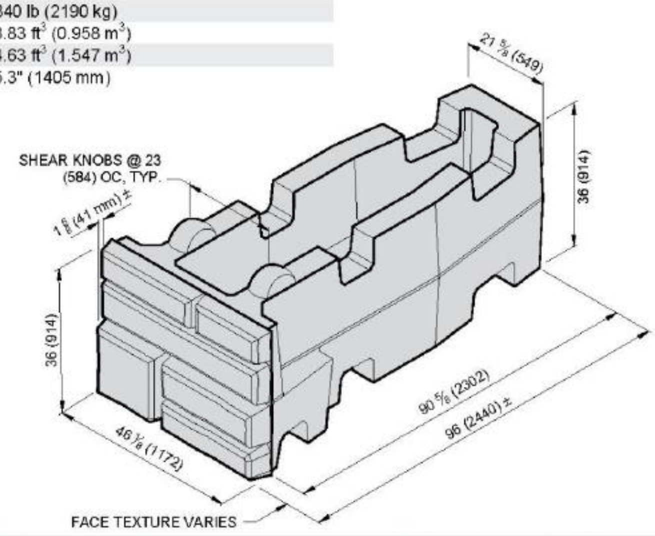
R-7236HC 72" (1830 mm) XL Hollow-Core

Face Texture:	Ledgestone
Block Weight:	4160 lb (1890 kg)
Block Volume:	29.10 ft^3 (0.824 m^3)
Infill Volume:	36.29 ft^3 (1.028 m^3)
Center of Gravity:	39.9" (1013 mm)



R-9636HC 96" (2440 mm) XL Hollow-Core

Face Texture:	Ledgestone
Block Weight:	4840 lb (2190 kg)
Block Volume:	33.83 ft^3 (0.958 m^3)
Infill Volume:	54.63 ft^3 (1.547 m^3)
Center of Gravity:	55.3" (1405 mm)



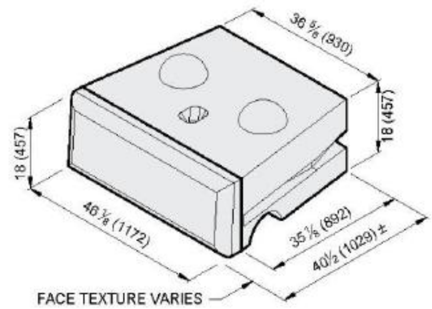
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block, excluding stone infill.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. Interface Shear knobs are nominally 10" (254mm) diameter by 4" (102 mm) tall.

RETAINING BLOCKS

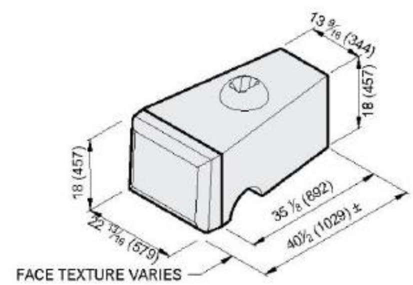
Block Library

R-419M — 41" (1030mm) MIDDLE 9" (230mm) SETBACK — R-419HM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone	Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2320 lb (1050 kg)	2250 lb (1020 kg)	Block Weight:	1030 lb (470 kg)	1000 lb (450 kg)
Block Volume:	16.21 ft^3 (0.46 m^3)	15.72 ft^3 (0.44 m^3)	Block Volume:	7.20 ft^3 (0.20 m^3)	6.96 ft^3 (0.20 m^3)
Center of Gravity:	20.2" (514 mm)	19.7" (500 mm)	Center of Gravity:	21.3" (540 mm)	20.7" (525 mm)



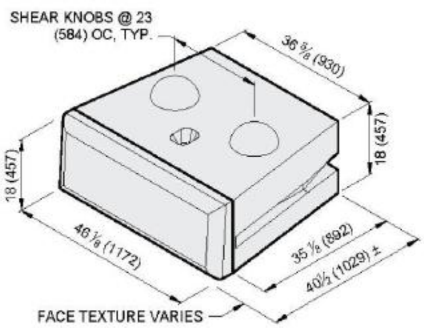
FULL MIDDLE



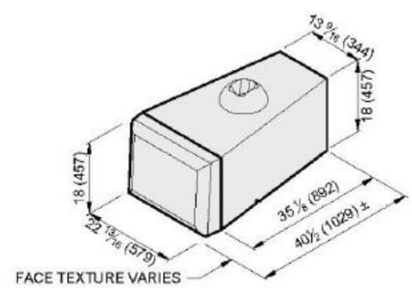
HALF MIDDLE

R-419B — 41" (1030mm) BOTTOM 9" (230mm) SETBACK — R-419HB

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone	Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2450 lb (1110 kg)	2380 lb (1080 kg)	Block Weight:	1090 lb (500 kg)	1060 lb (480 kg)
Block Volume:	17.13 ft^3 (0.48 m^3)	16.63 ft^3 (0.47 m^3)	Block Volume:	7.63 ft^3 (0.22 m^3)	7.39 ft^3 (0.21 m^3)
Center of Gravity:	20.6" (523 mm)	20.1" (510 mm)	Center of Gravity:	21.6" (548 mm)	21.0" (534 mm)



FULL BOTTOM



HALF BOTTOM

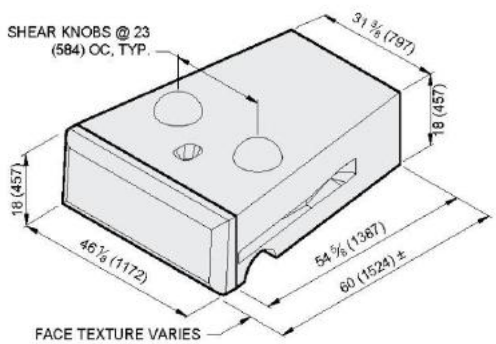
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. Half blocks contain a fork slot on only one side of the block.
7. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102 mm) tall.

RETAINING BLOCKS

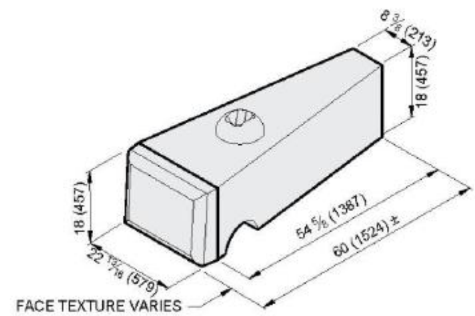
Block Library

R-609M 60" (1520mm) MIDDLE 9" (230mm) SETBACK R-609HM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone	Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	3300 lb (1500 kg)	3230 lb (1460 kg)	Block Weight:	1340 lb (610 kg)	1310 lb (590 kg)
Block Volume:	23.06 ft^3 (0.65 m^3)	22.56 ft^3 (0.64 m^3)	Block Volume:	9.37 ft^3 (0.26 m^3)	9.12 ft^3 (0.26 m^3)
Center of Gravity:	30.9" (785 mm)	30.3" (770 mm)	Center of Gravity:	33.6" (855 mm)	33.0" (839 mm)



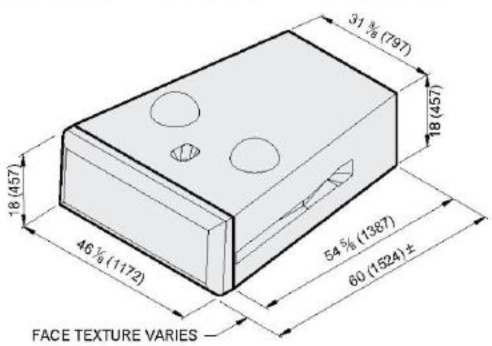
FULL MIDDLE



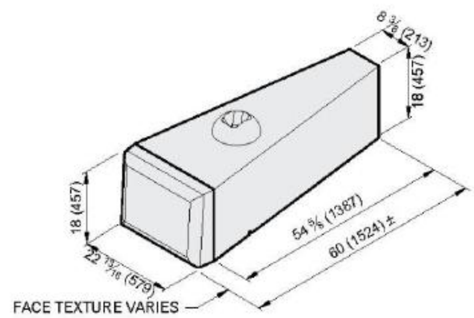
HALF MIDDLE

R-609B 60" (1520mm) BOTTOM 9" (230mm) SETBACK R-609HB

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone	Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	3430 lb (1550 kg)	3360 lb (1520 kg)	Block Weight:	1400 lb (640 kg)	1370 lb (620 kg)
Block Volume:	23.97 ft^3 (0.68 m^3)	23.47 ft^3 (0.66 m^3)	Block Volume:	9.80 ft^3 (0.28 m^3)	9.55 ft^3 (0.27 m^3)
Center of Gravity:	31.5" (800 mm)	30.9" (786 mm)	Center of Gravity:	34.2" (869 mm)	33.6" (854 mm)



FULL BOTTOM



HALF BOTTOM

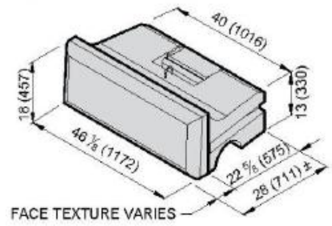
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291 kg/m^3).
6. Half blocks contain a fork slot on only one side of the block.
7. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102 mm) tall.
8. 60" (1520 mm) Blocks are typically used at the bottom of taller walls.

RETAINING BLOCKS

Block Library

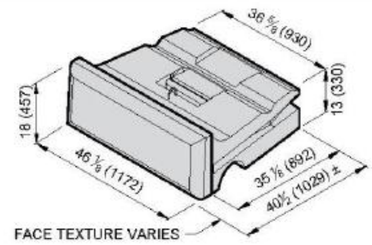
R-28PCT 28" (710mm) PC TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1170 lb (530 kg)	1100 lb (500 kg)
Block Volume:	8.16 ft^3 (0.231 m^3)	7.66 ft^3 (0.217 m^3)
Center of Gravity:	15.3" (388 mm)	14.6" (372 mm)



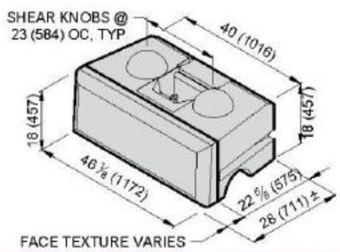
R-41PCT 41" (1030mm) PC TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1630 lb (740 kg)	1560 lb (710 kg)
Block Volume:	11.38 ft^3 (0.32 m^3)	10.88 ft^3 (0.31 m^3)
Center of Gravity:	21.8" (554 mm)	21.1" (536 mm)



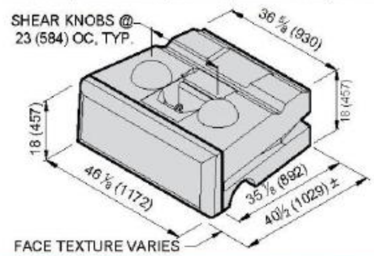
R-28PCM 28" (710mm) PC MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1520 lb (690 kg)	1450 lb (660 kg)
Block Volume:	10.62 ft^3 (0.301 m^3)	10.12 ft^3 (0.287 m^3)
Center of Gravity:	14.2" (360 mm)	13.6" (346 mm)



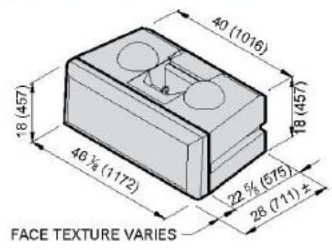
R-41PCM 41" (1030mm) PC MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2170 lb (990 kg)	2100 lb (950 kg)
Block Volume:	15.2 ft^3 (0.43 m^3)	14.69 ft^3 (0.42 m^3)
Center of Gravity:	20.6" (522 mm)	20.0" (508 mm)



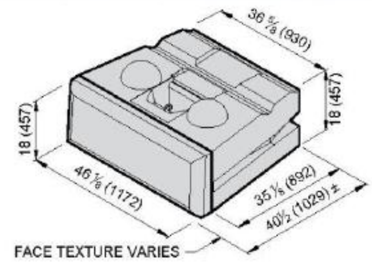
R-28PCB 28" (710mm) PC BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1620 lb (740 kg)	1550 lb (700 kg)
Block Volume:	11.34 ft^3 (0.321 m^3)	10.85 ft^3 (0.307 m^3)
Center of Gravity:	14.2" (362 mm)	13.7" (349 mm)



R-41PCB 41" (1030mm) PC BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2280 lb (1030 kg)	2210 lb (1000 kg)
Block Volume:	15.92 ft^3 (0.45 m^3)	15.42 ft^3 (0.44 m^3)
Center of Gravity:	20.2" (514mm)	19.7" (501mm)



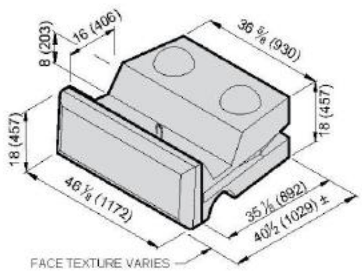
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. Blocks contain a vertical slot for a 12" (300 mm) strip of geogrid soil reinforcement.
7. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102 mm) tall. Smaller knob diameters are available.

RETAINING BLOCKS

Block Library

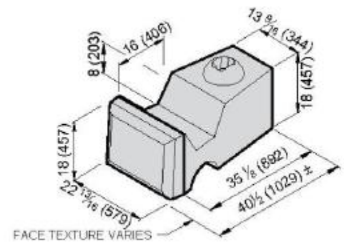
R-41PL 41" (1030mm) PLANTER

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2010 lb (910 kg)	1930 lb (880 kg)
Block Volume:	14.02 ft³ (0.40 m³)	13.53 ft³ (0.38 m³)
Center of Gravity:	19.1" (485 mm)	18.4" (468 mm)



R-41HPL 41" (1030mm) HALF PLANTER

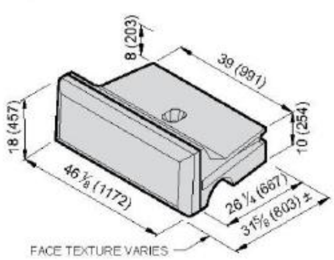
Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	880 lb (400 kg)	840 lb (380 kg)
Block Volume:	6.14 ft³ (0.17 m³)	5.89 ft³ (0.17 m³)
Center of Gravity:	20.2" (513 mm)	19.5" (495 mm)



R-MT MODIFIED TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1200 lb (540 kg)	1130 lb (510 kg)
Block Volume:	8.38 ft³ (0.24 m³)	7.88 ft³ (0.22 m³)
Center of Gravity:	17.9" (455 mm)	17.2" (438 mm)

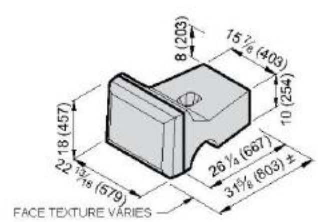
SPECIALITY BLOCK



R-MHT MODIFIED HALF TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	710 lb (320 kg)	640 lb (290 kg)
Block Volume:	4.95 ft³ (0.14 m³)	4.45 ft³ (0.13 m³)
Center of Gravity:	20.7" (527 mm)	19.8" (504 mm)

SPECIALITY BLOCK



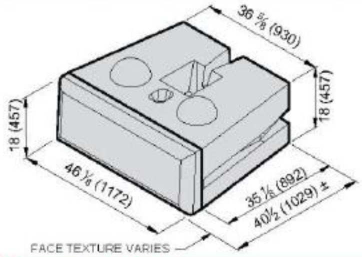
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft³ (2291kg/m³).
6. Half blocks contain a fork slot on only one side of the block.
7. Interface Shear knobs are typically 10" (254 mm) diameter by 4" (102 mm) tall.

RETAINING BLOCKS

Block Library

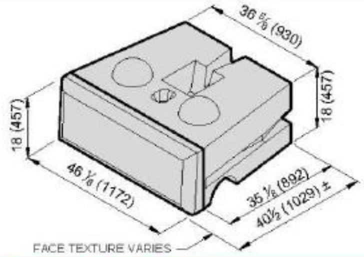
R-AB ANCHOR BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2370 lb (1070 kg)	2290 lb (1040 kg)
Block Volume:	16.54 ft^3 (0.47 m^3)	16.04 ft^3 (0.45 m^3)
Center of Gravity:	21.0" (533 mm)	20.4" (519 mm)



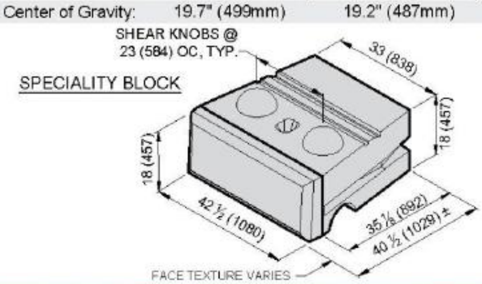
R-AM ANCHOR MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2240 lb (1010 kg)	2160 lb (980 kg)
Block Volume:	15.63 ft^3 (0.44 m^3)	15.13 ft^3 (0.43 m^3)
Center of Gravity:	20.6" (523 mm)	20.0" (509 mm)



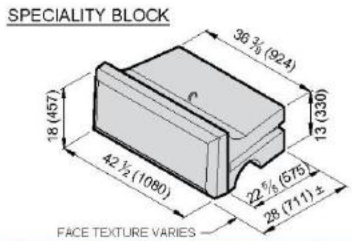
R-SM SHORT MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	2140 lb (970 kg)	2080 lb (940 kg)
Block Volume:	14.95 ft^3 (0.42 m^3)	14.51 ft^3 (0.41 m^3)
Center of Gravity:	19.7" (499mm)	19.2" (487mm)



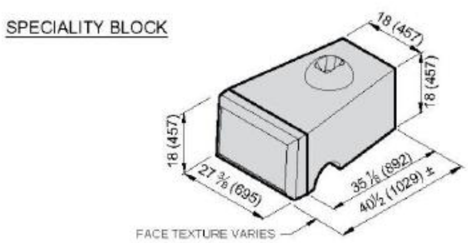
R-ST SHORT TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1110 lb (500 kg)	1050 lb (480 kg)
Block Volume:	7.77 ft^3 (0.22 m^3)	7.33 ft^3 (0.21 m^3)
Center of Gravity:	13.7" (349mm)	13.2" (336mm)



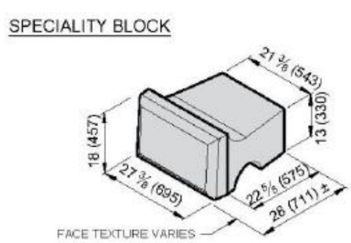
R-419SM 9" (230mm) SETBACK SHORT MID

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1280 lb (580 kg)	1240 lb (560 kg)
Block Volume:	8.96 ft^3 (0.25 m^3)	8.66 ft^3 (0.24 m^3)
Center of Gravity:	20.0" (507mm)	19.5" (494mm)



R-419ST 9" (230mm) SETBACK SHORT TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	710 lb (320 kg)	660 lb (300 kg)
Block Volume:	4.94 ft^3 (0.14 m^3)	4.64 ft^3 (0.13 m^3)
Center of Gravity:	13.9" (352mm)	13.3" (339mm)



1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Center of Gravity is measured from the back of block.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291kg/m^3).
6. 27" (695) wide blocks contain a fork slot on only one side of the block. These are speciality blocks and may have limited availability and is only used in double 90 degree corner applications.
7. Interface Shear knobs are typically 10" (254mm) diameter by 4" (102 mm) tall. Smaller knob diameters are available.

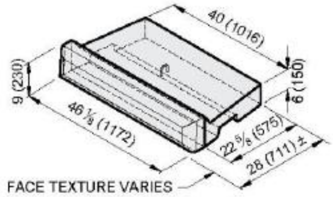
FREESTANDING BLOCKS

Block Library

9" (230 mm) STEPDOWN TOP

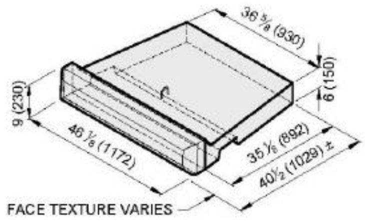
R-28SDT

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	600 lb (270 kg)	500 lb (230 kg)
Block Volume:	4.2 ft³ (0.12 m³)	3.4 ft³ (0.10 m³)



R-41SDT

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	840 lb (380 kg)	740 lb (340 kg)
Block Volume:	5.9 ft³ (0.17 m³)	5.1 ft³ (0.14 m³)



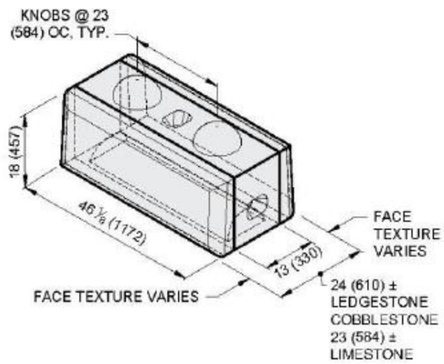
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Architectural faces on the blocks have varying texture.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft³ (2291 kg/m³).

FREESTANDING BLOCKS

Block Library

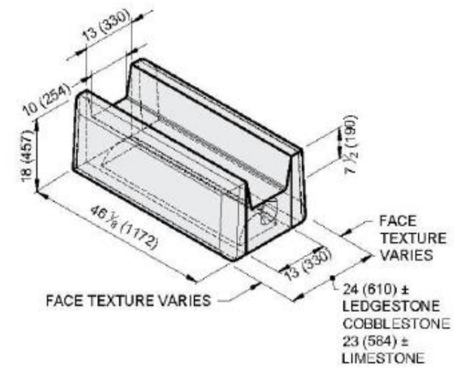
F-SM STRAIGHT MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1410 lb (640 kg)	1260 lb (570 kg)
Block Volume:	9.84 ft^3 (0.279 m^3)	8.84 ft^3 (0.250 m^3)



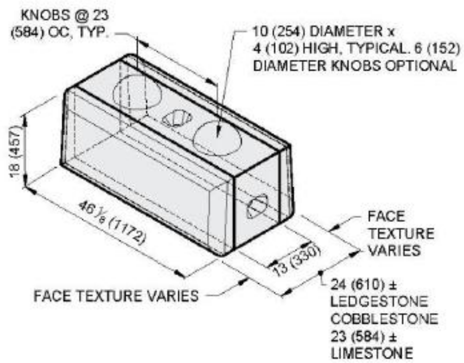
F-SG STRAIGHT GARDEN TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1050 lb (480 kg)	910 lb (410 kg)
Block Volume:	7.35 ft^3 (0.208 m^3)	6.35 ft^3 (0.180 m^3)



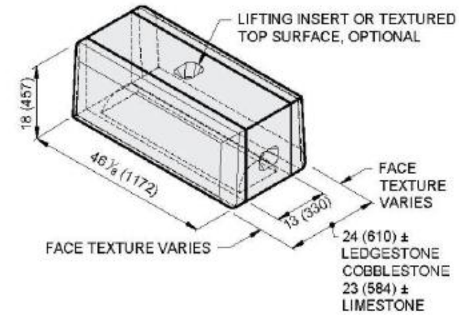
F-SB STRAIGHT BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1520 lb (690 kg)	1380 lb (630 kg)
Block Volume:	10.65 ft^3 (0.302 m^3)	9.66 ft^3 (0.273 m^3)



F-ST STRAIGHT TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1380 lb (620 kg)	1230 lb (560 kg)
Block Volume:	9.61 ft^3 (0.272 m^3)	8.62 ft^3 (0.244 m^3)



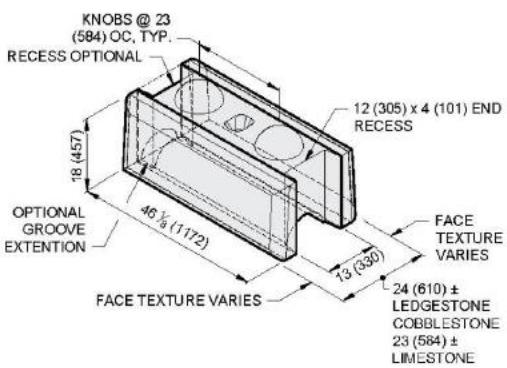
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Architectural faces on the blocks have varying texture.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291 kg/m^3).
6. 6" (152 mm) diameter vertical semi-clyindrical voids at the ends of the block for mechanical tie-down are available, refer to Force Protection blocks for additional information.
7. Knobs are typically 10" (254mm) diameter by 4" (102 mm) tall. Smaller knobs are available.

FREESTANDING BLOCKS

Block Library

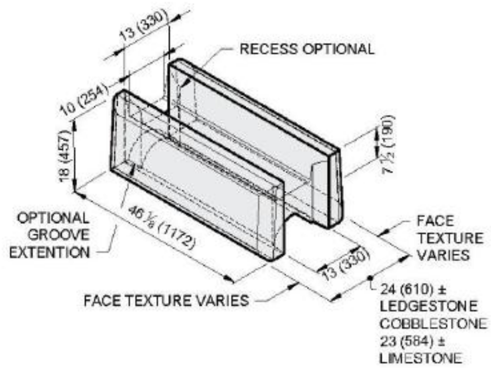
F-VM VARIABLE RADIUS MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1270 lb (570 kg)	1120 lb (510 kg)
Block Volume:	8.86 ft^3 (0.251 m^3)	7.86 ft^3 (0.223 m^3)



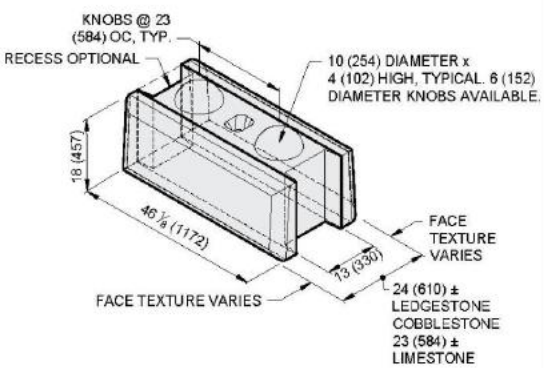
F-VG VARIABLE RADIUS GARDEN TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	970 lb (440 kg)	820 lb (370 kg)
Block Volume:	6.76 ft^3 (0.191 m^3)	5.76 ft^3 (0.163 m^3)



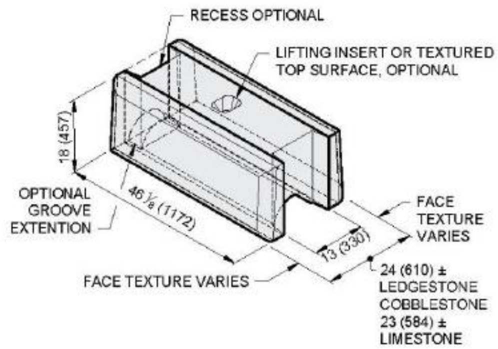
F-VB VARIABLE RADIUS BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1380 lb (630 kg)	1240 lb (560 kg)
Block Volume:	9.65 ft^3 (0.273 m^3)	8.66 ft^3 (0.245 m^3)



F-VT VARIABLE RADIUS TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1240 lb (560 kg)	1090 lb (500 kg)
Block Volume:	8.63 ft^3 (0.244 m^3)	7.64 ft^3 (0.216 m^3)



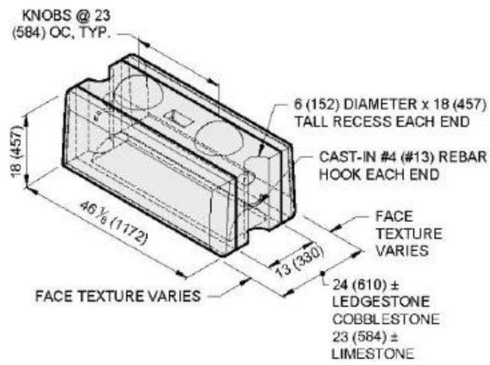
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Variable radius feature can be cast on only one end, coordinate.
4. Architectural faces on the blocks have varying texture.
5. Actual block volumes and weights may vary.
6. Weights are based upon a concrete density of 143 lb/ft³ (2291 kg/m³).
7. Knobs are typically 10" (254 mm) diameter by 4" (102 mm) tall. Smaller knobs are available.

FREESTANDING BLOCKS

Block Library

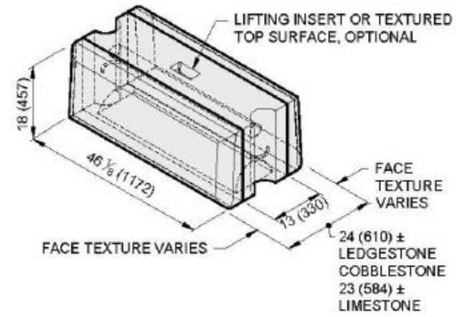
F-FM FORCE PROTECTION MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1350 lb (610 kg)	1200 lb (550 kg)
Block Volume:	9.41 ft^3 (0.267 m^3)	8.42 ft^3 (0.238 m^3)



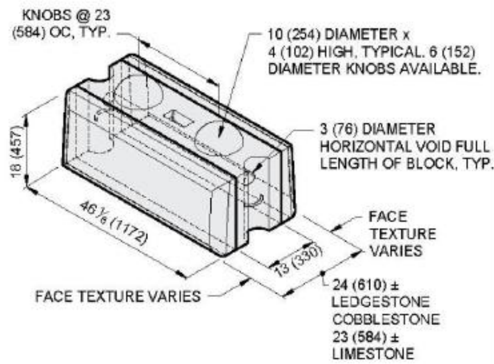
F-FT FORCE PROTECTION TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1310 lb (600 kg)	1170 lb (530 kg)
Block Volume:	9.19 ft^3 (0.260 m^3)	8.19 ft^3 (0.232 m^3)



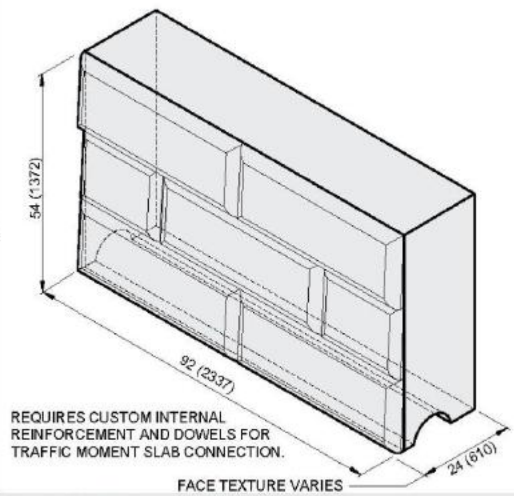
F-FB FORCE PROTECTION BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1460 lb (660 kg)	1320 lb (600 kg)
Block Volume:	10.23 ft^3 (0.290 m^3)	9.23 ft^3 (0.261 m^3)



F-BB BARRIER BLOCK

Block Weight:	9,350 lb (4,240 kg)
Block Volume:	65.4 ft^3 (1.85 m^3)



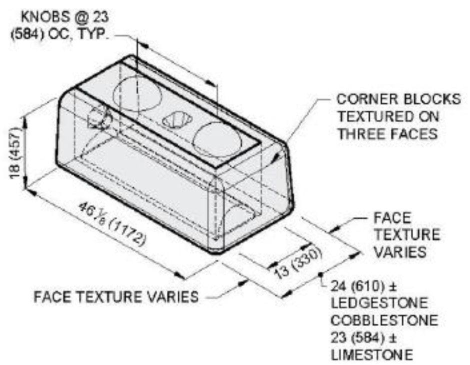
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Architectural faces on the blocks have varying texture.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291 kg/m^3).
6. Knobs are typically 10" (254mm) diameter by 4" (102 mm) tall. Smaller knobs are available.

FREESTANDING BLOCKS

Block Library

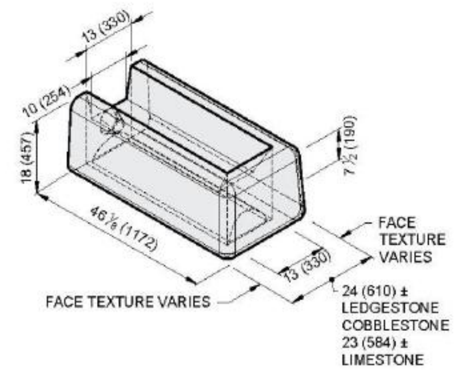
F-CM CORNER MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1370 lb (620 kg)	1360 lb (620 kg)
Block Volume:	9.6 ft^3 (0.27m^3)	9.5 ft^3 (0.27m^3)



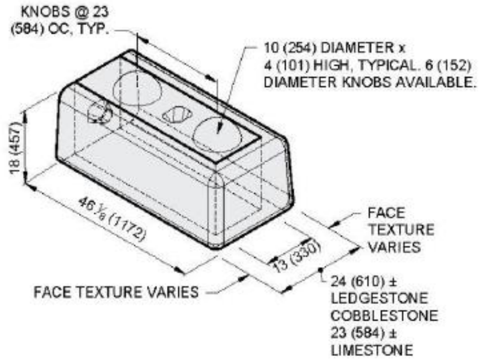
F-CG CORNER GARDEN TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1070 lb (480 kg)	1060 lb (480 kg)
Block Volume:	7.5 ft^3 (0.21m^3)	7.4 ft^3 (0.21m^3)



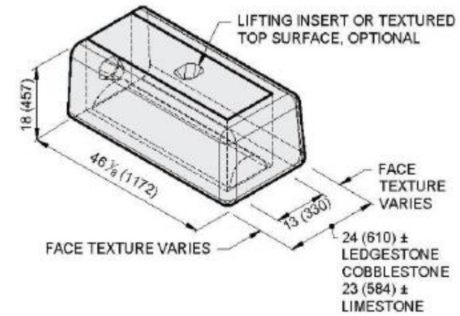
F-CB CORNER BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1490 lb (680 kg)	1480 lb (670 kg)
Block Volume:	10.4 ft^3 (0.30m^3)	10.3 ft^3 (0.29m^3)



F-CT CORNER TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1340 lb (610 kg)	1330 lb (600 kg)
Block Volume:	9.4 ft^3 (0.26m^3)	9.3 ft^3 (0.26m^3)



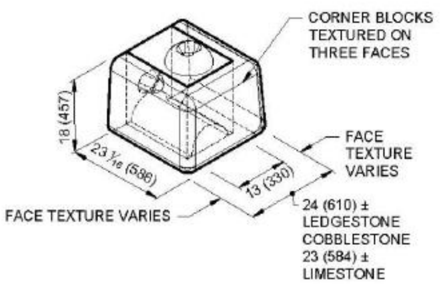
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Architectural faces on the blocks have varying texture.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291 kg/m^3).
6. Knobs are typically 10" (254mm) diameter by 4" (102 mm) tall. Smaller knobs are available.

FREESTANDING BLOCKS

Block Library

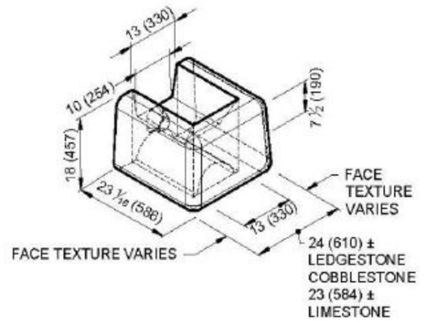
F-HCM HALF CORNER MIDDLE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	660 lb (300 kg)	650 lb (300 kg)
Block Volume:	4.6 ft^3 (0.13m^3)	4.6 ft^3 (0.13m^3)



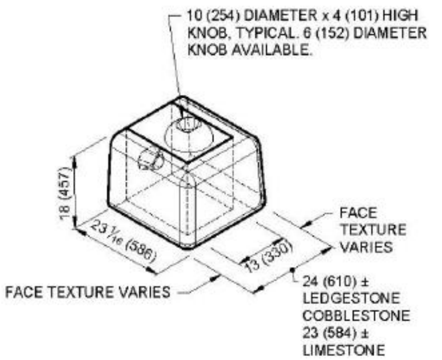
F-HCG HALF CORNER GARDEN TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	530 lb (240 kg)	530 lb (240 kg)
Block Volume:	3.7 ft^3 (0.11m^3)	3.7 ft^3 (0.10m^3)



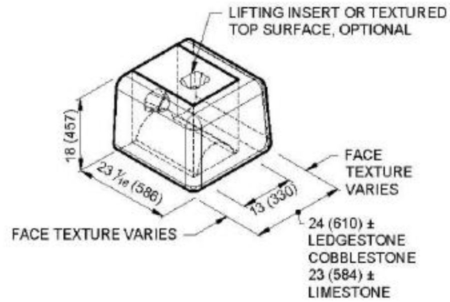
F-HCB HALF CORNER BOTTOM

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	710 lb (320 kg)	700 lb (320 kg)
Block Volume:	5.0 ft^3 (0.14m^3)	4.9 ft^3 (0.14m^3)



F-HCT HALF CORNER TOP

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	640 lb (290 kg)	630 lb (290 kg)
Block Volume:	4.5 ft^3 (0.13m^3)	4.4 ft^3 (0.13m^3)



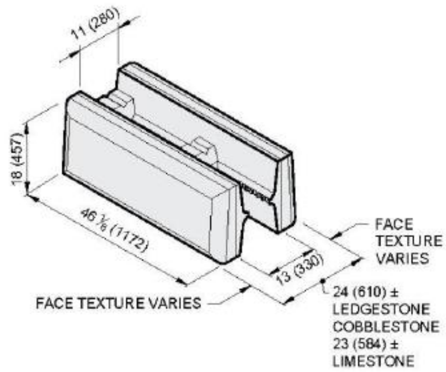
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Architectural faces on the blocks have varying texture.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291 kg/m^3).
6. Knobs are typically 10" (254mm) diameter by 4" (102 mm) tall. Smaller knobs are available.

FREESTANDING BLOCKS

Block Library

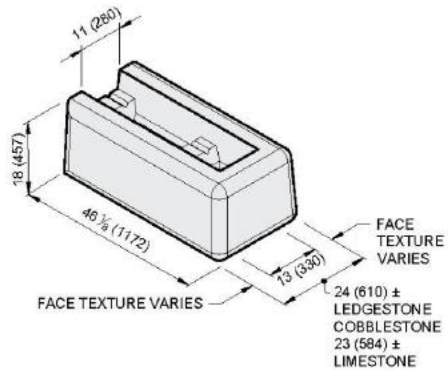
F-HC HOLLOW-CORE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	910 lb (410 kg)	770 lb (350 kg)
Block Volume:	6.38 ft³ (0.181 m³)	5.38 ft³ (0.152 m³)
Infill Volume:	4.09 ft³ (0.116 m³)	



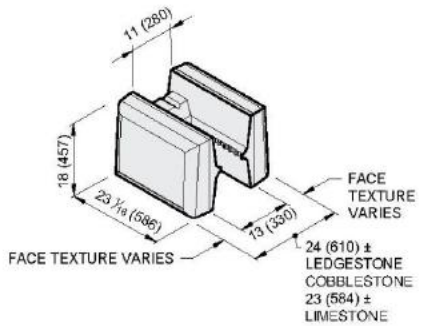
F-CHC CORNER HOLLOW-CORE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1000 lb (460 kg)	970 lb (440 kg)
Block Volume:	7.01 ft³ (0.198 m³)	6.80 ft³ (0.192 m³)
Infill Volume:	3.37 ft³ (0.095 m³)	



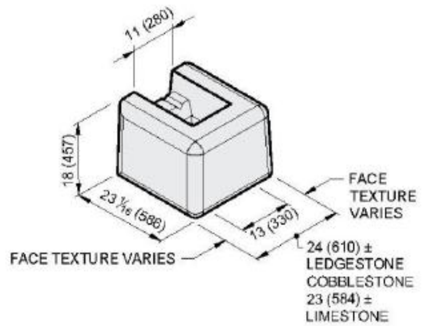
F-HHC HALF HOLLOW-CORE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	460 lb (210 kg)	390 lb (180 kg)
Block Volume:	3.19 ft³ (0.090 m³)	2.69 ft³ (0.076 m³)
Infill Volume:	2.04 ft³ (0.058 m³)	



F-HCHC HALF CORNER HOLLOW-CORE

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	550 lb (250 kg)	510 lb (230 kg)
Block Volume:	3.81 ft³ (0.108 m³)	3.53 ft³ (0.100 m³)
Infill Volume:	1.31 ft³ (0.037 m³)	



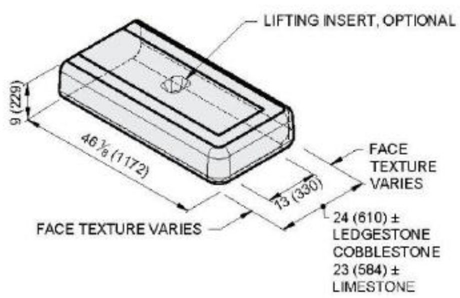
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Confirm block production with licensed Redi-Rock manufacturer.
3. Architectural faces on the blocks have varying texture.
4. Average block weights shown. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft³ (2291 kg/m³).

FREESTANDING BLOCKS

Block Library

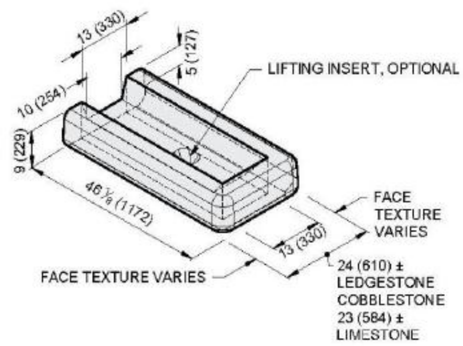
F-9SC 9" (230) STEPDOWN CORNER

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	740 lb (340 kg)	660 lb (300 kg)
Block Volume:	5.17 ft^3 (0.146 m^3)	4.60 ft^3 (0.130 m^3)



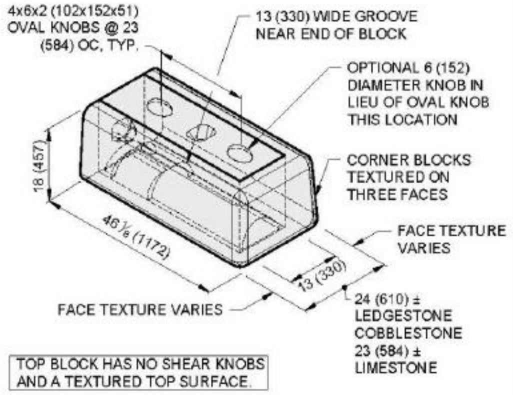
F-9SG 9" (230) STEPDOWN GARDEN

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	550 lb (250 kg)	470 lb (210 kg)
Block Volume:	3.86 ft^3 (0.109 m^3)	3.30 ft^3 (0.093 m^3)



F-90C 90 DEGREE CORNER

Face Texture:	Cobble / Limestone	Kingstone / Ledgestone
Block Weight:	1330 lb (600 kg)	1320 lb (600 kg)
Block Volume:	9.3 ft^3 (0.26m^3)	9.2 ft^3 (0.26m^3)



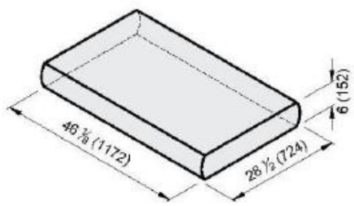
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Architectural faces on the blocks have varying texture.
4. Actual block volumes and weights may vary.
5. Weights are based upon a concrete density of 143 lb/ft^3 (2291 kg/m^3).

ACCESSORIES (CAP AND STEP BLOCKS)

Block Library

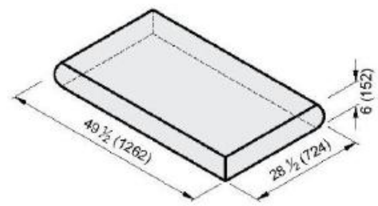
A-2SC TWO-SIDED

Block Weight:	630 lb (290 kg)
Block Volume:	4.42 ft³ (0.125 m³)



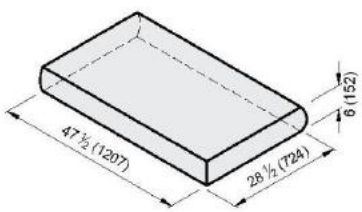
A-4SC FOUR-SIDED

Block Weight:	670 lb (300 kg)
Block Volume:	4.65 ft³ (0.132 m³)



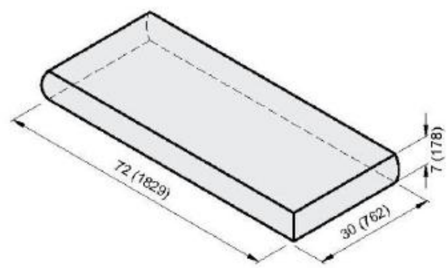
A-3SC THREE-SIDED

Block Weight:	660 lb (300 kg)
Block Volume:	4.59 ft³ (0.130 m³)



A-3S72 THREE-SIDED STEP 72"

Block Weight:	1,230 lb (560 kg)
Block Volume:	8.58 ft³ (0.243 m³)



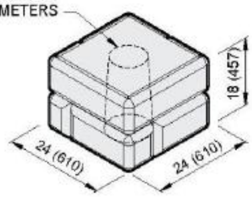
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Actual block volumes and weights may vary.
4. Weights are based upon a concrete density of 143 lb/ft³ (2291 kg/m³).

ACCESSORIES (COLUMN BLOCKS)

Block Library

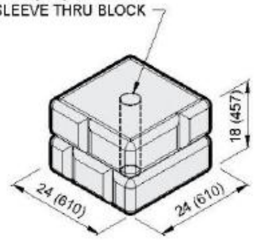
A-COL8 COLUMN - 8" (203mm) CORE

Block Weight:	730 lb (330 kg)
Block Volume:	5.1 ft^3 (0.14 m^3)



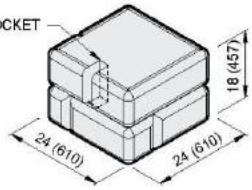
A-COL4 COLUMN - 4" (102mm) CORE

Block Weight:	810 lb (370 kg)
Block Volume:	5.6 ft^3 (0.16 m^3)



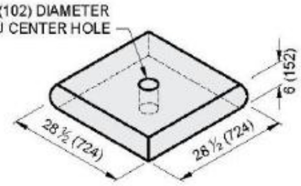
A-COLS COLUMN - SOLID CORE

Block Weight:	830 lb (380 kg)
Block Volume:	5.8 ft^3 (0.16 m^3)



A-CC COLUMN CAP

Block Weight:	390 lb (180 kg)
Block Volume:	2.7 ft^3 (0.08 m^3)



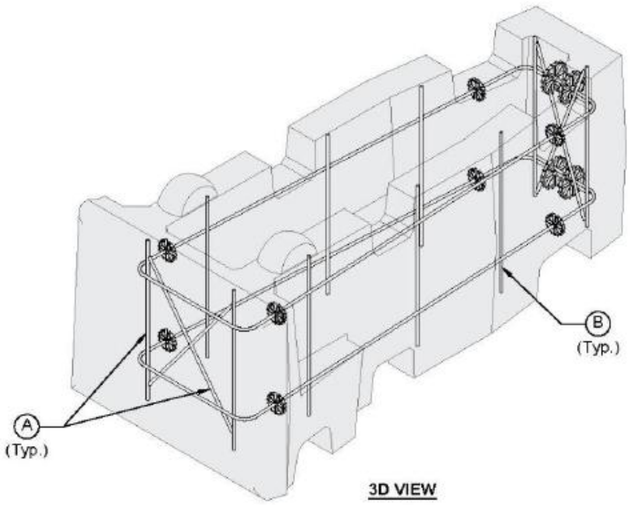
1. Units for dimensions are inches (mm), typical unless noted otherwise.
2. Block production varies with each licensed Redi-Rock manufacturer. Confirm availability before Specifying or Ordering.
3. Actual block volumes and weights may vary.
4. Weights are based upon a concrete density of 143 lb/ft^3 (2291 kg/m^3).
5. Weight and volume ranges represents the blocks with the maximum hole size shown and with no hole.
6. Optional fence rail pockets available upon request. Typical pocket size is: 2 (50) wide x 5 (130) deep x 9 (230) tall.

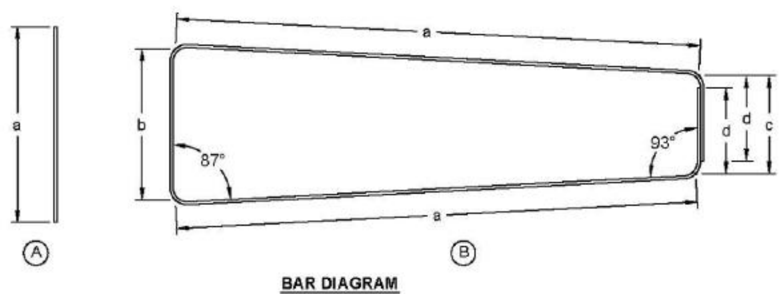
APPENDIX: 1.1.5B XL REINFORCING

RETAINING BLOCKS

Reinforcing Steel

R-9636HC 96" (2,440 mm) Hollow Core Retaining Block





BAR SCHEDULE

BAR*	DIMENSIONS				LENGTH/BAR	NO. BARS	TOTAL LENGTH
	a	b	c	d			
(A)	2'-8" (813 mm)				2'-8" (0.81 m)	14	37'-4" (11.38 m)
(B)**	7'-1½" (2172 mm)	2'-0¾" (629 mm)	1'-4" (406 mm)	1'-2" (356 mm)	18'-8" (5.69 m)	2	37'-4" (11.38 m)
						TOTAL:	74'-8" (22.76 m)

*All bars #4, ASTM A615 or A706 Grade 60 (13 mm, 420 mPa)

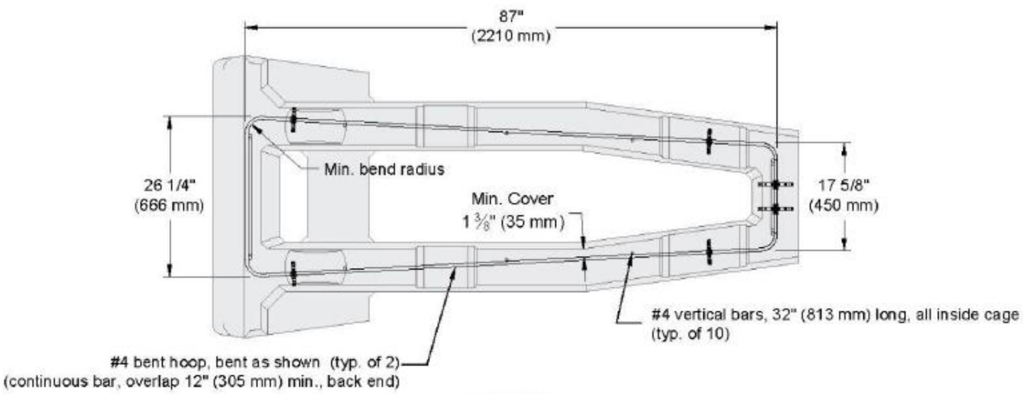
**Bar (B) may be supplied in two parts, with a lap splice along the front dimension, "b". Minimum lap splice length is 12 inches (305 mm).

1 OF 2

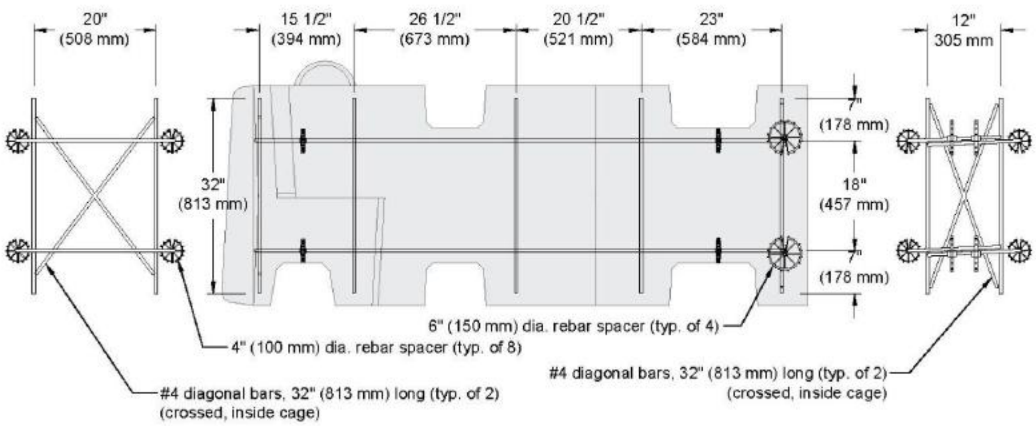
RETAINING BLOCKS

Reinforcing Steel

R-9636HC 96" (2,440 mm) Hollow Core Retaining Block



TOP VIEW



FRONT VIEW SIDE VIEW BACK VIEW

Notes:

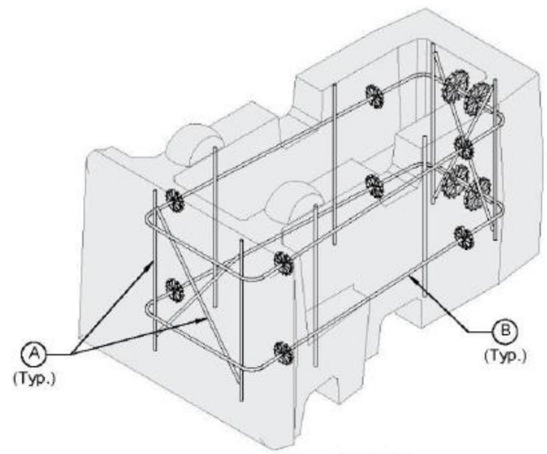
1. All bar shall comply with ASTM A615 or A706, Grade 60 (13 mm, 420 MPa).
2. Secure all bar intersections.
3. Maintain concrete cover of no less than 1 inch (25 mm) over all reinforcing steel. Actual cover varies.

2 OF 2

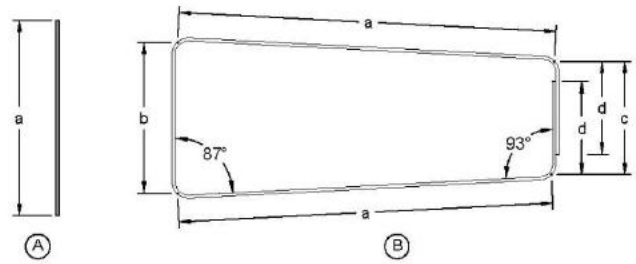
RETAINING BLOCKS

Reinforcing Steel

R-7236HC 72" (1,830 mm) Hollow Core Retaining Block



3D VIEW



BAR DIAGRAM

BAR SCHEDULE

BAR*	DIMENSIONS				LENGTH/BAR	NO. BARS	TOTAL LENGTH
	a	b	c	d			
(A)	2'-8" (813 mm)				2'-8" (0.81 m)	12	32'-0" (9.75 m)
(B)	5'-1½" (1562 mm)	2'-0¾" (629 mm)	1'-6½" (470 mm)	1'-3¼" (387 mm)	14'-10" (4.52 m)	2	29'-8" (9.04 m)
						TOTAL:	61'-8" (18.79 m)

*All bars #4, ASTM A615 or A706 Grade 60 (13 mm, 420 mPa)

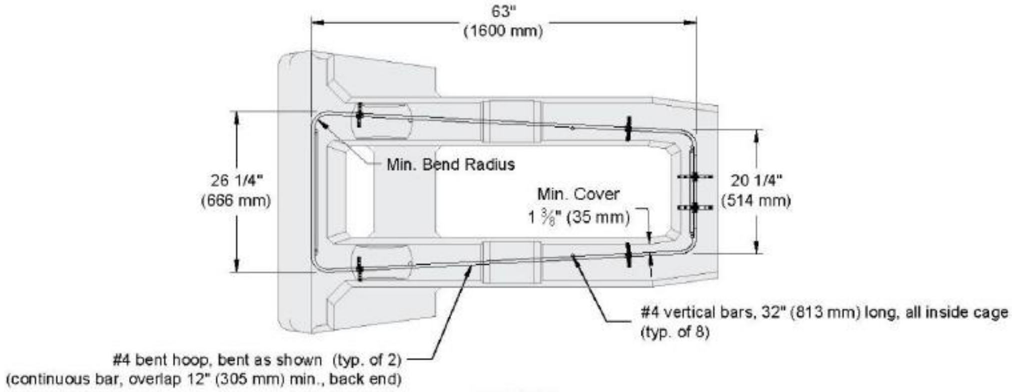
**Bar (B) may be supplied in two parts, with a lap splice along the front dimension, "b". Minimum lap splice length is 12 inches (305 mm).

1 OF 2

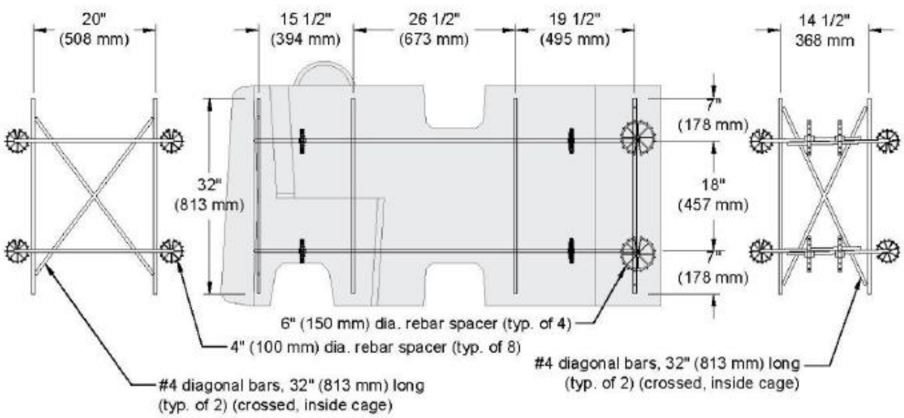
RETAINING BLOCKS

Reinforcing Steel

R-7236HC 72" (1,830 mm) Hollow Core Retaining Block



TOP VIEW



FRONT VIEW SIDE VIEW BACK VIEW

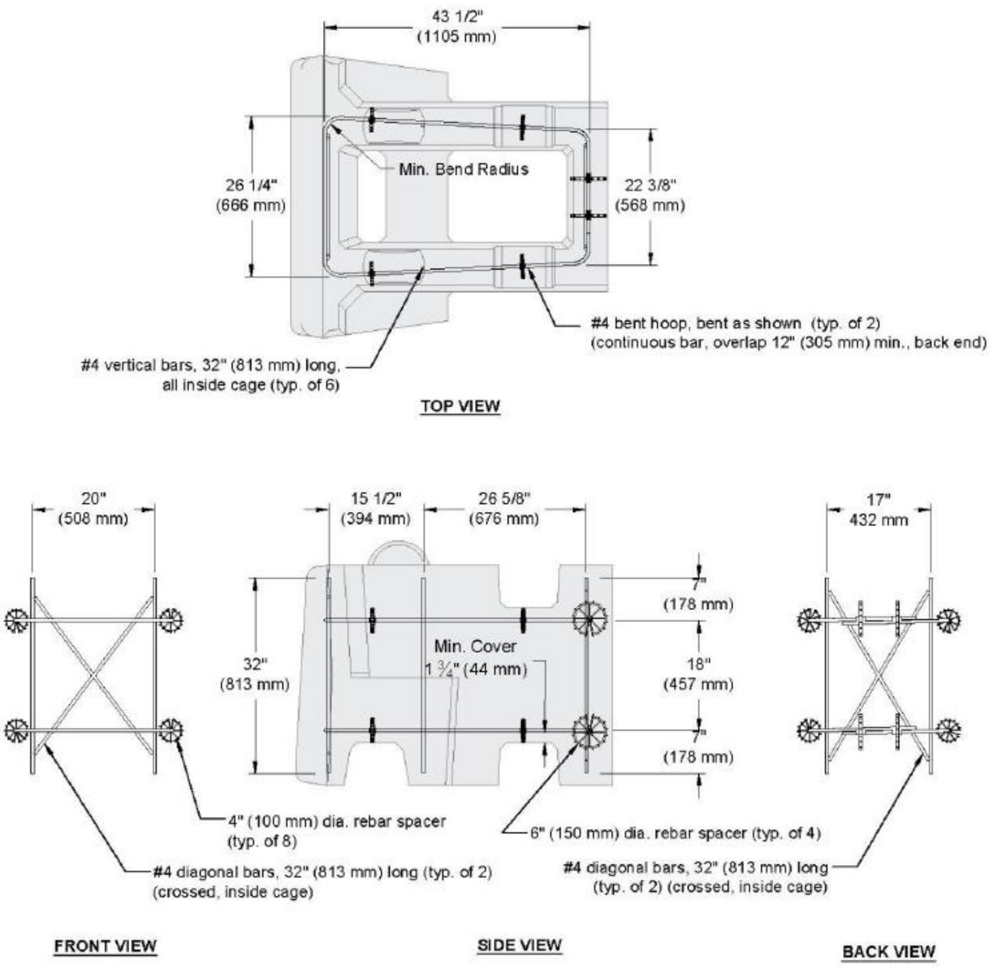
Notes:
1. All bar shall comply with ASTM A615 or A706, Grade 60 (13 mm, 420 MPa).
2. Secure all bar intersections.
3. Maintain concrete cover of no less than 1 inch (25 mm) over all reinforcing steel. Actual cover varies.

2 OF 2

RETAINING BLOCKS

Reinforcing Steel

R-5236HC 52" (1,320 mm) Hollow Core Retaining Block



Notes:

1. All bar shall comply with ASTM A615 or A706, Grade 60 (13 mm, 420 MPa).
2. Secure all bar intersections.
3. Maintain concrete cover of no less than 1 inch (25 mm) over all reinforcing steel. Actual cover varies.

2 OF 2

Reinforcement calculations for Redi-Rock XL Units

Overview

Redi-Rock XL units are 36” (0.91 m) high and 46 1/8” (1.17 m) long, hollow-core, precast modular block retaining wall units. They are constructed in 52” (1.32 m), 72” (1.83 m), and 96” (2.44 m) widths. XL units are shown in Figure 1.

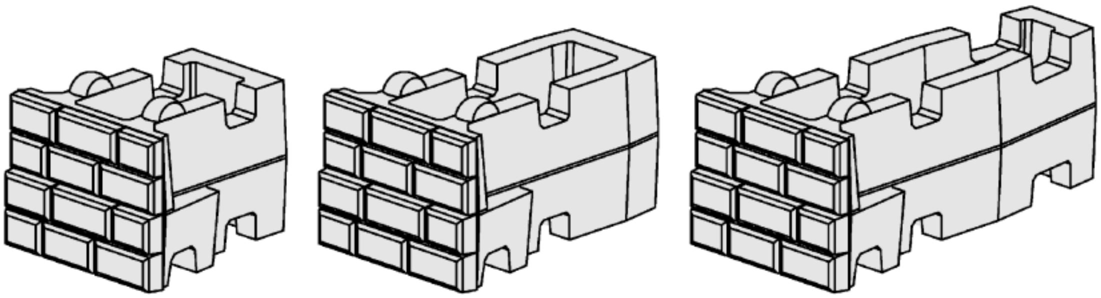


Fig. 1. Redi-Rock XL units.

XL units are reinforced with a light cage of reinforcement made from #4 A615 Grade 60 rebar. The reinforcement cage for XL units is shown in Figure 2.

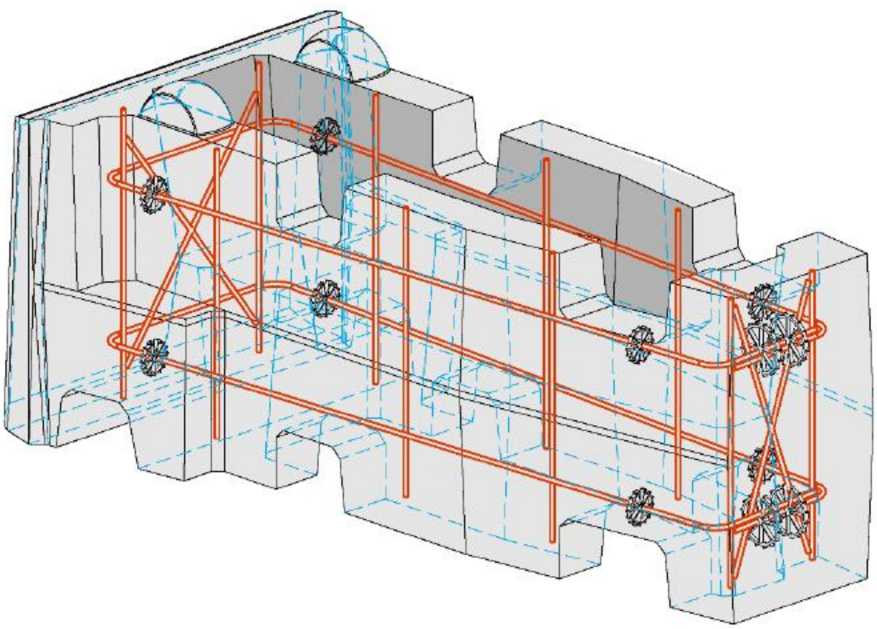


Fig. 2. Reinforcement cage for Redi-Rock XL units.

Reinforcement Calculations

First, a check is made of the reinforcement requirements to resist bin pressure from the infill stone placed in the core of the XL unit. Stone is placed in the cores and between units and retained soil is placed on the back of the units. As such, the pressure from the infilled stone is balanced on the sides and back of the units, leaving only the front face of the unit to evaluate. An isometric view and top view of the front face subject to flexure is shown in Figures 3 and 4.

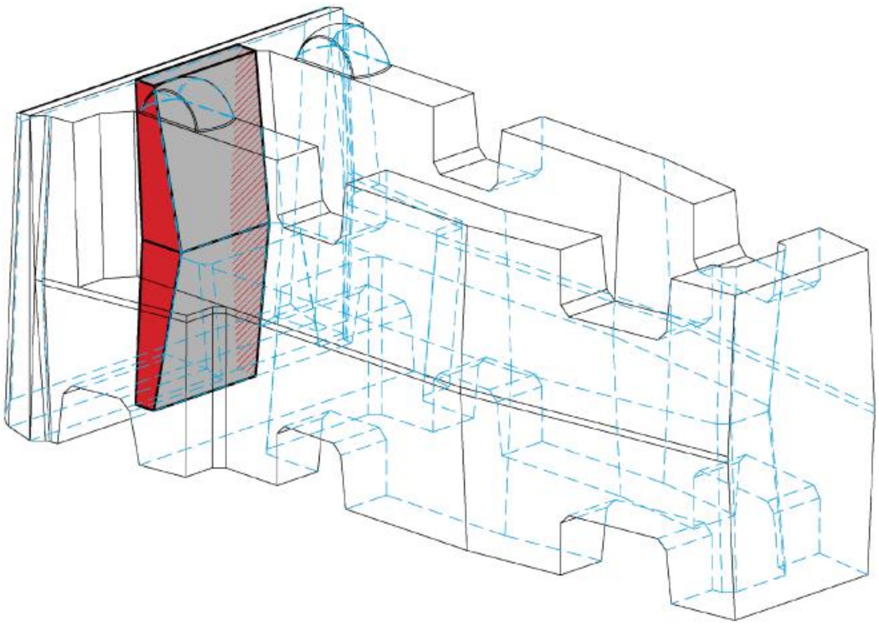


Fig. 3. Isometric view of front face subject to flexure.

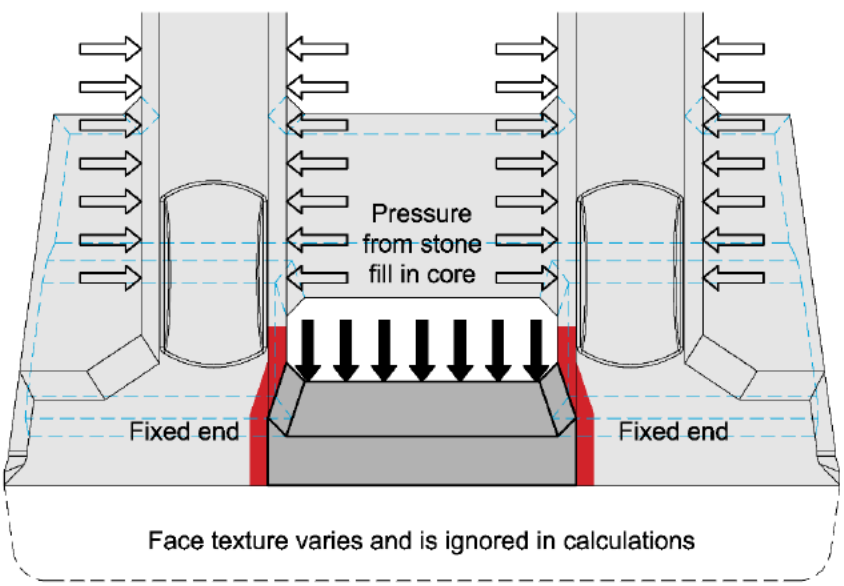


Fig. 4. Top view of front face subject to flexure.

The center portion of the front face is subject to unbalanced pressure from the infill stone. It can be assumed to behave like a fixed-fixed beam with loading, shear, and bending moment diagrams as shown in Figure 5.

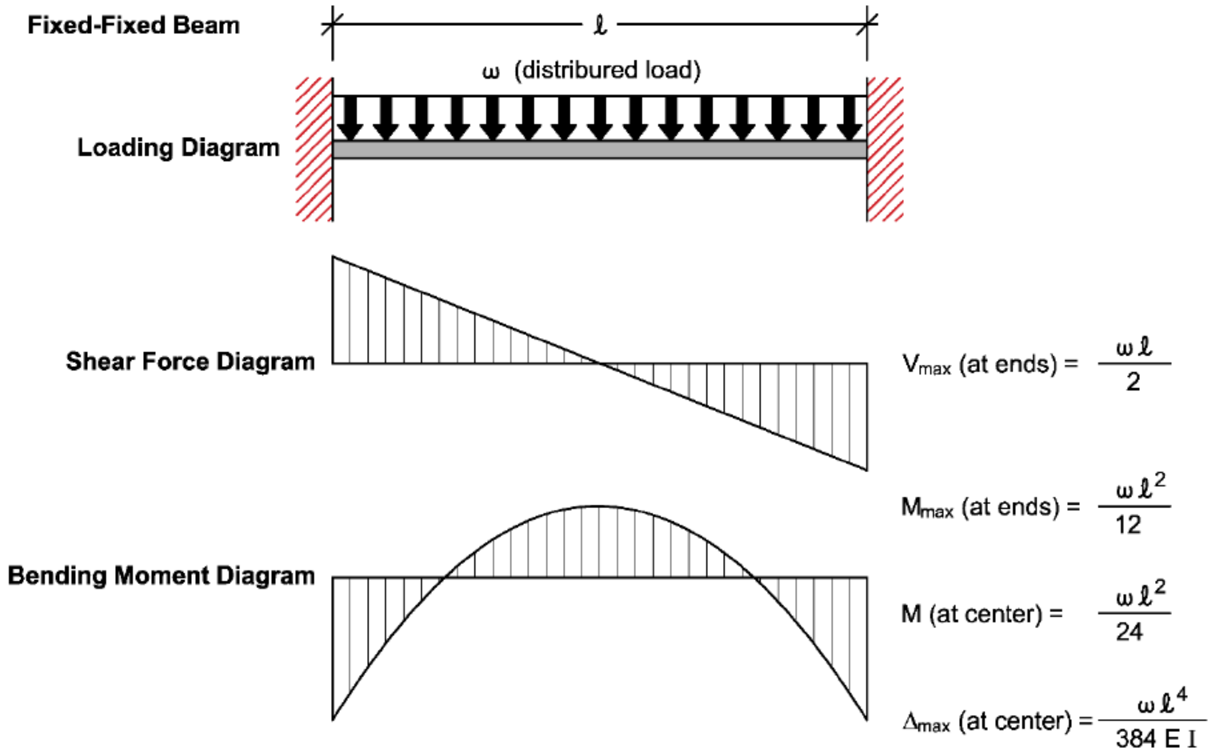


Fig. 5. Beam diagrams for a fixed-fixed beam.

The cross-section of the unsupported front face is shown in Figure 6.

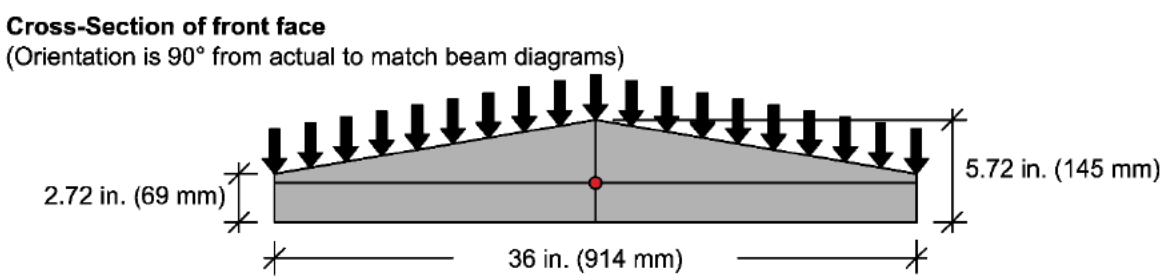


Fig. 6. Cross-section of the front face.

The centroid, area moment of inertia, and elastic section modulus of the unsupported front face are shown in Figure 7.

Centroid

$$\bar{y} = \frac{\Sigma A_i y_i}{\Sigma A_i} = \frac{(2.72 \times 36)(2.72 / 2) + (0.5 \times 3.00 \times 36)(2.72 + 3.00 / 3)}{(2.72 \times 36) + (0.5 \times 3.00 \times 36)}$$

= 2.20 in. (measured from the bottom of the rectangle which is the side in tension)

Area Moment of Inertia

$$I = \Sigma (I_i + A_i d_i^2) = \frac{(36)(2.72)^3}{12} + (97.92)(2.20 - 1.36)^2 + \frac{(36)(3.00)^3}{36} + (54.00)(2.72 + 1.00 - 2.20)^2 = 281.2 \text{ in}^4$$

Elastic Section Modulus

$$S = \frac{I}{\bar{y}} = \frac{281.2}{2.20} = 127.8 \text{ in}^3$$

Fig. 7. Centroid, area moment of inertia, and elastic section modulus of the front face.

The maximum bending moment on the front face from the infill stone is calculated as follows:

γ_{infill} = 100 lb / ft^3

k_0 = 0.5 (at-rest earth pressure coefficient)

Pressure from Infill Stone at bottom of 30 ft tall wall, P_{Infill} = (30) (100) (0.5) = 1,500 lb / ft^2
Force on inside of front face of 3 ft tall XL block, F_{Infill} = (3) (1,500) = 4,500 lb / ft = 375 lb / in

Load Factor, $\gamma_{p\,max}$ = 1.35 AASHTO (2020) Table 3.4.1-2 (EH, at-rest earth pressure)

The average width of the unsupported span of the inside of the front face = 15 in.

$$M_u = 1.35 \frac{w\, l^2}{12} = 1.35 \frac{(375)\,(15)^2}{12} = 9{,}492 \text{ lb. - in.}$$

The maximum resisting to bending of the front face is calculated as follows:

Reduction factor, ϕ = 0.6 ACI 318 9.3.5
Modification factor, λ = 1.0 ACI 318 8.6.1

$\phi M_n = (0.6)\,(5\,\lambda \sqrt{f'_c}\;S)$ ACI 318 (22-2)

$\phi M_n = (0.6)\,(5)\,(1.0)\,(\sqrt{4000})\;(127.8) = 24{,}248 \text{ lb} \bullet \text{in}$

Since the factored resistance to bending is greater than the maximum bending moment ($\varphi M_n > M_u$), steel reinforcement is not needed to resist bending in the unsupported front face.

Second, a check is made of the reinforcement requirements to maintain structural integrity of the block subject to bending from front to back of the block. Properly installed XL blocks are completely supported over their entire surface area by the blocks and infill stone below. However, there is the possibility that block manufacturing tolerances or post-construction settlement can produce unsupported portions of a block, causing point loading which may lead to block cracking in bending.

The maximum amount of unsupported gap for any particular unit should be less than or equal 0.375 in. (10 mm). This value is twice the maximum block height tolerance and could occur if a XL unit is resting on two blocks below that were at the maximum and minimum allowable heights. The worst case scenario would occur if the block is resting on high points in the front and the back. A side view and critical cross-section of the worst case is shown in Figure 8.

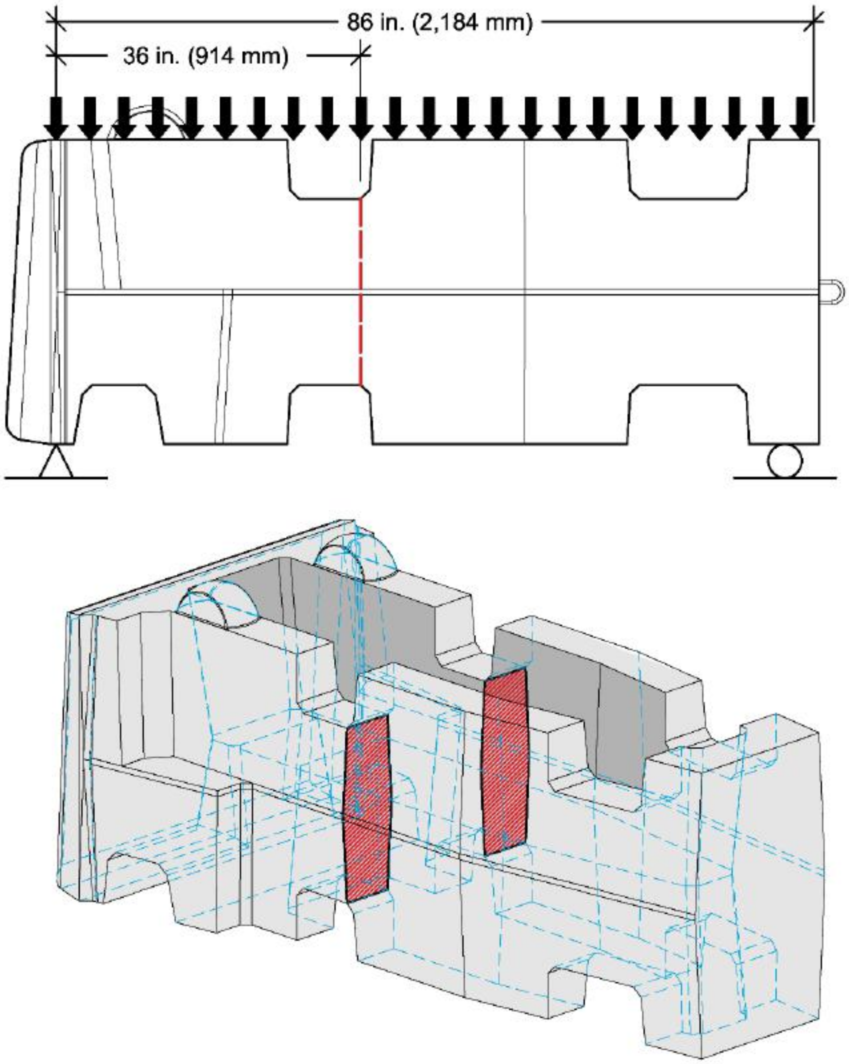


Fig. 8. Side view and critical cross-section of worst case.

The worst case scenario can be assumed to behave like a simply-supported beam with loading, shear, and bending moment diagrams as shown in Figure 9.

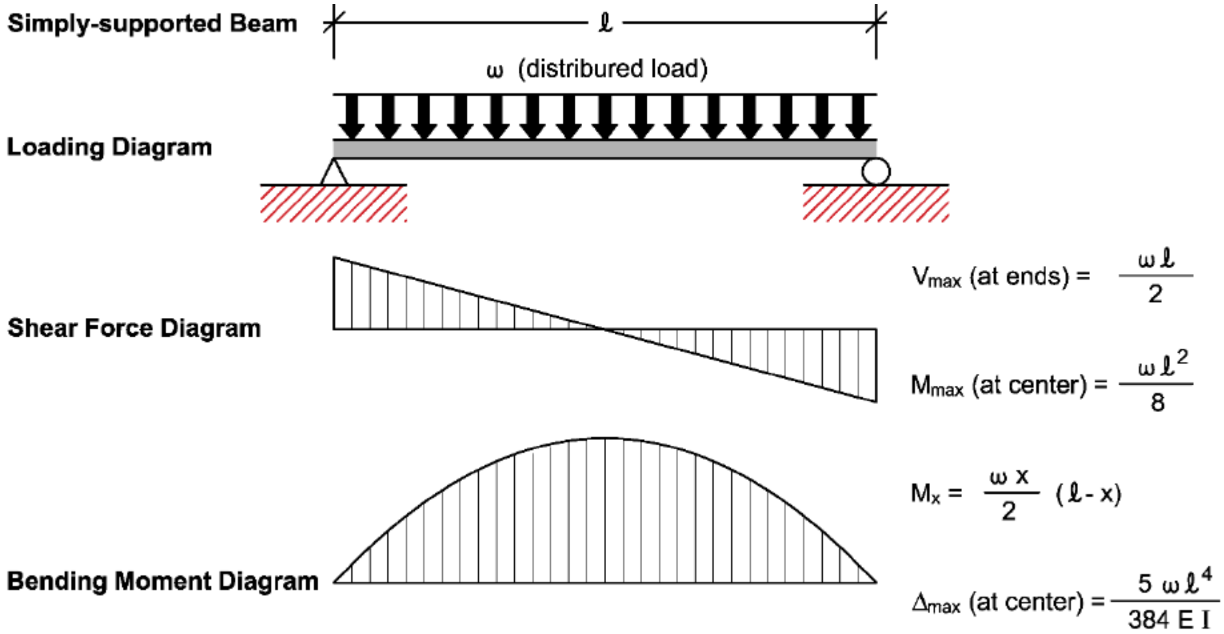


Fig. 9. Beam diagrams for a simply-supported beam.

The critical cross-section in shown in Figure 10.

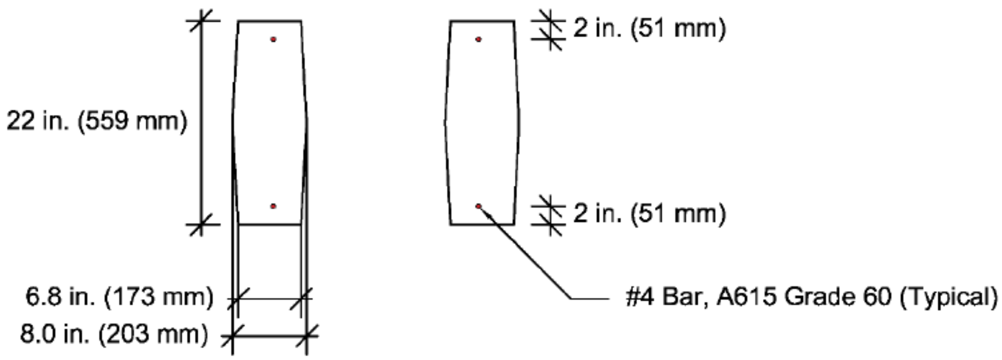


Fig. 10. Critical cross-section.

The moment capacity of two reinforced beams (one for each leg of the block) can be calculated and used to determine the height of the wall where it would be possible for the first yield to occur. The calculations are as follows:

$A_s = 0.20\ in^2$ (each leg)
$f_y = 60{,}000$ psi
$b \approx 7$ in (for analysis)

$$a = \frac{A_s\ f_y}{0.85\ f'_c\ b} = \frac{0.20 \times 60{,}000}{0.85 \times 4{,}000 \times 7} = 0.50 \text{ in.}$$

$$M_y = 2\ [\ A_s\ f_y\ (d - a/2)\ ] = 2\ [\ 0.20 \times 60{,}000\ (20 - 0.50/2)\ ] = 474{,}000 \text{ lb} \bullet \text{in}$$

Set maximum bending moment equal to moment capacity and solve for load where first yield could occur:

$$M_x = M_y \qquad \frac{\omega\ x}{2}\ (\ell - x) = M_y \qquad \frac{\omega\ 36}{2}\ (86 - 36) = 474{,}000 \qquad \omega = 527 \text{ lb / in} = 6{,}320 \text{ lb / ft}$$

Use design infilled weight of XL blocks to calculate height where first yield could occur:

Design infilled unit weight of wall, $\gamma_{wall} = 112$ lb /ft^3 (includes infill stone and concrete blocks)

$$\omega = \gamma_{wall} \times \text{Width} \times H \qquad 6{,}320 = 112 \times 8.0 \times H \qquad H = 7.0 \text{ ft.}$$

Full scale lab testing of XL blocks was performed at the Aster Brands test laboratory in Charlevoix, Michigan. The test setup is shown Figure 11. Results of testing on an unreinforced block is shown in Figure 12. Results of testing on a reinforced block is shown in Figure 13.

Fig. 11. Setup for flexural testing of R-9636HC XL blocks.

Fig 12. Results of testing on an unreinforced block.

Fig. 13. Results of testing on a block reinforced with the specified cage for XL blocks.

The test setup utilized a point load instead of a uniform load shown above. The calculated load that would produce the first yield is 22,046 lb. Three tests were run with measured values of 21,693 lb, 22,150 lb, and 23,910. The average value of all three tests was within 2.4% of the calculated load. Failure occurred at the critical cross-section in all tests. After the blocks cracked, the XL blocks continued to sustain increasing load and ultimate failure was only reached after 1.5 inches (38 mm) or more of deflection. Load-deflection curves for the three tests are shown in Figure 14 and a close-up view of the load-deflection curves at first yield is shown in Figure 15. Maximum settlement of XL blocks in the field should be limited to a maximum of about 0.375 inch (10 mm) after which point the blocks will no longer be unsupported.

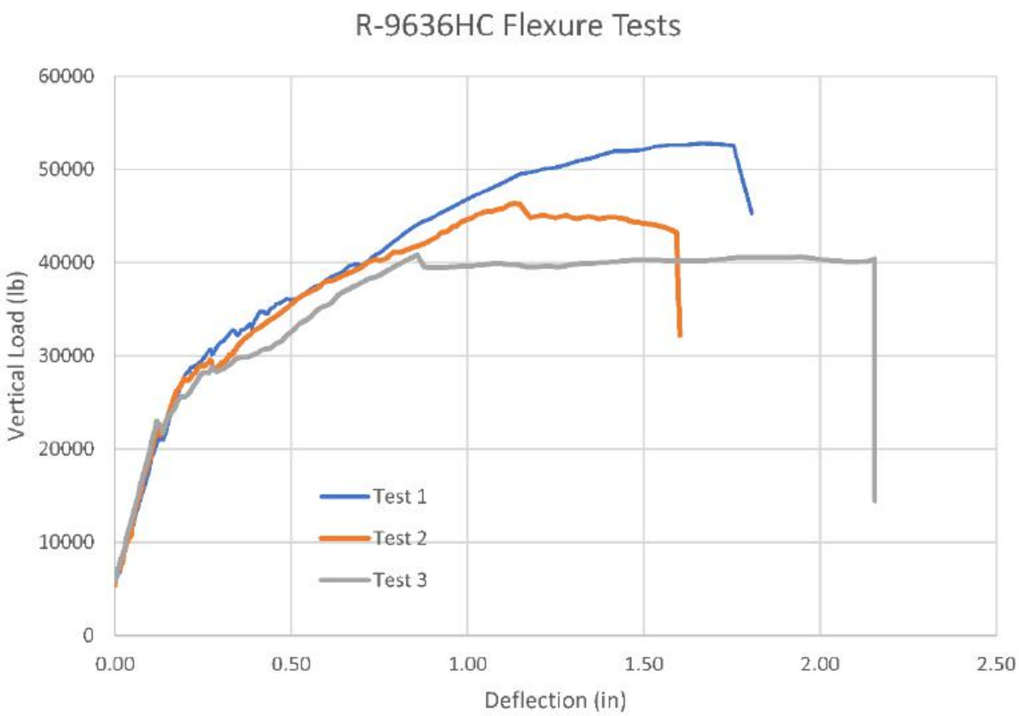


Fig. 14. Load-deflection curves from flexure tests in the Aster Brands Laboratory.

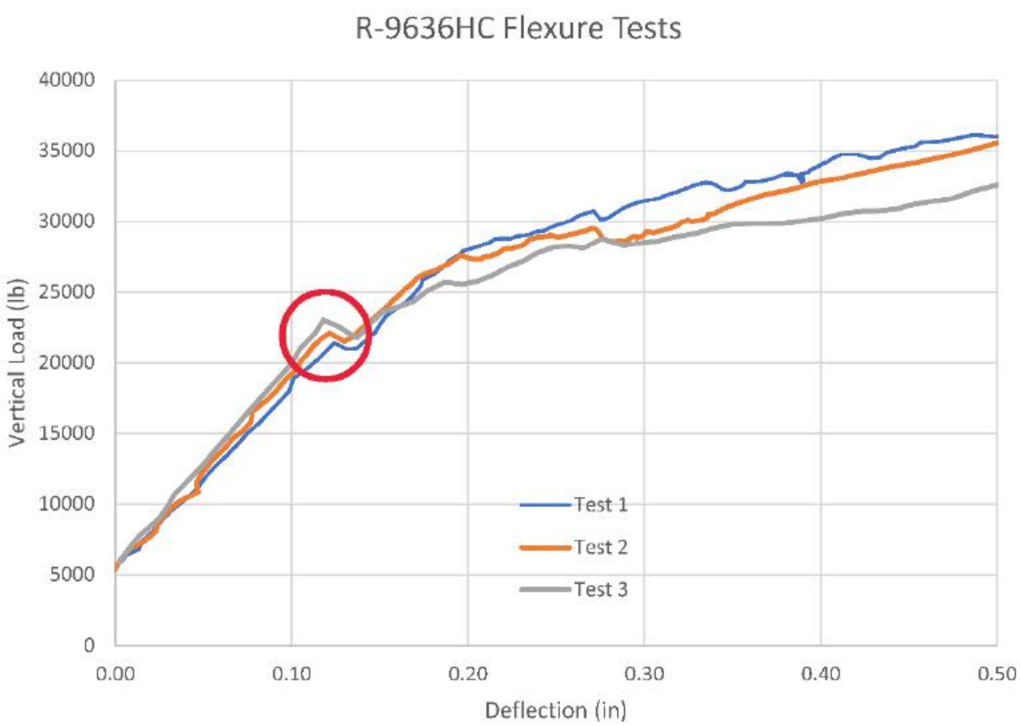


Fig. 15. Close-up view of the load-deflection curves at first yield.

Reinforcement is REQUIRED in Redi-Rock XL blocks to maintain block integrity in the event that manufacturing tolerances, construction tolerances, or post-construction settlement produce point loading and block cracking.

The reinforcement cage as detailed demonstrates adequate capacity through full-scale lab testing to maintain block integrity throughout the entire range of anticipated settlement of cracked XL blocks.

APPENDIX: 1.1.10 UNIT-UNIT INTERFACE SHEAR TEST REPORTS

REDI-ROCK

INTERFACE SHEAR DESIGN PARAMETERS

05481 US 31 SOUTH • CHARLEVOIX, MI 49720 • 866-222-8400 • WWW.REDI-ROCK.COM

Test Methods: ASTM D6916 & NCMA SRWU-2
Block Type: 28" Positive Connection (PC) Block

Test Facility: Bathurst, Clarabut Geotechnical Testing, Inc.
Test Dates: 10/21/2011 - 6.75" Shear Knob Test
10/14/2011 - 10" Shear Knob Test

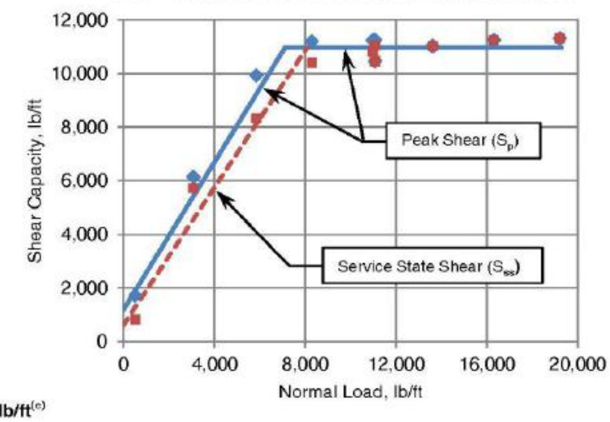
6.75" KNOB INTERFACE SHEAR DATA[a]

Test No.	Normal Load, lb/ft	Service State Shear, lb/ft[c]	Peak Shear, lb/ft	Observed Failure[d]
1	522	838	1,724	Test Stopped
2	19,209	11,324	11,324	Test Stopped
3	16,303	11,252	11,252	Test Stopped
4	13,612	11,036	11,036	Test Stopped
5	11,075	10,462	10,462	Test Stopped
6	11,074	11,060	11,252	Knob Shear
7	8,299	10,408	11,204	Test Stopped
8	5,854	8,337	9,935	Knob Shear
9	3,077	5,722	6,153	Knob Shear
10	10,981	10,821	11,252	Knob Shear

Peak Shear: $S_p = 1{,}178 + N \tan 54°$, $S_{p(max)} = 10{,}970$ **lb/ft**[e]

Service State Shear: $S_{ss} = 616 + N \tan 52°$, $S_{ss(max)} = 10{,}970$ **lb/ft**[e]

6.75" KNOB INTERFACE SHEAR CAPACITY



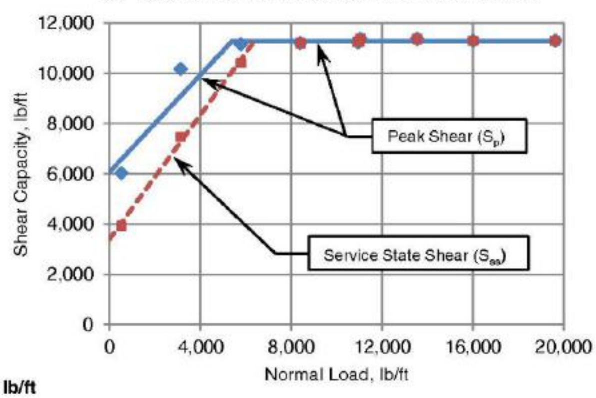
10" KNOB INTERFACE SHEAR DATA[b]

Test No.	Normal Load, lb/ft	Service State Shear, lb/ft[c]	Peak Shear, lb/ft	Observed Failure[d]
1	19,619	11,300	11,300	Test Stopped
2	16,007	11,300	11,300	Test Stopped
3	13,546	11,371	11,371	Test Stopped
4	11,042	11,371	11,371	Test Stopped
5	8,400	11,204	11,204	Test Stopped
6	10,999	11,252	11,252	Test Stopped
7	10,922	11,252	11,252	Test Stopped
8	5,786	10,414	11,156	Test Stopped
9	3,137	7,469	10,174	Test Stopped
10	522	3,926	6,033	Test Stopped

Peak Shear: $S_p = 6{,}061 + N \tan 44°$, $S_{p(max)} = 11{,}276$ **lb/ft**

Service State Shear: $S_{ss} = 3{,}390 + N \tan 51°$, $S_{ss(max)} = 11{,}276$ **lb/ft**

10" KNOB INTERFACE SHEAR CAPACITY



(a) The maximum 28-day compressive strength of all concrete blocks tested in the 6.75 inch knob interface shear test series was 4,694 psi.
(b) The 28-day compressive strength of all concrete blocks tested in the 10 inch knob interface shear test series was 4,474 psi.
(c) Service State Shear is measured at a horizontal displacement equal to 2% of the block height. For Redi-Rock blocks, displacement = 0.36 inches.
(d) In most cases, the test was stopped before block rupture or knob shear occured to prevent damage to the test apparatus.
(e) Design shear capacity inferred from the test data reported herein should be lowered when test failure results from block rupture or knob shear if the compressive strength of the blocks used in design is less than the blocks used in this test. The data reported represents the actual laboratory test results. The equations for peak and service state shear conditions have been modified to reflect the interface shear performance of concrete with a minimum 28-day compressive strength equal to 4,000 psi. No further adjustments have been made. Appropriate factors of safety for design should be added.

The information contained in this report has been compiled by Redi-Rock International, LLC as a recommendation of peak interface shear capacity. It is accurate to the best of our knowledge as of the date of its issue. However, final determination of the suitability of any design information and the appropriateness of this data for a given design purpose is the sole responsibility of the user. No warranty of performance is expressed or implied by the publishing of the foregoing laboratory test results. Issue date: February 21, 2012.

REPORT

RESULTS OF

REDI-ROCK 28 INCH PC BLOCK UNIT

(6 INCH DOME)

INTERFACE SHEAR CAPACITY TESTING

submitted to

REDI-ROCK INTERNATIONAL

CONFIDENTIAL

Distribution:

2 copies Redi-Rock International LLC.
05481 US 31 South
Charlevoix, Michigan 49720
USA

2 copies Bathurst, Clarabut Geotechnical Testing, Inc.
1167 Clyde Court, Kingston, Ontario
K7P 2E4 CANADA

Introduction

This report gives the results of an interface shear testing program carried out to evaluate the mechanical/frictional performance of the shear capacity between Redi-Rock® 28 inch PC modular concrete block units.

The test program was initiated in response to a verbal authorization to proceed from Mr. Jamie Johnson of Redi-Rock International, LLC received 9 August 2011.

The tests were carried out at the laboratories of Bathurst, Clarabut Geotechnical Testing, Inc. in Kingston, Ontario, under the supervision of Mr. Peter Clarabut.

Objectives of test program

The interface shear capacity between Redi-Rock 28 inch PC block units (6 inch dome) was investigated using a large-scale test apparatus.

The principal objective of the testing was to evaluate the mechanical/frictional performance of the shear capacity between successive layers of Redi-Rock block units. A second objective was to make recommendations for the selection of interface shear capacities to be used in the design and analysis of retaining wall systems that employ Redi-Rock block units.

Materials

Redi-Rock 28 inch PC Middle Block units are solid concrete blocks weighing approximately 1540 lb per unit (estimated weight based on volume of concrete and assuming a concrete unit weight of 143 lb/ft^3). The nominal dimensions of the block are 28 inches (toe to heel) by 18 inches high by 46 inches long. Construction alignment and interface shear is achieved by means of two 6.75 inch (6 inch) diameter dome shaped concrete shear keys cast into the top surface of the units. A photograph of the dome shaped shear key is shown in **Figure 1**. A photograph of the block system in the large scale test frame is shown in **Figure 2** The blocks used in this series of tests were supplied by Redi-Rock International and were received at our laboratory on 9 August 2011. The specific blocks used in each test are reported on **Table 1**.

Apparatus and general test procedure

The SRWU-2 method of test as reported in the NCMA Segmental Retaining Wall Design Manual (1993) and ASTM D 6916-03 were used in this investigation. A brief description of the apparatus and test methodology is presented here. The test apparatus allows horizontal loads in excess of 12,000 lb/ft to be applied across the interface between two block layers. The segmental units were laterally restrained at the bottom and surcharged vertically. Wall heights were simulated by placing a single block over the interface and applying additional normal load using the hydraulic ram arrangement shown in **Figure 1**. The horizontal (shear) force was applied at a constant rate of displacement using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and displacement transducers were recorded continuously during the test by a microcomputer/data acquisition system. Each test was continued until the safe working limit of the apparatus was reached or block dialation/ rotation occured. Following each test, the blocks were removed and the units examined to confirm failure modes (if any).

The only variable in this series of connection tests was the magnitude of surcharge load.

Test results

Results of interface shear tests are summarized in **Table 1**. Peak interface shear capacities and shear capacity at the displacement criterion (if achieved) are plotted against normal load in **Figure 4**. The displacement criterion was calculated to be 0.36 inches based on 2% of the block height. The minimum *peak* shear capacity recorded from the test series was 6153 lb/ft. **Test 1** was stopped after significant block dilation and some column rotation was observed. **Tests 2, 3, 4, 5** and **7** were stopped before failure of the blocks occurred in order to prevent damage to the test apparatus. **Tests 6, 8, 9** and **10** ended in shearing of the concrete shear dome. In **Tests 2, 3, 4** and **5** measured peak shear capacity was achieved before 0.36 inches of displacement.

Implications to interface shear capacity design and construction with Redi-Rock 28 inch PC block units

The maximum shear capacity values for **Tests 2, 3, 4, 5** and **7** reported herein are conservative estimates of the peak shear capacity of the Redi-Rock block system because the safe working capacity of the test apparatus was exceeded. Hence, the use of the maximum shear capacity values reported herein will result in an unquantified additional margin of safety for the nominal identical system in the field. The NCMA Segmental Retaining Wall Design Manual (First Edition, 1993) recommends that the design shear capacity at a given normal load for a critical wall structure be the lesser of: a) the peak capacity divided by a minimum factor of safety (not less than 1.5) or; b) the capacity based on the 0.36 inch displacement criterion. Nevertheless, the design shear capacity envelope inferred from the test data reported herein should be used with caution. The actual design capacity envelope should be lower if the quality of construction in the field is less than that adopted in this controlled laboratory investigation and/or lower quality concrete is used in the manufacture of the blocks. In addition, the interface concrete surfaces should be free of aggregate particles in order to maximize the frictional resistance that is developed between the concrete surfaces.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional performance of the shear capacity between Redi-Rock 28 inch PC block segmental concrete units. The following conclusions can be drawn:

1. The minimum *peak* shear capacity recorded from this test series was 6153 lb/ft (height above interface equal to approximately 1 block unit).

2. Care must be taken during the installation of Redi-Rock block units in order to prevent accumulation of soil and rock debris at the concrete block interface surfaces. This debris may significantly reduce the shear capacity of the Redi-Rock block facing unit system.
3. The actual peak shear capacity of the Redi – Rock 28 inch PC block system may be expected to be greater than the values reported herein since the safe working capacity of the test apparatus was exceeded before shear failure of the blocks could be achieved.

Concluding remarks

The test results presented here are applicable to gravity and geosynthetic reinforced-soil segmental retaining wall designs that employ Redi-Rock 28 inch (6 inch dome) PC block units. However, the inclusion of a layer of geosynthetic reinforcement between courses may reduce the interface shear capacity to values less than those reported in this investigation.

Table 1:

Test program:
Interface shear capacity of Redi-Rock 28 inch PC segmental concrete block units

Test number	normal load (lb/ft)	shear strength at 0.36 inches displacement (lb/ft)	peak shear capacity (lb/ft)	block reference
1	522	838	1724	RR061611-10 over RR061611-6
2	19209	11324	11324	RR062411-10 over RR062411-6
3	16303	11252	11252	RR062411-10 over RR062411-6
4	13612	11036	11036	RR062411-10 over RR062411-6
5	11075	10462	10462	RR061611-10 over RR062411-6
6	11074	11060	11252	RR061411-10 over RR062411-6
7	8299	10408	11204	RR061411-10 over RR061411-6
8	5854	8337	9935	RR061411-10 over RR061411-6
9	3077	5722	6153	RR062211-10 over RR062211-6
10	10981	10821	11252	RR062111-10 over RR062111-6

P. Clarabut

REFERENCE

ASTM D 6916-03. Standard Test Method for Determining Shear Strength between Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. *NCMA Segmental Retaining Wall Design Manual (First Edition),* National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406

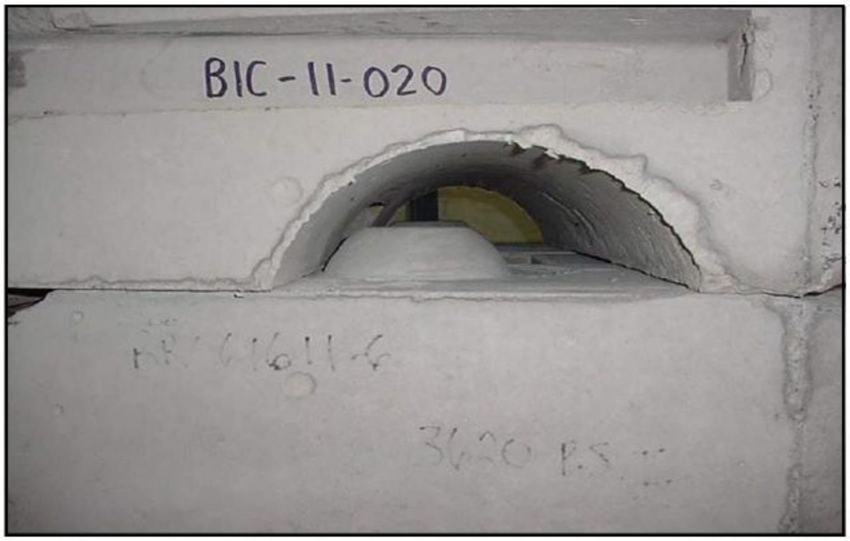


Figure 1: Photograph of the Redi-Rock blocks in the shear test frame

Figure 2: Photograph of the Redi-Rock blocks in the shear test frame

Redi-Rock PC block (6 inch dome) Interface Shear

Project # 211019

Series # BCGT3106

1	Redi-Rock block	6	actuator support	11	reaction beam
2	load cell	7	LVDT	12	computer controlled hydraulic actuator
3	loading platen	8	2 actuators		
4	piston	9	loading frame		
5	lateral restraining system	10	spacers		

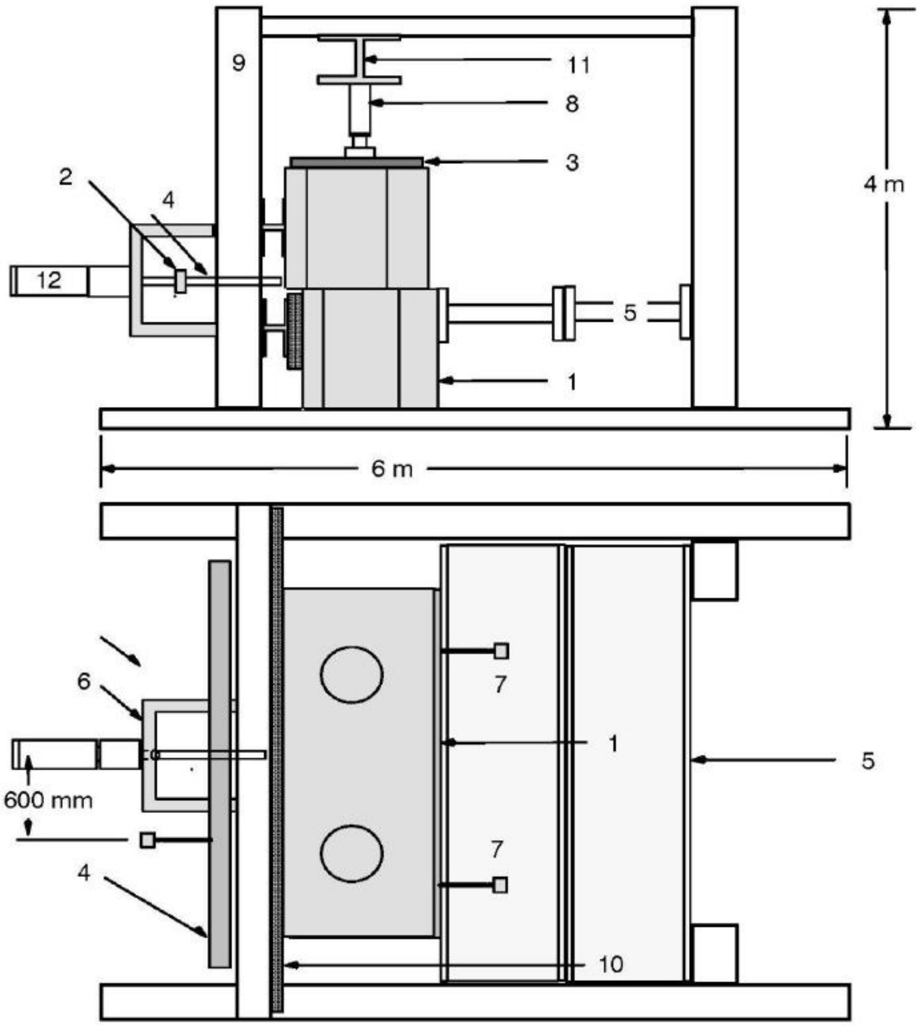


Figure 3: Schematic of large scale shear test apparatus showing Redi-Rock 28 inch PC block units

Redi-Rock PC block (6 inch dome) Interface Shear

Project # 211019

Series # BCGT3106

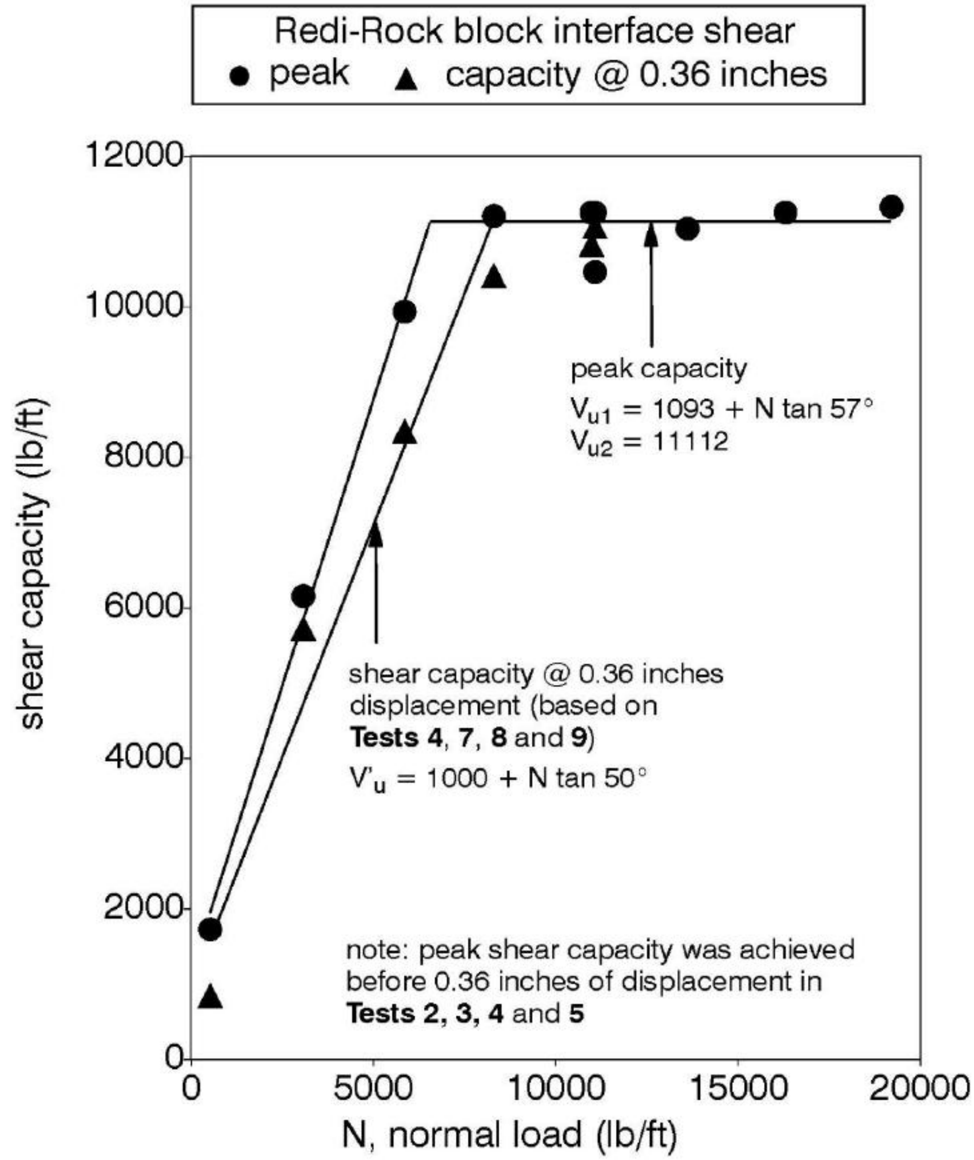


Figure 4: Summary of interface shear capacities for Redi-Rock 28 inch PC block units

Bathurst, Clarabut Geotechnical Testing, Inc. 21 October 2011

Telephone: (613) 384 6363 Email: petebcgt@kos.net

REPORT

RESULTS OF
REDI-ROCK 28 INCH PC BLOCK UNIT
(10 INCH DOME)
INTERFACE SHEAR CAPACITY TESTING

submitted to

REDI-ROCK INTERNATIONAL

CONFIDENTIAL

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2 copies	Redi-Rock International LLC. 05481 US 31 South Charlevoix, Michigan 49720 USA
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Introduction

This report gives the results of an interface shear testing program carried out to evaluate the mechanical/frictional performance of the shear capacity between Redi-Rock® 28 inch PC modular concrete block units.

The test program was initiated in response to a verbal authorization to proceed from Mr. Jamie Johnson of Redi-Rock International, LLC received 9 August 2011.

The tests were carried out at the laboratories of Bathurst, Clarabut Geotechnical Testing, Inc. in Kingston, Ontario, under the supervision of Mr. Peter Clarabut.

Objectives of test program

The interface shear capacity between Redi-Rock 28 inch PC block units (10 inch dome) was investigated using a large-scale test apparatus.

The principal objective of the testing was to evaluate the mechanical/frictional performance of the shear capacity between successive layers of Redi-Rock block units. A second objective was to make recommendations for the selection of interface shear capacities to be used in the design and analysis of retaining wall systems that employ Redi-Rock block units.

Materials

Redi-Rock 28 inch PC Middle Block units are solid concrete blocks weighing approximately 1540 lb per unit (estimated weight based on volume of concrete and assuming a concrete unit weight of 143 lb/ft^3). The nominal dimensions of the block are 28 inches (toe to heel) by 18 inches high by 46 inches long. Construction alignment and interface shear is achieved by means of two 10 inch diameter dome shaped concrete shear keys cast into the top surface of the units. A photograph of the dome shaped shear key is shown in **Figure 1**. A photograph of the block system in the large scale test frame is shown in **Figure 2** The blocks used in this series of tests were supplied by Redi-Rock International (Redi-Rock concrete batch #RR062211) and were received at our laboratory on 9 August 2011 and designated as BIC-11-023 and BIC-11-024. The tested compressive strength of the concrete from batch #RR062211 was 4474 psi (as reported by Redi-Rock International).

Apparatus and general test procedure

The SRWU-2 method of test as reported in the NCMA Segmental Retaining Wall Design Manual (1993) and ASTM D 6916-03 were used in this investigation. A brief description of the apparatus and test methodology is presented here. The test apparatus allows horizontal loads in excess of 12,000 lb/ft to be applied across the interface between two block layers. The segmental units were laterally restrained at the bottom and surcharged vertically. Wall heights were simulated by placing a single block over the interface and applying additional normal load using the hydraulic ram arrangement shown in **Figure 1**. The horizontal (shear) force was applied at a constant rate of displacement using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and displacement transducers were recorded continuously during the test by a microcomputer/data acquisition system. Each test was continued until the safe working limit of the apparatus was reached or block dialation/rotation occured. Following each test, the blocks were removed and the units examined to confirm failure modes (if any).

The only variable in this series of connection tests was the magnitude of surcharge load.

Test results

Results of interface shear tests are summarized in **Table 1**. Peak interface shear capacities and shear capacity at the displacement criterion (0.36 inches) are plotted against normal load in **Figure 4**. The displacement criterion was calculated to be 0.36 inches based on 2% of the block height. The minimum *peak* shear capacity recorded from the test series was 6033 lb/ft. **Tests 1-8** were stopped before failure of the blocks occurred in order to prevent damage to the test apparatus. Tests 9 and 10 were stopped after significant block dilation and some column rotation was observed. In **Tests 1-7** measured peak shear capacity was achieved before 0.36 inches of displacement.

Implications to interface shear capacity design and construction with Redi-Rock 28 inch PC block units

The maximum shear capacity values for **Tests 1-8** reported herein are conservative estimates of the peak shear capacity of the Redi-Rock block system because the safe working capacity of the test apparatus was exceeded. Hence, the use of the maximum shear capacity values reported herein will result in an unquantified additional margin of safety for the nominal identical system in the field. The NCMA Segmental Retaining Wall Design Manual (First Edition, 1993) recommends that the design shear capacity at a given normal load for a critical wall structure be the lesser of: a) the peak capacity divided by a minimum factor of safety (not less than 1.5) or; b) the capacity based on the 0.36 inch displacement criterion. Nevertheless, the design shear capacity envelope inferred from the test data reported herein should be used with caution. The actual design capacity envelope should be lower if the quality of construction in the field is less than that adopted in this controlled laboratory investigation and/or lower quality concrete is used in the manufacture of the blocks. In addition, the interface concrete surfaces should be free of aggregate particles in order to maximize the frictional resistance that is developed between the concrete surfaces.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional performance of the shear capacity between Redi-Rock 28 inch PC block segmental concrete units. The following conclusions can be drawn:

1. The minimum *peak* shear capacity recorded from this test series was 6033 lb/ft (height above interface equal to 1 block unit).

2. The average maximum shear capacity recorded from this test series was 11,276 lb/ft (**Tests 1-8**).
3. Care must be taken during the installation of Redi-Rock block units in order to prevent accumulation of soil and rock debris at the concrete block interface surfaces. This debris may significantly reduce the shear capacity of the Redi-Rock block facing unit system.
4. The actual peak shear capacity of the Redi – Rock 28 inch PC block system may be expected to be greater than the values reported herein since the safe working capacity of the test apparatus was exceeded before shear failure of the blocks could be achieved.

Concluding remarks

The test results presented here are applicable to gravity and geosynthetic reinforced-soil segmental retaining wall designs that employ Redi-Rock 28 inch PC block units. However, the inclusion of a layer of geosynthetic reinforcement between courses may reduce the interface shear capacity to values less than those reported in this investigation.

Table 1:

Test program:
Interface shear capacity of Redi-Rock 28 inch PC segmental concrete block units

Test number	normal load (lb/ft)	shear strength at 0.36 inches displacement (lb/ft)	peak shear capacity (lb/ft)
1	19619	11300	11300
2	16007	11300	11300
3	13546	11371	11371
4	11042	11371	11371
5	8400	11204	11204
6	10999	11252	11252
7	10922	11252	11252
8	5786	10414	11156
9	3137	7469	10174
10	522	3926	6033

P. Clarabut

REFERENCE

ASTM D 6916-03. Standard Test Method for Determining Shear Strength between Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. *NCMA Segmental Retaining Wall Design Manual (First Edition),* National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406

Figure 1: Photograph of the Redi-Rock blocks in the shear test frame

Figure 2: Photograph of the Redi-Rock blocks in the shear test frame

Redi-Rock PC block (10 inch dome) Interface Shear

Project # 211020

Series # BCGT3107

1	Redi-Rock block	6	actuator support	11	reaction beam
2	load cell	7	LVDT	12	computer controlled hydraulic actuator
3	loading platen	8	2 actuators		
4	piston	9	loading frame		
5	lateral restraining system	10	spacers		

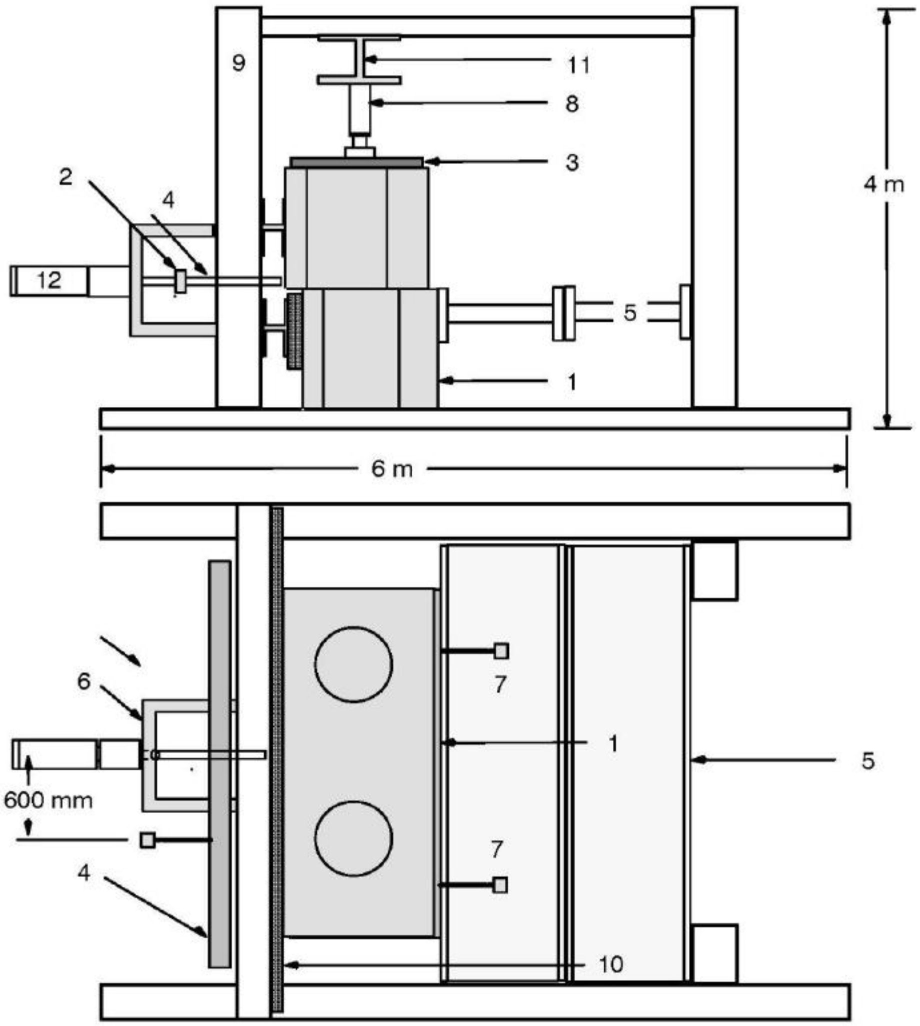


Figure 3: Schematic of large scale shear test apparatus showing Redi-Rock 28 inch PC block units

Redi-Rock PC block (10 inch dome) Interface Shear — Project # 211020

Series # BCGT3107

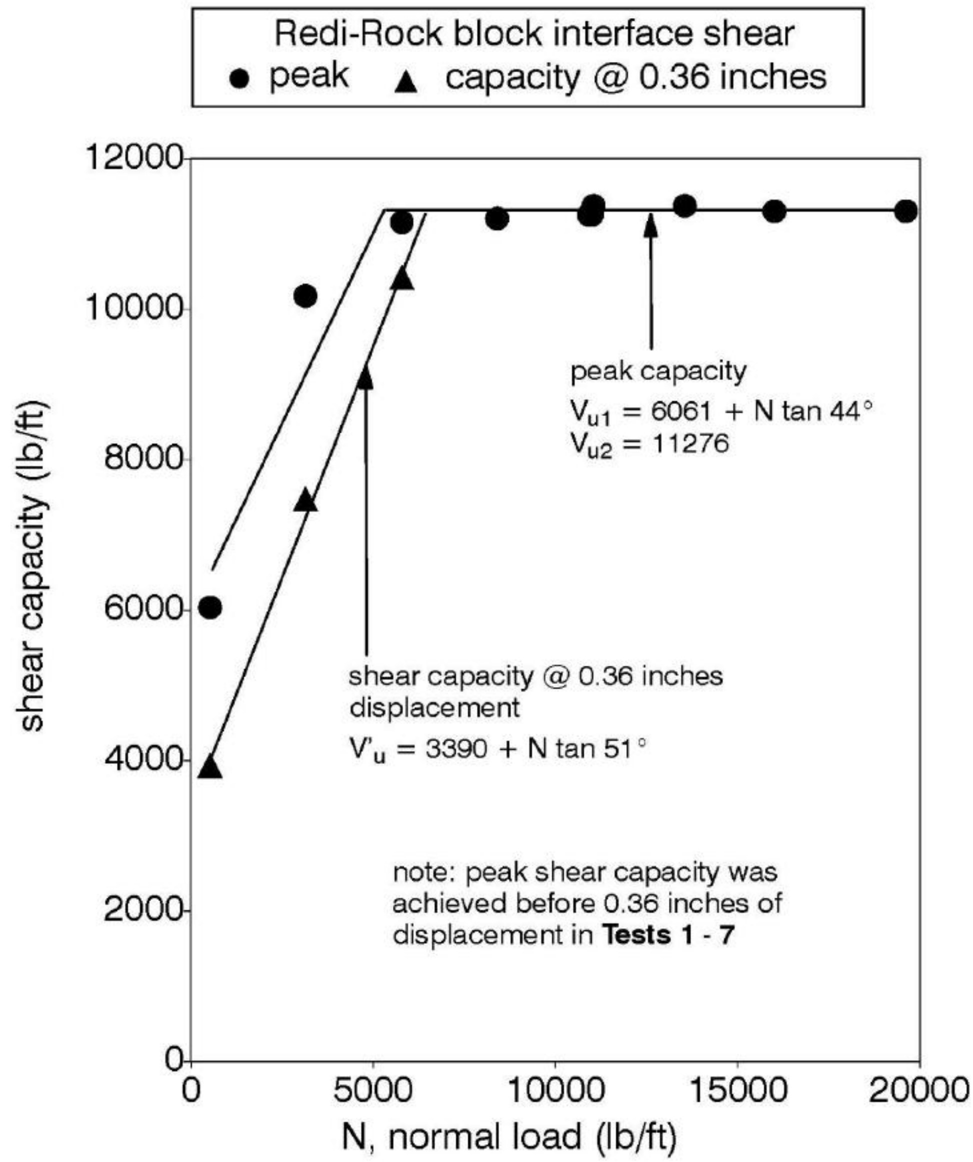


Figure 4: Summary of interface shear capacities for Redi-Rock 28 inch PC block units

REDI-ROCK

XL BLOCK INTERFACE SHEAR DESIGN PARAMETERS

Block Type: **R-5236 52" Hollow Core Retaining Block** Test Methods: ASTM D6916 & NCMA SRWU-2

INTERFACE SHEAR DATA[a]

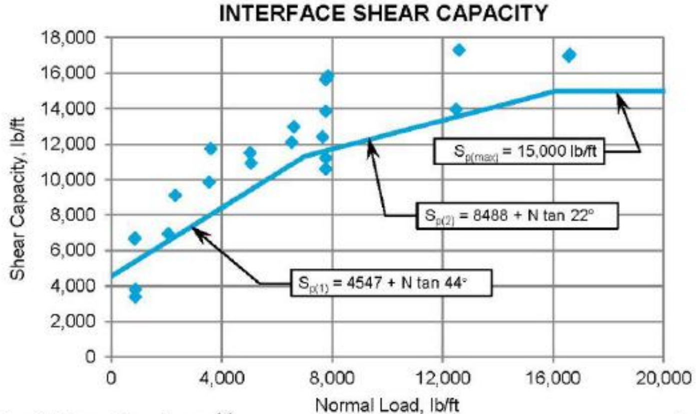
Tested By: TRI Environmental | Dec. 10-21, 2017

Test No.	Normal Load, lb/ft	Peak Shear, lb/ft	Observed Failure[b]
1	872	3,812	Test stopped - uplift
2	5,026	11,503	Knob/face shear
3	872	3,383	Test stopped - uplift
4	16,562	16,962	Test stopped - capacity
5	2,062	6,970	Test stopped - uplift
6	3,539	9,857	Test stopped - uplift
7	7,773	11,210	Knob/face shear
8	7,765	10,601	Test stopped - back cracked
9	7,656	12,405	Test stopped - back cracked
10	6,541	12,112	Test stopped - uplift
11	12,496	13,962	Test stopped - back cracked

Tested By: Redi-Rock International | Mar. 14-23, 2018

Test No.	Normal Load, lb/ft	Peak Shear, lb/ft	Observed Failure[b]
1	7,759	15,635	Test stopped - back cracked
2	7,840	15,843	Test stopped - back cracked
3	7,761	13,859	Knob/face shear
4	16,617	17,070	Test stopped - back cracked
5	12,588	17,305	Knob/face shear
6	842	6,643	Knob/face shear
7	858	6,708	Knob/face shear
8	2,324	9,102	Test stopped - back cracked
9	3,609	11,747	Test stopped - back cracked
10	5,060	10,943	Test stopped - back cracked
11	6,612	12,978	Test stopped - back cracked

INTERFACE SHEAR CAPACITY



Peak Shear Envelope:[c]

$S_{p(1)}$ = 4547 + N tan 44°	**(N < 7,017 lb/ft)**
$S_{p(2)}$ = 8488 + N tan 22°	**(7017 lb/ft ≤ N < 16,118 lb/ft)**
$S_{p(max)}$ = 15,000 lb/ft	**(N ≥ 16,118 lb/ft)**

Inflection Points:

N_1 = 0 lb/ft	**S_1 = 4547 lb/ft**
N_2 = 7017 lb/ft	**S_2 = 11,323 lb/ft**
N_3 = 16,118 lb/ft	**S_3 = 15,000 lb/ft**

(a) The average compressive strength of concrete blocks as-tested was 5,350 psi.
(b) In many cases, the test was stopped before peak shear load occured because of significant uplift of upper block, damage to the back of upper block where horizontal load was applied, or maximum capacity of test apparatus was reached.
(c) Design shear capacity inferred from the test data reported herein should be lowered when test failure results from block rupture or knob shear if the compressive strength of the blocks used in design is less than the blocks used in this test. The data reported represents the actual laboratory test results. The equations for peak shear conditions have been modified to reflect the interface shear performance of concrete with a minimum 28-day compressive strength equal to 4,000 psi. No further adjustments have been made. Appropriate factors of safety for design should be added.

The information contained in this report has been compiled by Redi-Rock International, LLC as a recommendation of peak interface shear capacity. It is accurate to the best of our knowledge as of the date of its issue. However, final determination of the suitability of any design information and the appropriateness of this data for a given design purpose is the sole responsibility of the user. No warranty of performance is expressed or implied by the publishing of the foregoing laboratory test results. Issue date: May 23, 2018.

TRI

Shear Test Report (TRI Log # 28156)
Redi-Rock 52" XL Hollow Core Retaining Blocks

REPORT

RESULTS OF

Redi-Rock 52" XL
Hollow Core Retaining Block
SHEAR CAPACITY TESTING

Submitted to

REDI-ROCK INTERNATIONAL

CONFIDENTIAL

Distribution:
Redi-Rock international
05481 US 31 South
Charlevoix, MI 49720

TRI Environmental, Inc.
9063 Bee Caves Road
Austin, Texas 78733
Phone: 512-263-2101

1 of 7
May 15, 2018

Shear Test Report (TRI Log # 28156)
Redi-Rock 52" XL Hollow Core Retaining Blocks

Introduction

This report gives the results of a block shear testing program carried out to evaluate the mechanical/frictional performance of the shear capacity between Redi-Rock 52" XL Hollow Core Retaining Blocks (Redi-Rock 52" XL Blocks). The test program was initiated in response to an email authorization to proceed from Mr. Matt Walz of Redi-Rock international on November 28, 2017. The tests were carried out at the laboratories of TRI Environmental, Inc. in Austin Texas.

Objective of the Testing Program

The interface shear capacity between Redi-Rock 52" XL Blocks placed in a staggered joint (running bond) configuration was investigated using a very large-scale test apparatus. The principal objective of the testing was to evaluate the mechanical/frictional performance of the shear between successive layers of Redi-Rock 52" XL Block units.

Materials

Redi-Rock 52" XL Block units are hollow concrete blocks weighing approximately 3300 lbs per unit (weight/unit provided by Redi-Rock international). The nominal dimensions of the block are 46.6 inches wide (toe to heel) by 36 inches high by 46.1 inches long. Construction alignment and wall batter is achieved by means of concrete knobs on the top surface of the blocks with a corresponding channel along the bottom of each block. The installation arrangement is illustrated in **Figure 1**. A photograph of the Redi-Rock 52" XL Block units used in this series of tests is shown in **Figure 2**. A photograph of the block system in the connection frame is shown in **Figure 3**. The blocks used in this series of tests were supplied by Redi-Rock international and received at our laboratory in Austin Texas, on 30 November 2017. These block units were manufactured by MDC Contracting between the dates of 3rd and 14th of November, 2017. Concrete compression strengths for each block were determined by Redi-Rock international. No infill materials were utilized in this testing program.

Test Procedure

The SRWU-2 method of test as reported in the NCMA Segmental Retaining Wall Design Manual (1993) and ASTM D6916 was used in this investigation. A brief description of the apparatus and test methodology is presented here. The apparatus used to perform the tests is illustrated in Figure 1. The test apparatus allows horizontal loads of up to 289 kN (force) (65,000 lbf) to be applied across the interface between two block layers. The segmental units were laterally restrained at the bottom and surcharged vertically. A single block was placed over one centrally located running bond (joint) formed by the two underlying units to simulate the staggered construction procedure typically used in the field. Wall heights were simulated by placing a single block over the interface and applying additional normal load using a manually controlled hydraulic pump. The horizontal (shear) force was applied at a constant rate of displacement (i.e. 5 mm/minute) using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and displacement transducers were recorded continuously during the test by a microcomputer/data acquisition system. Each test was continued until large shear displacements were achieved, block overturning/rotation was observed, or cracking of the blocks was observed. Following each test, the blocks were removed and the units examined to confirm failure modes.

Test results for shear testing with Redi-Rock 52" XL Block units

The principal variable in this series of interface shear tests was the magnitude of surcharge (i.e. the magnitude of normal load applied to the top segmental unit). Results of interface shear tests are summarized in **Table 1**. The maximum measured interface shear loads are plotted against normal load and a summary of observations for each test are given in **Figure 4**. A plot of shear load versus displacement is shown in **Figure 5**.

Closing

We appreciate the opportunity to work with you on this project and look forward to providing additional services in the future.

Jeffrey A. Kuhn, Ph.D., P.E.	Mike Domingo
Division Director	Senior Technician
Geotechnical and Interaction Laboratories	Interaction Laboratory

REFERENCES

ASTM D 6916-03. Standard Test Method for Determining Shear Strength between Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Bathurst, R.J. and Simac, M.R., 1993. Laboratory Testing of Modular Unit / Geogrid Facing Connections, ASTM Symposium on Geosynthetic Soil Reinforcement Testing Procedures, San Antonio, 19 January 1993.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. NCMA Segmental Retaining Wall Design Manual (First Edition), National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406.

1	Block unit	6	actuator support	11	reaction beam
2	Geogrid (optional)	7	potentiometer	12	computer controlled hydraulic actuator
3	loading platen	8	surcharge actuators	13	ridgid platform base
4	steel piston	9	loading frame		
5	lateral restraining system	10	spacers		

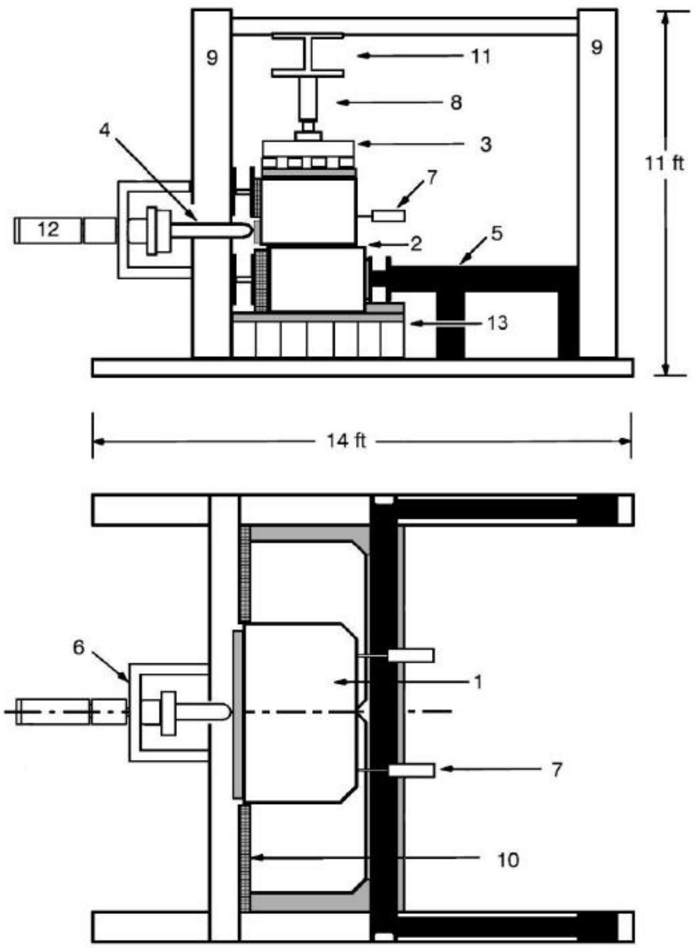


Figure 1: Schematic diagram of the shear test apparatus.

Figure 2: Photograph showing Redi-Rock 52" XL Block unit.

Figure 3: Photograph of the Redi-Rock 52" XL Block units in the test frame.

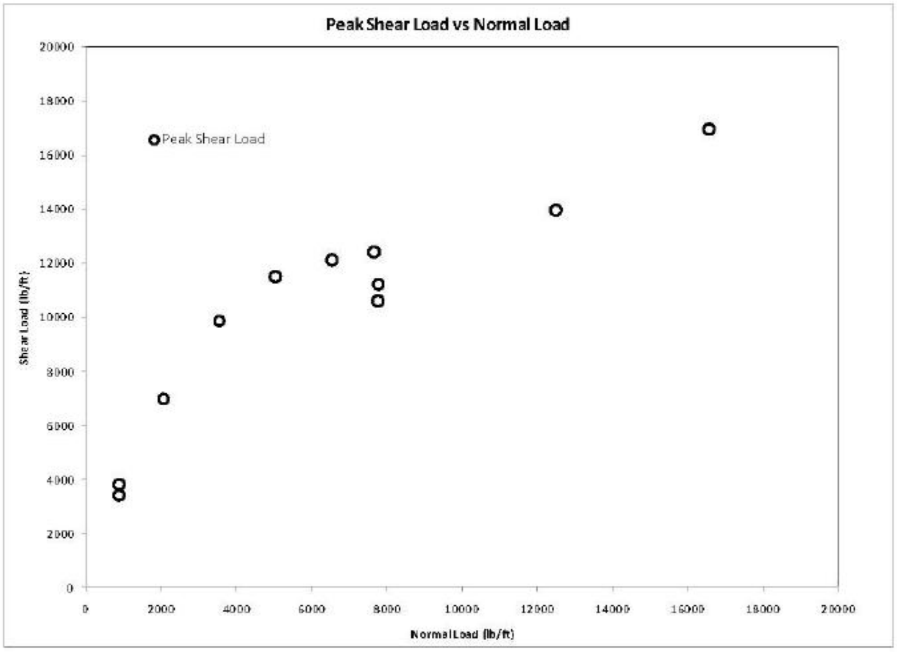


Figure 4: Summary of shear capacities for Redi-Rock 52" XL Block units

Table 1: Data Summary for Redi Redi-Rock 52" XL Block units

Test	Normal Load (lb/ft)	Peak Shear Load (lb/ft)	Observations
1	872	3812	stopped test after uplift of top block
2	5026	11503	broke upper left area of bottom right block
3	872	3383	stopped test after uplift of top block
4	16562	16962	stopped test after reaching over 65000 lbs of horizontal load
5	2062	6970	stopped test after uplift of top block
6	3539	9857	stopped test after uplift of top block, slight cracked formed at the back of the top block
7	7773	11210	cracked knob of bottom right block
8	7765	10601	back bottom of top block cracked
9	7656	12405	back bottom of top block cracked
10	6541	12112	block uplift
11	12496	13962	back bottom of top block cracked

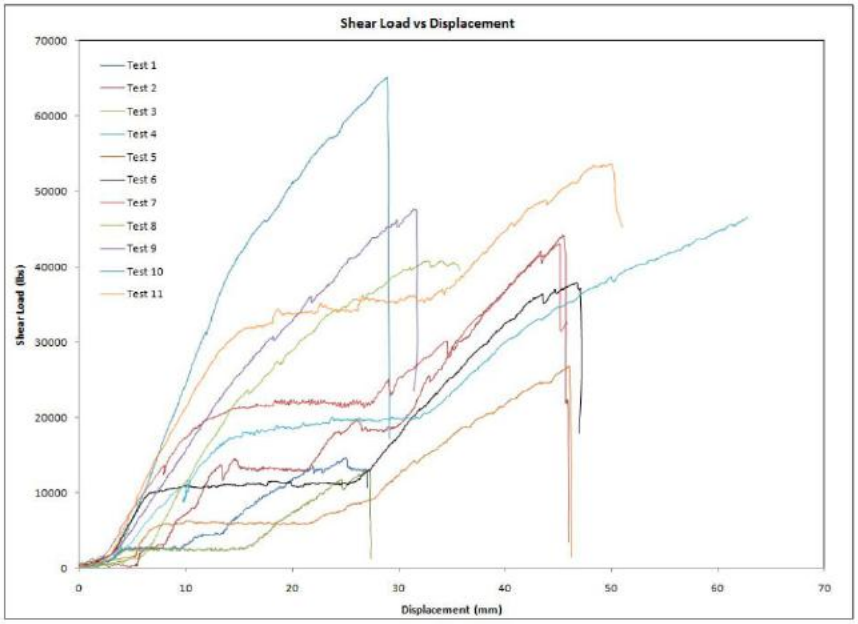


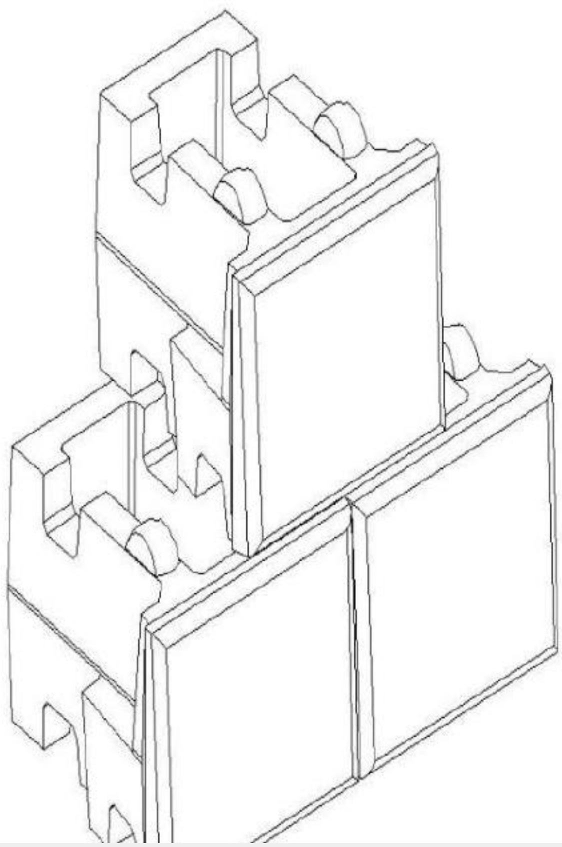
Figure 5: Summary plot of shear load versus displacement.

Test Report

Results from:

Block-to-Block Interface Shear Testing of

Redi-Rock 52" XL Hollow Core Retaining Block



Introduction and Objectives:

The purpose of this testing program was to evaluate the interface shear capacity of the Redi-Rock Hollow Core Retaining Block System. This block system consists of three sizes of concrete blocks that, when stacked and filled with stone, create an integral earth retaining structure. The test program was undertaken with the following objectives:

- Evaluate the interface shear capacity of a wall up to approximately 30' tall.
- Determine the typical structural failure modes of the Hollow Core Block.
- Validate the testing protocol and verify the repeatability of testing results.

Tests were carried out in the high-capacity structural testing frame of Redi-Rock International. Tests were completed between the dates of March 14th and March 23rd, 2018.

Materials:

Redi-Rock Hollow Core Retaining Blocks are cast from high-quality, wet-cast concrete with a minimum specified 28-day compressive strength of 4,000 psi. For additional strength, the blocks contain an integral rebar cage. Blocks are interconnected by two dome-shaped shear knobs protruding from the top of the block that interlock with a groove cast in the bottom of the block.

In order to provide the most conservative estimates of interface shear, the smallest of the blocks, the Redi-Rock 52" XL Hollow Core Retaining Block (Figure 1), was chosen for the tests. In addition, stone infill was not used in the cores for these tests.

Figure 1: Photo of Typical Redi-Rock 52" XL Hollow Core Retaining Block

Test blocks were cast between the dates of December 1st and December 20th, 2017. They were cured for a minimum of 28 days before testing and had an average 28-day compressive strength of 5,200 psi. Individual blocks were weighed and actual block weights were used in the calculation of the normal load. Average block weight was 3,250 lbs.

REDI-ROCK

Testing Frame and Systems:

All tests were completed in a high-capacity structural testing frame (Figure 2) located at the facilities of Redi-Rock International. This testing frame consists of a reconfigurable, steel reaction frame mounted to a 40" thick solid concrete "strong floor" with the capacity to test up to several hundred thousand pounds in any direction.

Figure 2: Photo of Redi-Rock 52" XL Hollow Core Retaining Block in Test Frame

Testing forces are induced by a precision hydraulic actuator system. This system is capable of providing up to 12" of movement and a maximum of 150,000 pound force simultaneously in two directions. This is acheived by two separate hydraulic pump systems which allow for precise control of both horizontal and vertical loading. The hydraulic system is controlled by high-precision directional flow control, needle, and pressure relief valves.

Forces, pressures, and displacements are recorded with electronic sensing devices. Forces were measured with load cells mounted to the ends of the hydraulic cylinders and pushing directly on the block. Forces can be also verified with electronic pressure gauges installed in the hydraulic systems. Displacements were measured with two linear potentiometers with a 2" stroke length capacity. In addition, position of the horizontal hydraulic cylinder is know due to an integral LVDT sensor mounted inside the cylinder.

All measurements were recorded with a National Instruments cDAQ, data acquisition module and Labview data acquisition software. Data was recorded a minimum of one datum per sensor per second.

REDI-ROCK

Test Procedure:

Interface shear capacity testing was completed in general accordance with ASTM D6916 "Standard Test Method for Determining the Shear Strength Between Segmental Concrete Units (Modular Concrete Blocks)". In this test method one block is set on top of two blocks in a staggered, running bond pattern. Base blocks are firmly fixed and a normal load is applied vertically to simulate varied height walls. The upper block is then pushed horizontally to failure to determine the peak interface shear capacity between the block units. Several tests are run at different normal loads until there is excessive deflection or visible cracking seen in the test blocks. See Figure 3 for a schematic drawing of the test frame set-up.

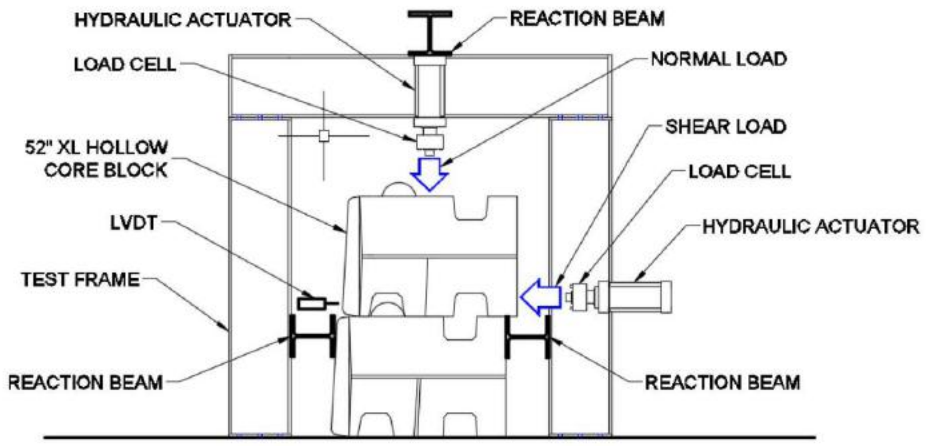


Figure 3: Test Procedure

For this testing program, normal load levels were determined based on a maximum stone-filled gravity wall height of 30 ft. Testing began with three identical tests simulating a mid-range height (approx 18' wall) to check repeatability of the testing protocol. Two tests were then completed above this range to determine the upper end capacity of the wall system. It was anticipated that most gravity walls with this block system will be designed under 18' tall, so more points were chosen in the lower normal load levels. Six tests were completed at these levels, including two tests with just the weight of the block as normal load.

The only known deviation from the ASTM D6916 test method was in the displacement rate (velocity) at which the blocks were tested. Tests were manually controlled with an average displacement rate of 2 mm/min (0.094" per minute) instead of the 5 mm/min (0.197" per minute) rate specified in the ASTM. This displacement rate was chosen to slow down the test due to high anticipated loads and unknown failure modes. It was deemed appropriate because of the intent of the test to mimic static conditions in the field.

Test Results:

Upon completion of the tests, the horizontal shear force was plotted versus horizontal displacement of the upper block (Figure 4). A peak shear force was determined from each of these graphs and is summarized in Table 1. Peak shear force is plotted versus normal load in Figure 5. Note that repeated tests, tests 1 through 3, are within the within the general range of repeatability (within 10% of average) as stated in Section 7.2.8 of ASTM D6916.

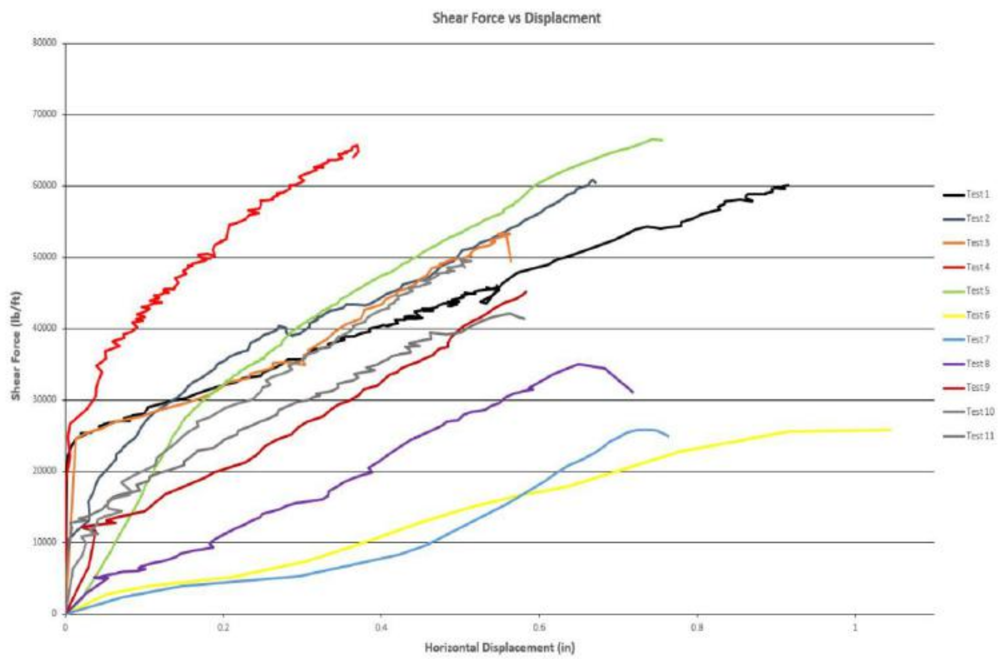


Figure 4: Horizontal Shear Force versus Horizontal Displacement

REDI ROCK

Table 1: Results from interface shear testing

Test Number	Normal Load (lb/ft)	Peak Shear Load (lb/ft)	Notes:
1	7759	15635	Stopped test due to cracking in back of top block.
2	7840	15843	Stopped test due to cracking in back of top block.
3	7761	13859	Cracked left-hand knob and through face of lower right-hand block.
4	16617	17070	Stopped test due to cracking in back of top block.
5	12588	17305	Cracked knobs on both lower blocks.
6	842	6643	Cracked through face of lower left-hand block. Partially cracked left-hand knob of lower right block.
7	858	6708	Cracked right-hand knob of lower left-hand block.
8	2324	9102	Completely crushed back of upper block. Did not break knobs.
9	3609	11747	Stopped test due to cracking in back of top block.
10	5060	10943	Completely crushed back of upper block.
11	6612	12978	Stopped test due to cracking in back of top block and large deflections.

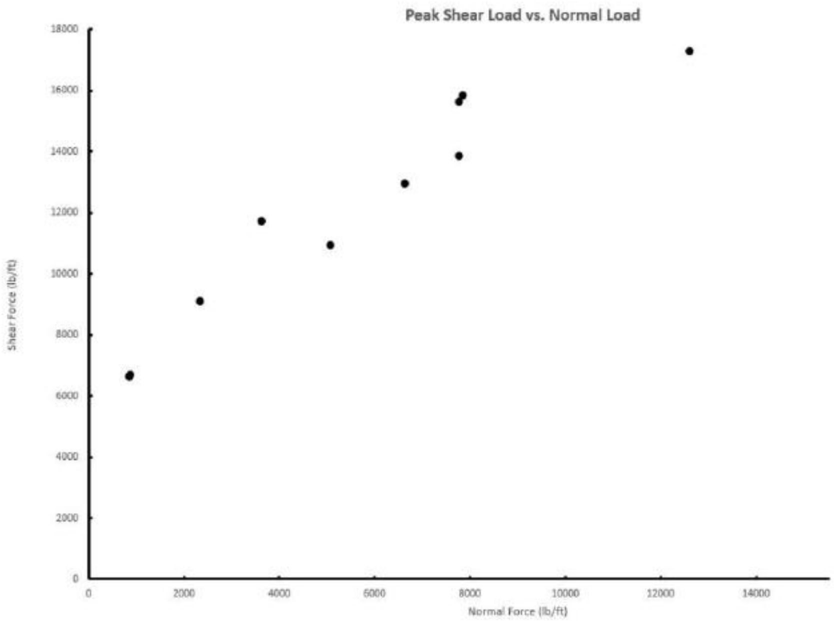


Figure 5: Graph of Peak Shear Force versus Normal Load

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January 10, 2019

Block Failure Modes:

Two main failure modes were seen at the horizontal shear interface between layers of blocks. These were cracking directly through the shear knob (Figure 6) or cracking at an angle down and below the shear knob (Figure 7). In each case, the failure began with localized crushing of the knob into the groove in the block above. However, no significant damage beyond localized crushing was noted in the grooves. It is interesting to note that, even at low normal loads, blocks only slightly uplifted or rotated throughout testing.

Figure 6: Typical Broken Shear Knob Failure

Figure 7: Typical Deep-Seated Shear Knob Failure

TEST REPORT:

REDI-ROCK 41-INCH SOLID RETAINING BLOCK ON 52-INCH HOLLOW CORE XL RETAINING BLOCK
BLOCK TO BLOCK INTERFACE SHEAR CAPACITY

Tested By:
Aster Brands
2940 Parkview Drive
Petoskey, Michigan 49770
866-222-8400

September 27, 2021

ASTER BRANDS

REDI-ROCK ROSETTA pole base

1.0 Introduction

This report documents testing to evaluate the block-to-block interface shear capacity between Redi-Rock 41-inch (1030 mm) solid (R-41M) retaining units and 52-inch (1320 mm) hollow core XL (R-5236HC) units. The testing was performed by Aster Brands at its testing facility in Charlevoix, Michigan in May and June 2018. Redi-Rock is an Aster Brands company.

2.0 Purpose

The objective of the test series was to investigate the block-to-block interface shear capacity of full-size Redi-Rock solid retaining units on hollow-core XL units under varying normal loads using a large testing frame. Crushed stone core fill material was not included in this testing. No attempt has been made to quantify the additional interface shear capacity provided by properly installed core fill.

3.0 Materials

Redi-Rock R-41M blocks are wet-cast concrete, precast modular block (PMB) units with a nominal width of 40½ inches (1,029 mm), length of 46⅛ inches (1172 mm), and height of 18 inches (457 mm). They weigh approximately 1,625 lbs (7.23 kN) each.

Redi-Rock R-5236HC XL blocks are also wet-cast concrete, precast modular block (PMB) units with a nominal length of 40½ inches (1,029 mm). These XL units have a width of 52 inches (1320 mm) and a height of 36 inches (914 mm). They weigh approximately 3,330 lbs (14.8 kN) each.

Block dimensions are shown in **Figure 1**. The blocks are manufactured from wet-cast, first purpose, non-reconstituted, structural-grade concrete mixes in accordance with ASTM C94 or ASTM C685 and have a minimum specified 28-day compressive strength of 4,000 psi (27.6 MPa).

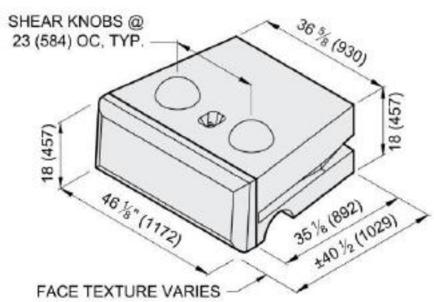


Figure 1 - R-41M block

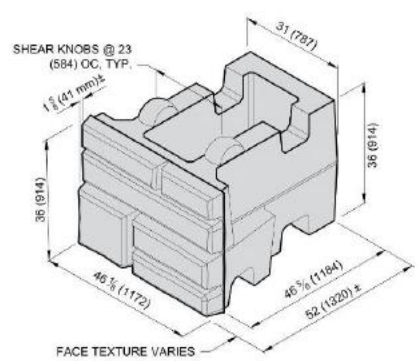


Figure 2 - R-5236HC

Shear engagement between subsequent rows of blocks is achieved by two dome-shaped shear knobs protruding from the top of each block that interlock with a groove cast in the bottom of each overlying block. The shear knobs and groove also set the wall batter at a nominal value of 5 degrees (1 5/8 inches (41 mm) per 18-inch (457 mm) course). Blocks are typically stacked in a staggered, or running bond, configuration.

Blocks used in this series of testing were produced by MDC Contracting, LLC at its Charlevoix, Michigan facility. Blocks were produced in November 2017 through May 2018 and cured for 37 to 225 days prior to testing. Average compressive strength of the concrete on the day of testing was 4,639 psi (32.0 MPa) for the 41-inch blocks and 5,147 psi (35.5 MPa) for the XL test blocks, as determined by ASTM C39 on 4-inch by 8-inch (102 mm by 203 mm) field-cured concrete cylinder specimens tested on the day the blocks were tested.

4.0 Test Apparatus

All tests were completed in a high-capacity structural testing frame located at the Aster Brand testing facilities in Charlevoix, Michigan, USA. This testing frame consists of a reconfigurable, steel reaction frame mounted to a 40-inch (1.0 m) thick solid concrete "strong floor".

Testing forces were induced by a precision hydraulic actuator system. The system is capable of providing up to 12 inches (300 mm) of movement and a maximum of 150,000 pounds of force (670 kN) simultaneously in two directions through the use of two separate hydraulic pump systems. This allows for precise control of both horizontal and vertical loading. The hydraulic systems are controlled by high-precision directional flow control, needle, and pressure relief valves.

Forces, pressures, and displacements were recorded with electronic sensing devices. Forces were measured with load cells mounted to the ends of the hydraulic cylinders and pushing directly on the block. Forces were verified with electronic pressure gauges installed in the hydraulic systems. Displacements were measured with a pair of LVDTs and an integral LDT sensor mounted inside the horizontal hydraulic cylinder.

All measurements were recorded with a National Instruments cDAQ, data acquisition module and Labview data acquisition software. Data was recorded at a minimum of one datum per sensor per second.

5.0 Methodology

Interface shear capacity testing was completed in general accordance with ASTM D6916 "Standard Test Method for Determining the Shear Strength Between Segmental Concrete Units (Modular Concrete Blocks)". In this test method one block is set on top of two blocks in a staggered, running bond pattern. Base blocks are firmly fixed and a normal load is applied vertically to simulate varied height walls. The upper block is then pushed horizontally to failure to determine the peak interface shear capacity between the block units. Tests are run until there is excessive deflection, visible cracking seen in the test blocks, or significant reduction in applied load. Details of the test set-up are shown in **Figure 2**.

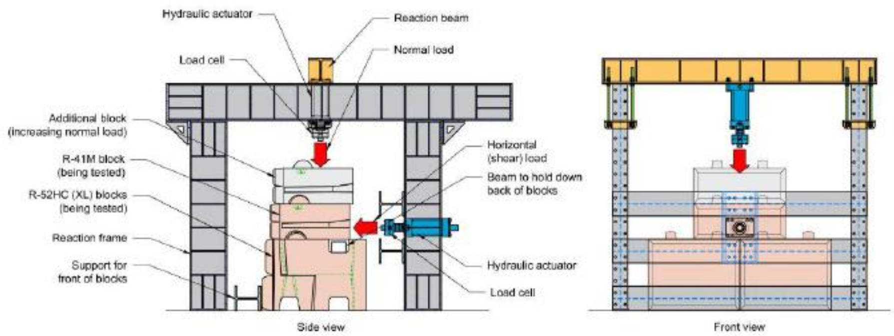


Figure 2: Schematic test frame set-up

For this testing program, normal load levels were varied from 561 to 16,621 lb/ft (8.2 to 243 kN/m) to simulate the performance of block to block interface shear at different vertical locations in a wall cross-section. These values correspond to approximate wall heights from 1.5 to 40 feet (0.5 to 12 m). Three tests were run at the same normal load near the middle of the range of loads tested to check repeatability of the testing protocol.

Blocks were initially set such that the shear grooves were not firmly engaged with the shear knobs on the underlying blocks. Normal load was applied and horizontal load was applied in two stages: an initial sliding friction stage to measure the coefficient of friction between precast blocks (without the shear knobs engaged) and the final shear resistance stage with the shear knbs engaged to obtain the full interface shear capacity.

Blocks were preloaded with an average of approximately 1,000 lb (4.5 kN) to set the blocks. Displacement was measured using a pair of LVDTs. The displacement rate (velocity) at which the blocks were tested was manually controlled with a displacement rate generally around 1.1 mm/min (0.04 in per minute) instead of the 5 mm/min +/- 1mm/min (0.197 in per minute +/- 0.04" per min) rate specified in ASTM D6916.

6.0 Results

All tests were taken to block failure. Failure generally involved cracking that started behind the knob and exited through the block face, as shown in **Figure 3**.

Figure 3 - Failure through block face

Block displacement plotted against horizontal load is shown in **Figure 4**. Peak loads were taken as the maximum measured load during each test and are summarized in **Table 1**. Peak loads plotted against normal loads are shown in **Figure 5**.

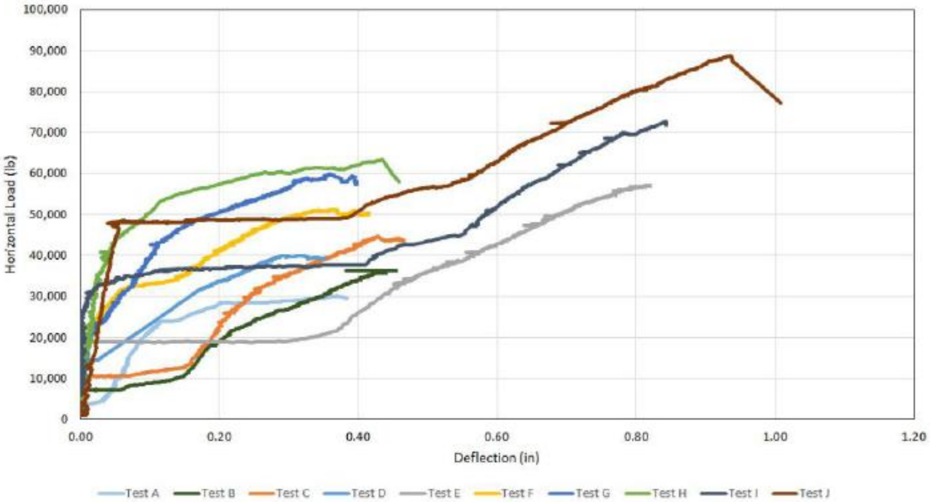


Figure 4 - Horizontal Shear Force versus Horizontal Displacement

Table 1 - Sliding friction and interface shear results

Test Number	Normal Load		Sliding Friction[1]		Peak Shear[2]		Observed Failure[2]
	lb/ft	(kN/m)	lb/ft	(kN/m)	lb/ft	(kN/m)	
A	561	8.18	416	6.07	7,753	113.14	Failure through block face
B	2,333	34.05	1,886	27.53	10,485	153.01	Failure through block face
C	3,664	53.47	2,706	39.49	11,601	169.30	Failure through block face
D	5,066	73.93	3,538	51.64	10,276	149.97	Failure through block face
E	6,626	96.70	4,982	72.71	13,450	196.29	Failure through block face
F	7,777	113.49	5,698	83.15	13,268	193.63	Failure through block face
G	7,784	113.60	6,140	89.60	15,089	220.21	Failure through block face
H	7,785	113.61	--	--	15,610	227.80	Failure through block face
I	12,697	185.30	9,522	138.96	18,211	265.77	Failure through block face
J	16,621	242.56	12,514	182.62	22,634	330.31	Failure through block face

(1) Shear knobs not engaged.
(2) Shear knobs engaged.

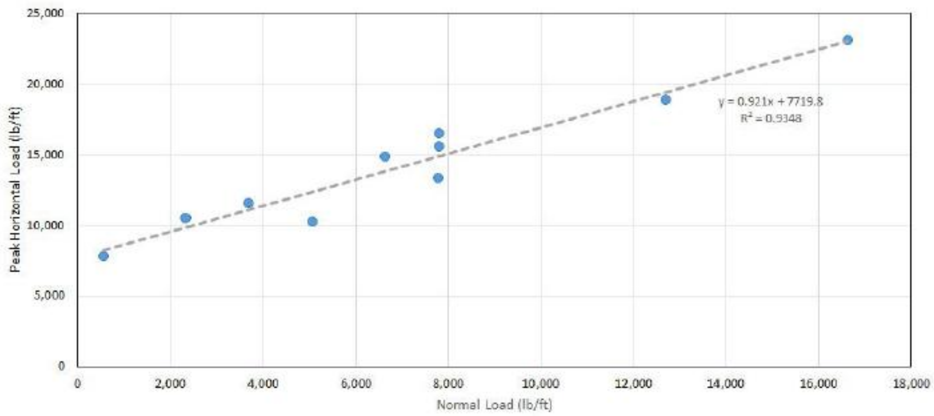


Figure 5 - Interface shear strength versus normal load (shear knobs engaged)

Three tests were run at approximately 7,780 lb/ft (113.5 kN/m) normal load to check repeatability of the testing protocol. ASTM D6916 uses a value of ±10% variation for each test from the mean of the tests as a measure of repeatability. Maximum variability of the three repeatability tests was 9 percent.

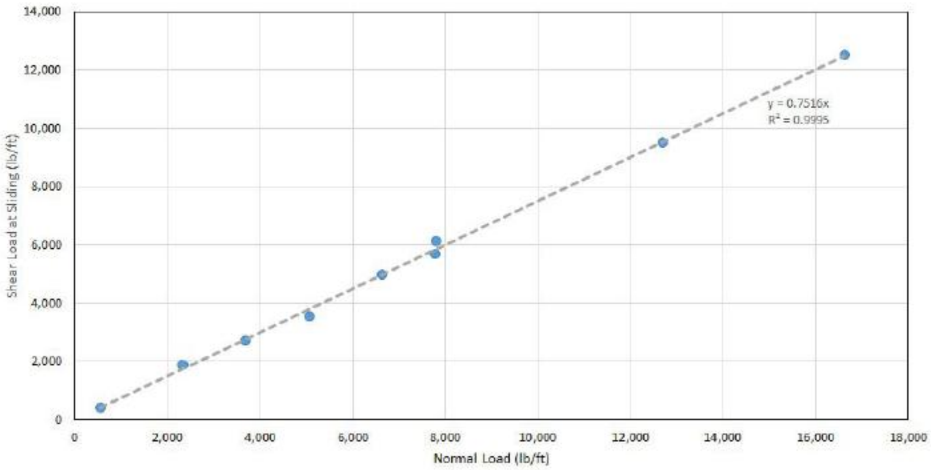


Figure 6 -Sliding friction load versus normal load (shear knobs not engaged)

Normal load versus sliding friction load appeared to follow a very linear relationship. Linear regression trendline resulted in a best-fit line with a slope of 0.7516, which is equivalent to a friction angle of 36.9°.

7.0 Closure

This data and conclusions should be used with care. The user should verify that project conditions are equivalent to laboratory conditions and account for variations.

This test data is accurate to the best of our knowledge. It is the responsibility of the user to determine suitability for the intended use.

ASTER BRANDS

Matthew A. Walz, P.E.
Testing Manager

Nils W. Lindwall, P.E.
Chief Engineer

REDI-ROCK

41" HOLLOW-CORE RETAINING BLOCK INTERFACE SHEAR DESIGN PARAMETERS

Block Type: **R-41HC 41" Hollow-Core Retaining Block**

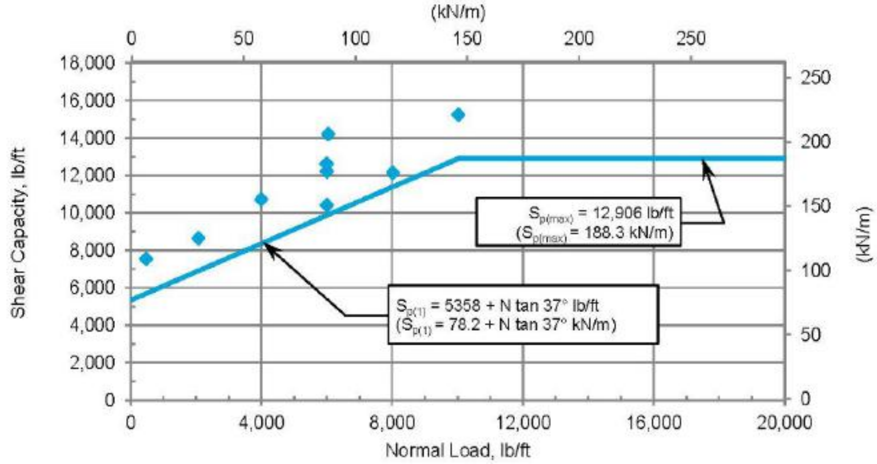
Test Methods: ASTM D6916 & NCMA SRWU-2

Tested By: ': Aster Brands | Nov. 19-25, 2019

INTERFACE SHEAR DATA[(a)]

Test No.	Normal Load		Peak Shear		Observed Failure
	lb/ft	(kN/m)	lb/ft	(kN/m)	
1	5,993	(87.5)	12,620	(184.2)	Failure through face
2	6,039	(88.1)	14,209	(207.4)	Failure through face
3	472	(6.9)	7,552	(110.2)	Failure through face
4	2,064	(30.1)	8,644	(126.1)	Failure through face
5	3,991	(58.2)	10,715	(156.4)	Failure through face
6	8,019	(117.0)	12,146	(177.3)	Knobs sheared
7	6,000	(87.6)	10,414	(152.0)	Knobs sheared
8	10,016	(146.2)	15,243	(222.5)	Knobs sheared
9	5,998	(87.5)	12,221	(178.3)	Knobs sheared

INTERFACE SHEAR CAPACITY



Peak Shear Envelope:[(b)]

S_p = 5358 lb/ft + N tan 37° ≤ 12,906 lb/ft

(S_p = 78.2 kN/m + N tan 37° ≤ 188.3 kN/m)

Inflection Points:

N_1 = 0 lb/ft (0 kN/m) — **S_1 = 5358 lb/ft (78.2 kN/m)**

N_2 = 10,016 lb/ft (146.2 kN/m) — **S_2 = 12,906 lb/ft (188.3 kN/m)**

(a) The average compressive strength of concrete blocks as-tested ranged from 2,865 psi (19.8 MPa) to 3,872 psi (26.7 MPa), with an average of 3,323 psi (22.9 MPa). The data reported represents the actual laboratory test results. No statistically-significant correlation between block strength and interface shear resistance was found.

(b) The equations for peak shear envelope represent the slope of the trend line of the raw data, offset to pass thorugh the lower 95% confidence limit for the repeatability values, with no increase in shear capacity for normal load values above those tested. No further adjustments have been made. Appropriate factors of safety for design should be added.

Issue date: January 7, 2020

TEST REPORT:

REDI-ROCK 41-INCH HOLLOW-CORE RETAINING BLOCK BLOCK TO BLOCK INTERFACE SHEAR CAPACITY

Tested By:
Aster Brands
2940 Parkview Drive
Petoskey, Michigan 49770
866-222-8400

June 16, 2020

ASTER BRANDS

REDI-ROCK ROSETTA pole base

1.0 Introduction

This report documents testing to evaluate the block to block interface shear capacity between Redi-Rock 41-inch (1030 mm) Hollow-Core (R-41HC) retaining units. The testing was performed by Aster Brands at its testing facility in Charlevoix, Michigan in November 2019. Redi-Rock is an Aster Brands company.

2.0 Purpose

The objective of the test series was to investigate the block to block interface shear capacity of full size Redi-Rock 41-inch (1030 mm) Hollow-Core (R-41HC) retaining units under varying normal loads using a large testing frame. Crushed stone core fill material was not included in this testing. No attempt has been made to quantify the additional interface shear capacity provided by properly installed core fill.

3.0 Materials

Redi-Rock R-41HC blocks are wet-cast concrete, precast modular block (PMB) units with a nominal width of 40½ inches (1,029 mm), length of 46⅛ inches (1172 mm), and height of 18 inches (457 mm). Block dimensions are shown in **Figure 1**. The blocks are manufactured from wet-cast, first purpose, non-reconstituted, structural grade concrete mixes in accordance with ASTM C94 or ASTM C685. They have a minimum specified 28-day compressive strength of 4,000 psi (27.6 MPa) and weigh approximately 1,625 lbs (7.23 kN).

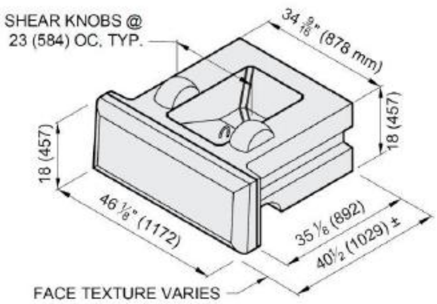


Figure 1 - R-41HC block

Shear engagement between subsequent rows of blocks is achieved by two dome-shaped shear knobs protruding from the top of the block that interlock with a groove cast in the bottom of the block. The shear knobs and groove also set the wall batter at a nominal value of 5 degrees (1⅝ inches (41 mm) per course). Blocks are typically stacked in a staggered, or running bond, configuration.

Blocks used in this series of testing were produced by MDC Contracting, LLC at its Charlevoix, Michigan facility. Blocks were produced in late September and early October 2019 and cured for 50 to 54 days prior to testing. Average compressive strength of the concrete used to produce the test blocks was 3,320 psi (22.9 MPa), as determined by ASTM C39 on 4-inch by 8-inch (102 mm by 203 mm) field-cured concrete cylinder specimens. Because all test blocks had compressive strength values at the time of testing below the minimum specified 28-day value for Redi-Rock R-41HC blocks, tested interface shear values were assumed to be lower bound values and no attempt was made to adjust test results for concrete strength.

4.0 Test Apparatus

All tests were completed in a high-capacity structural testing frame located at the Aster Brand testing facilities in Charlevoix, Michigan, USA. This testing frame consists of a reconfigurable, steel reaction frame mounted to a 40" (1.0 m) thick solid concrete "strong floor".

Testing forces were induced by a precision hydraulic actuator system. The system is capable of providing up to 12" (300 mm) of movement and a maximum of 150,000 pound force (670 kN) simultaneously in two directions through the use of two separate hydraulic pump systems. This allows for precise control of both horizontal and vertical loading. The hydraulic systems are controlled by high-precision directional flow control, needle, and pressure relief valves.

Forces, pressures, and displacements were recorded with electronic sensing devices. Forces were measured with load cells mounted to the ends of the hydraulic cylinders and pushing directly on the block. Forces were verified with electronic pressure gauges installed in the hydraulic systems. Displacements were measured with a string potentiometer and an integral LDT sensor mounted inside the horizontal hydraulic cylinder.

All measurements were recorded with a National Instruments cDAQ, data acquisition module and Labview data acquisition software. Data was recorded a minimum of one datum per sensor per second.

5.0 Methodology

Interface shear capacity testing was completed in general accordance with ASTM D6916 "Standard Test Method for Determining the Shear Strength Between Segmental Concrete Units (Modular Concrete Blocks)". In this test method one block is set on top of two blocks in a staggered, running bond pattern. Base blocks are firmly fixed and a normal load is applied vertically to simulate varied height walls. The upper block is then pushed horizontally to failure to determine the peak interface shear capacity between the block units. Tests are run until there is excessive deflection, visible cracking seen in the test blocks, or significant reduction in applied load. Details of the test set-up are shown in **Figure 2**.

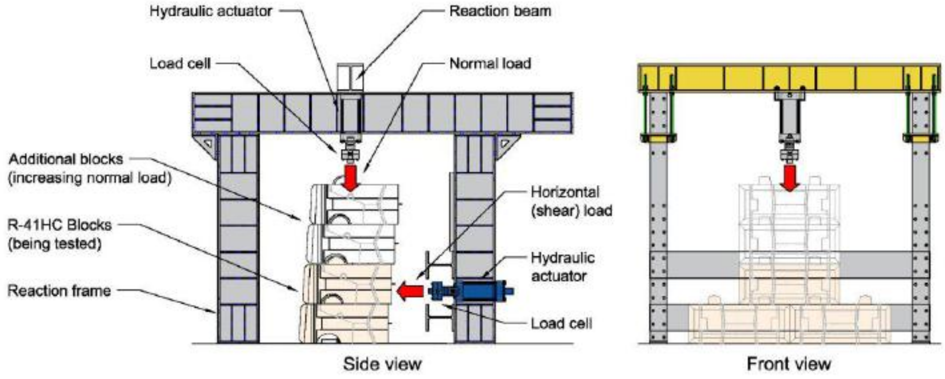


Figure 2: Schematic test frame set-up

For this testing program, normal load levels were varied from 472 to 10,016 lb/ft (6.9 to 146.2 kN/m) to simulate the performance of block to block interface shear at different vertical locations in a wall cross-section. These values correspond to approximate wall heights from 1 to 25 feet (0.3 to 7.5 m). Four tests were run at the same normal load near the middle of the range of loads tested to check repeatability of the testing protocol.

Blocks were preloaded with an average of approximately 950 lb (4.2 kN) to set the blocks. Displacement was measured at the point of load by the integral LDT sensor mounted inside the horizontal hydraulic cylinder. The displacement rate (velocity) at which the blocks were tested was manually controlled with an average displacement rate of 4.3 mm/min (0.17" per minute) which is within the tolerance of 5 mm/min +/- 1mm/min (0.197" per minute +/- 0.04" per min) rate specified in ASTM D6916.

6.0 Results

All tests were taken to block failure. Two modes of failure were observed during the tests. In the first mode, shown in **Figure 3**, the block cracked starting behind the knob and running through the block face. In the second mode, shown in **Figure 4**, failure occurred either in the knob or at the interface between the knob and the block.

Figure 3 - Failure through block face

Figure 4 - Failure by knob shear

Block displacement plotted against horizontal load is shown in **Figure 5**. Peak loads were taken as the maximum measured load during each test and are summarized in **Table 1**. Peak loads plotted against normal loads are shown in **Figure 6**. The two failure modes are shown with different markers for ease in distinguishing them.

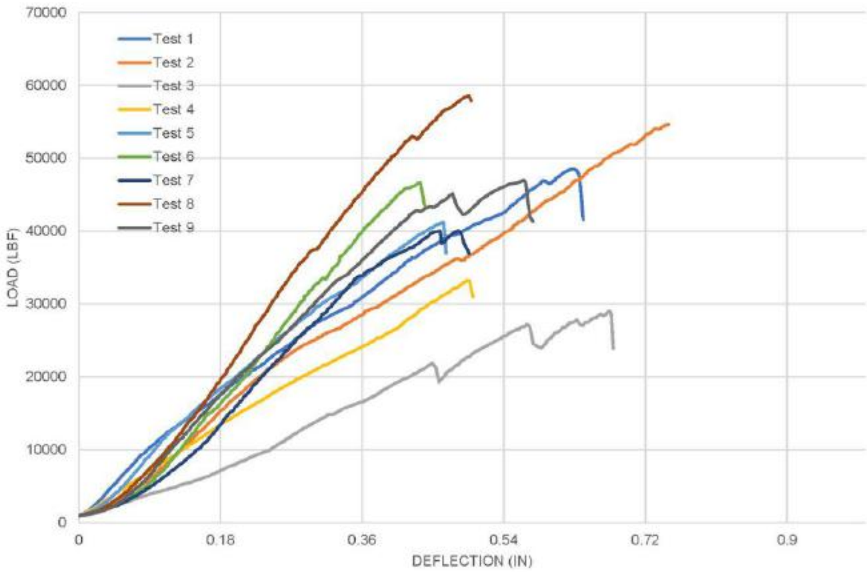


Figure 5 - Horizontal Shear Force versus Horizontal Displacement

Table 1 - Results

Test Number	Normal Load		Peak Shear		Observed Failure
	lb/ft	(kN/m)	lb/ft	(kN/m)	
1	5,993	(87.5)	12,620	(184.2)	Failure through block face
2	6,039	(88.1)	14,209	(207.4)	Failure through block face
3	472	(6.9)	7,552	(110.2)	Failure through block face
4	2,064	(30.1)	8,644	(126.1)	Failure through block face
5	3,991	(58.3)	10,735	(156.7)	Failure through block face
6	8,019	(117.0)	12,146	(177.3)	Knob shear
7	5,951	(86.9)	10,418	(152.0)	Knob shear
8	10,016	(146.2)	15,243	(222.5)	Failure through block face
9	5,998	(87.5)	12,221	(178.4)	Knob shear

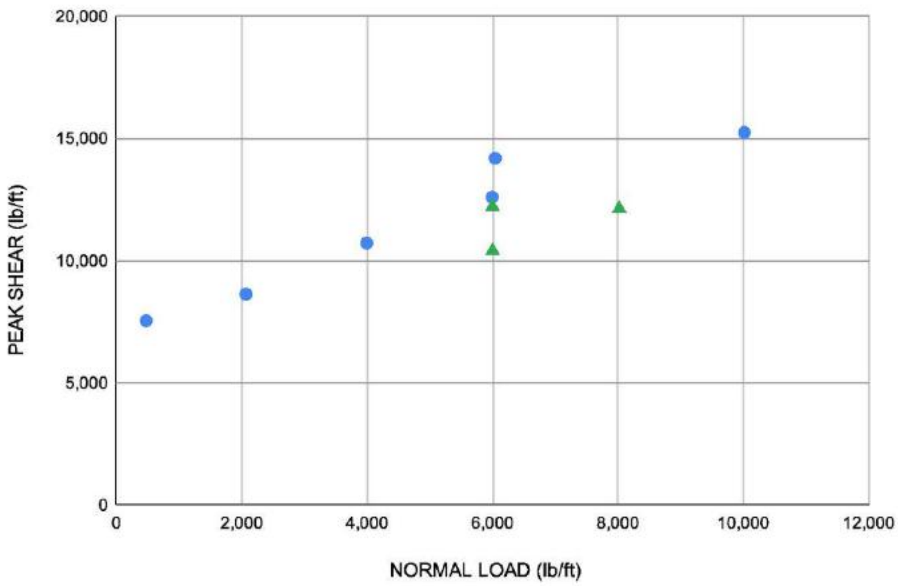


Figure 6 - Shear strength versus Normal loads

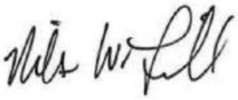
Four tests were run at approximately 6,000 lb/ft (87.6 kN/m) normal load to check repeatability of the testing protocol. ASTM D6916 uses a value of ±10% variation for each test from the mean of the tests as a measure of repeatability. In testing, two different failure mechanisms were observed in the repeat tests. When looking at the total combined data, the high and low values do not fall within 10% of the mean of the tests. If the high and low values are averaged, the average high and low value and the two middle values vary less than 1.3% from the mean of the tests. If the two failure modes are analyzed separately, both tests vary less than 10% from the mean of the tests.

7.0 Closure

This data and conclusions should be used with care. The user should verify that project conditions are equivalent to laboratory conditions and account for variations.

This test data is accurate to the best of our knowledge. It is the responsibility of the user to determine suitability for the intended use.

ASTER BRANDS



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Testing Manager

Nils W. Lindwall, P.E.
Chief Engineer

APPENDIX: 1.2.4 NTPEP REPORT

2019 NTPEP Report Series

NTPEP Report REGEO-2016-01-[Tencate-Miragrid XT]

ANNIVERSARY 15

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NTPEP

LABORATORY EVALUATION OF GEOSYNTHETIC REINFORCEMENT

FINAL PRODUCT QUALIFICATION REPORT FOR MIRAGRID XT GEOGRID PRODUCT LINE

AASHTO
THE VOICE OF TRANSPORTATION

Report Issued: June 2019
Report Expiration Date: June 2028
Next Quality Verification Update Reports: 2022

American Association of State Highway and Transportation Officials (AASHTO)

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2019 NTPEP Report Series

National Transportation Product Evaluation Program (NTPEP)

NTPEP Report REGEO-2016-01-[Tencate-Miragrid XT]

LABORATORY EVALUATION OF GEOSYNTHETIC REINFORCEMENT

2016 PRODUCT SUBMISSIONS
SAMPLED MARCH 2017

Laboratory Evaluation by:

TRI/Environmental, Inc.
9063 Bee Caves Road
Austin, TX 78733-6201

Product Line Manufactured by:

TenCate Geosynthetics
365 South Holland Drive
Pendergrass, GA 30567

DOWNLOAD DATA FILES FOR THIS NTPEP REPORT @ NTPEP.org

PROLOGUE

General Facts about NTPEP Reports:

- NTPEP Reports contain data collected according to laboratory testing and field evaluation protocols developed through consensus-based decision by the AASHTO's NTPEP Oversight Committee. These test and evaluation protocols are described in the *Project Work Plan* (see NTPEP website).
- Products are voluntarily submitted by manufacturers for testing by NTPEP. Testing fees are assessed from manufacturers to reimburse AASHTO member departments for conducting testing and to report results. AASHTO member departments provide a voluntary yearly contribution to support the administrative functions of NTPEP.
- AASHTO/NTPEP does not endorse any manufacturer's product over another. Use of certain proprietary products as "primary products" does not constitute endorsement of those products.
- AASHTO/NTPEP does not issue product approval or disapproval; rather, test data are furnished for the User to make judgment for product prequalification or approval for their transportation agency.

Guidelines for Proper Use of NTPEP Results:

- The User is urged to carefully read any introductory notes at the beginning of this Report, and also to consider any special clauses, footnotes or conditions which may apply to any test reported herein. Any of these notes may be relevant to the proper use of NTPEP test data.
- The User of this Report must be sufficiently familiar with the product performance requirements and/or (standard) specification of their agency in order to determine which test data are relevant to meeting those qualifying factors.
- NTPEP test data is intended to be predictive of actual product performance. Where a transportation agency has successful historical experience with a given product, it is suggested to factor that precedence in granting or withholding product approval or prequalification.

NTPEP Report Special Advisory for Geosynthetic Reinforcement (REGEO):

- This report contains product data that are intended to be applied to a product line, based on the test results obtained for specific products that are used to represent the product line for the purposes of NTPEP testing. It is expected that the User will estimate the properties of specific products in the line not specifically tested through interpolation or a lower or upper bound approach.
- It is intended that this data be used by the User to add products to their Qualified Products or Approved Products List, and/or to develop geosynthetic reinforcement strength design parameters in accordance with AASHTO, FHWA, or other widely accepted design specifications/guidelines. It is also intended that the User will conduct further, but limited, evaluation and testing of the products identified in this report for product acceptance purposes to verify product quality.
- Products included in this report must be resubmitted to NTPEP every three (3) years for a quality verification evaluation and every nine (9) years for a full qualification evaluation in accordance with the work plan. Hence, all product test results included in this Report supersede data provided in previous Editions of this report.
- The User is guided to read the document entitled "Use and Application of NTPEP Geosynthetic Reinforcement Test Results" (see NTPEP website) for instructions and background on how to apply the results of the data contained in this report.

Scott Hidden **(North Carolina DOT)**
Chairman, Geosynthetics
Technical Committee

Sophie Brown **(Oregon DOT)**
Vice Chairman, Geosynthetics
Technical Committee

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Tables

Figures

Executive Summary

This test report provides data that can be used to characterize the short-term and long-term tensile strength of the Miragrid XT polyester, PVC coated geogrid reinforcement product line using testing conducted on representative products within the product line. The purpose of this report is to provide data for product qualification purposes.

The test results contained herein were obtained in accordance with AASHTO R69-15 and the NTPEP work plan (see www.NTPEP.org) and can be used to determine the long-term strength of the geosynthetic reinforcement, including the long-term strength reduction factors RF_{ID}, RF_{CR}, and RF_D, and also used to determine low strain creep stiffness values.

All testing reported herein was performed on the materials tested in the direction of manufacture, i.e., the machine direction.

Product Line Description: The product line evaluated includes the following specific polyester, PVC coated geogrid reinforcement products:

Miragrid 2XT, 3XT, 5XT, 7XT, 8XT, 10XT, 20XT, 22XT, and 24XT.

This product line was evaluated through detailed testing of three representative products in the Miragrid XT product line, and very limited testing of the other remaining products in the product line. Miragrid 8XT was used as the primary product for product line characterization purposes (i.e., the baseline to which the other products were compared), and Miragrid 2XT and 24XT were used as secondary products to evaluate the properties of the range of products in the Miragrid XT product line. Products are manufactured at the Miragrid manufacturing plant located in Cornelia, GA and samples of these products were taken by an independent sampler on behalf of NTPEP on March 10, 2017, at the Miragrid warehouse located in Pendergrass, GA.

Statistical Validation of Use of SIM and Validation of Product Line: The creep rupture test results obtained were evaluated in accordance with R69-15 to assess the validity of using SIM to extend the creep rupture data and to assess the validity of treating the products submitted as a single product line. The following was verified:

i. The SIM creep test results were characterized by data statistically consistent with conventional creep tests conducted at the reference temperature up to 10,000 hours, including comparison of single rib and multi-rib test data (see Figure F-21 in Appendix F for details).

ii. Based on the available creep data for all the products tested, the product line submitted by the manufacturer statistically qualifies to be a product line and can therefore be represented using test results from representative products in the product line (see Figure F-22 in Appendix F for details). Recommendations on application of the representative product data to the rest of the product line for installation damage, durability and creep stiffness are provided in their respective report sections and summarized below in this executive summary.

Test Results for T_{ult}: All wide width test results (ASTM D6637) obtained for this product line through the NTPEP testing were greater than the minimum average roll values (MARV's) provided by the manufacturer (see Table 3-1).

Test Results for RF_{ID}: Installation damage testing on this product line resulted in values of RF_{ID} that ranged as follows:

$$RF_{ID} = 1.01 \text{ to } 2.01$$

The RF_{ID} factor of 1.01corresponds to the 3XT product in sandy gravel and 2.01 to the lightest product in coarse gravel.

In general, as the test material gradation becomes more coarse, the value of RF_{ID} increased. Therefore, interpolation of this data to intermediate gradations appears to be feasible. The values of RF_{ID} for all of the products tested did demonstrate a trend of decreasing RF_{ID} as product unit weight/tensile strength increases, at least for the 57 stone gradation, that would allow interpolation of RF_{ID} to products not tested. Therefore, interpolation of these test results to products in the line not tested is feasible. This trend was not as clear for the other gradations. See Table 4-3 and Figures 4-5 through 4-9 for details. Laboratory installation damage test data in accordance with ISO/EN 10722 are also provided for future use in comparison to quality verification testing (see Table 4-6).

It should be noted that the installation damage testing conducted represents an increase in compaction and spreading equipment size (i.e., a 15,000 lb wheeled front end loader – Caterpillar 416E, and a 25,000 lb single drum vibratory roller) and a reduced aggregate lift thickness over the geogrid of 6 inches relative to the installation damage testing reported in previous NTPEP test reports. Therefore, the decrease in strength retained values relative to previous NTPEP test reports for this product line does not represent a change in the products, but instead is the result of the more severe installation damage conditions which represent a likely upper bound installation condition for geosynthetic reinforced soil structures. Actual RF_{ID} values could be lower if installation conditions are less severe (e.g., greater initial lift thickness over the geogrid, use of lighter weight equipment, etc.). Actual RF_{ID} values could be higher if the spreading or compacting equipment tires or tracks are allowed to be in direct contact with the geosynthetic before or during fill placement and compaction, if the thickness of the fill material between the equipment tires or tracks is inadequate (especially for high tire pressure equipment such as dump trucks), or if excessive rutting of the first lift of soil over the geosynthetic (e.g., due to soft subgrade soil) is allowed to occur.

Test Results for RF_{CR}: The creep rupture testing conducted indicates that the following value of RF_{CR} may be used:

$$RF_{CR} = 1.44$$

This value of RF_{CR} is applicable to a 75 year life at 68° F (20° C), and may be used to characterize the full product line as defined herein. See Figure 5-1 for detailed creep rupture envelope or to obtain values for other design lives.

Test Results for RF_D: The chemical durability index testing results meet the requirements in AASHTO R69-15 to allow use of a default reduction factor for RF_D. See Table 6-2 for specific test results, and see AASHTO R69-15 or the document entitled "Use and Application of NTPEP Geosynthetic Reinforcement Test Results" (www.NTPEP.org) for recommended default reduction factors for RF_D. The UV test results (ASTM D4355) for this product line, as represented by the lightest weight product from each manufacturing plant, indicate strength retained at 500 hours in the weatherometer of 94%. These values of UV strength retained should be considered to be a lower bound value for the product line.

Test Results for Creep Stiffness: The 1000 hr, 2% strain secant stiffness ($J_{2\%,1000hr}$) test results ranged from 19,801 lb/ft for the lowest strength style to 190,759 lb/ft for the highest strength style. There exists a strong linear relationship between creep stiffness and the short-term tensile strength (T_{lot}), therefore the 1000 hr, 2% strain secant stiffness can be reasonably expressed for any product in the product line as:

$$J_{2\%,1000\,hr} = 6.6609(T_{lot}) + 942.87$$

Where, T_{lot} is the roll/lot specific single rib tensile strength per ASTM D6637. See Table 7-2 and Figure 7-1 for details. Note that once the stiffness is determined from this equation, an equivalent MARV for this property can be determined by multiplying the stiffness by the ratio of T_{MARV}/T_{lot}.

1.0 Product Line Description and Testing Strategy

1.1 Product Description

The **Miragrid XT Series** family of geogrids are high-strength woven, PVC coated geogrids. The product line evaluated consists of the products as manufactured by TenCate Geosynthetics listed in Table 1-1.

Table 1-1. Product designations included in product line.

Miragrid Reinforcement Product Designations (i.e., Styles)		
Miragrid® 2XT	Miragrid® 7XT	Miragrid® 20XT
Miragrid® 3XT	Miragrid® 8XT	Miragrid® 22XT
Miragrid® 5XT	Miragrid® 10XT	Miragrid® 24XT

The scope of the evaluation is limited to the strength in the machine direction (MD). The cross-machine direction (XD) was not specifically evaluated.

1.2 Product Line Testing Approach

This product line was evaluated through detailed testing of three representative products in the Miragrid XT product line, and very limited testing of the other remaining products in the product line. Miragrid 8XT was used as the primary product for product line characterization purposes (i.e., the baseline to which the other products were compared), and Miragrid 2XT and 24XT were used as secondary products to evaluate the properties of the range of products in the Miragrid XT product line. Products are manufactured at the Miragrid manufacturing plant located in Cornelia, GA and samples of these products were taken by an independent sampler on behalf of NTPEP on March 10, 2017, at the Miragrid warehouse located in Pendergrass, GA.

Photographs of all the products tested are provided in figures 1-1 through 1-9

Figure 1-1. Photo of Miragrid 2XT (machine direction is perpendicular to ruler shown).

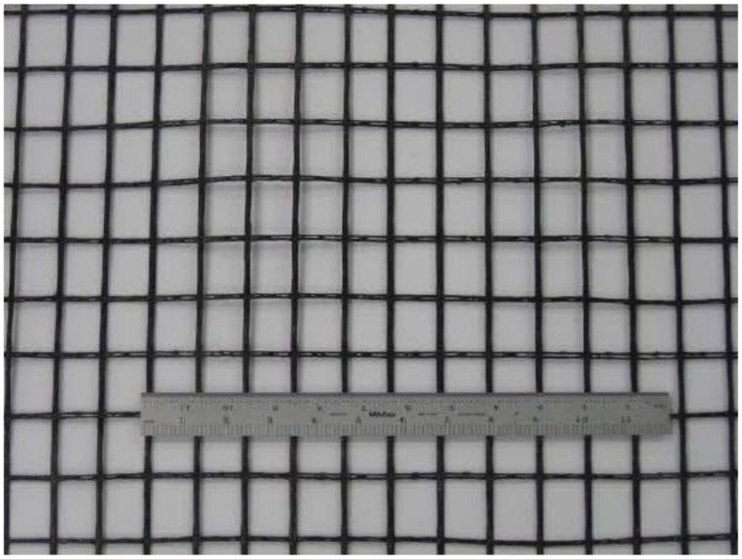


Figure 1-2. Photo of Miragrid 3XT (machine direction is perpendicular to ruler shown).

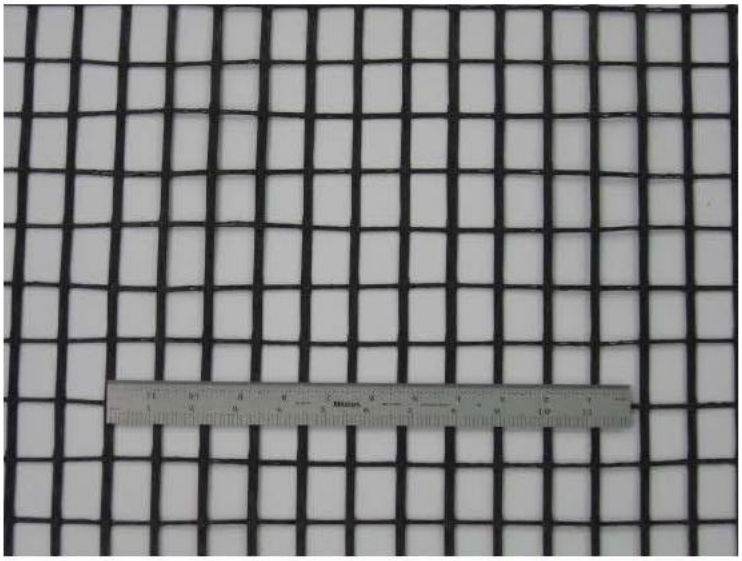


Figure 1-3. Photo of Miragrid 5XT (machine direction is perpendicular to ruler shown).

Figure 1-4. Photo of Miragrid 7XT (machine direction is perpendicular to ruler shown).

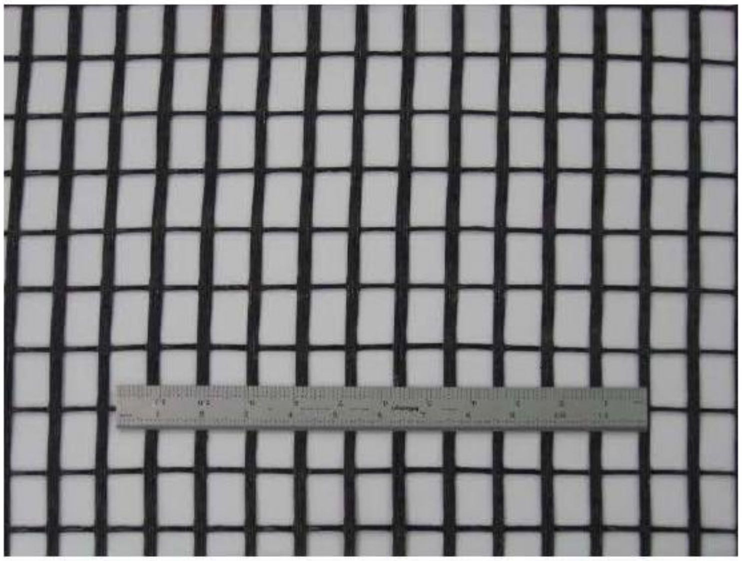


Figure 1-5. Photo of Miragrid 8XT (machine direction is perpendicular to ruler shown).

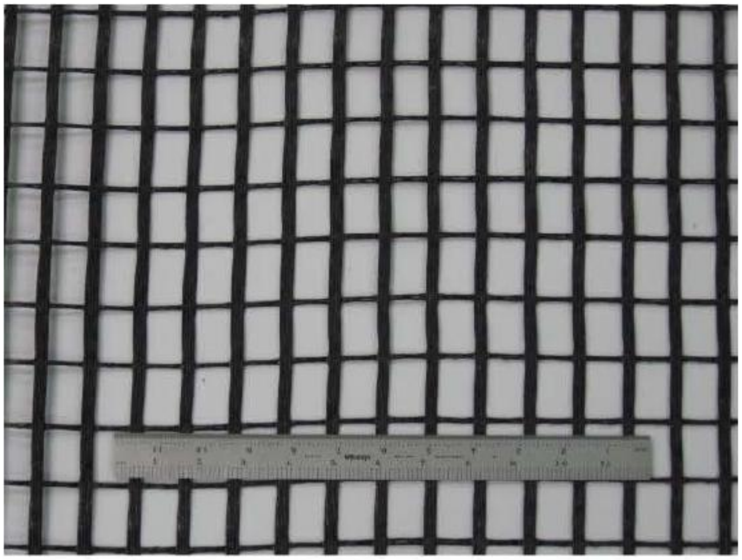


Figure 1-6. Photo of Miragrid 10XT (machine direction is perpendicular to ruler shown).

Figure 1-7. Photo of Miragrid 20XT (machine direction is perpendicular to ruler shown).

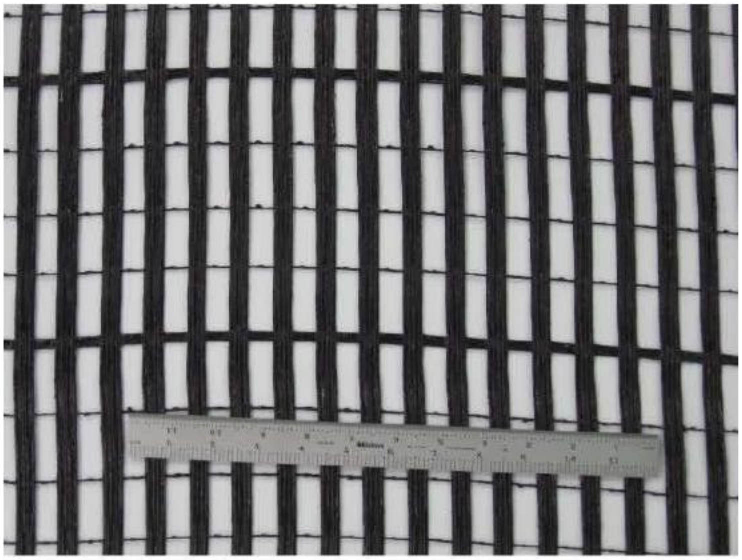


Figure 1-8. Photo of Miragrid 22XT (machine direction is perpendicular to ruler shown).

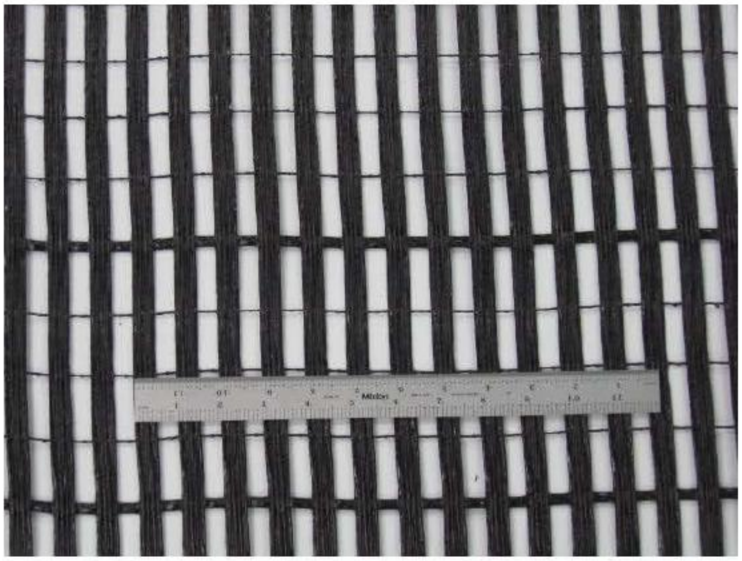


Figure 1-9. Photo of Miragrid 24XT (machine direction is perpendicular to ruler shown).

2.0 Product Polymer, Geometry, and Manufacturing Information

2.1 Product/Polymer Descriptors

Yarn used in all **Miragrid XT Series** geogrids is a high molecular weight, low CEG, high tenacity polyester (PET) with UV inhibitors. The source of the yarns is proprietary. Coating used in all **Miragrid XT Series** geogrids is a PVC-based coating with no post-consumer recycled materials. The source of coating is confidential.

For the PET yarns, key descriptors include minimum production number average molecular weight (GRI-GG7 and ASTM D 4603) and maximum carboxyl end group content (GRI-GG8):

- Minimum Molecular Weight > 25,000 (Measured value is 32,783)
- Maximum CEG < 30 (Measured value is 15.9)
- % of regrind used in product: 0%.
- % of post-consumer recycled material by weight: 0%

2.2 Geometric Properties of Geogrids

Rib width, spacing, thickness, and product weight/unit area vary depending on geogrid style. While such data are generally not used for design, it can be useful for identification purposes, and to be able to detect any changes in the product. Measurements of geogrid rib spacing are also used to convert tensile test results (i.e., load at peak strength, T_{ult}, and load at a specified strain to obtain stiffness, J) to a load per unit width value (i.e., lbs/ft or kN/m). Detailed measurement results, as well as the typical values supplied by the manufacturer for each product, are provided in Appendix B, Section B.1.

2.3 Product Production Data and Manufacturing Quality Control

Geogrid roll sizes and weights, lot sizes, and a summary of the manufacturer's quality control program are provided in Appendix B, Sections B.2 and B.3. Such information can be useful in working with the manufacturer if product quality issues occur.

3.0 Wide Width Tensile Strength Data

Minimum average roll values supplied by the manufacturer and test results obtained on all the products in the product line for this NTPEP testing program are provided in Table 3-1. Wide width tensile tests were conducted in accordance with ASTM D6637. The measured geogrid dimensions discussed in Section 2 and provided in Appendix B, Section B.1, were used to convert test loads to load per unit width values. Note that the independently measured T_{ult} values only indicate that the sampled products have a tensile strength that exceeds the Manufacturer's minimum average roll values (MARV's). As such, these independently measured T_{ult} values should not be used directly for design purposes. However, these independently measured T_{ult} test results have been used as roll specific tensile strengths used for developing installation damage and creep reduction factors. Detailed test results are provided in Appendix C.

Table 3-1. Wide width tensile strength, T_{ult}, for the Miragrid Geogrid XT product line.

Product Style/Type	Test Method	MARV for T_{ult}, in MD (lb/ft)	T_{ult}, Independently Measured in MD (lb/ft)*
2XT	ASTM D 6637	2,000	2,710
3XT	ASTM D 6637	3,500	
5XT	ASTM D 6637	4,700	
7XT	ASTM D 6637	5,900	
8XT	ASTM D 6637	7,400	8,484
10XT	ASTM D 6637	9,500	
20XT	ASTM D 6637	13,705	
22XT	ASTM D 6637	20,559	
24XT	ASTM D 6637	27,415	31,443

(Conversion: 1 lb/ft = 0.0146 kN/m)
MD = machine direction
*Average of 5 specimens obtained during NTPEP testing.

4.0 Installation Damage Data (RF_{ID})

4.1 Installation Damage Test Program

Installation damage testing and interpretation was conducted in accordance with AASHTO R69-15, except as noted herein. Samples were exposed to four "standard" soils: a coarse gravel, a medium gravel, a sandy gravel, and a sand. Additional laboratory installation damage testing in accordance with ISO/EN 10722 was also conducted. The specific installation damage test program is summarized in Table 4-1.

Table 4-1. Independent installation damage testing required for NTPEP qualification.

Manufacturer: TenCate Geosynthetics **PRODUCT Line:** 2XT to 24XT			
Tests Conducted	**Qualification (every 9 yrs) / Verification (every 3 yrs)**		
	Products Tested		**# of Tests (see Note 1)**
	Qualification	**Verification**	
Index tensile tests on undamaged material (ASTM D 6637)	2XT, 3XT, 7XT, 8XT, 24XT	NA	5
Three field exposures, including soil characterization and compaction measurements (ASTM D5818)	2XT, 3XT, 7XT, 8XT, 24XT in 57 stone, Types 1, 2, and 3 soils	NA	20
Tensile tests on damaged specimens (ASTM D 6637)	2XT, 3XT, 7XT, 8XT, 24XT in 57 stone, Types 1, 2, and 3 soils	NA	20
Laboratory installation damage testing –as basis for future QA and to help interpolate full scale field results to products ont full scale field tested (ISO/EN 10722)	2XT, 3XT, 5XT, 7XT, 8XT, 10XT, 20XT, 22XT, 24XT	NA	9
Note 1	Each test is performed using the number of specimens required by the test standard. For example, for index tensile testing, a test is defined 5 to 6 specimens. See the specific test procedures for details on this.		

4.2 Installation Damage Full Scale Field Exposure Procedures and Materials Used

Four "standard" soils were used for the field exposure of the geogrid samples to installation damage. Soil gradation curves for each soil are provided in Figure 4-1. Photographs of each soil illustrating particle angularity are provided in figures 4-2 through 4-5. LA Abrasion tests conducted to characterize the backfill materials indicted a maximum loss of 20%, which is well within the requirements stated in R69-15.

The approach specifically used for applying installation damage to the geosynthetic samples that allows for exhumation of the test samples while avoiding unintended damage was initially developed by Watts and Brady[1] of the Transport Research Laboratory (TRL) in the United Kingdom. The procedure generally conforms to R69-15 and ASTM D 5818 requirements.

Since compaction typically occurs parallel to the face of retaining walls and the contour lines of slopes, the machine direction was placed perpendicular to the running direction of the compaction equipment. To initiate the exposure procedure, four steel plates each measuring 42-inches x 52-inches (1.07 m x 1.32 m), equipped with lifting chains, were placed on a flat clean surface of hardened limestone rock. The longer side of the plates is parallel to the running direction of the compaction equipment. A layer of soil/aggregate was then placed over the adjacent plates to an approximate compacted thickness of 6 inches (0.15 m) except for 57 stone which used a compacted thickness of 8 inches (0.20 m). Next, each of four coupons of the tested geosynthetic sample was placed on the compacted soil over an area corresponding to an underlying steel plate. To complete the installation, the second layer of soil was placed over the coupons using spreading equipment and compacted to a thickness of 6 inches (0.15 m) using a vibratory compactor. The spreading equipment used included a wheeled front end loader and a 23,000 -26,000 lb single drum vibratory roller with pneumatic rear wheels. The front end loader was allowed to spread the aggregate by driving over the geosynthetic with a 6 inch aggregate lift between the wheels and the geosynthetic.

The following construction quality control measures were followed during exposure:

- Proctor and sieve analyses were performed on each soil/aggregate, when possible. (Proctors could not be performed on 57 stone, Gradations 1 and 2.)
- Lift thickness measurements were made after soil/aggregate compaction.
- When possible, moisture and density measurements were made on each lift using a nuclear density gage to confirm that densities >90% of modified Proctor (per ASTM D 1557) were being achieved.

To exhume the geosynthetic, railroad ties were removed and one end of each plate was raised with lifting chains. After raising the plate to about 45°, soil located near the bottom of the leaning plate was removed and, if necessary, the plate was struck with a sledgehammer to loosen the fill. The covering soil/aggregate was then carefully removed from the surface while "rolling" the geosynthetic away from the underlying soil/aggregate. This procedure assured a minimum of

[1] G.R.A. Watts and K.C. Brady (1990), *Site Damage trials on geogrids*, Geogrids, Geomembranes and Related Produts, Balkema Rotterdam.

exhumation stress. Photographs of the installation damage field exposures are provided in Appendix D. A detailed tabulation of each soil gradation is provided in Appendix D, Table D-21.

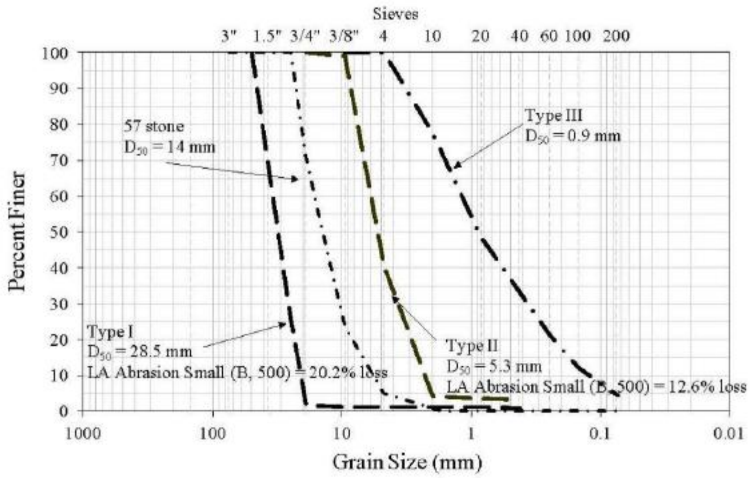


Figure 4-1. Test soil grain size distribution.

Figure 4-2. Installation damage Type 1 test aggregate.

Figure 4-4. Installation damage 57 stone test aggregate.

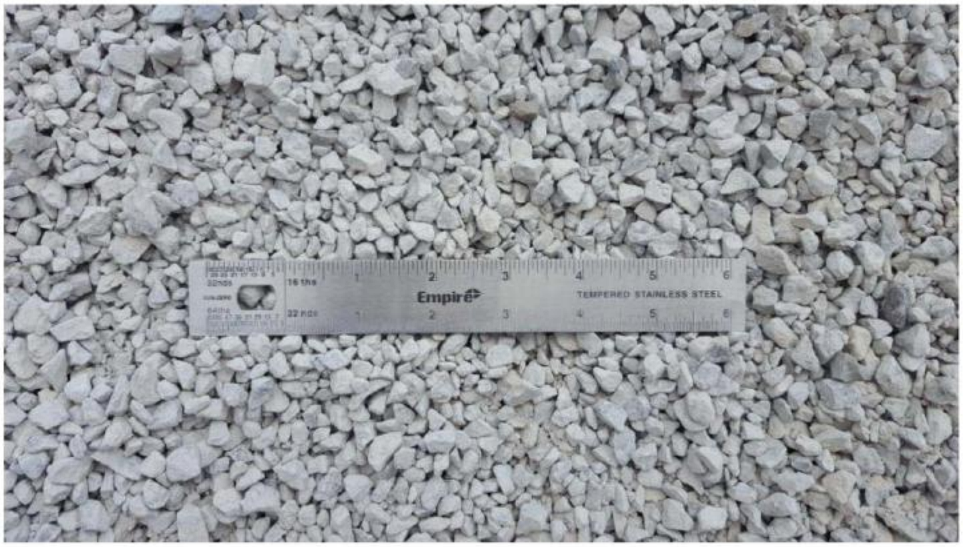


Figure 4-4. Installation damage Type 2 test aggregate.

Figure 4-5. Installation damage Type 3 test aggregate.

4.3 Summary of Installation Damage Full Scale Field Exposure Test Results

The roll specific ultimate tensile strength (ASTM D6637) test results for the baseline, T_{lot} (i.e., undamaged tensile strength tested prior to sample installation in the ground) and the ultimate tensile strength of the installation damaged geogrid samples, T_{dam}, are provided in Table 4-2. RF_{ID}, calculated using the results shown in Table 4-2, are summarized in Table 4-3. Strength retained is calculated as the ratio of the average exhumed strength T_{dam} divided by the average baseline strength T_{lot} for the product sample. RF_{ID} is the inverse of the retained strength (i.e. 1 / 0.779 = 1.28). Detailed test results for each specimen tested are provided in Appendix D, Tables D-1 through D-20.

Table 4-2. Summary of installation damage tensile test results.

Backfill Type	Style	Baseline		Exhumed	
		[1]T_{lot} (lb/ft)	COV (%)	[2]T_{dam} (lb/ft)	COV (%)
Type 1 Coarse Gravel (GP)	2XT	2,710	1.39	1,346	14.95
	3XT	3,795	1.35	2,965	8.33
	7XT	6,579	1.47	4,237	7.92
	8XT	8,488	2.37	5,670	8.61
	24XT	31,443	2.97	22,493	6.37
57 stone (GP)	2XT	2,710	1.39	1,861	13.67
	3XT	3,795	1.35	2,844	14.91
	7XT	6,579	1.47	4,655	9.87
	8XT	8,488	2.37	6,180	6.06
	24XT	31,443	2.97	25,598	4.40
Type 2 Sandy Gravel (GP)	2XT	2,710	1.39	2,578	1.20
	3XT	3,795	1.35	3,740	1.92
	7XT	6,579	1.47	5,981	3.50
	8XT	8,488	2.37	7,613	2.78
	24XT	31,443	2.97	29,991	1.42
Type 3 Silty Sand (SM)	2XT	2,710	1.39	2,494	4.35
	3XT	3,795	1.35	3,680	1.52
	7XT	6,579	1.47	6,121	4.06
	8XT	8,488	2.37	7,111	5.48
	24XT	31,443	2.97	28,781	2.84

[1]Average of 5 specimens.
[2]Average of 10 specimens.
(Conversion: 1 lb/ft = 0.0146 kN/m)

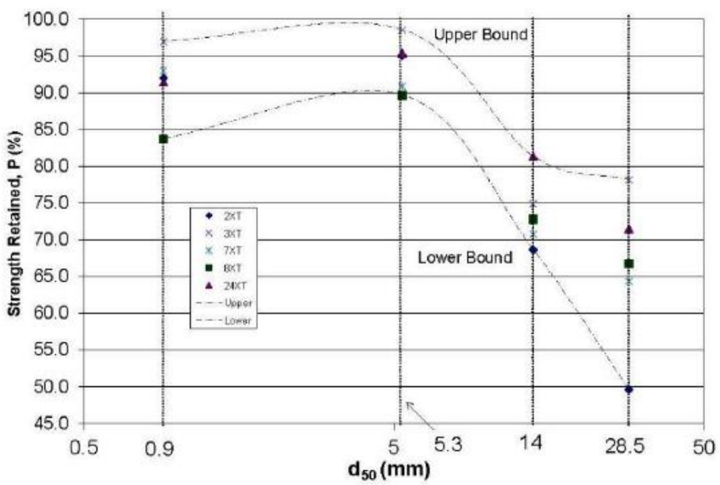
Table 4-3. Measured RF_{ID}.

Style	Mass / Area (oz./yd^2)	Type 1 Coarse Gravel		57 stone		Type 2 Sandy Gravel		Type 3 Silty Sand	
		% Retained	RF_{ID}	% Retained	RF_{ID}	% Retained	RF_{ID}	% Retained	RF_{ID}
2XT	6.52	49.7	2.01	68.7	1.46	95.1	1.05	92.0	1.09
3XT	6.51	78.1	1.28	74.9	1.33	98.6	1.01	97.0	1.03
7XT	8.66	64.4	1.55	70.8	1.41	90.9	1.10	93.0	1.07
8XT	10.08	66.8	1.50	72.8	1.37	89.7	1.11	83.8	1.19
24XT	30.74	71.5	1.40	81.4	1.23	95.4	1.05	91.5	1.09

4.4 Estimating RF_{ID} for Specific Soils or for Products not Tested

In general, as the test material gradation becomes more coarse, the value of strength retained decreased (i.e., RF_{ID} increased). Trend lines plotted in Figure 4-5 for the upper bound and lower bound for all the installation damage data obtained for the product line illustrate the general trend of the installation damage data with regard to soil d_{50} size. Interpolation of this data to intermediate gradations appears to be feasible based on these test results, though the scatter in that trend should be recognized when estimating values of RF_{ID} for specific soils.

Only representative products in the product line were installation damage tested for the full range of soil gradations (57 stone and Gradations 1 through 3). However, bench scale installation damage tests (ISO/EN 10722) were conducted for the remaining products in the line to verify whether or not interpolation of the installation damage test results was feasible for the remaining products in the line not fully evaluated for installation damage resistance. The Miragrid XT product line generally exhibited moderately strong relationships between the weight or the tensile strength of the product and the strength retained after installation damage for 57 stone but showed no consistent relationship with product weight or tensile strength for gradations 1, 2 and 3. See figures 4-6 through 4-9 for illustrations of those relationships. Therefore, interpolation of these test results to products in the line not tested based on product weight or strength may be only feasible for 57 stone, though caution should be exercised and appropriate judgment applied to insure a safe estimate of RF_{ID} each product. For products in the product line not tested in the full scale installation damage tests, for gradations 1, 2 and 3, use of a lower bound value of strength retained for the products not tested in the full scale installation damage tests (i.e., (P_{dmin} in Figure 4-6) appears to be appropriate for design.



Note: $RF_{ID} = 1/P$; d_{50} = sieve size at which 50% of soil passes by weight

Figure 4-5. Miragrid XT product line installation damage as a function of soil d_{50} size.

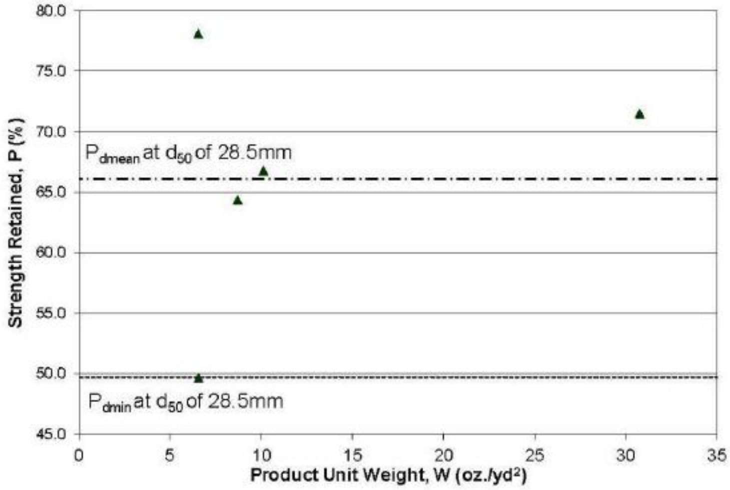


Figure 4-6. Miragrid XT product line installation damage as a function of product unit weight for type 1 soil (coarse gravel - GP).

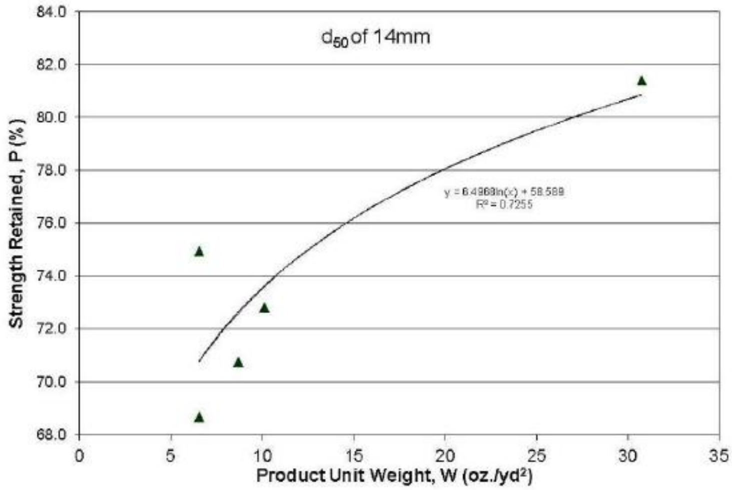


Figure 4-7. Miragrid XT product line installation damage as a function of product unit weight for 57 stone (GP).

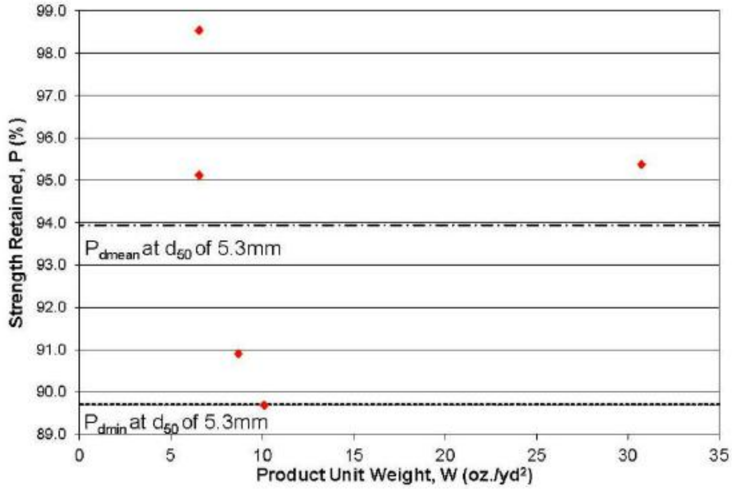


Figure 4-8. Miragrid XT product line installation damage as a function of product unit weight for type 2 soil (sandy gravel - GP).

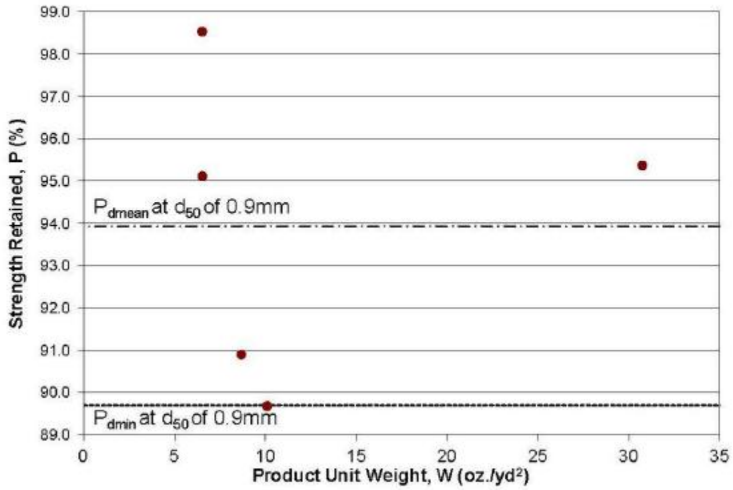


Figure 4-9. Miragrid XT product line installation damage as a function of product unit weight for type 3 soil (silty sand – SM).

It should be noted that the installation damage testing conducted represents an increase in compaction and spreading equipment size (i.e., a 15,000 lb wheeled front end loader – Caterpillar 416E, and a 25,000 lb single drum vibratory roller – a 10,000 lb roller was used in past testing) and a reduced aggregate lift thickness over the geogrid of 6 inches (an 8 inch lift thickness was used in past testing) relative to the installation damage testing reported in previous NTPEP test reports. Therefore, the decrease in strength retained values relative to previous NTPEP test reports for this product line does not represent a change in the products, but instead is the result of the more severe installation damage conditions which represent a likely upper bound installation condition for geosynthetic reinforced soil structures. Actual RF_{ID} values could be lower if installation conditions are less severe (e.g., greater initial lift thickness over the geogrid, use of lighter weight equipment, etc.). Actual RF_{ID} values could be higher if the spreading or compacting equipment tires or tracks are allowed to be in direct contact with the geosynthetic before or during fill placement and compaction, if the thickness of the fill material between the equipment tires or tracks is inadequate (especially for high tire pressure equipment such as dump trucks), or if excessive rutting of the first lift of soil over the geosynthetic (e.g., due to soft subgrade soil) is allowed to occur.

4.5 Laboratory Installation Damage Test Results per ISO/EN 10722

Laboratory Installation damage testing and interpretation was conducted in accordance with ISO/EN 10722. In this procedure, geosynthetic specimens are exposed to simulated installation stresses and abrasion using a standard "backfill" material in a bench scale device. Once exposed, they are tested for tensile strength to determine the retained strength after damage. Five baseline and five exposed specimens from each product were tested. The test results are summarized in Table 4-4. Detailed test results are provided in Appendix E, as well as a photograph of the test set-up and a close up of the standard backfill material used.

This procedure is intended to be a reproducible index test to assess relative susceptibility of the geosynthetic to damage. In this NTPEP testing program, the results from this test are primarily intended to be used for future quality assurance to assess the consistency in the product's susceptibility to installation damage. It is not intended to be used directly in the determination of RF_{ID} for a given soil backfill gradation.

Table 4-4. Summary of laboratory (ISO procedure) installation damage test results.

Miragrid XT Style	Mean Baseline Tensile Strength (lb/ft)	Coefficient of Variation (%)	Mean Exposed Tensile Strength (lb/ft)	Coefficient of Variation (%)	Strength Retained (%)
2XT	2,759	2	2,483	6	90
3XT	4,020	2	3,528	7	88
5XT	5,127	2	4,737	5	92
7XT	6,734	2	5,394	10	80
8XT	8,286	2	7,078	5	85
10XT	11,491	3	9,820	6	85
20XT	17,648	2	15,860	4	90
22XT	24,164	3	22,307	3	92
24XT	32,917	1	29,139	3	89

(Conversion: 1 lb/ft = 0.0146 kN/m)

5.0 Creep Rupture Data (RF_{CR})

5.1 Creep Rupture Test Program

Creep testing and interpretation has been conducted in accordance with AASHTO R69-15. A baseline (i.e., reference) temperature of 68° F (20° C) was used. 8XT was used as the primary product to establish the creep rupture envelope, with limited creep testing of the other Miragrid XT geogrids (i.e., 2XT and 24XT) to verify the ability to interpolate creep rupture behavior to the Miragrid geogrid products not specifically tested (i.e., to treat all the products submitted for evaluation as a product line per R69-15 and the NTPEP work plan).

The creep rupture testing program is summarized in Figure 5-1. Creep testing was conducted using both ASTM D5262 (termed "conventional" creep testing) and ASTM D6992 (i.e., the Stepped Isothermal Method - SIM). A limited number (6) of tests using ASTM D5262, conducted only at the reference temperature of 68° F (20° C) for up to a maximum time of 10,000 hrs were used for comparison purposes to verify the accuracy of the SIM creep tests. Since the SIM creep tests are conducted as single rib tests and conventional creep tests (ASTM D5262) conducted as single-rib and multi-rib tests, both single rib and wide width (multi-rib) short-term tensile tests were conducted for the primary product, 8XT. This was done for comparison purposes to establish the validity of using single rib creep test data as well as to ensure that the correct index tensile strength is used, since the creep load is expressed as a percent of T_{ult}.

Table 5-1. Independent creep rupture testing required for NTPEP qualification.

Manufacturer: TenCate Geosynthetics PRODUCT Line: 2XT to 24XT			
Tests Conducted	Qualification (every 9 yrs) / Verification (every 3 yrs)		
	Products Tested		# of Tests (see Note 1)
	Qualification	Verification	
Index single rib tensile tests on lot specific material (ASTM D6637)	2XT, 8XT, 24XT	NA	3
Index wide width tensile tests on lot specific material (ASTM D6637)	NA	NA	0
PRIMARY PRODUCT 6 Rupture Points – Conventional Creep testing up to 1000 hrs (ASTM D5262)	8XT @ 6 load levels	NA	6
PRIMARY PRODUCT 6 Rupture Points – Accelerated Creep rupture testing (SIM). (ASTM D6992)	8XT @ 6 load levels	NA	6
SECONDARY PRODUCT(S) Conventional Creep Testing (ASTM D5262)	None	NA	0
SECONDARY PRODUCT(S) Accelerated Creep rupture testing (SIM). (ASTM D6992)	2XT and 24XT @ 4 load levels	NA	8
Note 1: Each test is performed using the number of specimens required by the test standard. For example, for index tensile testing, a test is defined 5 to 6 specimens. See the specific test procedures for details on this.			

5.2 Baseline Tensile Strength Test Results

All creep testing using SIM (ASTM D6992) was performed on single rib specimens, whereas single-rib and multi-rib specimens were used for the conventional (ASTM D5262) creep tests. Both types of tests were only conducted for the 8XT geogrid product. To facilitate use of both single rib to wide width specimens for the creep testing, rapid loading tensile and creep tests were conducted, in accordance with R69-15. The multi-rib rupture points fit closely with the single rib rupture curve (see Figure 5-1). The tensile test specimens tested were taken from the same rolls of material that were used for the creep testing. The measured geogrid dimensions discussed in Section 2 and provided in Appendix B, Section B.1, were used to convert tensile test loads to load per unit width values.

Table 5-2. Ultimate tensile strength (UTS) and associated strain.

Product	Single Rib UTS per ASTM D6637, T_{lot} (lb/ft @ % Strain)
2XT	2,753 @ 9.87%
8XT	8,636 @ 13.4%
24XT	28,474 @ 13.0%

(Conversion: 1 lb/ft = 0.0146 kN/m)

5.3 Creep Rupture Test Results

A total of 14 Stepped Isothermal Method (SIM) tests and 6 conventional creep tests were run to fulfill the qualification requirements. Table 5-3 summarize the tests performed and their outcomes. Detailed test results, including creep curves for each specimen tested, are provided in Appendix F, Figures F-1 through F-20.

Table 5-3. Creep rupture test results for all tests conducted.

Style & Test Type	Creep Load (% of T_{lot})	Time to Rupture (log hrs)
2XT - SIM	70.96	5.4100
2XT - SIM	75.00	4.1304
2XT - SIM	79.00	2.4319
2XT - SIM	83.00	1.3981
8XT - SIM	68.00	6.2548
8XT - SIM	71.00	5.0359
8XT - SIM	74.00	4.8030
8XT - SIM	77.00	3.1833
8XT - SIM	80.00	2.2342
8XT - SIM	83.00	1.5275
8XT - Conv.+	81.00	2.0423
8XT - Conv.+	80.00	2.1602
8XT - Conv.+	79.00	2.6325
8XT - Conv.+	77.50	3.8328
8XT - Conv.	76.00	3.3958
8XT - Conv.	74.00	4.0000*
24XT - SIM	70.00	5.4648
24XT - SIM	74.00	4.5842
24XT - SIM	78.00	3.3838
24XT - SIM	82.00	1.5877

+ Multi-rib specimen, * Finished without rupture

5.3.1 Statistical Validation to Allow the Use of SIM Data to Establish Rupture Envelope

Details of the confidence limits evaluation conducted in accordance with R69-15 are contained in Appendix F. Figure F-21 provides a plot of the creep rupture envelope with the confidence limits and the rupture envelopes for the conventional creep and SIM creep data, illustrating this statistical test. Detailed calculation results for this statistical analysis are provided in Table F-2, and summarized in Table F-6. The results indicate that the SIM data meet the statistical validation requirements in R69-15 (i.e., the SIM rupture envelope is within the specified 90% confidence limits of the "conventional" creep rupture data). Thus, the conventional and accelerated (SIM) data may be used together to construct the characteristic creep rupture curve of the primary product, and SIM data may also be used for creep testing of the other two geogrid products to evaluate the potential to construct a composite creep curve for the product line.

5.3.2 Statistical Validation to Allow the Use of Composite Rupture Envelope for Product Line

Details of the confidence limits evaluation for the product line conducted in accordance with R69-15 are contained in Appendix F. Figure F-22 provides a plot of the creep rupture envelope with the confidence limits and the rupture envelopes for the primary product and the other tested products (i.e., 2XT and 24XT), illustrating this statistical test. Detailed calculation results for this statistical analysis are provided in Tables F-3 and F-4, and summarized in Table F-7. The results indicate that the rupture envelopes for the 2XT and 24XT products are within the specified 90% confidence limits of the primary product (i.e., 8XT) creep rupture data, meeting R69-15 requirements. Thus, all the Miragrid XT products tested (i.e., 2XT, 8XT and 24XT) can be used to construct a composite creep rupture envelope representing the entire product line. The calculation results for the statistical analysis and regression to create the full composite creep curve are provided in Table F-5.

5.4 Creep Rupture Envelope Development and Determination of RF_{CR}

In consideration of the statistical validation described in Section 5.3 of this report, a composite creep rupture envelope, using log-linear regression, was constructed as shown in Figure 5-1. The mix of conventional and accelerated (SIM) creep rupture test data points meets R69-15 requirements. Based on this plot of all data, the regression of the data shows that the r^2 value is 0.97 (see Table F-5 in Appendix F for details). Per R69-15, this degree of scatter in the data is acceptable for a composite rupture envelope.

The creep rupture envelope in Figure 5-1 should be considered valid for the entire Miragrid XT geogrid product line evaluated in this report. Since the temperature accelerated creep results produced through the SIM testing allowed time shifting of the creep rupture data points to over 1,000,000 hours (i.e., 114 years), no extrapolation uncertainty factor in accordance with R69-15 need be applied. Table 5-4 provides the estimated value of RF_{CR} for the Miragrid XT geogrid product line based on the reported testing for a period of long-term loading of up to 100 years.

This rupture envelope can be used to determine RF_{CR} for times other than 3, 75 and 100 years, if desired.

Table 5-4. RF_{CR} value for Miragrid XT series geogrids for 3, 75 and 100 yr periods of loading/use.

Period of Use (in years)	RF_{CR} for Rupture – All XT Styles
3	1.36
75	1.44
100	1.45

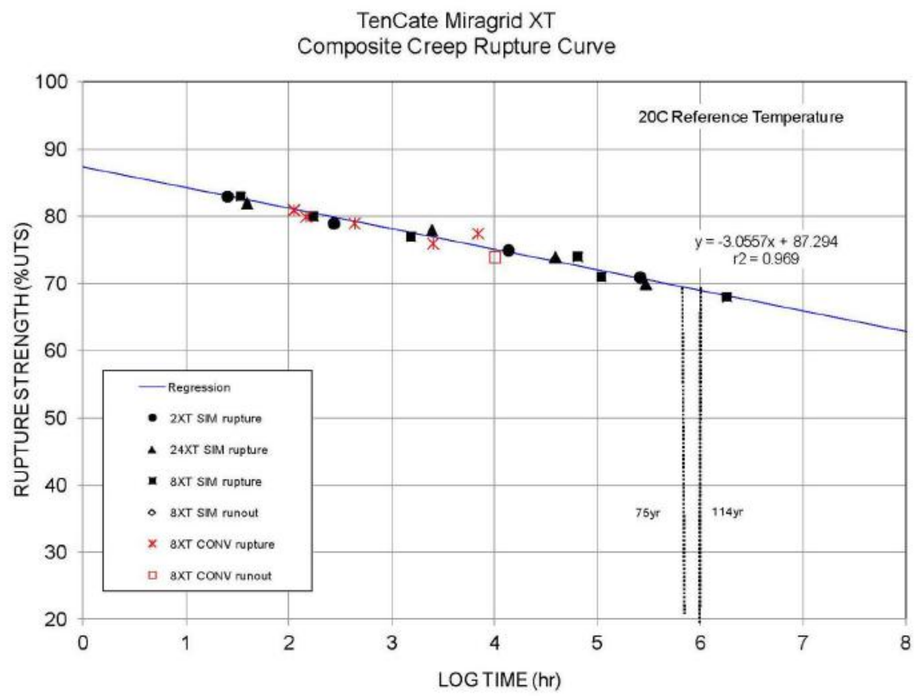


Figure 5-1. Composite creep rupture data/envelope for the Miragrid XT geogrid product line.

6.0 Long-Term Durability Data (RF_D)

6.1 Durability Test Program

Basic molecular properties relating to durability were evaluated, allowing a "default" RF_D to be used in accordance with AASHTO R69-15, provided that the long-term environment in which the geosynthetic is to be used is considered to be non-aggressive in accordance with the AASHTO LRFD Bridge Design Specifications and R69-15. A non-aggressive long-term environment is described in these documents as follows:

- A soil ph of 4.5 to 9.0,
- A maximum particle size of 0.75 inches or less unless installation damage effects are specifically evaluated using full scale installation damage testing in accordance with ASTM D 5818,
- A soil organic content of 1% or less, and
- An effective design temperature at the site of 86°F (30°C) or less.

Other specific soil/environmental conditions that could be of concern to consider the site environment to be aggressive are discussed in Elias[2].

The index properties/test results obtained can be related to long-term performance of the polymer through correlation to longer-term laboratory durability performance tests and long-term experience. Note that long-term durability performance testing in accordance with R69-15 and the NTPEP work plan to allow direct calculation of RF_D was not available from the manufacturer, nor evaluated as part of the testing program for this product line.

For polyester (PET) geosynthetics, key durability issues to address include hydrolysis and ultraviolet (UV) oxidative degradation. To assess the potential for these types of degradation, index property tests to assess molecular weight, carboxyl end group content, and ultraviolet (UV) oxidative degradation are conducted. Criteria for test results obtained from each of these tests are provided in R69-15 as well as the AASHTO LRFD Bridge Design Specifications.

The UV degradation tests were conducted on the lightest weight product in the product line (2XT) as recommended in R69-15. Since UV degradation attacks from the surface of the geosynthetic, the heavier the product, the more resistant it will be to UV degradation. Therefore, UV testing the lightest weight product should produce the most conservative result.

The molecular weight and carboxyl end group content tests are conducted on the base yarn for the product series. Since for a product line the base yarn used must be the same for all products in the line, these tests on the base yarn will be applicable to all products in the product line.

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[2] Elias, V., 2000, *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, FHWA-NHI-09-087, Federal Highway Administration, Washington, D.C.

Table 6-1. Independent durability testing required for NTPEP qualification.

Manufacturer: TenCate Geosynthetics PRODUCT Line: 2XT to 24XT			
Tests Conducted	**Qualification (every 9 yrs) / Verification (every 3 yrs)**		
	Products Tested		**# of Tests (see Note 1)**
	Qualification	**Verification**	
All polymers, resistance to weathering @ 500 hrs (ASTM D4355), including before/after tensile strength	2XT	NA	1
For polyesters, molecular weight determination (ASTM D4603 and GRI-GG7) – **on yarn/strip**	Miragrid XT yarn	NA	1
For polyesters, carboxyl end group content determination (GRI-GG8) – **on yarn/strip**	Miragrid XT yarn	NA	1
CEG-MW Testing Coating Removal, if necessary	NA	NA	0
Brittleness (AASHTO R69-15)	NA	NA	0
For polyolefins, long-term evaluation via Oxidative degradation (ISO/EN 13438:1999)	NA	NA	0
For polyesters, long-term evaluation via Hydrolytic degradation (AASHTO R69-15)	None	None	0
For polyolefins, long-term evaluation via Oxidative degradation (AASHTO R69-15)	NA	NA	0
Note 1: Each test is performed using the number of specimens required by the test standard. For example, for index tensile testing, a test is defined 5 to 6 specimens. See the specific test procedures for details on this.			

6.2 Durability Test Results

A summary of the test results is provided in Table 6-2. This table also includes the criteria to allow the use of a default reduction factor for RF_D provided in R69-15 and the AASHTO LRFD Bridge Design Specifications. Detailed durability test results are provided in Appendix G.

Table 6-2. NTPEP durability test results for the Miragrid XT geogrid product line and criteria to allow use of a default value for RF_D.

Polymer Type	Property	Test Method	Criteria to Allow Use of Default RF*	Test Result Obtained as Part of NTPEP Program
PP and HDPE	UV Oxidation Resistance	ASTM D4355	Min. 70% strength retained after 500 hrs in weatherometer	NA
PET	UV Oxidation Resistance	ASTM D4355	Min. 50% strength retained after 500 hrs in weatherometer if geosynthetic will be buried within one week, 70% if left exposed for more than one week.	94% strength retained
PP and HDPE	Thermo-Oxidation Resistance	ENV ISO 13438:1999, Method A (PP) or B (HDPE)	Min. 50% strength retained after 28 days (PP) or 56 days (HDPE)	NA
PET	Hydrolysis Resistance	Inherent Viscosity Method (ASTM D4603 and GRI Test Method GG8)	Min. Number Average Molecular Weight of 25,000	32,783
PET	Hydrolysis Resistance	GRI Test Method GG7	Max. Carboxyl End Group Content of 30	15.9

Note: PP = polypropylene, HDPE = high density polyethylene, PET = polyester

Based on these test results, all products in the product line meet the minimum UV requirement shown in Table 6-2. Regarding hydrolysis resistance, these test results shown in Table 6-2 indicate that this product line has adequate long-term resistance to hydrolysis to justify the use of a default value for RF_D, meeting the requirements in AASHTO R69-15.

Note that while no specific tests, other than installation damage, were conducted to evaluate the durability of the coating, because the hydrolysis resistance characterization was determined based on the base polymer, any potential coating degradation should have very little effect on the long-term durability of the geogrid product and the default value of RF_D selected. Typically, a default value of 1.3 for RF_D is selected. See AASHTO R69-15, or the document entitled "Use and Application of NTPEP Geosynthetic Reinforcement Test Results" (www.NTPEP.org), for guidance on the selection of a default value for RF_D.

7.0 Low Strain Creep Stiffness Data

7.1 Low Strain Creep Stiffness Test Program

Creep stiffness testing was conducted in accordance with AASHTO R69-15 and the NTPEP work plan. The creep stiffness determination was targeted to 2% strain at 1,000 hours.

Products selected to represent the XT product line (i.e., 2XT, 8XT, and 24XT) were tested for creep stiffness. Roll specific single rib short-term rapid loading tensile strength tests (T_{lot}) were conducted for each product for correlation purposes and to calculate load levels. A total of nine Ramp and Hold (R&H), 1,000 second creep tests, were conducted on each product. Three specimens were R&H tested at each of the following stresses: 5, 10 and 20% of the ultimate tensile strength (UTS). A linear regression based on %UTS and % strain at 0.1 hour was used to normalize strain curves to reduce the variability of the elastic portion of the strain curve. The % UTS required to obtain 2% strain at 1,000 hours was then determined. Three R&H tests and two 1,000 hour conventional creep tests (ASTM D5262, but as modified for low strain in R69-15 and using a single rib specimen) were conducted at this load. All tests were conducted at 68° F (20° C).

7.2 Ultimate Tensile Test Results for Creep Stiffness Test Program

The values provided in Table 7-1 represent the baseline, roll specific, ultimate tensile strength used to normalize the load level for the creep stiffness testing. Sample specific geogrid dimensions were used to convert tensile test loads to load per unit width values.

Table 7-1. Ultimate tensile strength (UTS) & associated strain.

Product	T_{lot} for Single Rib (lb/ft @ % Strain)
2XT	2,753 @ 9.87%
8XT	8,636 @ 13.4%
24XT	28,474 @ 13.0%

(Conversion: 1 lb/ft = 0.0146 kN/m)

7.3 Creep Stiffness Test Results

Detailed test results are provided in Appendix H. Table 7-2 provides a summary of the creep stiffness values obtained. Note that the creep stiffness values at 1,000 hours and 5%UTS, 10%UTS and 20%UTS represent stiffness values at strains other than 2% strain. See Appendix H for details. Figure 7-1 shows the relationship between the measured tensile strength and the creep stiffness. Considering the strong linear relationship between the creep stiffness and the product tensile strength, interpolation to other products in the product line not tested to determine creep stiffness values for those products is acceptable.

Table 7-2. Summary of creep stiffness test results.

Miragrid XT Series Style	Average Creep Stiffness @ 1000 hours for 5% UTS Ramp & Hold (lb/ft)	Average Creep Stiffness @ 1000 hours for 10% UTS Ramp & Hold (lb/ft)	Average Creep Stiffness @ 1000 hours for 20% UTS Ramp & Hold (lb/ft)	Average Creep Stiffness for 2% strain @ 1000 hrs (lb/ft)
2XT	64,509	19,130	19,073	**19,801**
8XT	126,611	68,936	43,470	**57,791**
24XT	772,557	247,151	120,789	**190,759**

(Conversion: 1 lb/ft = 0.0146 kN/m)

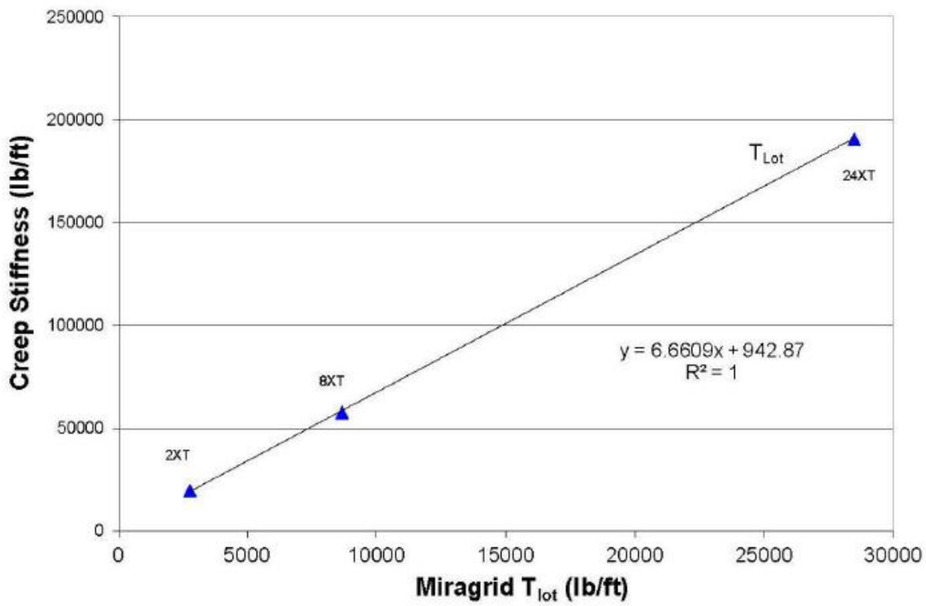

Figure 7-1. Miragrid XT creep stiffness for 2 % strain @ 1000 hours.

To obtain the minimum likely stiffness value for each product in consideration of the MARV tensile strength, multiply the stiffness value from the plot by the ratio of T_{MARV}/T_{lot}. T_{MARV} is the minimum tensile strength, as provided by the manufacturer, for each product in the product line. T_{lot} is the actual roll specific tensile strength for the sample used in the creep stiffness testing.

APPENDICES

Appendix A: NTPEP Oversight Committee

Name	Email Address	Agency Name	Designation	Member Type
Hidden, Scott	shidden@ncdot.gov	North Carolina Department of Transportation	Chair	Voting
Golden, Shannon G.	goldens@dot.state.al.us	Alabama Department of Transportation	Member	Voting
Herrera, Rodrigo A	rodrigo.herrera@dot.state.fl.us	Florida Department of Transportation	Member	Voting
Hughes, Scott Eric	Scott.Hughes@illinois.gov	Illinois Department of Transportation	Member	Voting
Sommers, Scott Michael	scott.sommers@iowadot.us	Iowa Department of Transportation	Member	Voting
Davis, Jason	jason.davis@la.gov	Louisiana Department of Transportation and Development	Member	Voting
Sajedi, Dan	dsajedi@sha.state.md.us	Maryland Department of Transportation	Member	Voting
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La Cour, Ian	ilacour@mdot.ms.gov	Mississippi Department of Transportation	Member	Voting
Mclain, Kevin Wade	kevin.mclain@modot.mo.gov	Missouri Department of Transportation	Member	Voting
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Berg, Ryan	RyanBerg@att.net	Ryan R. Berg & Associates, Inc.	Member	Non-Voting
Lostumbo, John	j.lostumbo@tencategeo.com	TenCate Geosynthetics	Member	Non-Voting
Kern, Claudia	claudia.kern@txdot.gov	Texas Department of Transportation	Member	Voting
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Shi, Bin	bshi@utah.gov	Utah Department of Transportation	Member	Voting
Kim, Wan Soo	wansoo.kim@vdot.virginia.gov	Virginia Department of Transportation	Member	Voting
Allen, Tony M	allent@wsdot.wa.gov	Washington State Department of Transportation	Member	Voting

Appendix B: Product Geometric and Production Details

B.1 Product Geometric Information

Table B-1. Typical and measured MD geogrid geometry for the Miragrid XT product line.

Machine Direction (MD) Ribs								
Style	Width (in)		Spacing (in)		Aperture Size (in)		Rib Thickness (in)	
	Typical Values	As Measured*	Typical Values	As Measured*	Typical Values	As Measured *	Typical Values	As Measured*
2XT	N/A	0.098	N/A	1.126	0.875	0.840	N/A	0.054
3XT	N/A	0.054	N/A	1.104	1.0	1.520	N/A	0.054
5XT	N/A	0.193	N/A	1.107	1.2	1.573	N/A	0.057
7XT	N/A	0.246	N/A	1.116	1.3	1.459	N/A	0.053
8XT	N/A	0.271	N/A	1.080	1.3	1.573	N/A	0.050
10XT	N/A	0.325	N/A	1.110	1.3	1.498	N/A	0.058
20XT	N/A	0.418	N/A	1.012	1.5	1.395	N/A	0.081
22XT	N/A	0.460	N/A	0.969	1.4	1.404	N/A	0.092
24XT	N/A	0.569	N/A	1.009	1.4	1.403	N/A	0.086

(Conversions: 1 in = 25.4 mm)

*Average of 5 readings obtained during NTPEP testing. Full test results in tables B-5 through B-13.

Table B-2. Typical and measured XD geogrid geometry for the Miragrid XT product line.

Cross-Machine Direction (XD) Ribs								
Style	Width (in)		Spacing (in)		Aperture Size (in)		Rib Thickness (in)	
	Typical Values	As Measured*	Typical Values	As Measured*	Typical Values	As Measured*	Typical Values	As Measured*
2XT	N/A	0.099	N/A	0.939	1.0	1.028	N/A	0.053
3XT	N/A	0.110	N/A	1.630	1.0	0.950	N/A	0.055
5XT	N/A	0.115	N/A	1.687	1.0	0.914	N/A	0.044
7XT	N/A	0.108	N/A	1.566	0.9	0.870	N/A	0.047
8XT	N/A	0.101	N/A	1.674	0.9	0.809	N/A	0.053
10XT	N/A	0.253	N/A	1.751	0.8	0.785	N/A	0.064
20XT	N/A	0.263	N/A	1.658	0.6	0.594	N/A	0.053
22XT	N/A	0.232	N/A	1.636	0.6	0.509	N/A	0.069
24XT	N/A	0.229	N/A	1.632	0.5	0.439	N/A	0.062

(Conversions: 1 in = 25.4 mm)

*Average of 5 readings obtained during NTPEP testing. Full test results in tables B-5 through B-13.

Table B-3. Typical and measured geogrid junction thickness for the Miragrid XT product line.

Style	Junction Thickness (in)	
	Typical Values	As Measured*
2XT	Not tested	0.056
3XT	Not tested	0.056
5XT	Not tested	0.059
7XT	Not tested	0.061
8XT	Not tested	0.061
10XT	Not tested	0.073
20XT	Not tested	0.095
22XT	Not tested	0.106
24XT	Not tested	0.106

(Conversions: 1 in = 25.4 mm)

*Average of 5 readings obtained during NTPEP testing. Full test results in tables B-5 through B-13.

Table B-4. Typical and measured geogrid unit weight for the Miragrid XT product line.

Geogrid Style/Type	Typical Weight (oz/yd^2)	Measured Weight*, per ASTM D5261 (oz/yd^2)
2XT	7.50	6.52
3XT	8.17	6.51
5XT	9.00	8.69
7XT	10.21	8.66
8XT	11.42	10.08
10XT	14.31	12.82
20XT	22.12	19.03
22XT	30.50	25.29
24XT	38.02	30.74

(Conversion: 1 oz/yd^2 = 33.9 g/m^2)

*Average of 5 readings obtained during NTPEP testing. Full test results in tables B-5 through B-13.

Table B-5. Geogrid geometric measurements for 2XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)							
Specimen Width (in) 7.77							
Specimen Length (in) 7.4							
Mass(g)	8.02	8.28	8.31	8.23	8.23		
Mass/unit area (oz/sq.yd)	6.37	6.58	6.60	6.54	6.54	**6.52**	0.09
Mass/unit area (g/sq.meter)	216	223	224	222	222	**221**	3
Aperature Size (Calipers)							
MD - Aperature Size (in)	0.863	0.790	0.836	0.868	0.845	**0.840**	0.031
MD - Aperature Size (mm)	21.9	20.1	21.2	22.0	21.5	**21.3**	0.8
TD - Aperature Size (in)	1.017	1.035	1.035	1.019	1.036	**1.028**	0.010
TD - Aperature Size (mm)	25.8	26.3	26.3	25.9	26.3	**26.1**	0.2
Rib Width (Calipers)							
MD - Width (in)	0.110	0.094	0.095	0.097	0.095	**0.098**	0.007
MD - Width (mm)	2.78	2.37	2.40	2.46	2.41	**2.49**	0.17
TD - Width (in)	0.102	0.106	0.100	0.094	0.095	**0.099**	0.005
TD - Width (mm)	2.58	2.68	2.54	2.37	2.41	**2.52**	0.12
Rib Thickness (Calipers)							
MD - Thickness (in)	0.051	0.053	0.056	0.054	0.055	**0.054**	0.002
MD - Thickness (mm)	1.30	1.35	1.41	1.36	1.38	**1.36**	0.04
TD - Thickness (in)	0.053	0.049	0.054	0.060	0.049	**0.053**	0.005
TD - Thickness (mm)	1.33	1.23	1.36	1.52	1.23	**1.34**	0.12
Node/Junction Thickness (Calipers)							
Thickness (in)	0.054	0.056	0.056	0.061	0.053	**0.056**	0.003
Thickness (mm)	1.37	1.41	1.42	1.55	1.35	**1.42**	0.08

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-6. Geogrid geometric measurements for 3XT

PARAMETER		TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)								
Specimen Width (in)	7.81							
Specimen Length (in)	8.21							
Mass(g)		8.88	9.26	9.27	9.03	9.23		
Mass/unit area (oz/sq.yd)		6.33	6.60	6.60	6.43	6.57	6.51	0.12
Mass/unit area (g/sq.meter)		214	224	224	218	223	221	4
Aperature Size (Calipers)								
MD - Aperature Size (in)		1.476	1.507	1.499	1.596	1.522	1.520	0.045
MD - Aperature Size (mm)		37.5	38.3	38.1	40.5	38.6	38.6	1.2
TD - Aperature Size (in)		0.937	0.945	0.970	0.955	0.946	0.950	0.013
TD - Aperature Size (mm)		23.8	24.0	24.6	24.2	24.0	24.1	0.3
Rib Width (Calipers)								
MD - Width (in)		0.151	0.151	0.157	0.150	0.158	0.153	0.004
MD - Width (mm)		3.82	3.84	3.99	3.81	4.00	3.89	0.09
TD - Width (in)		0.108	0.105	0.107	0.115	0.116	0.110	0.005
TD - Width (mm)		2.74	2.67	2.71	2.92	2.93	2.79	0.12
Rib Thickness (Calipers)								
MD - Thickness (in)		0.053	0.056	0.053	0.055	0.055	0.054	0.001
MD - Thickness (mm)		1.35	1.42	1.35	1.38	1.38	1.38	0.03
TD - Thickness (in)		0.047	0.048	0.067	0.057	0.059	0.055	0.008
TD - Thickness (mm)		1.18	1.22	1.69	1.45	1.50	1.41	0.21
Node/Junction Thickness (Calipers)								
Thickness (in)		0.057	0.057	0.054	0.058	0.053	0.056	0.002
Thickness (mm)		1.45	1.45	1.37	1.47	1.35	1.42	0.06

MD - Machine Direction   TD - Transverse/Cross Machine Direction   NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-7. Geogrid geometric measurements for 5XT

PARAMETER		TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)								
Specimen Width (in)	7.85							
Specimen Length (in)	7.97							
Mass(g)		11.53	11.71	12.16	12.03	12.06		
Mass/unit area (oz/sq.yd)		8.42	8.55	8.88	8.78	8.80	8.69	0.19
Mass/unit area (g/sq.meter)		285	290	301	298	298	294	7
Aperature Size (Calipers)								
MD - Aperature Size (in)		1.601	1.601	1.533	1.576	1.554	1.573	0.030
MD - Aperature Size (mm)		40.7	40.7	38.9	40.0	39.5	39.9	0.8
TD - Aperature Size (in)		0.927	0.917	0.929	0.898	0.902	0.914	0.014
TD - Aperature Size (mm)		23.5	23.3	23.6	22.8	22.9	23.2	0.4
Rib Width (Calipers)								
MD - Width (in)		0.196	0.186	0.200	0.199	0.185	0.193	0.007
MD - Width (mm)		4.97	4.72	5.08	5.05	4.70	4.90	0.18
TD - Width (in)		0.126	0.107	0.099	0.125	0.118	0.115	0.012
TD - Width (mm)		3.20	2.71	2.51	3.16	2.98	2.91	0.30
Rib Thickness (Calipers)								
MD - Thickness (in)		0.058	0.055	0.054	0.056	0.062	0.057	0.003
MD - Thickness (mm)		1.46	1.38	1.36	1.41	1.56	1.44	0.08
TD - Thickness (in)		0.047	0.043	0.054	0.040	0.036	0.044	0.007
TD - Thickness (mm)		1.18	1.08	1.36	1.02	0.90	1.11	0.17
Node/Junction Thickness (Calipers)								
Thickness (in)		0.059	0.060	0.059	0.057	0.062	0.059	0.002
Thickness (mm)		1.49	1.51	1.49	1.45	1.57	1.50	0.05

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-8. Geogrid geometric measurements for 7XT

PARAMETER		TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)								
Specimen Width (in)	7.86							
Specimen Length (in)	7.98							
Mass(g)		11.76	12.12	11.69	11.89	11.99		
Mass/unit area (oz/sq.yd)		8.56	8.83	8.51	8.66	8.73	**8.66**	0.13
Mass/unit area (g/sq.meter)		290	299	289	294	296	**294**	4
Aperature Size (Calipers)								
MD - Aperature Size (in)		1.480	1.482	1.401	1.465	1.465	**1.459**	0.033
MD - Aperature Size (mm)		37.6	37.6	35.6	37.2	37.2	**37.0**	0.8
TD - Aperature Size (in)		0.866	0.885	0.851	0.878	0.870	**0.870**	0.013
TD - Aperature Size (mm)		22.0	22.5	21.6	22.3	22.1	**22.1**	0.3
Rib Width (Calipers)								
MD - Width (in)		0.245	0.245	0.249	0.248	0.244	**0.246**	0.002
MD - Width (mm)		6.21	6.21	6.31	6.30	6.18	**6.24**	0.06
TD - Width (in)		0.110	0.091	0.095	0.147	0.097	**0.108**	0.023
TD - Width (mm)		2.78	2.30	2.40	3.72	2.45	**2.73**	0.58
Rib Thickness (Calipers)								
MD - Thickness (in)		0.051	0.050	0.051	0.057	0.057	**0.053**	0.003
MD - Thickness (mm)		1.30	1.27	1.28	1.44	1.44	**1.34**	0.08
TD - Thickness (in)		0.056	0.044	0.038	0.048	0.050	**0.047**	0.007
TD - Thickness (mm)		1.42	1.10	0.97	1.22	1.27	**1.20**	0.17
Node/Junction Thickness (Calipers)								
Thickness (in)		0.061	0.057	0.061	0.065	0.064	**0.061**	0.003
Thickness (mm)		1.55	1.44	1.54	1.65	1.61	**1.56**	0.08

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-9. Geogrid geometric measurements for 8XT

PARAMETER		TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)								
Specimen Width (in)	7.7							
Specimen Length (in)	7.98							
Mass(g)		13.54	13.39	13.76	13.46	13.64		
Mass/unit area (oz/sq.yd)		10.06	9.95	10.23	10.01	10.14	**10.08**	0.11
Mass/unit area (g/sq.meter)		341	337	347	339	344	**342**	4
Aperature Size (Calipers)								
MD - Aperature Size (in)		1.406	1.663	1.642	1.532	1.625	**1.573**	0.106
MD - Aperature Size (mm)		35.7	42.2	41.7	38.9	41.3	**40.0**	2.7
TD - Aperature Size (in)		0.874	0.817	0.751	0.730	0.875	**0.809**	0.068
TD - Aperature Size (mm)		22.2	20.7	19.1	18.5	22.2	**20.6**	1.7
Rib Width (Calipers)								
MD - Width (in)		0.266	0.272	0.276	0.271	0.269	**0.271**	0.004
MD - Width (mm)		6.74	6.90	7.00	6.88	6.83	**6.87**	0.09
TD - Width (in)		0.096	0.096	0.120	0.096	0.096	**0.101**	0.011
TD - Width (mm)		2.43	2.44	3.05	2.44	2.44	**2.56**	0.27
Rib Thickness (Calipers)								
MD - Thickness (in)		0.051	0.053	0.048	0.048	0.050	**0.050**	0.002
MD - Thickness (mm)		1.30	1.33	1.22	1.22	1.27	**1.27**	0.05
TD - Thickness (in)		0.062	0.057	0.045	0.054	0.047	**0.053**	0.007
TD - Thickness (mm)		1.56	1.44	1.14	1.36	1.18	**1.34**	0.18
Node/Junction Thickness (Calipers)								
Thickness (in)		0.061	0.061	0.061	0.062	0.063	**0.061**	0.001
Thickness (mm)		1.54	1.55	1.54	1.57	1.60	**1.56**	0.03

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-10. Geogrid geometric measurements for 10XT

PARAMETER		TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)								
Specimen Width (in)	7.79							
Specimen Length (in)	8.01							
Mass(g)		17.63	17.58	17.45	17.55	17.34		
Mass/unit area (oz/sq.yd)		12.90	12.87	12.77	12.85	12.69	**12.82**	0.08
Mass/unit area (g/sq.meter)		437	436	433	435	430	**434**	3
Aperature Size (Calipers)								
MD - Aperature Size (in)		1.511	1.507	1.457	1.443	1.572	**1.498**	0.051
MD - Aperature Size (mm)		38.4	38.3	37.0	36.7	39.9	**38.0**	1.3
TD - Aperature Size (in)		0.813	0.774	0.772	0.812	0.752	**0.785**	0.027
TD - Aperature Size (mm)		20.7	19.6	19.6	20.6	19.1	**19.9**	0.7
Rib Width (Calipers)								
MD - Width (in)		0.328	0.329	0.321	0.323	0.327	**0.325**	0.004
MD - Width (mm)		8.32	8.36	8.14	8.20	8.31	**8.27**	0.09
TD - Width (in)		0.094	0.875	0.098	0.093	0.104	**0.253**	0.348
TD - Width (mm)		2.39	22.23	2.49	2.36	2.64	**6.42**	8.84
Rib Thickness (Calipers)								
MD - Thickness (in)		0.058	0.061	0.057	0.054	0.060	**0.058**	0.003
MD - Thickness (mm)		1.46	1.54	1.44	1.37	1.52	**1.47**	0.07
TD - Thickness (in)		0.061	0.068	0.059	0.065	0.067	**0.064**	0.004
TD - Thickness (mm)		1.55	1.73	1.50	1.64	1.69	**1.62**	0.10
Node/Junction Thickness (Calipers)								
Thickness (in)		0.075	0.074	0.073	0.070	0.075	**0.073**	0.002
Thickness (mm)		1.89	1.88	1.84	1.78	1.89	**1.86**	0.05

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-11. Geogrid geometric measurements for 20XT

PARAMETER		TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)								
Specimen Width (in)	8.93							
Specimen Length (in)	9.22							
Mass(g)		35.27	35.35	33.12	35.24	32.51		
Mass/unit area (oz/sq.yd)		19.57	19.61	18.37	19.55	18.03	**19.03**	0.76
Mass/unit area (g/sq.meter)		663	665	623	663	611	**645**	26
Aperature Size (Calipers)								
MD - Aperature Size (in)		1.451	1.372	1.350	1.384	1.420	**1.395**	0.040
MD - Aperature Size (mm)		36.9	34.8	34.3	35.1	36.1	**35.4**	1.0
TD - Aperature Size (in)		0.591	0.586	0.597	0.610	0.588	**0.594**	0.010
TD - Aperature Size (mm)		15.0	14.9	15.2	15.5	14.9	**15.1**	0.2
Rib Width (Calipers)								
MD - Width (in)		0.430	0.396	0.416	0.388	0.460	**0.418**	0.029
MD - Width (mm)		10.91	10.05	10.55	9.86	11.67	**10.61**	0.73
TD - Width (in)		0.245	0.253	0.242	0.330	0.247	**0.263**	0.038
TD - Width (mm)		6.22	6.43	6.13	8.38	6.26	**6.69**	0.95
Rib Thickness (Calipers)								
MD - Thickness (in)		0.084	0.080	0.079	0.072	0.091	**0.081**	0.007
MD - Thickness (mm)		2.12	2.03	2.01	1.83	2.31	**2.06**	0.18
TD - Thickness (in)		0.048	0.063	0.068	0.041	0.047	**0.053**	0.011
TD - Thickness (mm)		1.22	1.59	1.71	1.04	1.18	**1.35**	0.29
Node/Junction Thickness (Calipers)								
Thickness (in)		0.096	0.100	0.093	0.091	0.095	**0.095**	0.003
Thickness (mm)		2.43	2.54	2.35	2.31	2.40	**2.41**	0.09

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-12. Geogrid geometric measurements for 22XT

PARAMETER		TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)								
Specimen Width (in)	8.93							
Specimen Length (in)	9.21							
Mass(g)		44.77	46.08	45.08	45.12	46.65		
Mass/unit area (oz/sq.yd)		24.86	25.59	25.03	25.06	25.91	**25.29**	0.44
Mass/unit area (g/sq.meter)		843	868	849	849	878	**857**	15
Aperature Size (Calipers)								
MD - Aperature Size (in)		1.431	1.341	1.492	1.320	1.436	**1.404**	0.071
MD - Aperature Size (mm)		36.3	34.1	37.9	33.5	36.5	**35.7**	1.8
TD - Aperature Size (in)		0.506	0.503	0.510	0.502	0.526	**0.509**	0.010
TD - Aperature Size (mm)		12.8	12.8	13.0	12.7	13.3	**12.9**	0.2
Rib Width (Calipers)								
MD - Width (in)		0.438	0.457	0.456	0.485	0.466	**0.460**	0.017
MD - Width (mm)		11.13	11.60	11.57	12.32	11.82	**11.69**	0.43
TD - Width (in)		0.228	0.232	0.235	0.231	0.235	**0.232**	0.003
TD - Width (mm)		5.78	5.88	5.97	5.85	5.96	**5.89**	0.08
Rib Thickness (Calipers)								
MD - Thickness (in)		0.100	0.100	0.082	0.084	0.094	**0.092**	0.009
MD - Thickness (mm)		2.54	2.54	2.08	2.12	2.37	**2.33**	0.22
TD - Thickness (in)		0.080	0.075	0.069	0.064	0.060	**0.069**	0.008
TD - Thickness (mm)		2.02	1.91	1.74	1.61	1.51	**1.76**	0.21
Node/Junction Thickness (Calipers)								
Thickness (in)		0.110	0.099	0.109	0.108	0.103	**0.106**	0.005
Thickness (mm)		2.78	2.51	2.77	2.73	2.60	**2.68**	0.12

MD - Machine Direction   TD - Transverse/Cross Machine Direction   NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table B-13. Geogrid geometric measurements for 24XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.
Mass/Unit Area (ASTM D 5261)							
Specimen Width (in) 8.92							
Specimen Length (in) 9.1							
Mass(g)	55.96	53.70	54.08	56.48	52.93		
Mass/unit area (oz/sq.yd)	31.49	30.22	30.43	31.78	29.78	**30.74**	0.86
Mass/unit area (g/sq.meter)	1067	1024	1032	1077	1010	**1042**	29
Aperature Size (Calipers)							
MD - Aperature Size (in)	1.420	1.342	1.485	1.327	1.441	**1.403**	0.067
MD - Aperature Size (mm)	36.1	34.1	37.7	33.7	36.6	**35.6**	1.7
TD - Aperature Size (in)	0.388	0.443	0.438	0.502	0.427	**0.439**	0.041
TD - Aperature Size (mm)	9.9	11.2	11.1	12.8	10.8	**11.2**	1.0
Rib Width (Calipers)							
MD - Width (in)	0.576	0.557	0.571	0.558	0.586	**0.569**	0.012
MD - Width (mm)	14.62	14.14	14.49	14.17	14.88	**14.46**	0.31
TD - Width (in)	0.241	0.233	0.229	0.238	0.206	**0.229**	0.014
TD - Width (mm)	6.11	5.91	5.80	6.05	5.22	**5.82**	0.35
Rib Thickness (Calipers)							
MD - Thickness (in)	0.083	0.087	0.081	0.091	0.089	**0.086**	0.004
MD - Thickness (mm)	2.10	2.21	2.06	2.30	2.26	**2.18**	0.10
TD - Thickness (in)	0.058	0.063	0.061	0.068	0.059	**0.062**	0.004
TD - Thickness (mm)	1.47	1.60	1.55	1.71	1.50	**1.57**	0.10
Node/Junction Thickness (Calipers)							
Thickness (in)	0.110	0.107	0.097	0.103	0.116	**0.106**	0.007
Thickness (mm)	2.79	2.71	2.46	2.62	2.93	**2.70**	0.18

MD - Machine Direction   TD - Transverse/Cross Machine Direction   NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

B.2 Product Production Information

Table B-14. Typical geogrid roll dimensions for the Miragrid XT product line.

Style/Type	Width (ft)	Length (ft)	Area (yd²)	Roll Diameter (ft)	Gross weight (lbs)
2XT	12	150	200	12.0	121
3XT	6 / 12	150	100 / 200	12.3 / 11.7	152 / 295
5XT	6 / 12	150	100 / 200	11.8	168 / 333
7XT	12	200	266	13.2	437
8XT	6 / 12	150 / 200	100 / 266	13.6 / 13.2	196 / 494
10XT	12	200	266	14.1	589
20XT	12	200	266	14.7	675
22XT	12	200	266	15.5	913
24XT	12	200	266	16.5	966

(Conversions: 1 ft = 0.3048 m; 1 yd^2 = 0.836 m^2)

B.3 Product Manufacturing Quality Control Program

Testing/sampling is done per the Miragrid Quality Control Plan Document. A summary of the program is provided in Table B-15.

Table B-15. Typical summary of quality control testing conducted by the manufacturer for the Miragrid XT product line.

Test Method	Property	Testing Frequency
ASTM D 5261	Mass / Unit Area	Per LOT (every 10,000 SY to 15,000 SY)
ASTM D6637	Single Rib Tensile	Per LOT (every 10,000 SY to 15,000 SY)
ASTM D6637	Multi-Rib Tensile	Per LOT (every 10,000 SY to 15,000 SY)
Hand measure	Aperture Size	Bi-Annually
Hand measure	Width	Per LOT
GRI-GG2	Junction Strength	Bi-Annually or change in product knit construction
GRI-GG7	CEG	Bi-Annually or change in PET fiber LOT/Merge
GRI-GG8	MW	Bi-Annually or change in PET fiber LOT/Merge

Table B-16. Typical production lot size for the Miragrid XT product line.

Style/Type	Lot Size (yd^2)	# of rolls per Lot
2XT	14,040	70
3XT	14,040	70
5XT	14,040	70
7XT	14,040	70
8XT	14,040	70
10XT	14,040	70
20XT	14,040	70
22XT	14,040	70
24XT	14,040	70

Appendix C: Tensile Strength Detailed Test Results

Table C-1. Geogrid single rib tensile test results for 2XT

PARAMETER	TEST REPLICATE NUMBER					MEAN	STD. DEV.	MARV
	1	2	3	4	5			
Single Rib Tensile Properties (ASTM D 6637, Method A)								
MD - Number of Ribs per foot:	10.80							
MD Maximum Strength (lbs)	255.7	253.0	256.5	259.1	250.4	**254.9**	3.3	
MD Maximum Strength (lbs/ft)	2762	2732	2770	2798	2704	**2753**	36	2,000
MD Maximum Strength (kN/m)	40.3	39.9	40.4	40.9	39.5	**40.2**	0.5	
MD Break Elongation (%)	9.83	9.91	9.98	9.95	9.66	**9.87**	0.13	

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table C-2. Geogrid single rib tensile test results for 8XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	MARV
Single Rib Tensile Properties (ASTM D 6637, Method A)								
MD - Number of Ribs per foot:	10.91							
MD Maximum Strength (lbs)	787.1	798.7	768.8	808.4	796.6	**791.9**	15.0	
MD Maximum Strength (lbs/ft)	8583	8710	8384	8816	8687	**8636**	163	7,400
MD Maximum Strength (kN/m)	125.3	127.2	122.4	128.7	126.8	**126.1**	2.4	
MD Break Elongation (%)	13.1	13.0	13.0	14.3	13.5	**13.4**	0.6	

MD - Machine Direction   TD - Transverse/Cross Machine Direction   NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

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Table C-3. Geogrid single rib tensile test results for 24XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	MARV
Single Rib Tensile Properties (ASTM D 6637, Method A)								
MD - Number of Ribs per foot:	12.10							
MD Maximum Strength (lbs)	2413	2301	2305	2329	2418	2353	58	
MD Maximum Strength (lbs/ft)	29200	27842	27889	28177	29261	28474	703	27,415
MD Maximum Strength (kN/m)	426.3	406.5	407.2	411.4	427.2	415.7	10.3	
MD Break Elongation (%)	12.8	14.5	12.5	12.6	12.6	13.0	0.8	

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table C-4. Geogrid wide width tensile test results for 2XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	MARV
Wide Width Tensile Properties (ASTM D 6637, Method B)								
MD Number of Ribs per Specimen:	7							
MD Number of Ribs per foot:	10.80							
MD Ultimate Strength (lbs)	1771	1743	1721	1764	1782	1756	24	
MD Ultimate Strength (lbs/ft)	2733	2689	2655	2722	2749	2710	38	2,000
MD Ultimate Strength (kN/m)	39.9	39.3	38.8	39.7	40.1	39.6	0.5	
MD Strength @ 2% Strain (lbs)	440	433	436	425	422	431	8	
MD Strength @ 2% Strain (lbs/ft)	680	667	672	656	651	665	12	
MD Strength @ 2% Strain (kN/m)	9.9	9.7	9.8	9.6	9.5	9.7	0.2	
MD Strength @ 5% Strain (lbs)	956	963	963	935	933	950	15	
MD Strength @ 5% Strain (lbs/ft)	1474	1486	1486	1443	1440	1466	23	
MD Strength @ 5% Strain (kN/m)	21.5	21.7	21.7	21.1	21.0	21.4	0.3	
MD Break Elongation (%)	9.17	9.06	8.88	9.28	9.33	9.14	0.18	

MD - Machine Direction   TD - Transverse/Cross Machine Direction   NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table C-5. Geogrid wide width tensile test results for 8XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	MARV
Wide Width Tensile Properties (ASTM D 6637, Method B)								
MD Number of Ribs per Specimen:	7							
MD Number of Ribs per foot:	10.91							
MD Ultimate Strength (lbs)	5584	5564	5389	5274	5418	**5446**	129	
MD Ultimate Strength (lbs/ft)	8699	8668	8395	8217	8440	**8484**	201	7,400
MD Ultimate Strength (kN/m)	127.0	126.6	122.6	120.0	123.2	**123.9**	2.9	
MD Strength @ 2% Strain (lbs)	1119	1123	1132	1135	1129	**1128**	7	
MD Strength @ 2% Strain (lbs/ft)	1744	1749	1764	1768	1759	**1757**	10	
MD Strength @ 2% Strain (kN/m)	25.5	25.5	25.8	25.8	25.7	**25.6**	0.2	
MD Strength @ 5% Strain (lbs)	1964	1971	1987	1993	1965	**1976**	13	
MD Strength @ 5% Strain (lbs/ft)	3059	3070	3096	3104	3061	**3078**	21	
MD Strength @ 5% Strain (kN/m)	44.7	44.8	45.2	45.3	44.7	**44.9**	0.3	
MD Strength @ 10% Strain (lbs)	4472	4436	4429	4408	4417	**4432**	25	
MD Strength @ 10% Strain (lbs/ft)	6967	6911	6899	6866	6881	**6905**	39	
MD Strength @ 10% Strain (kN/m)	101.7	100.9	100.7	100.2	100.5	**100.8**	0.6	
MD Break Elongation (%)	13.2	13.5	12.7	12.4	13.3	**13.0**	0.4	

MD - Machine Direction TD - Transverse/Cross Machine Direction NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table C-6. Geogrid wide width tensile test results for 24XT

PARAMETER	TEST REPLICATE NUMBER					MEAN	STD. DEV.	MARV
	1	2	3	4	5			
Wide Width Tensile Properties (ASTM D 6637, Method B)								
MD Number of Ribs per Specimen:	8							
MD Number of Ribs per foot:	12.10							
MD Ultimate Strength (lbs)	21182	20833	21277	20917	19736	**20789**	616	
MD Ultimate Strength (lbs/ft)	32038	31510	32182	31636	29851	**31443**	932	27,415
MD Ultimate Strength (kN/m)	467.8	460.0	469.9	461.9	435.8	**459.1**	13.6	
MD Strength @ 2% Strain (lbs)	3519	3596	3618	3621	3656	**3602**	51	
MD Strength @ 2% Strain (lbs/ft)	5322	5439	5471	5477	5529	**5448**	77	
MD Strength @ 2% Strain (kN/m)	77.7	79.4	79.9	80.0	80.7	**79.5**	1.1	
MD Strength @ 5% Strain (lbs)	5500	5596	5592	5608	5707	**5601**	73	
MD Strength @ 5% Strain (lbs/ft)	8319	8464	8458	8482	8632	**8471**	111	
MD Strength @ 5% Strain (kN/m)	121.5	123.6	123.5	123.8	126.0	**123.7**	1.6	
MD Strength @ 10% Strain (lbs)	11763	12043	12311	12107	12477	**12140**	272	
MD Strength @ 10% Strain (lbs/ft)	17792	18214	18621	18312	18871	**18362**	411	
MD Strength @ 10% Strain (kN/m)	259.8	265.9	271.9	267.4	275.5	**268.1**	6.0	
MD Break Elongation (%)	16.2	15.1	15.5	15.3	15.6	**15.5**	0.4	

MD - Machine Direction   TD - Transverse/Cross Machine Direction   NP - Not Provided

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

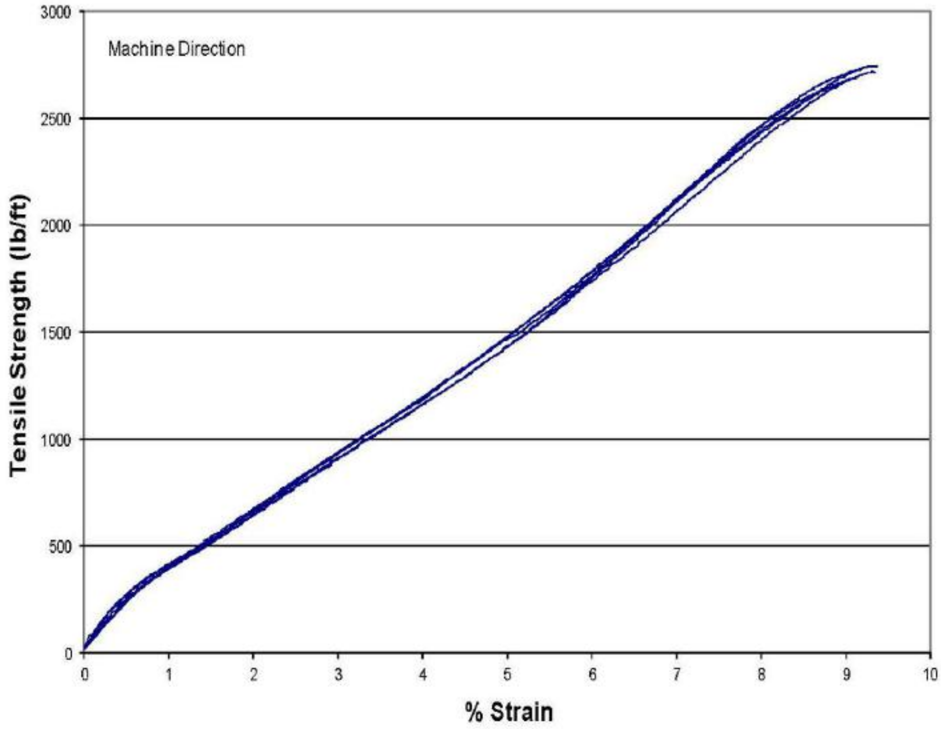

Figure C-1. Geogrid tensile test load-strain curve for 2XT

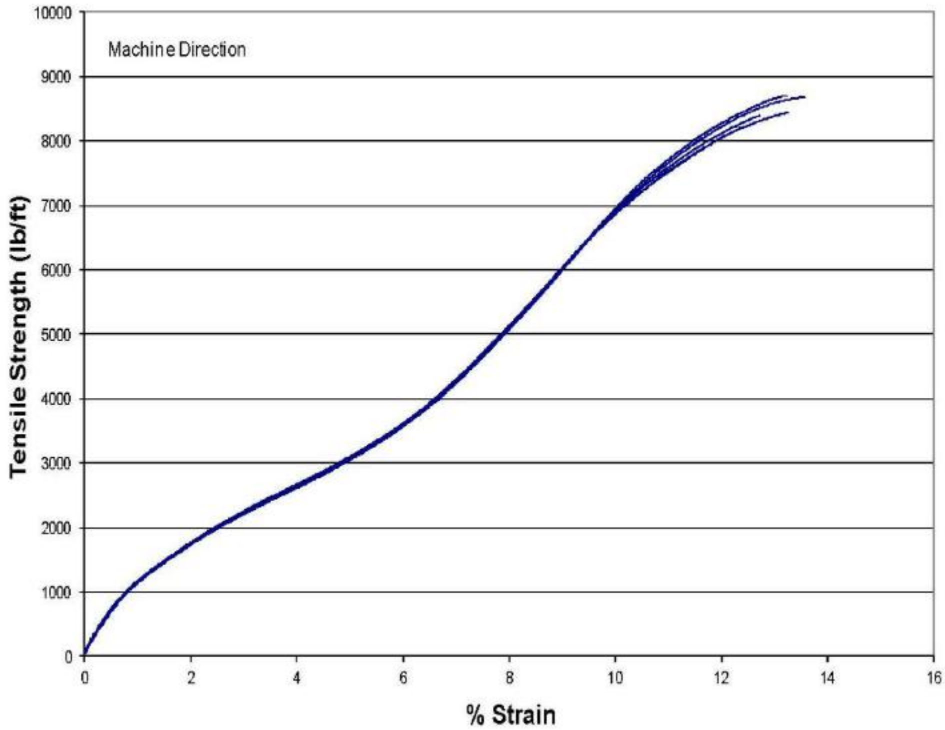

Figure C-2. Geogrid tensile test load-strain curve for 8XT

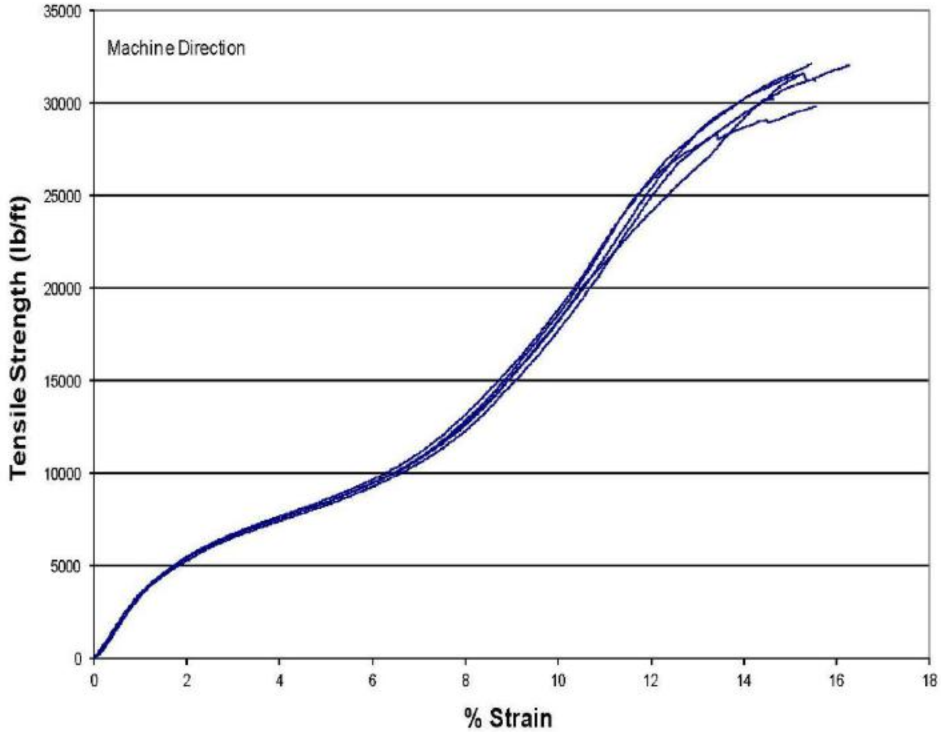

Figure C-3. Geogrid tensile test load-strain curve for 24XT

Appendix D: Installation Damage Detailed Test Results

Table D-1. Installation damage wide width tensile test results for TenCate Miragrid 2XT geogrid, soil gradation 1.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT Baseline	1	10.80	7	1771	2733	39.9	9.17	440	680	9.92	956	1474	21.5			
	2	10.80	7	1743	2689	39.3	9.06	433	667	9.74	963	1486	21.7			
	3	10.80	7	1721	2655	38.8	8.88	436	672	9.82	963	1486	21.7			
	4	10.80	7	1764	2722	39.7	9.28	425	656	9.58	935	1443	21.1			
	5	10.80	7	1782	2749	40.1	9.33	422	651	9.51	933	1440	21.0			
Average				1756	2710	39.6	9.14	431	665	9.71	950	1466	21.4			
Standard Deviation				24.4	37.6	0.55	0.18	7.5	11.6	0.17	14.7	22.7	0.33			
% COV				1.39	1.39	1.39	1.98	1.75	1.75	1.75	1.55	1.55	1.55			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT installed in Gradation 1 (Coarse Gravel)	1	10.80	7	721	1112	16.2	3.99	395	609	8.90						
	2	10.80	7	718	1108	16.2	6.08	321	495	7.23	601	927	13.5			
	3	10.80	7	825	1273	18.6	5.00	363	560	8.18	825	1273	18.6			
	4	10.80	7	717	1106	16.2	5.78	361	557	8.13	628	969	14.1			
	5	10.80	7	800	1234	18.0	6.17	376	580	8.47	699	1078	15.7			
	6	10.80	7	991	1529	22.3	6.43	378	583	8.51	758	1169	17.1			
	7	10.80	7	914	1410	20.6	4.82	424	654	9.55						
	8	10.80	7	993	1532	22.4	5.36	422	651	9.51	917	1415	20.7			
	9	10.80	7	1021	1575	23.0	5.47	399	616	8.99	911	1406	20.5			
	10	10.80	7	1021	1575	23.0	6.61	404	623	9.10	944	1456	21.3			
Average				872	1346	19.6	5.57	384	593	8.66	785	1212	17.7			
Standard Deviation				130.3	201	2.94	0.81	31.32	48.32	0.71	134.6	207.7	3.03			
% COV				14.95	14.95	14.95	14.56	8.15	8.15	8.15	17.14	17.14	17.14			

Percent Retained			49.7	49.7	49.7	60.9	89.1	89.1	89.1	82.7	82.7	82.7			
RFid			**2.01**	**2.01**	**2.01**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-2. Installation damage wide width tensile test results for TenCate Miragrid 2XT geogrid, 57 stone.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT Baseline	1	10.80	7	1771	2733	39.9	9.17	440	680	9.92	956	1474	21.5			
	2	10.80	7	1743	2689	39.3	9.06	433	667	9.74	963	1486	21.7			
	3	10.80	7	1721	2655	38.8	8.88	436	672	9.82	963	1486	21.7			
	4	10.80	7	1764	2722	39.7	9.28	425	656	9.58	935	1443	21.1			
	5	10.80	7	1782	2749	40.1	9.33	422	651	9.51	933	1440	21.0			
Average				1756	2710	39.6	9.14	431	665	9.71	950	1466	21.4			
Standard Deviation				24.4	37.6	0.55	0.18	7.5	11.6	0.17	14.7	22.7	0.33			
% COV				1.39	1.39	1.39	1.98	1.75	1.75	1.75	1.55	1.55	1.55			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT installed in 57 Stone	1	10.80	7	1268	1956	28.6	6.82	400	617	9.01	887	1369	20.0			
	2	10.80	7	1386	2138	31.2	7.80	388	599	8.74	862	1330	19.4			
	3	10.80	7	1391	2146	31.3	8.10	390	602	8.79	851	1313	19.2			
	4	10.80	7	1049	1618	23.6	6.73	394	608	8.88	874	1348	19.7			
	5	10.80	7	1295	1998	29.2	7.50	392	605	8.83	867	1338	19.5			
	6	10.80	7	1384	2135	31.2	7.47	387	597	8.72	882	1361	19.9			
	7	10.80	7	1068	1648	24.1	6.24	377	582	8.49	852	1315	19.2			
	8	10.80	7	1120	1728	25.2	6.68	384	592	8.65	845	1304	19.0			
	9	10.80	7	918	1416	20.7	6.55	360	555	8.11	784	1210	17.7			
	10	10.80	7	1182	1824	26.6	8.08	385	594	8.67	879	1356	19.8			
Average				1206	1861	27.2	7.20	386	595	8.69	858	1324	19.3			
Standard Deviation				164.9	254	3.71	0.67	10.94	16.89	0.25	29.7	45.8	0.67			
% COV				13.67	13.67	13.67	9.36	2.84	2.84	2.84	3.46	3.46	3.46			

Percent Retained				68.7	68.7	68.7	78.7	89.4	89.4	89.4	90.3	90.3	90.3			
RFid				**1.46**	**1.46**	**1.46**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-3. Installation damage wide width tensile test results for TenCate Miragrid 2XT geogrid, soil gradation 2.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT Baseline	1	10.80	7	1771	2733	39.9	9.17	440	680	9.92	956	1474	21.5			
	2	10.80	7	1743	2689	39.3	9.06	433	667	9.74	963	1486	21.7			
	3	10.80	7	1721	2655	38.8	8.88	436	672	9.82	963	1486	21.7			
	4	10.80	7	1764	2722	39.7	9.28	425	656	9.58	935	1443	21.1			
	5	10.80	7	1782	2749	40.1	9.33	422	651	9.51	933	1440	21.0			
Average				1756	2710	39.6	9.14	431	665	9.71	950	1466	21.4			
Standard Deviation				24.4	37.6	0.55	0.18	7.5	11.6	0.17	14.7	22.7	0.33			
% COV				1.39	1.39	1.39	1.98	1.75	1.75	1.75	1.55	1.55	1.55			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT installed in Gradation 2 (Sandy Gravel)	1	10.80	7	1651	2547	37.2	8.57	419	646	9.44	931	1436	21.0			
	2	10.80	7	1692	2611	38.1	9.05	412	636	9.28	917	1415	20.7			
	3	10.80	7	1639	2529	36.9	8.77	391	603	8.81	901	1390	20.3			
	4	10.80	7	1672	2580	37.7	8.76	414	639	9.33	911	1406	20.5			
	5	10.80	7	1674	2583	37.7	8.86	401	619	9.03	919	1418	20.7			
	6	10.80	7	1659	2560	37.4	8.76	374	577	8.42	885	1365	19.9			
	7	10.80	7	1695	2615	38.2	9.04	396	611	8.92	899	1387	20.3			
	8	10.80	7	1654	2552	37.3	8.35	416	642	9.37	908	1401	20.5			
	9	10.80	7	1674	2583	37.7	8.79	407	628	9.17	904	1395	20.4			
	10	10.80	7	1698	2620	38.2	9.33	407	628	9.17	926	1429	20.9			
Average				1671	2578	37.6	8.83	404	623	9.09	910	1404	20.5			
Standard Deviation				20.1	31	0.45	0.27	13.71	21.16	0.31	13.7	21.2	0.31			
% COV				1.20	1.20	1.20	3.06	3.40	3.40	3.40	1.51	1.51	1.51			

Percent Retained			95.1	95.1	95.1	96.5	93.6	93.6	93.6	95.8	95.8	95.8			
RFid			**1.05**	**1.05**	**1.05**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-4. Installation damage wide width tensile test results for TenCate Miragrid 2XT geogrid, soil gradation 3.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT Baseline	1	10.80	7	1771	2733	39.9	9.2	440	680	9.92	956	1474	21.5			
	2	10.80	7	1743	2689	39.3	9.1	433	667	9.74	963	1486	21.7			
	3	10.80	7	1721	2655	38.8	8.9	436	672	9.82	963	1486	21.7			
	4	10.80	7	1764	2722	39.7	9.3	425	656	9.58	935	1443	21.1			
	5	10.80	7	1782	2749	40.1	9.3	422	651	9.51	933	1440	21.0			
Average				1756	2710	39.6	9.1	431	665	9.71	950	1466	21.4			
Standard Deviation				24.4	37.6	0.55	0.18	7.5	11.6	0.17	14.7	22.7	0.33			
% COV				1.39	1.39	1.39	1.98	1.75	1.75	1.75	1.55	1.55	1.55			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
2XT installed in Gradation 3 (Sand)	1	10.80	7	1607	2479	36.2	8.59	384	592	8.65	873	1347	19.7			
	2	10.80	7	1577	2433	35.5	8.49	372	574	8.38	875	1350	19.7			
	3	10.80	7	1601	2470	36.1	8.52	387	597	8.72	890	1373	20.0			
	4	10.80	7	1629	2513	36.7	8.89	362	559	8.15	856	1321	19.3			
	5	10.80	7	1445	2229	32.5	8.04	335	517	7.55	829	1279	18.7			
	6	10.80	7	1681	2594	37.9	8.96	386	596	8.69	884	1364	19.9			
	7	10.80	7	1653	2550	37.2	8.74	396	611	8.92	904	1395	20.4			
	8	10.80	7	1633	2519	36.8	8.60	401	619	9.03	908	1401	20.5			
	9	10.80	7	1698	2620	38.2	9.11	395	609	8.90	899	1387	20.3			
	10	10.80	7	1640	2530	36.9	8.60	409	631	9.21	914	1410	20.6			
Average				1616	2494	36.4	8.65	383	590	8.62	883	1363	19.9			
Standard Deviation				70.3	108	1.58	0.30	21.61	33.35	0.49	26.1	40.3	0.59			
% COV				4.35	4.35	4.35	3.44	5.65	5.65	5.65	2.96	2.96	2.96			

Percent Retained			92.0	92.0	92.0	94.6	88.7	88.7	88.7	93.0	93.0	93.0			
RFid			**1.09**	**1.09**	**1.09**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-5. Installation damage wide width tensile test results for TenCate Miragrid 3XT geogrid, soil gradation 1.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT Baseline	1	10.75	7	2457	3773	55.1	8.91	585	898	13.12	1185	1820	26.6			
	2	10.75	7	2428	3729	54.4	8.91	582	894	13.05	1182	1815	26.5			
	3	10.75	7	2475	3801	55.5	9.07	570	875	12.78	1163	1786	26.1			
	4	10.75	7	2520	3870	56.5	9.29	592	909	13.27	1180	1812	26.5			
	5	10.75	7	2475	3801	55.5	8.98	597	917	13.39	1204	1849	27.0			
Average				2471	3795	55.4	9.03	585	899	13.12	1183	1816	26.5			
Standard Deviation				33.5	51.4	0.75	0.16	10.3	15.9	0.23	14.6	22.4	0.33			
% COV				1.35	1.35	1.35	1.75	1.77	1.77	1.77	1.24	1.24	1.24			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT installed in Gradation 1 (Coarse Gravel)	1	10.75	7	1847	2836	41.4	7.39	558	857	12.51	1154	1772	25.9			
	2	10.75	7	2180	3348	48.9	8.26	533	819	11.95	1140	1751	25.6			
	3	10.75	7	2129	3270	47.7	8.11	559	858	12.53	1158	1778	26.0			
	4	10.75	7	2002	3075	44.9	7.95	557	855	12.49	1153	1771	25.9			
	5	10.75	7	2032	3121	45.6	7.92	560	860	12.56	1176	1806	26.4			
	6	10.75	7	1692	2598	37.9	7.84	559	858	12.53	1144	1757	25.7			
	7	10.75	7	1720	2641	38.6	7.11	547	840	12.26	1148	1763	25.7			
	8	10.75	7	1914	2939	42.9	7.89	573	880	12.85	1177	1808	26.4			
	9	10.75	7	1944	2985	43.6	7.63	569	874	12.76	1172	1800	26.3			
	10	10.75	7	1845	2833	41.4	7.93	542	832	12.15	1125	1728	25.2			
Average				1931	2965	43.3	7.80	556	853	12.46	1155	1773	25.9			
Standard Deviation				160.9	247	3.61	0.34	12.03	18.47	0.27	16.7	25.7	0.38			
% COV				8.33	8.33	8.33	4.37	2.16	2.16	2.16	1.45	1.45	1.45			

Percent Retained			78.1	78.1	78.1	86.4	95.0	95.0	95.0	97.6	97.6	97.6			
RFid			**1.28**	**1.28**	**1.28**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-6. Installation damage wide width tensile test results for TenCate Miragrid 3XT geogrid, 57 stone.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT Baseline	1	10.75	7	2457	3773	55.1	8.91	585	898	13.12	1185	1820	26.6			
	2	10.75	7	2428	3729	54.4	8.91	582	894	13.05	1182	1815	26.5			
	3	10.75	7	2475	3801	55.5	9.07	570	875	12.78	1163	1786	26.1			
	4	10.75	7	2520	3870	56.5	9.29	592	909	13.27	1180	1812	26.5			
	5	10.75	7	2475	3801	55.5	8.98	597	917	13.39	1204	1849	27.0			
Average				2471	3795	55.4	9.03	585	899	13.12	1183	1816	26.5			
Standard Deviation				33.5	51.4	0.75	0.16	10.3	15.9	0.23	14.6	22.4	0.33			
% COV				1.35	1.35	1.35	1.75	1.77	1.77	1.77	1.24	1.24	1.24			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT installed in 57 Stone	1	10.75	7	1580	2426	35.4	7.60	538	826	12.06	1132	1738	25.4			
	2	10.75	7	1592	2445	35.7	6.69	559	858	12.53	1177	1808	26.4			
	3	10.75	7	2050	3148	46.0	8.29	540	829	12.11	1136	1745	25.5			
	4	10.75	7	1574	2417	35.3	7.42	552	848	12.38	1144	1757	25.7			
	5	10.75	7	1593	2446	35.7	6.77	547	840	12.26	1159	1780	26.0			
	6	10.75	7	2088	3207	46.8	8.25	555	852	12.44	1150	1766	25.8			
	7	10.75	7	2298	3529	51.5	9.01	559	858	12.53	1162	1785	26.1			
	8	10.75	7	2150	3302	48.2	8.38	561	862	12.58	1176	1806	26.4			
	9	10.75	7	1869	2870	41.9	8.59	566	869	12.69	1177	1808	26.4			
	10	10.75	7	1722	2645	38.6	7.90	553	849	12.40	1000	1536	22.4			
Average				1852	2844	41.5	7.89	553	849	12.40	1141	1753	25.6			
Standard Deviation				276.0	424	6.19	0.77	9.07	13.93	0.20	52.3	80.4	1.17			
% COV				14.91	14.91	14.91	9.70	1.64	1.64	1.64	4.59	4.59	4.59			

Percent Retained			74.9	74.9	74.9	87.4	94.5	94.5	94.5	96.5	96.5	96.5				
RFid			**1.33**	**1.33**	**1.33**											

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-7. Installation damage wide width tensile test results for TenCate Miragrid 3XT geogrid, soil gradation 2.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT Baseline	1	10.75	7	2457	3773	55.1	8.91	585	898	13.12	1185	1820	26.6			
	2	10.75	7	2428	3729	54.4	8.91	582	894	13.05	1182	1815	26.5			
	3	10.75	7	2475	3801	55.5	9.07	570	875	12.78	1163	1786	26.1			
	4	10.75	7	2520	3870	56.5	9.29	592	909	13.27	1180	1812	26.5			
	5	10.75	7	2475	3801	55.5	8.98	597	917	13.39	1204	1849	27.0			
Average				2471	3795	55.4	9.03	585	899	13.12	1183	1816	26.5			
Standard Deviation				33.5	51.4	0.75	0.16	10.3	15.9	0.23	14.6	22.4	0.33			
% COV				1.35	1.35	1.35	1.75	1.77	1.77	1.77	1.24	1.24	1.24			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT installed in Gradation 2 (Sandy Gravel)	1	10.75	7	2380	3655	53.4	8.53	584	897	13.09	1207	1854	27.1			
	2	10.75	7	2460	3778	55.2	8.92	584	897	13.09	1195	1835	26.8			
	3	10.75	7	2447	3758	54.9	8.71	593	911	13.30	1225	1881	27.5			
	4	10.75	7	2455	3770	55.0	8.89	575	883	12.89	1191	1829	26.7			
	5	10.75	7	2488	3821	55.8	9.03	584	897	13.09	1187	1823	26.6			
	6	10.75	7	2441	3749	54.7	8.82	576	885	12.91	1207	1854	27.1			
	7	10.75	7	2331	3580	52.3	8.64	571	877	12.80	1176	1806	26.4			
	8	10.75	7	2460	3778	55.2	8.95	575	883	12.89	1201	1844	26.9			
	9	10.75	7	2422	3720	54.3	8.87	563	865	12.62	1180	1812	26.5			
	10	10.75	7	2467	3789	55.3	9.02	578	888	12.96	1192	1831	26.7			
Average				2435	3740	54.6	8.84	578	888	12.97	1196	1837	26.8			
Standard Deviation				46.8	72	1.05	0.16	8.35	12.83	0.19	14.5	22.2	0.32			
% COV				1.92	1.92	1.92	1.86	1.44	1.44	1.44	1.21	1.21	1.21			

Percent Retained				98.5	98.5	98.5	97.9	98.8	98.8	98.8	101.1	101.1	101.1			
RFid				**1.01**	**1.01**	**1.01**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

**Table D-8. Installation damage wide width tensile test results for TenCate Miragrid 3XT geogrid, soil gradation 3.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).**

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT Baseline	1	10.75	7	2457	3773	55.1	8.91	585	898	13.12	1185	1820	26.6			
	2	10.75	7	2428	3729	54.4	8.91	582	894	13.05	1182	1815	26.5			
	3	10.75	7	2475	3801	55.5	9.07	570	875	12.78	1163	1786	26.1			
	4	10.75	7	2520	3870	56.5	9.29	592	909	13.27	1180	1812	26.5			
	5	10.75	7	2475	3801	55.5	8.98	597	917	13.39	1204	1849	27.0			
Average				2471	3795	55.4	9.03	585	899	13.12	1183	1816	26.5			
Standard Deviation				33.5	51.4	0.75	0.16	10.3	15.9	0.23	14.6	22.4	0.33			
% COV				1.35	1.35	1.35	1.75	1.77	1.77	1.77	1.24	1.24	1.24			

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
3XT installed in Gradation 3 (Sand)	1	10.75	7	2417	3712	54.2	8.83	572	878	12.83	1174	1803	26.3			
	2	10.75	7	2360	3624	52.9	8.66	568	872	12.74	1185	1820	26.6			
	3	10.75	7	2393	3675	53.7	8.59	611	938	13.70	1221	1875	27.4			
	4	10.75	7	2394	3677	53.7	8.71	580	891	13.00	1187	1823	26.6			
	5	10.75	7	2398	3683	53.8	8.86	545	837	12.22	1185	1820	26.6			
	6	10.75	7	2327	3574	52.2	8.94	561	862	12.58	1149	1765	25.8			
	7	10.75	7	2419	3715	54.2	8.75	570	875	12.78	1180	1812	26.5			
	8	10.75	7	2461	3779	55.2	9.06	570	875	12.78	1182	1815	26.5			
	9	10.75	7	2380	3655	53.4	8.66	568	872	12.74	1174	1803	26.3			
	10	10.75	7	2416	3710	54.2	9.12	572	878	12.83	1168	1794	26.2			
Average				2397	3680	53.7	8.82	572	878	12.82	1181	1813	26.5			
Standard Deviation				36.4	56	0.82	0.18	16.58	25.46	0.37	18.1	27.8	0.41			
% COV				1.52	1.52	1.52	2.02	2.90	2.90	2.90	1.54	1.54	1.54			

Percent Retained				97.0	97.0	97.0	97.6	97.7	97.7	97.7	99.8	99.8	99.8			
RFid				**1.03**	**1.03**	**1.03**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-9. Installation damage wide width tensile test results for TenCate Miragrid 7XT geogrid, soil gradation 1.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT Baseline	1	10.68	7	4405	6721	98.1	10.2	991	1512	22.07	2006	3061	44.7	4371	6669	97.4
	2	10.68	7	4273	6519	95.2	10.2	970	1480	21.61	1973	3010	43.9	4239	6468	94.4
	3	10.68	7	4286	6539	95.5	10.1	954	1456	21.25	1933	2949	43.1	4271	6516	95.1
	4	10.68	7	4348	6634	96.9	9.96	974	1486	21.70	1969	3004	43.9			
	5	10.68	7	4249	6483	94.6	9.62	969	1478	21.58	1983	3025	44.2			
Average				4312	6579	96.1	10.0	972	1482	21.64	1973	3010	43.9	4294	6551	95.6
Standard Deviation				63.5	96.8	1.41	0.24	13.2	20.2	0.29	26.5	40.4	0.59	68.9	105	1.53
% COV				1.47	1.47	1.47	2.42	1.36	1.36	1.36	1.34	1.34	1.34	1.60	1.60	1.60

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT installed in Gradation 1 (Coarse Gravel)	1	10.68	7	2515	3837	56.0	6.47	909	1387	20.25	1912	2917	42.6			
	2	10.68	7	2882	4397	64.2	7.29	931	1420	20.74	1931	2946	43.0			
	3	10.68	7	2668	4071	59.4	6.76	887	1353	19.76	1898	2896	42.3			
	4	10.68	7	3111	4746	69.3	7.54	972	1483	21.65	1961	2992	43.7			
	5	10.68	7	3024	4614	67.4	8.34	924	1410	20.58	1883	2873	41.9			
	6	10.68	7	2410	3677	53.7	7.29	851	1298	18.96	1809	2760	40.3			
	7	10.68	7	2788	4254	62.1	7.79	936	1428	20.85	1962	2993	43.7			
	8	10.68	7	2879	4393	64.1	7.30	868	1324	19.34	1871	2855	41.7			
	9	10.68	7	2636	4022	58.7	6.66	928	1416	20.67	1907	2910	42.5			
	10	10.68	7	2859	4362	63.7	7.10	944	1440	21.03	1895	2891	42.2			
Average				2777	4237	61.9	7.25	915	1396	20.38	1903	2903	42.4			
Standard Deviation				220.1	336	4.90	0.56	36.76	56.09	0.82	44.8	68.4	1.00			
% COV				7.92	7.92	7.92	7.67	4.02	4.02	4.02	2.36	2.36	2.36			

Percent Retained			64.4	64.4	64.4	72.4	94.2	94.2	94.2	96.5	96.5	96.5			
RFid			**1.55**	**1.55**	**1.55**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-10. Installation damage wide width tensile test results for TenCate Miragrid 7XT geogrid, 57 stone.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT Baseline	1	10.68	7	4405	6721	98.1	10.2	991	1512	22.07	2006	3061	44.7	4371	6669	97.4
	2	10.68	7	4273	6519	95.2	10.2	970	1480	21.61	1973	3010	43.9	4239	6468	94.4
	3	10.68	7	4286	6539	95.5	10.1	954	1456	21.25	1933	2949	43.1	4271	6516	95.1
	4	10.68	7	4348	6634	96.9	10.0	974	1486	21.70	1969	3004	43.9			
	5	10.68	7	4249	6483	94.6	9.6	969	1478	21.58	1983	3025	44.2			
Average				4312	6579	96.1	10.0	972	1482	21.64	1973	3010	43.9	4294	6551	95.6
Standard Deviation				63.5	96.8	1.41	0.24	13.2	20.2	0.29	26.5	40.4	0.59	68.9	105	1.53
% COV				1.47	1.47	1.47	2.42	1.36	1.36	1.36	1.34	1.34	1.34	1.60	1.60	1.60

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT installed in 57 Stone	1	10.68	7	3224	4919	71.8	9.72	868	1324	19.34	1487	2269	33.1			
	2	10.68	7	3372	5145	75.1	9.47	903	1378	20.11	1547	2360	34.5			
	3	10.68	7	3280	5004	73.1	9.49	906	1382	20.18	1534	2340	34.2			
	4	10.68	7	2717	4145	60.5	9.19	865	1320	19.27	1476	2252	32.9			
	5	10.68	7	3092	4718	68.9	9.25	854	1303	19.02	1460	2228	32.5			
	6	10.68	7	3191	4869	71.1	9.49	876	1337	19.51	1483	2263	33.0			
	7	10.68	7	2885	4402	64.3	9.36	861	1314	19.18	1474	2249	32.8			
	8	10.68	7	2470	3769	55.0	7.80	868	1324	19.34	1486	2267	33.1			
	9	10.68	7	2898	4422	64.6	9.14	846	1291	18.85	1478	2255	32.9			
	10	10.68	7	3382	5160	75.3	9.61	857	1308	19.09	1496	2282	33.3			
Average				3051	4655	68.0	9.25	870	1328	19.39	1492	2277	33.2			
Standard Deviation				301.2	460	6.71	0.54	19.82	30.23	0.44	27.4	41.8	0.61			
% COV				9.87	9.87	9.87	5.86	2.28	2.28	2.28	1.83	1.83	1.83			

Percent Retained				70.8	70.8	70.8	92.4	89.6	89.6	89.6	75.6	75.6	75.6			
RFid				**1.41**	**1.41**	**1.41**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-11. Installation damage wide width tensile test results for TenCate Miragrid 7XT geogrid, soil gradation 2.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT Baseline	1	10.68	7	4405	6721	98.1	10.2	991	1512	22.07	2006	3061	44.7	4371	6669	97.4
	2	10.68	7	4273	6519	95.2	10.2	970	1480	21.61	1973	3010	43.9	4239	6468	94.4
	3	10.68	7	4286	6539	95.5	10.1	954	1456	21.25	1933	2949	43.1	4271	6516	95.1
	4	10.68	7	4348	6634	96.9	10.0	974	1486	21.70	1969	3004	43.9			
	5	10.68	7	4249	6483	94.6	9.6	969	1478	21.58	1983	3025	44.2			
Average				4312	6579	96.1	10.0	972	1482	21.64	1973	3010	43.9	4294	6551	95.6
Standard Deviation				63.5	96.8	1.41	0.24	13.2	20.2	0.29	26.5	40.4	0.59	68.9	105	1.53
% COV				1.47	1.47	1.47	2.42	1.36	1.36	1.36	1.34	1.34	1.34	1.60	1.60	1.60

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT installed in Gradation 2 (Sandy Gravel)	1	10.68	7	3966	6051	88.3	8.96	960	1465	21.38	1952	2978	43.5			
	2	10.68	7	3967	6053	88.4	9.17	965	1472	21.50	1939	2958	43.2			
	3	10.68	7	3950	6027	88.0	8.94	981	1497	21.85	1983	3025	44.2			
	4	10.68	7	3895	5943	86.8	8.82	976	1489	21.74	1935	2952	43.1			
	5	10.68	7	3581	5464	79.8	7.96	990	1510	22.05	2003	3056	44.6			
	6	10.68	7	3990	6088	88.9	9.10	974	1486	21.70	1952	2978	43.5			
	7	10.68	7	3861	5891	86.0	8.71	973	1485	21.67	1974	3012	44.0			
	8	10.68	7	4072	6213	90.7	9.33	960	1465	21.38	1937	2955	43.1			
	9	10.68	7	4043	6168	90.1	9.22	947	1445	21.09	1936	2954	43.1			
	10	10.68	7	3877	5915	86.4	9.27	949	1448	21.14	1928	2942	42.9			
Average				3920	5981	87.3	8.95	968	1476	21.55	1954	2981	43.5			
Standard Deviation				137.1	209	3.05	0.40	13.80	21.06	0.31	24.8	37.8	0.55			
% COV				3.50	3.50	3.50	4.48	1.43	1.43	1.43	1.27	1.27	1.27			

Percent Retained			90.9	90.9	90.9	89.3	99.6	99.6	99.6	99.0	99.0	99.0			
RFid			**1.10**	**1.10**	**1.10**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-12. Installation damage wide width tensile test results for TenCate Miragrid 7XT geogrid, soil gradation 3.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT Baseline	1	10.68	7	4405	6721	98.1	10.2	991	1512	22.07	2006	3061	44.7	4371	6669	97.4
	2	10.68	7	4273	6519	95.2	10.2	970	1480	21.61	1973	3010	43.9	4239	6468	94.4
	3	10.68	7	4286	6539	95.5	10.1	954	1456	21.25	1933	2949	43.1	4271	6516	95.1
	4	10.68	7	4348	6634	96.9	10.0	974	1486	21.70	1969	3004	43.9			
	5	10.68	7	4249	6483	94.6	9.6	969	1478	21.58	1983	3025	44.2			
Average				4312	6579	96.1	10.0	972	1482	21.64	1973	3010	43.9	4294	6551	95.6
Standard Deviation				63.5	96.8	1.41	0.24	13.2	20.2	0.29	26.5	40.4	0.59	68.9	105	1.53
% COV				1.47	1.47	1.47	2.42	1.36	1.36	1.36	1.34	1.34	1.34	1.60	1.60	1.60

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
7XT installed in Gradation 3 (Sand)	1	10.68	7	4051	6181	90.2	9.45	955	1457	21.27	1935	2952	43.1			
	2	10.68	7	4217	6434	93.9	9.90	965	1472	21.50	1943	2964	43.3			
	3	10.68	7	4027	6144	89.7	9.00	990	1510	22.05	2001	3053	44.6			
	4	10.68	7	4022	6136	89.6	9.22	987	1506	21.99	1979	3019	44.1			
	5	10.68	7	3779	5766	84.2	8.63	941	1436	20.96	1924	2935	42.9			
	6	10.68	7	3684	5621	82.1	8.45	972	1483	21.65	1957	2986	43.6			
	7	10.68	7	4104	6262	91.4	9.48	954	1456	21.25	1912	2917	42.6			
	8	10.68	7	4033	6153	89.8	9.28	954	1456	21.25	1935	2952	43.1			
	9	10.68	7	4042	6167	90.0	9.36	924	1410	20.58	1897	2894	42.3			
	10	10.68	7	4163	6352	92.7	9.83	960	1465	21.38	1927	2940	42.9			
Average				4012	6121	89.4	9.26	960	1465	21.39	1941	2961	43.2			
Standard Deviation				162.7	248	3.63	0.47	19.87	30.31	0.44	31.0	47.3	0.69			
% COV				4.06	4.06	4.06	5.03	2.07	2.07	2.07	1.60	1.60	1.60			

Percent Retained			93.0	93.0	93.0	92.5	98.8	98.8	98.8	98.4	98.4	98.4			
RFid			**1.07**	**1.07**	**1.07**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-13. Installation damage wide width tensile test results for TenCate Miragrid 8XT geogrid, soil gradation 1.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT Baseline	1	10.91	7	5584	8703	127.1	13.2	1119	1744	25.47	1964	3061	44.7	4472	6970	101.8
	2	10.91	7	5564	8672	126.6	13.5	1123	1750	25.54	1971	3072	44.8	4436	6915	101.0
	3	10.91	7	5389	8399	122.6	12.7	1132	1765	25.76	1987	3097	45.2	4429	6902	100.8
	4	10.91	7	5274	8220	120.0	12.4	1135	1769	25.83	1993	3106	45.3	4408	6869	100.3
	5	10.91	7	5418	8444	123.3	13.3	1129	1760	25.69	1965	3062	44.7	4417	6884	100.5
Average				5446	8488	123.9	13.0	1128	1758	25.66	1976	3079	45.0	4432	6908	100.9
Standard Deviation				129.1	201.1	2.94	0.45	6.6	10.3	0.15	13.3	20.8	0.30	24.8	39	0.56
% COV				2.37	2.37	2.37	3.46	0.59	0.59	0.59	0.68	0.68	0.68	0.56	0.56	0.56

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT installed in Gradation 1 (Coarse Gravel)	1	10.91	7	3136	4888	71.4	7.97	1114	1736	25.35	1957	3050	44.5			
	2	10.91	7	3343	5210	76.1	8.10	1108	1727	25.21	1937	3019	44.1			
	3	10.91	7	3326	5184	75.7	7.89	1138	1774	25.90	1991	3103	45.3			
	4	10.91	7	3431	5347	78.1	8.21	1090	1699	24.80	1934	3014	44.0			
	5	10.91	7	3759	5859	85.5	8.73	1094	1705	24.89	1924	2999	43.8			
	6	10.91	7	3794	5913	86.3	8.58	1110	1730	25.26	1984	3092	45.1			
	7	10.91	7	4113	6410	93.6	9.15	1091	1700	24.83	1945	3031	44.3			
	8	10.91	7	3943	6145	89.7	9.70	1076	1677	24.48	1922	2996	43.7			
	9	10.91	7	3692	5754	84.0	9.75	1067	1663	24.28	1909	2975	43.4			
	10	10.91	7	3844	5991	87.5	8.80	1108	1727	25.21	1940	3024	44.1			
Average				3638	5670	82.8	8.69	1100	1714	25.02	1944	3030	44.2			
Standard Deviation				313.1	488	7.12	0.68	20.41	31.81	0.46	26.4	41.1	0.60			
% COV				8.61	8.61	8.61	7.79	1.86	1.86	1.86	1.36	1.36	1.36			

Percent Retained			66.8	66.8	66.8	66.7	97.5	97.5	97.5	98.4	98.4	98.4			
RFid			**1.50**	**1.50**	**1.50**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-14. Installation damage wide width tensile test results for TenCate Miragrid 8XT geogrid, 57 stone.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT Baseline	1	10.91	7	5584	8703	127.1	13.2	1119	1744	25.47	1964	3061	44.7	4472	6970	101.8
	2	10.91	7	5564	8672	126.6	13.5	1123	1750	25.54	1971	3072	44.8	4436	6915	101.0
	3	10.91	7	5389	8399	122.6	12.7	1132	1765	25.76	1987	3097	45.2	4429	6902	100.8
	4	10.91	7	5274	8220	120.0	12.4	1135	1769	25.83	1993	3106	45.3	4408	6869	100.3
	5	10.91	7	5418	8444	123.3	13.3	1129	1760	25.69	1965	3062	44.7	4417	6884	100.5
Average				5446	8488	123.9	13.0	1128	1758	25.66	1976	3079	45.0	4432	6908	100.9
Standard Deviation				129.1	201.1	2.94	0.45	6.6	10.3	0.15	13.3	20.8	0.30	24.8	39	0.56
% COV				2.37	2.37	2.37	3.46	0.59	0.59	0.59	0.68	0.68	0.68	0.56	0.56	0.56

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT installed in 57 Stone	1	10.91	7	4205	6554	95.7	9.92	969	1510	22.05	1763	2748	40.1			
	2	10.91	7	3759	5859	85.5	9.06	985	1535	22.41	1788	2787	40.7			
	3	10.91	7	4163	6488	94.7	9.65	993	1548	22.60	1812	2824	41.2			
	4	10.91	7	4226	6587	96.2	9.59	1009	1573	22.96	1853	2888	42.2			
	5	10.91	7	3978	6200	90.5	10.53	988	1540	22.48	1772	2762	40.3			
	6	10.91	7	4075	6351	92.7	9.62	981	1529	22.32	1761	2745	40.1			
	7	10.91	7	3786	5901	86.2	9.62	962	1499	21.89	1705	2657	38.8			
	8	10.91	7	3760	5860	85.6	9.30	966	1506	21.98	1711	2667	38.9			
	9	10.91	7	3533	5506	80.4	9.69	973	1516	22.14	1736	2706	39.5			
	10	10.91	7	4165	6491	94.8	9.56	1006	1568	22.89	1804	2812	41.1			
Average				3965	6180	90.2	9.7	983	1532	22.37	1771	2759	40.3			
Standard Deviation				240.4	375	5.47	0.38	16.21	25.26	0.37	46.1	71.8	1.05			
% COV				6.06	6.06	6.06	3.99	1.65	1.65	1.65	2.60	2.60	2.60			

Percent Retained			72.8	72.8	72.8	74.2	87.2	87.2	87.2	89.6	89.6	89.6			
RFid			**1.37**	**1.37**	**1.37**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

**Table D-15. Installation damage wide width tensile test results for TenCate Miragrid 8XT geogrid, soil gradation 2.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).**

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT Baseline	1	10.91	7	5584	8703	127.1	13.2	1119	1744	25.47	1964	3061	44.7	4472	6970	101.8
	2	10.91	7	5564	8672	126.6	13.5	1123	1750	25.54	1971	3072	44.8	4436	6915	101.0
	3	10.91	7	5389	8399	122.6	12.7	1132	1765	25.76	1987	3097	45.2	4429	6902	100.8
	4	10.91	7	5274	8220	120.0	12.4	1135	1769	25.83	1993	3106	45.3	4408	6869	100.3
	5	10.91	7	5418	8444	123.3	13.3	1129	1760	25.69	1965	3062	44.7	4417	6884	100.5
Average				5446	8488	123.9	13.0	1128	1758	25.66	1976	3079	45.0	4432	6908	100.9
Standard Deviation				129.1	201.1	2.94	0.45	6.6	10.3	0.15	13.3	20.8	0.30	24.8	39	0.56
% COV				2.37	2.37	2.37	3.46	0.59	0.59	0.59	0.68	0.68	0.68	0.56	0.56	0.56

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT installed in Gradation 2 (Sandy Gravel)	1	10.91	7	5008	7805	114.0	10.8	1107	1725	25.19	1949	3038	44.3	4621	7202	105.2
	2	10.91	7	4872	7593	110.9	10.5	1114	1736	25.35	1968	3067	44.8	4654	7254	105.9
	3	10.91	7	4800	7481	109.2	11.1	1110	1730	25.26	1963	3059	44.7	4658	7260	106.0
	4	10.91	7	4794	7472	109.1	10.3	1100	1714	25.03	1945	3031	44.3	4662	7266	106.1
	5	10.91	7	4640	7232	105.6	10.1	1091	1700	24.83	1930	3008	43.9	4632	7219	105.4
	6	10.91	7	5005	7801	113.9	10.8	1104	1721	25.12	1945	3031	44.3	4632	7219	105.4
	7	10.91	7	4923	7673	112.0	10.6	1113	1735	25.33	1943	3028	44.2	4632	7219	105.4
	8	10.91	7	4980	7762	113.3	10.6	1112	1733	25.30	1954	3045	44.5	4689	7308	106.7
	9	10.91	7	5070	7902	115.4	10.8	1121	1747	25.51	1974	3077	44.9	4704	7332	107.0
	10	10.91	7	4757	7414	108.2	10.3	1112	1733	25.30	1944	3030	44.2	4657	7258	106.0
Average				4885	7613	111.2	10.6	1108	1728	25.22	1952	3042	44.4	4654	7254	105.9
Standard Deviation				135.9	212	3.09	0.30	8.40	13.09	0.19	13.3	20.8	0.30	26.6	41.4	0.60
% COV				2.78	2.78	2.78	2.83	0.76	0.76	0.76	0.68	0.68	0.68	0.57	0.57	0.57

Percent Retained			89.7	89.7	89.7	81.4	98.3	98.3	98.3	98.8	98.8	98.8	105.0	105.0	105.0
RFid			**1.11**	**1.11**	**1.11**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-16. Installation damage wide width tensile test results for TenCate Miragrid 8XT geogrid, soil gradation 3.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT Baseline	1	10.91	7	5584	8703	127.1	13.2	1119	1744	25.47	1964	3061	44.7	4472	6970	101.8
	2	10.91	7	5564	8672	126.6	13.5	1123	1750	25.54	1971	3072	44.8	4436	6915	101.0
	3	10.91	7	5389	8399	122.6	12.7	1132	1765	25.76	1987	3097	45.2	4429	6902	100.8
	4	10.91	7	5274	8220	120.0	12.4	1135	1769	25.83	1993	3106	45.3	4408	6869	100.3
	5	10.91	7	5418	8444	123.3	13.3	1129	1760	25.69	1965	3062	44.7	4417	6884	100.5
Average				5446	8488	123.9	13.0	1128	1758	25.66	1976	3079	45.0	4432	6908	100.9
Standard Deviation				129.1	201.1	2.94	0.45	6.6	10.3	0.15	13.3	20.8	0.30	24.8	39	0.56
% COV				2.37	2.37	2.37	3.46	0.59	0.59	0.59	0.68	0.68	0.68	0.56	0.56	0.56

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
8XT installed in Gradation 3 (Sand)	1	10.91	7	4770	7434	108.5	10.3	1096	1708	24.94	1894	2952	43.1	4617	7196	105.1
	2	10.91	7	4535	7068	103.2	9.79	1103	1719	25.10	1897	2957	43.2			
	3	10.91	7	4906	7646	111.6	10.4	1102	1718	25.08	1897	2957	43.2	4681	7296	106.5
	4	10.91	7	4390	6842	99.9	9.62	1086	1693	24.71	1876	2924	42.7			
	5	10.91	7	4041	6298	92.0	9.02	1102	1718	25.08	1918	2989	43.6			
	6	10.91	7	4440	6920	101.0	9.97	1091	1700	24.83	1895	2953	43.1			
	7	10.91	7	4428	6901	100.8	9.63	1089	1697	24.78	1880	2930	42.8			
	8	10.91	7	4706	7335	107.1	10.1	1088	1696	24.76	1876	2924	42.7	4657	7258	106.0
	9	10.91	7	4759	7417	108.3	10.3	1089	1697	24.78	1877	2925	42.7	4626	7210	105.3
	10	10.91	7	4650	7247	105.8	9.93	1111	1732	25.28	1925	3000	43.8			
Average				4563	7111	103.8	9.91	1096	1708	24.93	1894	2951	43.1	4645	7240	105.7
Standard Deviation				250.2	390	5.69	0.42	8.38	13.06	0.19	17.3	26.9	0.39	29.4	45.7	0.67
% COV				5.48	5.48	5.48	4.19	0.76	0.76	0.76	0.91	0.91	0.91	0.63	0.63	0.63

Percent Retained			83.8	83.8	83.8	76.1	97.2	97.2	97.2	95.8	95.8	95.8	104.8	104.8	104.8
RFid			**1.19**	**1.19**	**1.19**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-17. Installation damage wide width tensile test results for TenCate Miragrid 24XT geogrid, soil gradation 1.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT Baseline	1	12.10	8	21182	32038	467.8	16.2	3519	5322	77.70	5500	8319	121.5	11763	17792	259.8
	2	12.10	8	20833	31510	460.0	15.1	3596	5439	79.41	5596	8464	123.6	12043	18214	265.9
	3	12.10	8	21277	32182	469.9	15.5	3618	5471	79.88	5592	8458	123.5	12311	18621	271.9
	4	12.10	8	20917	31636	461.9	15.3	3621	5477	79.97	5608	8482	123.8	12107	18312	267.4
	5	12.10	8	19736	29851	435.8	15.6	3656	5529	80.73	5707	8632	126.0	12477	18871	275.5
Average				20789	31443	459.1	15.5	3602	5448	79.54	5601	8471	123.7	12140	18362	268.1
Standard Deviation				616.4	932.3	13.61	0.42	51.1	77.4	1.13	73.5	111.1	1.62	271.7	411	6.00
% COV				2.97	2.97	2.97	2.68	1.42	1.42	1.42	1.31	1.31	1.31	2.24	2.24	2.24

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT installed in Gradation 1 (Coarse Gravel)	1	12.10	8	15062	22781	332.6	11.1	3700	5596	81.71	5638	8527	124.5	12765	19307	281.9
	2	12.10	8	15714	23767	347.0	11.9	3638	5502	80.34	5537	8375	122.3	12705	19216	280.6
	3	12.10	8	15496	23438	342.2	11.2	3526	5333	77.86	5532	8367	122.2	12656	19142	279.5
	4	12.10	8	16062	24294	354.7	11.5	3741	5658	82.61	5740	8682	126.8	13483	20393	297.7
	5	12.10	8	15871	24005	350.5	10.9	3878	5865	85.64	5901	8925	130.3	13971	21131	308.5
	6	12.10	8	14641	22145	323.3	10.8	3744	5663	82.68	5850	8848	129.2	13972	21133	308.5
	7	12.10	8	13824	20909	305.3	10.9	3587	5425	79.21	5647	8541	124.7	12519	18935	276.5
	8	12.10	8	13143	19879	290.2	11.5	3604	5451	79.59	5585	8447	123.3	11904	18005	262.9
	9	12.10	8	14325	21667	316.3	11.6	3527	5335	77.88	5492	8307	121.3	12664	19154	279.7
	10	12.10	8	14573	22042	321.8	10.7	3592	5433	79.32	5603	8475	123.7	13042	19726	288.0
Average				14871	22493	328.4	11.2	3654	5526	80.68	5653	8549	124.8	12968	19614	286.4
Standard Deviation				947.4	1433	20.92	0.40	111.34	168.40	2.46	137.1	207.4	3.03	659.8	998.0	14.57
% COV				6.37	6.37	6.37	3.55	3.05	3.05	3.05	2.43	2.43	2.43	5.09	5.09	5.09

Percent Retained			71.5	71.5	71.5	72.1	101.4	101.4	101.4	100.9	100.9	100.9	106.8	106.8	106.8
RFid			**1.40**	**1.40**	**1.40**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-18. Installation damage wide width tensile test results for TenCate Miragrid 24XT geogrid, 57 stone.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT Baseline	1	12.10	8	21182	32038	467.8	16.2	3519	5322	77.70	5500	8319	121.5	11763	17792	259.8
	2	12.10	8	20833	31510	460.0	15.1	3596	5439	79.41	5596	8464	123.6	12043	18214	265.9
	3	12.10	8	21277	32182	469.9	15.5	3618	5471	79.88	5592	8458	123.5	12311	18621	271.9
	4	12.10	8	20917	31636	461.9	15.3	3621	5477	79.97	5608	8482	123.8	12107	18312	267.4
	5	12.10	8	19736	29851	435.8	15.6	3656	5529	80.73	5707	8632	126.0	12477	18871	275.5
Average				20789	31443	459.1	15.5	3602	5448	79.54	5601	8471	123.7	12140	18362	268.1
Standard Deviation				616.4	932.3	13.61	0.42	51.1	77.4	1.13	73.5	111.1	1.62	271.7	411	6.00
% COV				2.97	2.97	2.97	2.68	1.42	1.42	1.42	1.31	1.31	1.31	2.24	2.24	2.24

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT installed in 57 Stone	1	12.10	8	17439	26376	385.1	11.8	3813	5767	84.20	5764	8718	127.3	13845	20941	305.7
	2	12.10	8	17197	26010	379.8	11.4	3881	5870	85.70	5851	8850	129.2	13949	21098	308.0
	3	12.10	8	17523	26504	387.0	11.4	3965	5997	87.56	5976	9039	132.0	14522	21965	320.7
	4	12.10	8	17459	26407	385.5	11.7	3814	5769	84.22	5739	8680	126.7	13801	20874	304.8
	5	12.10	8	15258	23078	336.9	11.8	3684	5572	81.35	5662	8564	125.0	12754	19290	281.6
	6	12.10	8	16937	25617	374.0	11.6	3876	5862	85.59	5913	8943	130.6	13956	21108	308.2
	7	12.10	8	17761	26864	392.2	11.4	3934	5950	86.87	5953	9004	131.5	14521	21963	320.7
	8	12.10	8	16378	24772	361.7	11.9	3917	5924	86.50	5892	8912	130.1	14222	21511	314.1
	9	12.10	8	16849	25484	372.1	11.4	3835	5800	84.69	5823	8807	128.6	13657	20656	301.6
	10	12.10	8	16441	24867	363.1	11.5	3858	5835	85.19	5783	8747	127.7	13941	21086	307.9
Average				16924	25598	373.7	11.6	3858	5835	85.19	5836	8826	128.9	13917	21049	307.3
Standard Deviation				745.2	1127	16.46	0.20	79.11	119.65	1.75	100.2	151.6	2.21	501.8	758.9	11.08
% COV				4.40	4.40	4.40	1.70	2.05	2.05	2.05	1.72	1.72	1.72	3.61	3.61	3.61

Percent Retained			81.4	81.4	81.4	74.6	107.1	107.1	107.1	104.2	104.2	104.2	114.6	114.6	114.6
RFid			**1.23**	**1.23**	**1.23**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-19. Installation damage wide width tensile test results for TenCate Miragrid 24XT geogrid, soil gradation 2.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT Baseline	1	12.10	8	21182	32038	467.8	16.2	3519	5322	77.70	5500	8319	121.5	11763	17792	259.8
	2	12.10	8	20833	31510	460.0	15.1	3596	5439	79.41	5596	8464	123.6	12043	18214	265.9
	3	12.10	8	21277	32182	469.9	15.5	3618	5471	79.88	5592	8458	123.5	12311	18621	271.9
	4	12.10	8	20917	31636	461.9	15.3	3621	5477	79.97	5608	8482	123.8	12107	18312	267.4
	5	12.10	8	19736	29851	435.8	15.6	3656	5529	80.73	5707	8632	126.0	12477	18871	275.5
Average				20789	31443	459.1	15.5	3602	5448	79.54	5601	8471	123.7	12140	18362	268.1
Standard Deviation				616.4	932.3	13.61	0.42	51.1	77.4	1.13	73.5	111.1	1.62	271.7	411	6.00
% COV				2.97	2.97	2.97	2.68	1.42	1.42	1.42	1.31	1.31	1.31	2.24	2.24	2.24

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT installed in Gradation 2 (Sandy Gravel)	1	12.10	8	19617	29671	433.2	13.2	3753	5676	82.88	5721	8653	126.3	13503	20423	298.2
	2	12.10	8	19462	29436	429.8	13.0	3787	5728	83.63	5777	8738	127.6	13572	20528	299.7
	3	12.10	8	20045	30318	442.6	13.1	3756	5681	82.94	5775	8735	127.5	13495	20411	298.0
	4	12.10	8	19973	30209	441.1	13.3	3663	5540	80.89	5634	8521	124.4	13206	19974	291.6
	5	12.10	8	19681	29768	434.6	12.9	3800	5748	83.91	5752	8700	127.0	13510	20434	298.3
	6	12.10	8	20106	30410	444.0	13.2	3837	5803	84.73	5747	8692	126.9	14145	21394	312.4
	7	12.10	8	20282	30677	447.9	13.4	3861	5840	85.26	5824	8809	128.6	13997	21170	309.1
	8	12.10	8	19620	29675	433.3	12.9	3810	5763	84.13	5818	8800	128.5	13879	20992	306.5
	9	12.10	8	19980	30220	441.2	13.5	3749	5670	82.79	5691	8608	125.7	13814	20894	305.0
	10	12.10	8	19519	29522	431.0	13.0	3758	5684	82.99	5735	8674	126.6	13254	20047	292.7
Average				19829	29991	437.9	13.2	3777	5713	83.41	5747	8693	126.9	13638	20627	301.2
Standard Deviation				281.6	426	6.22	0.21	55.31	83.65	1.22	57.2	86.5	1.26	310.6	469.8	6.86
% COV				1.42	1.42	1.42	1.57	1.46	1.46	1.46	0.99	0.99	0.99	2.28	2.28	2.28

Percent Retained			95.4	95.4	95.4	84.6	104.9	104.9	104.9	102.6	102.6	102.6	112.3	112.3	112.3
RFid			**1.05**	**1.05**	**1.05**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-20. Installation damage wide width tensile test results for TenCate Miragrid 24XT geogrid, soil gradation 3.
Installation damage testing (ASTM D5818, as modified in AASHTO R69-15).
Wide wide tensile testing (ASTM D6637, Method B).

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT Baseline	1	12.10	8	21182	32038	467.8	16.2	3519	5322	77.70	5500	8319	121.5	11763	17792	259.8
	2	12.10	8	20833	31510	460.0	15.1	3596	5439	79.41	5596	8464	123.6	12043	18214	265.9
	3	12.10	8	21277	32182	469.9	15.5	3618	5471	79.88	5592	8458	123.5	12311	18621	271.9
	4	12.10	8	20917	31636	461.9	15.3	3621	5477	79.97	5608	8482	123.8	12107	18312	267.4
	5	12.10	8	19736	29851	435.8	15.6	3656	5529	80.73	5707	8632	126.0	12477	18871	275.5
Average				20789	31443	459.1	15.5	3602	5448	79.54	5601	8471	123.7	12140	18362	268.1
Standard Deviation				616.4	932.3	13.61	0.42	51.1	77.4	1.13	73.5	111.1	1.62	271.7	411	6.00
% COV				2.97	2.97	2.97	2.68	1.42	1.42	1.42	1.31	1.31	1.31	2.24	2.24	2.24

Machine Direction

Sample Identification	Specimen Number	Ribs per Foot Width	Number of Ribs Tested	Maximum Load (lbs)	Maximum Load (lbs/ft)	Maximum Load (kN/m)	Elongation @ Break (%)	Load @ 2% lbs	Load @ 2% (lbs/ft)	Load @ 2% (kN/m)	Load @ 5% lbs	Load @ 5% (lbs/ft)	Load @ 5% (kN/m)	Load @ 10% lbs	Load @ 10% (lbs/ft)	Load @ 10% (kN/m)
24XT installed in Gradation 3 (Sand)	1	12.10	8	19003	28742	419.6	12.6	3799	5746	83.89	5674	8582	125.3	13635	20623	301.1
	2	12.10	8	18989	28721	419.3	12.8	3671	5552	81.06	5534	8370	122.2	13242	20029	292.4
	3	12.10	8	19380	29312	428.0	12.9	3654	5527	80.69	5545	8387	122.4	13415	20290	296.2
	4	12.10	8	19368	29294	427.7	13.1	3673	5555	81.11	5472	8276	120.8	13247	20036	292.5
	5	12.10	8	18261	27620	403.2	12.4	3611	5462	79.74	5473	8278	120.9	12964	19608	286.3
	6	12.10	8	19858	30035	438.5	13.0	3858	5835	85.19	5699	8620	125.8	14212	21496	313.8
	7	12.10	8	19396	29336	428.3	12.8	3763	5692	83.10	5586	8449	123.4	13817	20898	305.1
	8	12.10	8	19205	29048	424.1	12.7	3738	5654	82.54	5595	8462	123.6	13522	20452	298.6
	9	12.10	8	18714	28305	413.3	12.3	3483	5268	76.91	5695	8614	125.8	13807	20883	304.9
	10	12.10	8	18113	27396	400.0	11.7	3967	6000	87.60	5831	8819	128.8	14240	21538	314.5
Average				19029	28781	420.2	12.6	3722	5629	82.18	5610	8486	123.9	13610	20585	300.5
Standard Deviation				539.7	816	11.92	0.41	135.59	205.08	2.99	113.9	172.2	2.51	417.9	632.1	9.23
% COV				2.84	2.84	2.84	3.25	3.64	3.64	3.64	2.03	2.03	2.03	3.07	3.07	3.07

Percent Retained			91.5	91.5	91.5	81.3	103.3	103.3	103.3	100.2	100.2	100.2	112.1	112.1	112.1
RFid			**1.09**	**1.09**	**1.09**										

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table D-21. Standard test soil gradations (% passing).

		Standard Installation Damage Soils Used for Field Exposures			
US Sieve No.	Sieve Size (mm)	Percent Passing by Weight			
		Type 1 (Coarse Gravel)	57 stone	Type2 (Sandy Gravel)	Type 3 (Silty Sand)
6 - in	150	100.0	100.0	100.0	100.0
3 - in.	75	100.0	100.0	100.0	100.0
2 - in.	50	100.0	100.0	100.0	100.0
1.5 - in.	38	-	100.0	100.0	100.0
1 - in.	25	26.4	100.0	100.0	100.0
3/4 - in.	19	1.6	71.0	100.0	100.0
1/2 - in.	12.5	-	42.0	-	100.0
3/8 - in.	9.5	1.1	23.5	99.1	100.0
No. 4	4.75	1.1	5	40.5	100.0
No. 10	1.7	1.1	0.0	4.2	77.6
No. 20	0.85	1.1	0.0	3.4	48.8
No. 40	0.425	1.0	0.0	3.3	33.1
No. 60	0.25	-	0.0	-	21.5
No. 100	0.15	-	0.0	-	12.2
No. 200	0.075	-	0.0	-	4.4
D50, mm		22.6	14	5.3	0.9
LA Abrasion Small Drum Method B 500 Cycles		20.2% loss		12.6% loss	
Liquid Limit, %		-		-	-
Plasticity Index, %		-		-	-
Angularity (ASTM D 2488)		Angular to Subangular	Angular to Subangular	Angular	Angular to Subangular
AASHTO Classification		No. 4 Aggregate	No. 57 Aggregate	No. 89 Aggregate	A-1b Soil
Soil Classification		GP	GP	GP	SM
		Poorly Graded Gravel	Poorly Graded Gravel	Poorly Graded Gravel with Sand	Well Graded Silty Sand

Figure D-1. Lifting Plates positioned between ties and covered with first lift of compacted soil/aggregate.

Figure D-2. Grid positioned over compacted base and covered. Cover soil/aggregate is uniformly spread and compacted using field-scale equipment and procedures.

Figure D-3. The density of the compacted soil is measured with a nuclear density gauge.

Figure D-4. The steel plates are tilted to facilitate exhumation.

Appendix E: ISO/EN Laboratory Installation Damage Detailed Test Results

E.1 ISO/EN Laboratory Installation Damage Test Program

Testing is done per the EN/ISO 10722. Five wide width tensile specimens are exposed to 200 cycles producing between 209 lb/ft^2 (10 kPa) minimum and 10,443 lb/ft^2 (500 kPa) maximum stress at a frequency of 1 Hz. The aggregate used is a sintered aluminum oxide with a grain size such that 100% shall pass a 10 mm sieve and 0% shall pass a 5 mm sieve. The exposed specimens and five baseline specimens are tested according to ISO/EN 10319.

Representative photos of test apparatus and aggregate are provided in Figures E-1 and E-2. Detailed test results are provided in Tables E-1 through E-9.

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Figure E-1. ISO/EN 10722, laboratory installation damage test apparatus.

Figure E-2. ISO/EN 10722, laboratory installation damage aggregate.

Table E-1. Laboratory installation damage (ISO/EN 10722) tensile test results for 2XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	7								
MD Number of Ribs per foot:	10.80								
MD - Tensile Strength (lbs) - B	1781	1770	1802	1821	1735	**1782**	33	2	
MD Tensile Strength (lbs/ft) - B	2748	2731	2780	2810	2677	**2749**	50	2	
MD Tensile Strength (kN/m) - B	40.1	39.9	40.6	41.0	39.1	**40.1**	0.7	1.8	
MD - Tensile Strength (lbs) - E	1529	1505	1727	1662	1595	**1604**	92	6	
MD Tensile Strength (lbs/ft) - E	2359	2322	2665	2564	2461	**2474**	142	6	**90**
MD Tensile Strength (kN/m) - E	34.4	33.9	38.9	37.4	35.9	**36.1**	2.1	5.7	
MD - Elong. @ Max. Load (%) - B	9.14	9.17	9.33	9.50	8.73	**9.17**	0.3	3.1	
MD - Elong. @ Max. Load (%) - E	7.73	7.87	9.05	8.61	8.26	**8.30**	0.5	6.5	**91**

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-2. Laboratory installation damage (ISO/EN 10722) tensile test results for 3XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	7								
MD Number of Ribs per foot:	10.75								
MD - Tensile Strength (lbs) - B	2469	2492	2540	2480	2580	2512	47	2	
MD Tensile Strength (lbs/ft) - B	3790	3826	3899	3807	3961	3857	72	2	
MD Tensile Strength (kN/m) - B	55.3	55.9	56.9	55.6	57.8	56.3	1.0	1.9	
MD - Tensile Strength (lbs) - E	2400	1999	2199	2302	2125	2205	155	7	
MD Tensile Strength (lbs/ft) - E	3684	3069	3376	3534	3262	3385	238	7	88
MD Tensile Strength (kN/m) - E	53.8	44.8	49.3	51.6	47.6	49.4	3.5	7.0	
MD - Elong. @ Max. Load (%) - B	9.13	9.39	10.4	9.38	9.98	9.66	0.5	5.4	
MD - Elong. @ Max. Load (%) - E	9.61	13.0	8.72	8.68	11.0	10.2	1.8	17.9	106

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-3. Laboratory installation damage (ISO/EN 10722) tensile test results for 5XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	7								
MD Number of Ribs per foot:	10.71								
MD - Tensile Strength (lbs) - B	3334	3359	3296	3245	3214	**3290**	60	2	
MD Tensile Strength (lbs/ft) - B	5100	5138	5042	4964	4916	**5032**	92	2	
MD Tensile Strength (kN/m) - B	74.5	75.0	73.6	72.5	71.8	**73.5**	1.3	1.8	
MD - Tensile Strength (lbs) - E	3091	2847	3142	3195	2922	**3039**	148	5	
MD Tensile Strength (lbs/ft) - E	4728	4355	4806	4887	4470	**4649**	227	5	**92**
MD Tensile Strength (kN/m) - E	69.0	63.6	70.2	71.4	65.3	**67.9**	3.3	4.9	
MD - Elong. @ Max. Load (%) - B	10.4	10.1	10.4	10.4	9.98	**10.3**	0.2	2.0	
MD - Elong. @ Max. Load (%) - E	9.94	9.37	10.8	10.3	9.74	**10.0**	0.5	5.4	**98**

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-4. Laboratory installation damage (ISO/EN 10722) tensile test results for 7XT

PARAMETER	TEST REPLICATE NUMBER					MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
	1	2	3	4	5				
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	7								
MD Number of Ribs per foot:	10.68								
MD - Tensile Strength (lbs) - B	4478	4383	4402	4286	4295	**4369**	80	2	
MD Tensile Strength (lbs/ft) - B	6830	6685	6714	6537	6551	**6663**	122	2	
MD Tensile Strength (kN/m) - B	99.7	97.6	98.0	95.4	95.6	**97.3**	1.8	1.8	
MD - Tensile Strength (lbs) - E	3529	3049	3285	3930	3705	**3500**	345	10	
MD Tensile Strength (lbs/ft) - E	5382	4650	5010	5994	5651	**5338**	527	10	**80**
MD Tensile Strength (kN/m) - E	78.6	67.9	73.2	87.5	82.5	**77.9**	7.7	9.9	
MD - Elong. @ Max. Load (%) - B	12.0	11.6	11.7	11.1	11.2	**11.5**	0.4	3.2	
MD - Elong. @ Max. Load (%) - E	9.56	9.24	9.58	10.7	10.1	**9.84**	0.6	5.8	**85**

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-5. Laboratory installation damage (ISO/EN 10722) tensile test results for 8XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	7								
MD Number of Ribs per foot:	10.91								
MD - Tensile Strength (lbs) - B	5431	5448	5267	5322	5289	5351	83	2	
MD Tensile Strength (lbs/ft) - B	8461	8487	8205	8291	8240	8337	129	2	
MD Tensile Strength (kN/m) - B	124	124	120	121	120	122	2	2	
MD - Tensile Strength (lbs) - E	4310	4507	4892	4661	4486	4571	218	5	
MD Tensile Strength (lbs/ft) - E	6714	7021	7621	7261	6989	7121	340	5	85
MD Tensile Strength (kN/m) - E	98	103	111	106	102	104	5	5	
MD - Elong. @ Max. Load (%) - B	11.9	11.9	11.7	11.7	11.7	11.8	0.1	0.9	
MD - Elong. @ Max. Load (%) - E	10.2	10.2	10.9	11.7	9.93	10.6	0.7	6.8	90

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-6. Laboratory installation damage (ISO/EN 10722) tensile test results for 10XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	7								
MD Number of Ribs per foot:	10.78								
MD - Tensile Strength (lbs) - B	7757	7221	7193	7567	7535	7455	242	3	
MD Tensile Strength (lbs/ft) - B	11947	11122	11079	11655	11605	11481	372	3	
MD Tensile Strength (kN/m) - B	174	162	162	170	169	168	5	3	
MD - Tensile Strength (lbs) - E	6700	6577	5787	6176	6612	6370	383	6	
MD Tensile Strength (lbs/ft) - E	10319	10130	8913	9512	10184	9812	590	6	85
MD Tensile Strength (kN/m) - E	151	148	130	139	149	143	9	6	
MD - Elong. @ Max. Load (%) - B	14.2	12.8	12.6	13.6	13.5	13.3	0.6	4.8	
MD - Elong. @ Max. Load (%) - E	13.0	12.0	11.0	11.3	11.9	11.8	0.8	6.5	89

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-7. Laboratory installation damage (ISO/EN 10722) tensile test results for 20XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	8								
MD Number of Ribs per foot:	12.09								
MD - Tensile Strength (lbs) - B	11213	11501	11707	11878	11801	11620	268	2	
MD Tensile Strength (lbs/ft) - B	16948	17383	17695	17953	17837	17563	405	2	
MD Tensile Strength (kN/m) - B	247	254	258	262	260	256	6	2	
MD - Tensile Strength (lbs) - E	9968	10258	10280	10850	10857	10443	395	4	
MD Tensile Strength (lbs/ft) - E	15066	15504	15538	16399	16410	15783	597	4	90
MD Tensile Strength (kN/m) - E	220	226	227	239	240	230	9	4	
MD - Elong. @ Max. Load (%) - B	12.3	12.1	12.7	12.7	12.5	12.5	0.3	2.1	
MD - Elong. @ Max. Load (%) - E	10.5	11.3	10.9	11.4	11.5	11.1	0.4	3.7	89

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-8. Laboratory installation damage (ISO/EN 10722) tensile test results for 22XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	8								
MD Number of Ribs per foot:	12.09								
MD - Tensile Strength (lbs) - B	15275	14914	15760	15930	16005	15577	467	3	
MD Tensile Strength (lbs/ft) - B	23092	22546	23825	24082	24195	23548	706	3	
MD Tensile Strength (kN/m) - B	337	329	348	352	353	344	10	3	
MD - Tensile Strength (lbs) - E	15043	14130	14088	14065	14575	14380	426	3	
MD Tensile Strength (lbs/ft) - E	22741	21361	21297	21262	22033	21739	643	3	92
MD Tensile Strength (kN/m) - E	332	312	311	310	322	317	9	3	
MD - Elong. @ Max. Load (%) - B	13.9	13.6	13.3	13.9	13.9	13.7	0.3	2.0	
MD - Elong. @ Max. Load (%) - E	13.4	12.5	12.4	12.1	13.0	12.7	0.5	4.1	92

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table E-9. Laboratory installation damage (ISO/EN 10722) tensile test results for 24XT

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	COEF. VARI.	PERCENT RETAINED
Laboratory Installation Damage (ISO/EN 10722)									
Strength Retained measured via wide width tensile (ISO/EN 10319)									
MD Number of Ribs per Specimen:	8								
MD Number of Ribs per foot:	12.10								
MD - Tensile Strength (lbs) - B	20750	20911	21124	21087	20925	20959	151	1	
MD Tensile Strength (lbs/ft) - B	32189	32439	32769	32712	32461	32514	234	1	
MD Tensile Strength (kN/m) - B	470	474	478	478	474	475	3	1	
MD - Tensile Strength (lbs) - E	18937	17610	19285	18341	18597	18554	636	3	
MD Tensile Strength (lbs/ft) - E	29377	27318	29916	28452	28849	28782	987	3	89
MD Tensile Strength (kN/m) - E	429	399	437	415	421	420	14	3	
MD - Elong. @ Max. Load (%) - B	13.9	13.8	14.1	13.9	14.2	14.0	0.2	1.2	
MD - Elong. @ Max. Load (%) - E	12.5	12.3	13.1	13.2	12.4	12.7	0.4	3.3	91

B - Baseline Unexposed
E - Exposed

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Appendix F: Creep Rupture Detailed Test Results

Table F-1: Explanation/Key for Individual Creep Test Data Tables/Figures

Accelerated Creep Rupture via SIM - ASTM D 6992

Spreadsheet Filename

SUMMARY CREEP PARAMETERS: NTPEP - Manufacturer Product

Specimen: Test Filename — Test Date: 01-Jan-07 — Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 65.0 kN/m — %UTS: 65.00

Ultimate Tensile Strength: 100.0 kN/m — Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	20.00	-
2	9500	10000	500	0.1	1.2600	34.00	0.0900
3	19500	20000	500	0.1	1.2600	48.00	0.0900
4	29500	30000	500	0.1	1.2600	62.00	0.0900
5	39500	40000	500	0.1	1.2600	76.00	0.0900
6	49500	50000	500	0.1	1.2600	90.00	0.0900
						AVG	0.0900

Summary	Initial	Final	Units	@20C refT
lab time	90	60000	sec	-
$logA_T(t-t')$	1.9542	4.7782	log hours	6.0000
$A_T(t-t')$	-	17.25	years	114.00
Strain	9.500	12.500	%	-
Modulus	800.0	600.0	kN/m	-

$logA_T/T$ = Horizontal shift factor for each temperature step expressed per degree C

Average temperature for each step

$logA_T$ = Horizontal shift factor for each temperature step

Vshift(%) = Vertical shift to offset system temperature expansion

Rupture Time expressed in log hours and years

% Strain and Creep Modulus at end of test

% Strain and Creep Modulus at onset of creep

t = The actual start time of each temperature step

t' = The theoritical start time of each temperature step

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Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 2XT

Specimen: 27463n2m-2XT-sim7 | Test Date: June 2017 | Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 1954 lb/ft | %UTS: 70.96
Ultimate Tensile Strength: 2753 lb/ft | Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$\log A_T$	Temp	$\log A_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9700	10020	320	0.095	1.4949	34.1	0.1034
3	19750	20010	260	0.1	1.5976	48.5	0.1109
4	29800	30000	200	0.14	1.7091	63.1	0.1174
5	39400	39990	590	0.13	1.2363	79.3	0.0762
6							
						AVG	0.1012

Summary	Initial	Final	Units	@20C refT
lab time	55.9	40320	sec	-
$\log A_T(t-t')$	1.7478	9.0015	log hours	5.4100
$A_T(t-t')$	-	31.80	years	29.32
Strain	7.59	12.009	%	-
Modulus	25764.2	3870.0	lb/ft	-

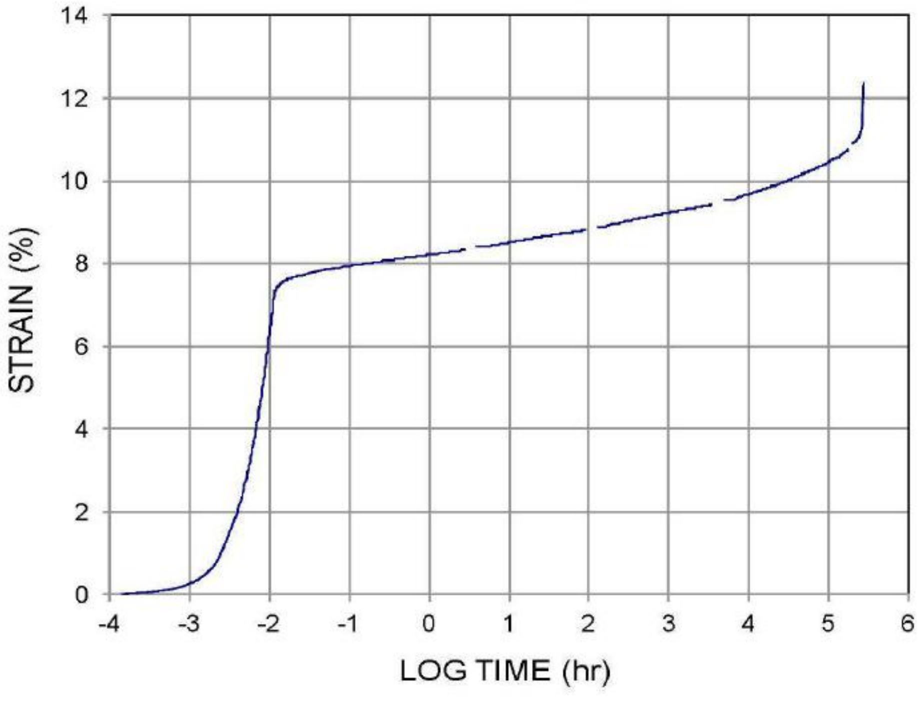

Figure F-1. SIM/Creep data/curve for 2XT at load level of 70.96% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 2XT

Specimen: 27463n2m-2XT-sim7 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 2065 lb/ft %UTS: 75.00
Ultimate Tensile Strength: 2753 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$\log A_T$	Temp	$\log A_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9500	10019	519	0.08	1.2840	34.1	0.0888
3	19750	20009	259	0.1	1.6063	48.5	0.1115
4	29800	29999	199	0.16	1.7096	63.8	0.1123
5							
6							
						AVG	0.1043

Summary	Initial	Final	Units	@20C refT
lab time	43.3	31109	sec	-
$\log A_T(t-t')$	1.6360	7.7169	log hours	4.1304
$A_T(t-t')$	-	1.65	years	1.54
Strain	7.60	11.442	%	-
Modulus	27379.6	18044.7	lb/ft	-

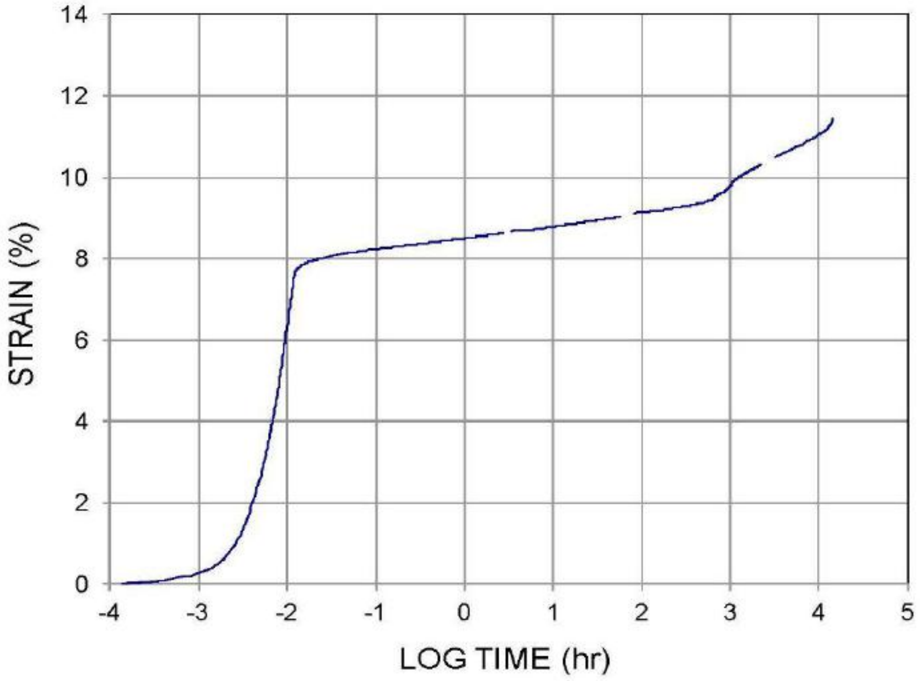

Figure F-2. SIM/Creep data/curve for 2XT at load level of 75.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 2XT

Specimen: 27463n2m-2XT-sim7 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 2175 lb/ft %UTS: 79.00
Ultimate Tensile Strength: 2753 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9500	10019	519	0.06	1.2841	34.1	0.0888
3	19600	20009	409	0.05	1.4082	49.1	0.0938
4							
5							
6							
						AVG	0.0914

Summary	Initial	Final	Units	@20C refT
lab time	38.0	21719	sec	-
$logA_T(t-t')$	1.5798	6.0185	log hours	2.4319
$A_T(t-t')$	-	0.03	years	0.03
Strain	6.04	9.664	%	-
Modulus	35936.8	22509.2	lb/ft	-

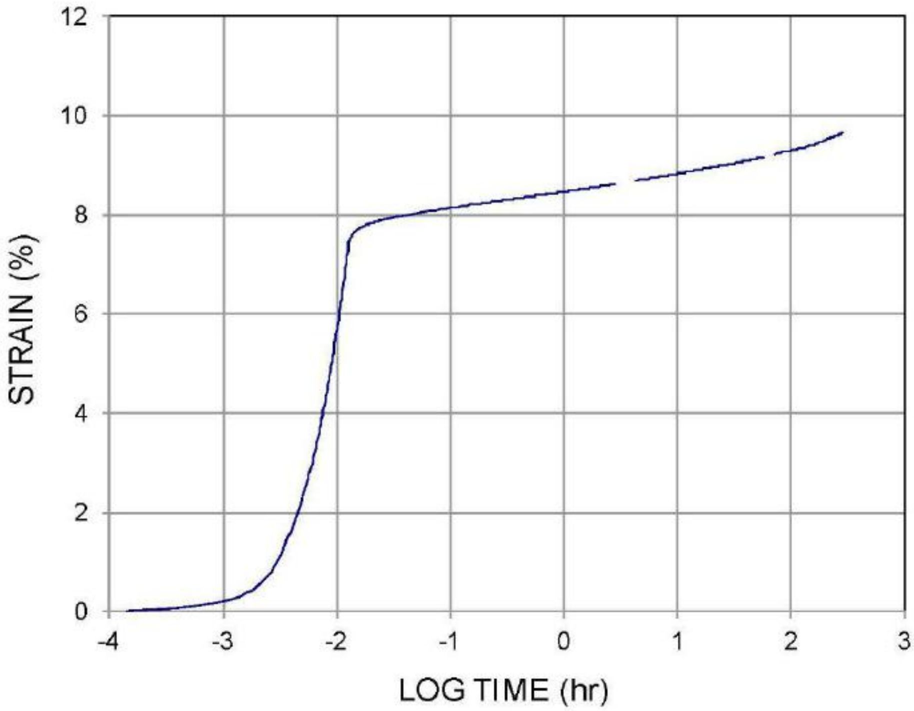

Figure F-3. SIM/Creep data/curve for 2XT at load level of 79.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 2XT

Specimen: 27463n2m-2XT-sim8 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 2285 lb/ft %UTS: 83.00
Ultimate Tensile Strength: 2753 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9750	10020	270	0.06	1.5688	34.5	0.1055
3							
4							
5							
6							

Summary	Initial	Final	Units	@20C refT
lab time	40.5	12390	sec	-
$logA_T(t-t')$	1.6075	4.9903	log hours	1.3981
$A_T(t-t')$	-	0.00	years	0.00
Strain	7.43	9.994	%	-
Modulus	29613.5	22865.2	lb/ft	-

AVG 0.1055

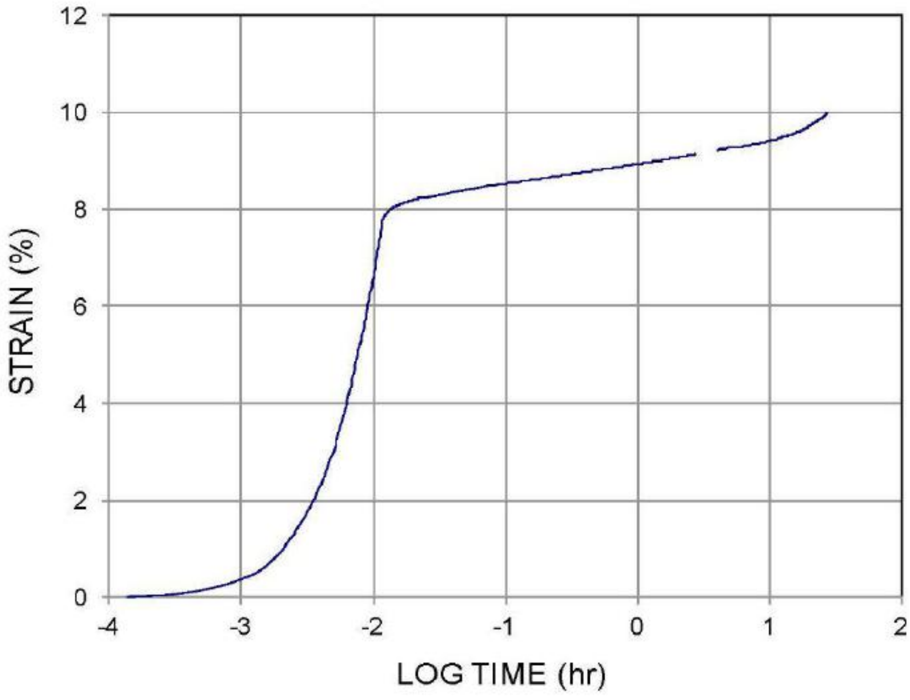

Figure F-4. SIM/Creep data/curve for 2XT at load level of 83.0% UTS.

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Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim6 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 5872 lb/ft %UTS: 68.00

Ultimate Tensile Strength: 8636 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9500	10020	520	0.115	1.2839	34.1	0.0888
3	19500	20010	510	0.13	1.3131	48.5	0.0912
4	29500	30000	500	0.09	1.3213	63.1	0.0908
5	39500	39990	490	0.13	1.3297	77.6	0.0913
6	49500	49980	480	0.18	1.3382	92.6	0.0897

Summary	Initial	Final	Units	@20C refT
lab time	51.3	51300	sec	-
$logA_T(t-t')$	1.7104	9.8413	log hours	6.2548
$A_T(t-t')$	-	219.90	years	205.12
Strain	8.64	12.084	%	-
Modulus	68166.7	48596.3	lb/ft	-

AVG 0.0903

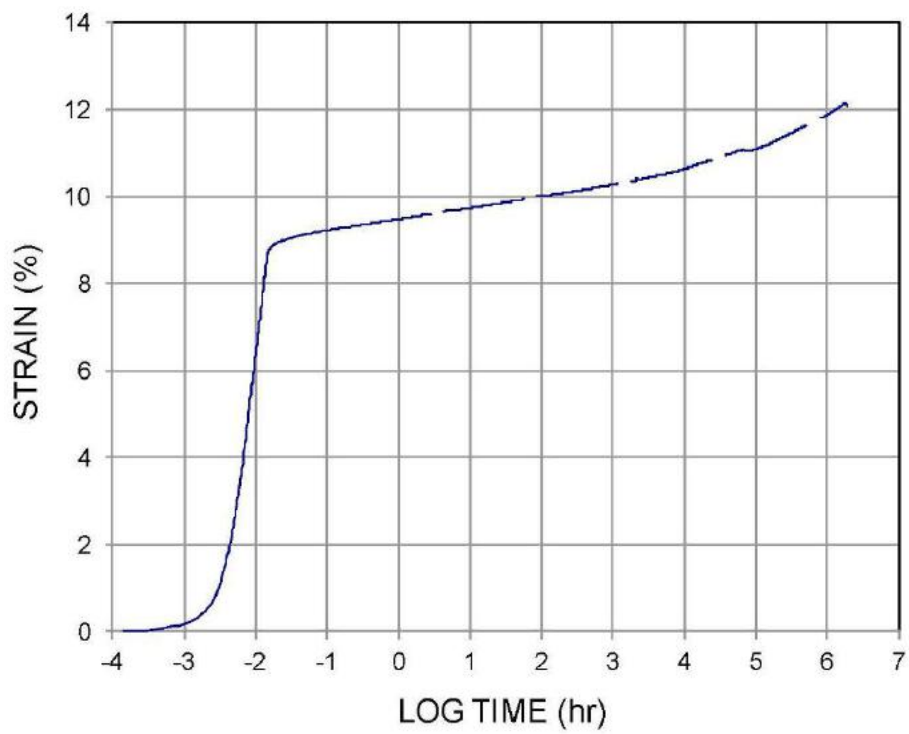

Figure F-5. SIM/Creep data/curve for 8XT at load level of 68.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim7 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 6132 lb/ft %UTS: 71.00
Ultimate Tensile Strength: 8636 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9000	10019	1019	0.1	0.9912	34.1	0.0685
3	19400	20009	609	0.12	1.2556	48.5	0.0872
4	29500	29999	499	0.05	1.3255	63.1	0.0911
5	39500	39989	489	0.05	1.3298	77.8	0.0903
6							

Summary	Initial	Final	Units	@20C refT
lab time	61.7	44669	sec	-
$logA_T(t-t')$	1.7900	8.6155	log hours	5.0359
$A_T(t-t')$	-	13.07	years	12.39
Strain	8.98	12.154	%	-
Modulus	68253.0	50449.9	lb/ft	-

AVG 0.0843

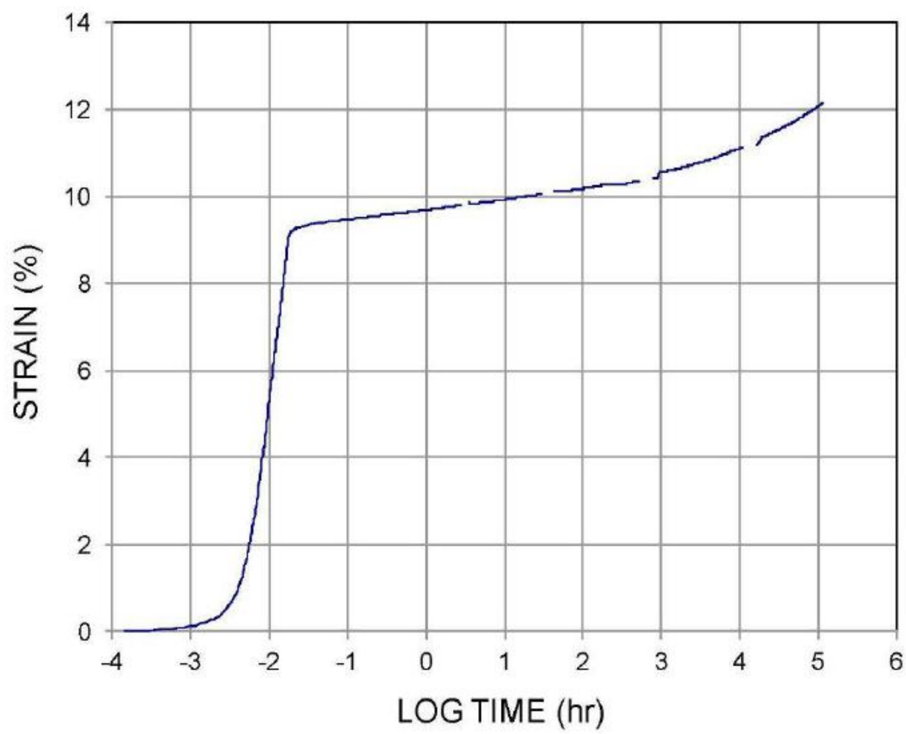

Figure F-6. SIM/Creep data/curve for 8XT at load level of 71.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim7 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 6391 lb/ft %UTS: 74.00

Ultimate Tensile Strength: 8636 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9200	10019	819	0.16	1.0860	34.1	0.0751
3	19200	20009	809	0.18	1.1244	48.5	0.0781
4	29600	29999	399	0.09	1.4307	63.1	0.0983
5	39500	39989	489	0.13	1.3256	77.9	0.0891
6							

Summary	Initial	Final	Units	@20C refT
lab time	55.7	42119	sec	-
$logA_T(t-t')$	1.7458	8.3849	log hours	4.8030
$A_T(t-t')$	-	7.69	years	7.25
Strain	8.72	11.605	%	-
Modulus	73502.2	55069.9	lb/ft	-

AVG 0.0852

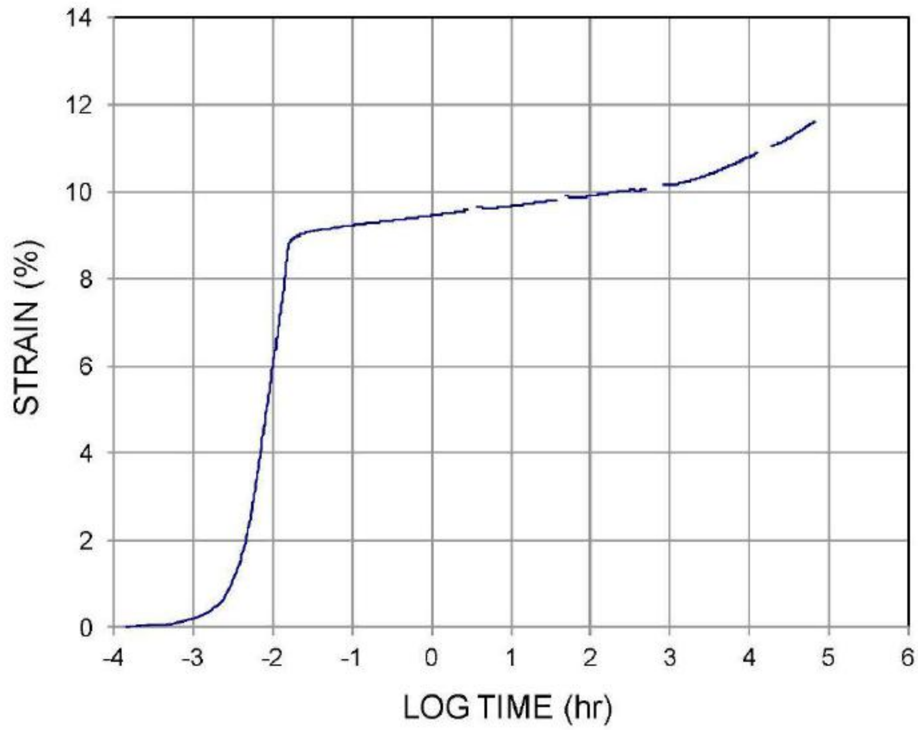

Figure F-7. SIM/Creep data/curve for 8XT at load level of 74.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim7 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress:	6650	lb/ft		%UTS:	77.00
Ultimate Tensile Strength:	8636	lb/ft		Rupture:	YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9500	10019	519	0.14	1.2841	34.1	0.0888
3	19500	20009	509	0.13	1.3134	48.5	0.0912
4	29500	29999	499	0.1	1.3216	66.1	0.0751
5							
6							
						AVG	0.0843

Summary	Initial	Final	Units	@20C refT
lab time	57.5	30209	sec	-
$logA_T(t-t')$	1.7597	6.7699	log hours	3.1833
$A_T(t-t')$	-	0.19	years	0.17
Strain	9.31	12.111	%	-
Modulus	71558.0	54907.4	lb/ft	-

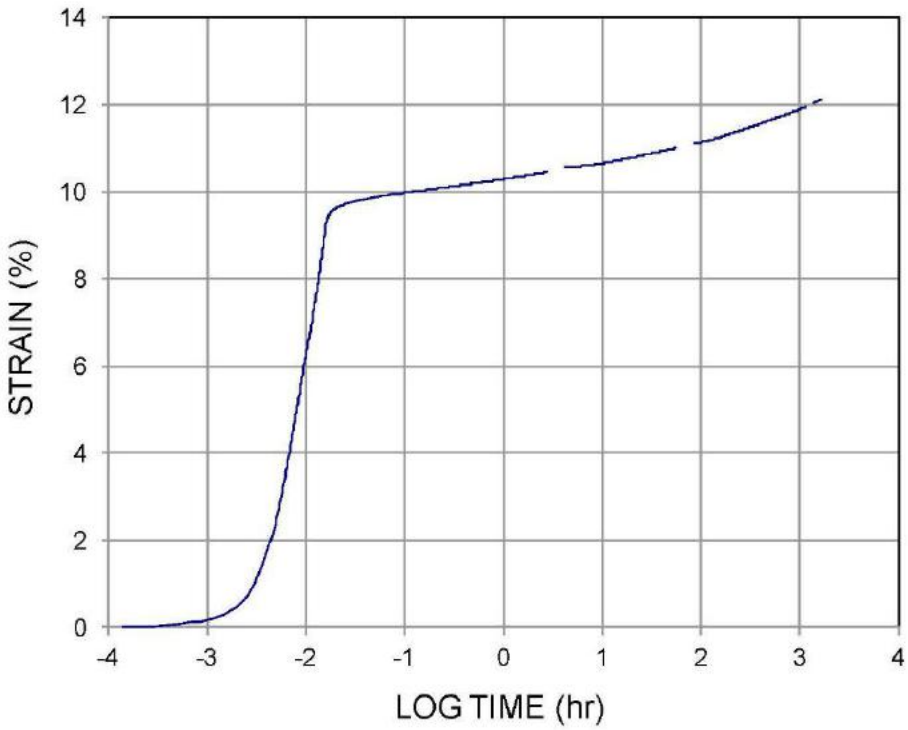

Figure F-8. SIM/Creep data/curve for 8XT at load level of 77.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim8 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 6909 lb/ft %UTS: 80.00
Ultimate Tensile Strength: 8636 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9500	10019	519	0.09	1.2840	34.1	0.0888
3	19300	20009	709	0.08	1.1694	49.2	0.0778
4							
5							
6							

Summary	Initial	Final	Units	@20C refT
lab time	71.5	21629	sec	-
$logA_T(t-t')$	1.8545	5.8207	log hours	2.2342
$A_T(t-t')$	-	0.02	years	0.02
Strain	10.55	13.538	%	-
Modulus	65634.4	51022.6	lb/ft	-

AVG 0.0832

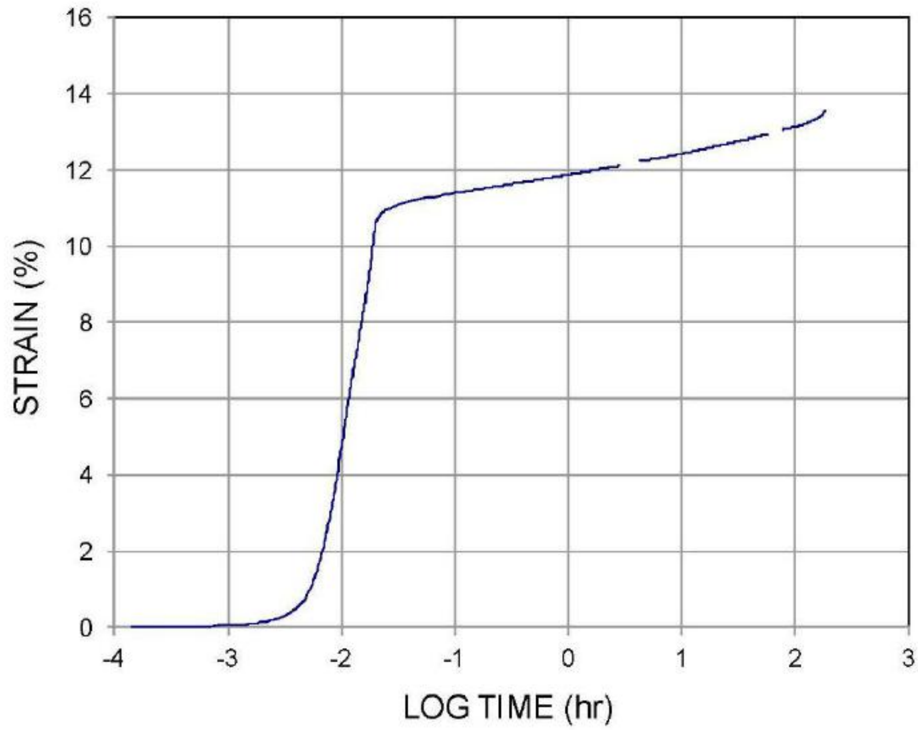

Figure F-9. SIM/Creep data/curve for 8XT at load level of 80.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim8 Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress:	7168	lb/ft	%UTS:	83.00
Ultimate Tensile Strength:	8636	lb/ft	Rupture:	YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9400	10020	620	0.04	1.2074	34.2	0.0831
3							
4							
5							
6							
						AVG	0.0831

Summary	Initial	Final	Units	@20C refT
lab time	73.3	17430	sec	-
$logA_T(t-t')$	1.8649	5.1121	log hours	1.5275
$A_T(t-t')$	-	0.00	years	0.00
Strain	10.84	14.023	%	-
Modulus	66106.4	51111.2	lb/ft	-

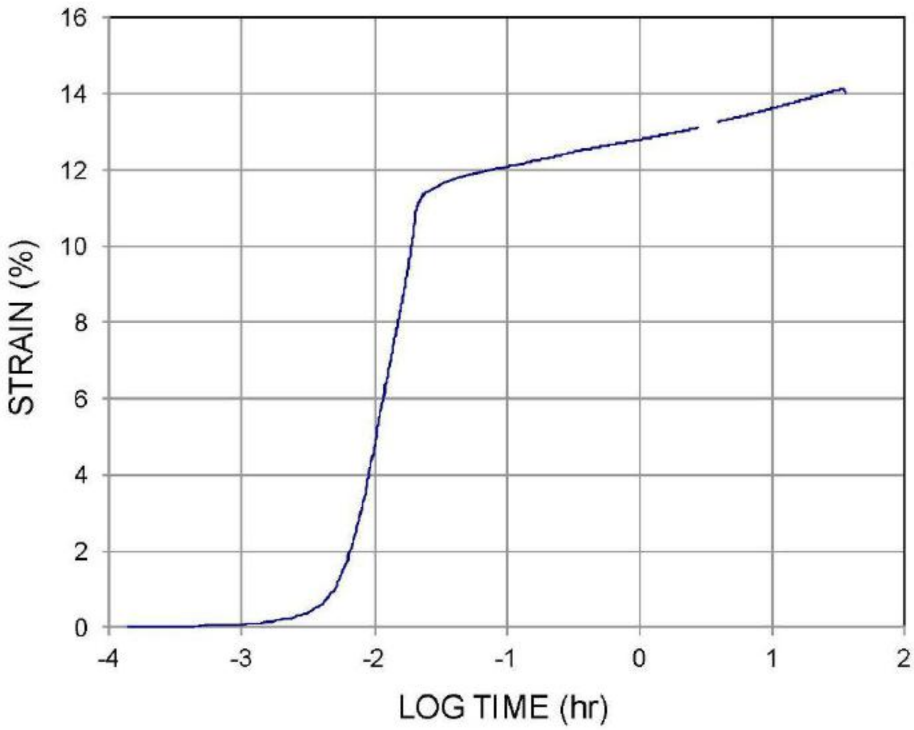

Figure F-10. SIM/Creep data/curve for 8XT at load level of 83.0% UTS.

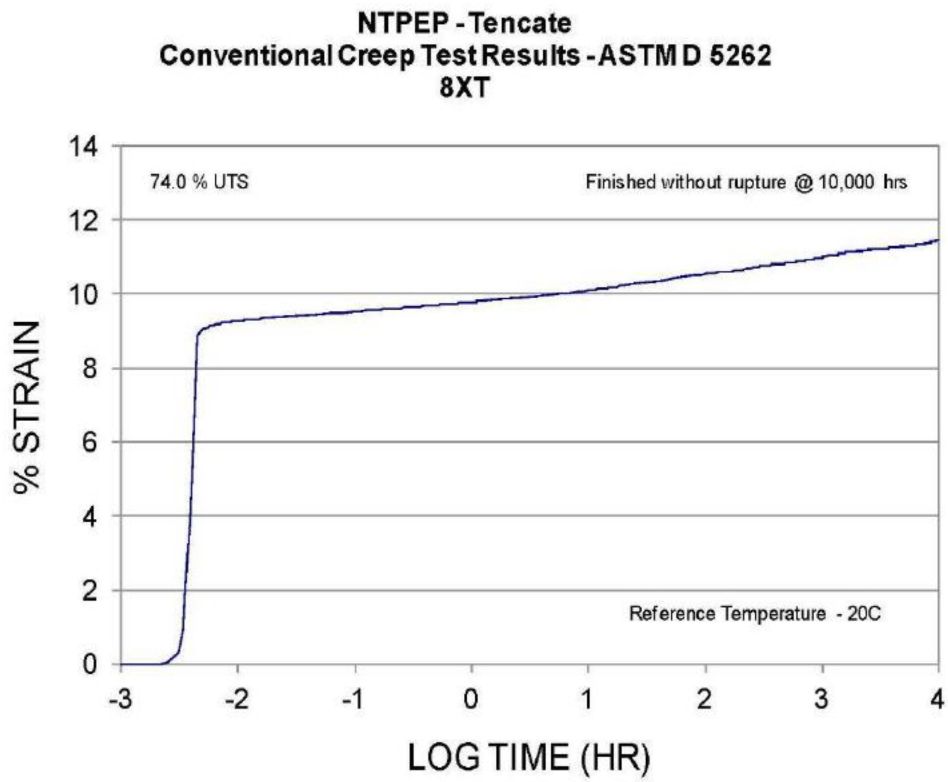

Figure F-11. Creep data/curve per ASTM D6262 for 8XT at a load level of 74.0% UTS and 68°F(20°C)

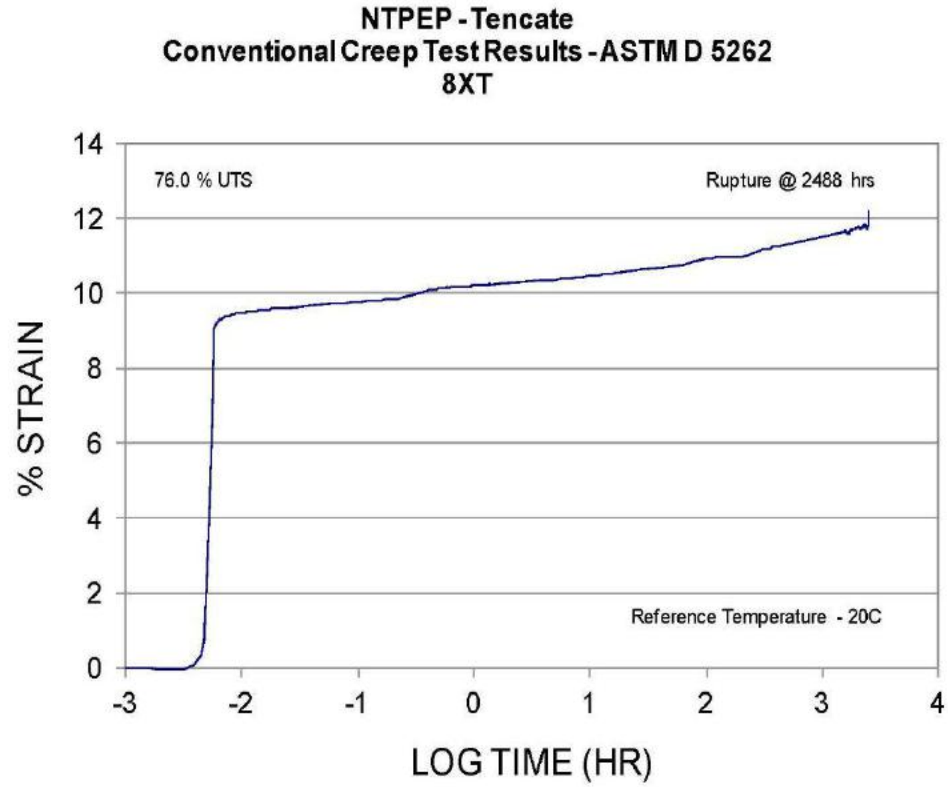

Figure F-12. Creep data/curve per ASTM D5262 for 8XT at a load level of 76.0% UTS and 68°F(20°C)

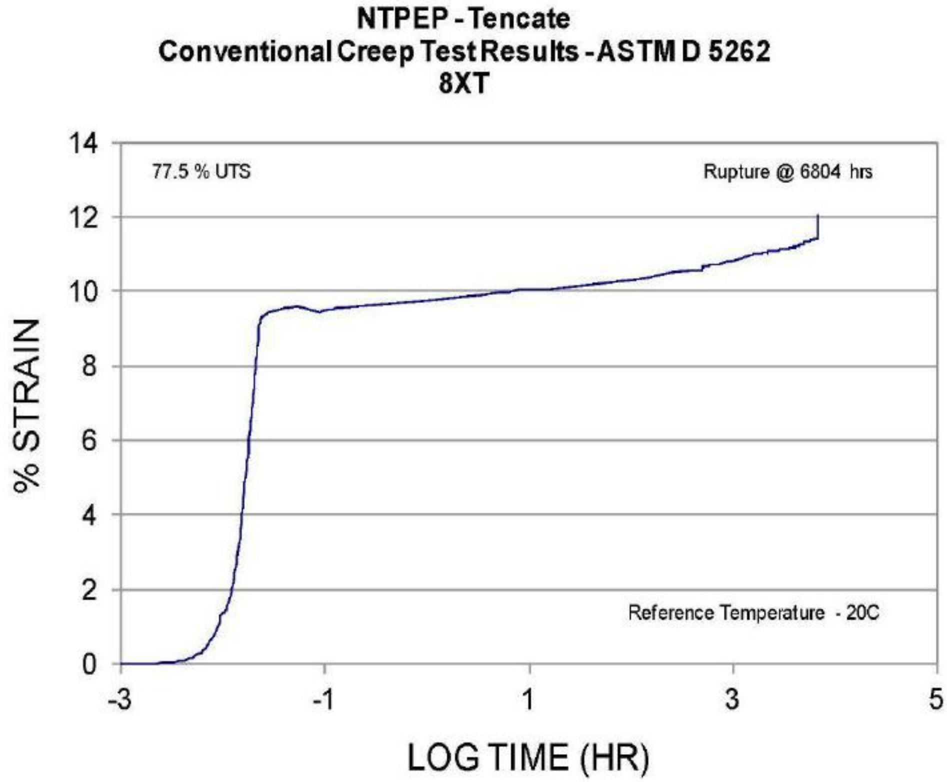

Figure F-13. Creep data/curve per ASTM D5262 for 8XT at a load level of 77.5% UTS and 68°F(20°C)

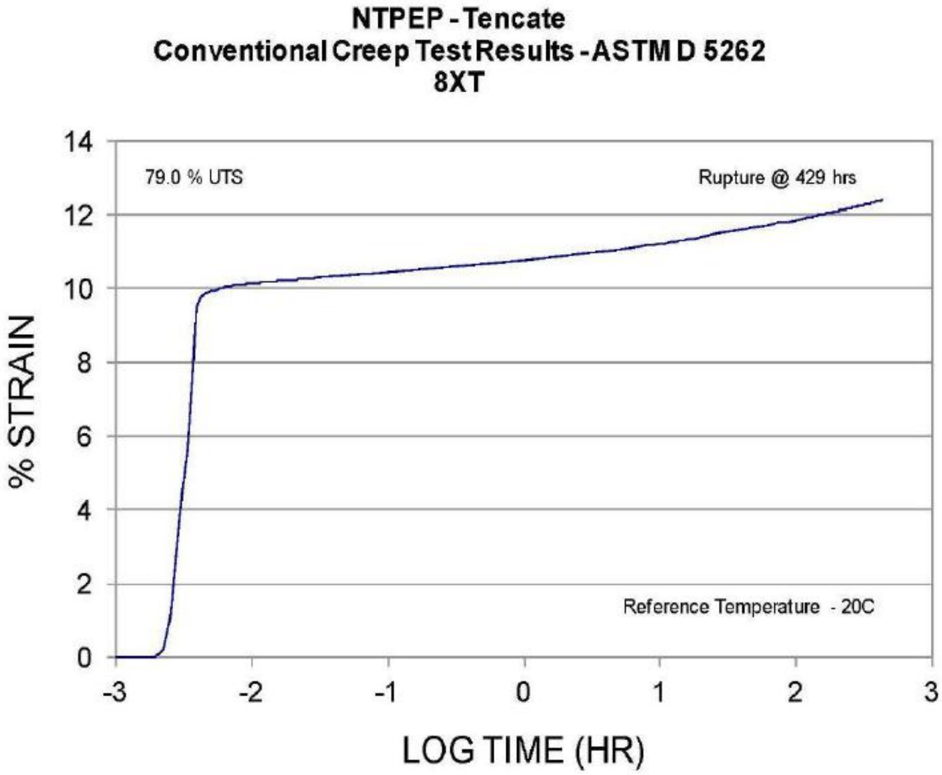

Figure F-14. Creep data/curve per ASTM D6262 for 8XT at a load level of 79.0% UTS and 68°F(20°C)

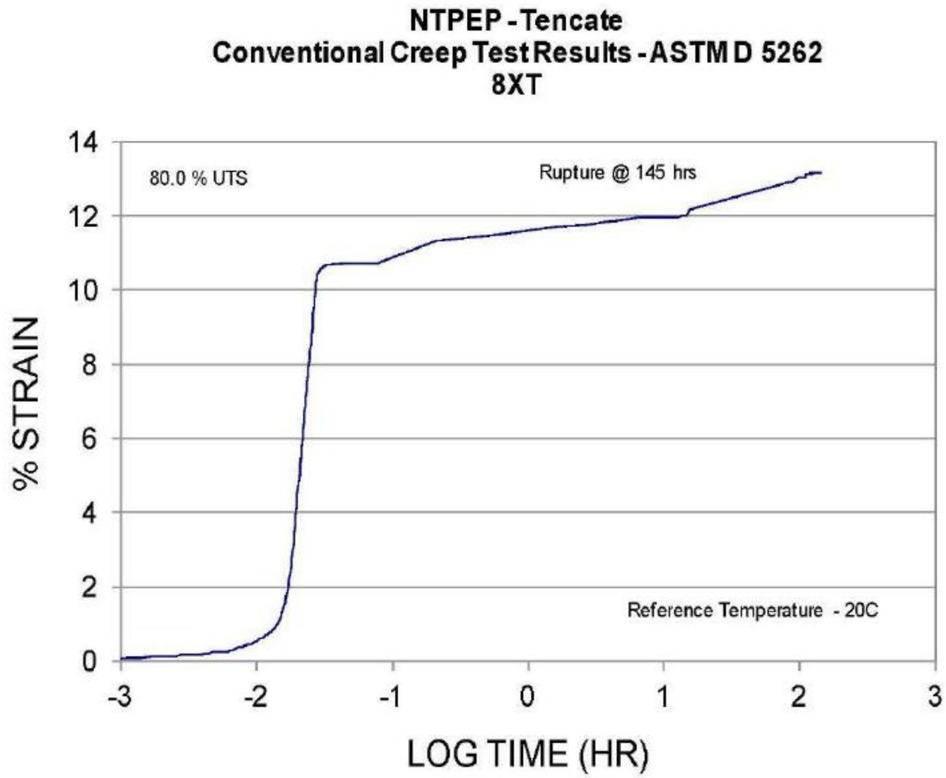

Figure F-15. Creep data/curve per ASTM D5262 for 8XT at a load level of 80.0% UTS and 68°F(20°C)

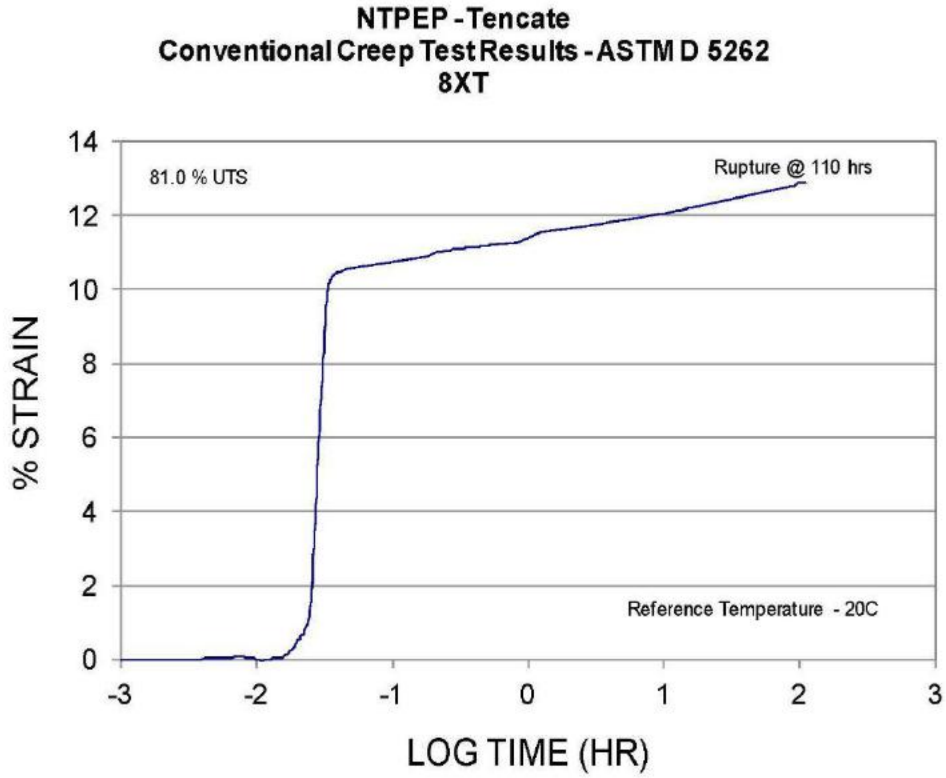

Figure F-16. Creep data/curve per ASTM D6262 for 8XT at a load level of 81.0% UTS and 68°F(20°C)

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 24XT

Specimen: 27463n2m-24XT-sim | Test Date: June 2017 | Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 19932 lb/ft | %UTS: 70.00
Ultimate Tensile Strength: 28474 lb/ft | Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9300	10020	720	0.12	1.1424	34.1	0.0790
3	19300	20010	710	0.13	1.1775	48.5	0.0817
4	29300	30000	700	0.11	1.1832	63.1	0.0813
5	39400	39990	590	0.15	1.2571	77.6	0.0863
6	49300	49980	680	0.16	1.1909	92.5	0.0801
						AVG	0.0817

Summary	Initial	Final	Units	@20C refT
lab time	76.2	50550	sec	-
$logA_T(t-t')$	1.8820	9.0480	log hours	5.4648
$A_T(t-t')$	-	35.39	years	33.26
Strain	9.75	12.015	%	-
Modulus	205824.8	165892.4	lb/ft	-

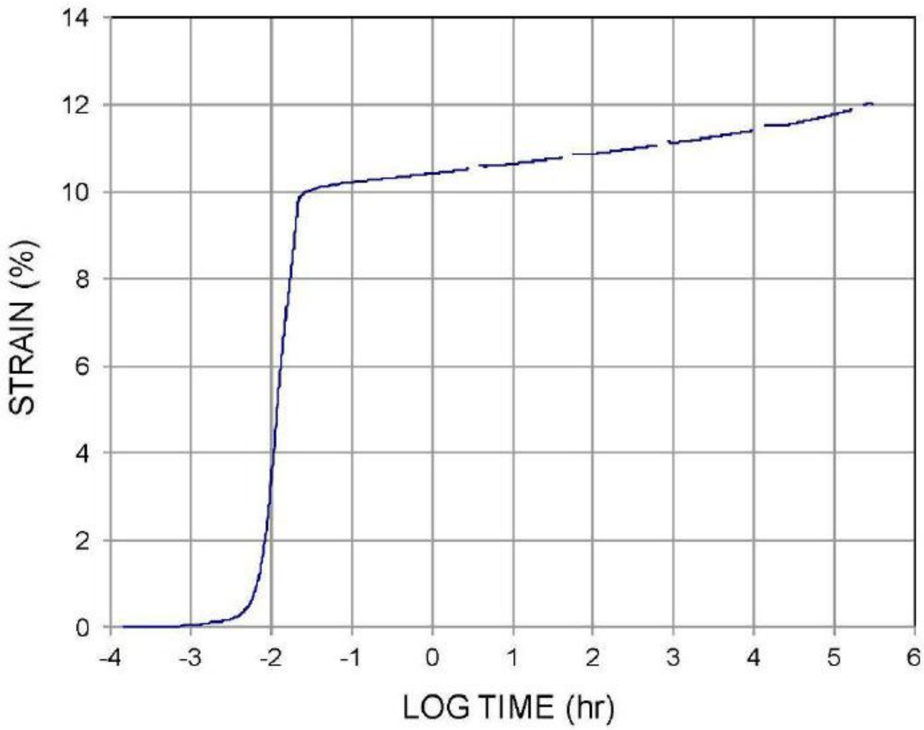

Figure F-17. SIM/Creep data/curve for 24XT at load level of 70.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 24XT

Specimen: 27463n2m-24XT-sim Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 21071 lb/ft %UTS: 74.00
Ultimate Tensile Strength: 28474 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$\log A_T$	Temp	$\log A_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9200	10020	820	0.1	1.0857	34.1	0.0751
3	19200	20010	810	0.12	1.1241	48.5	0.0780
4	29200	30000	800	0.1	1.1291	63.1	0.0776
5	39200	39990	790	0.12	1.1342	77.8	0.0770
6							
						AVG	0.0769

Summary	Initial	Final	Units	@20C refT
lab time	77.0	44130	sec	-
$\log A_T(t-t')$	1.8862	8.1660	log hours	4.5842
$A_T(t-t')$	-	4.64	years	4.38
Strain	9.95	12.673	%	-
Modulus	213185.4	166253.1	lb/ft	-

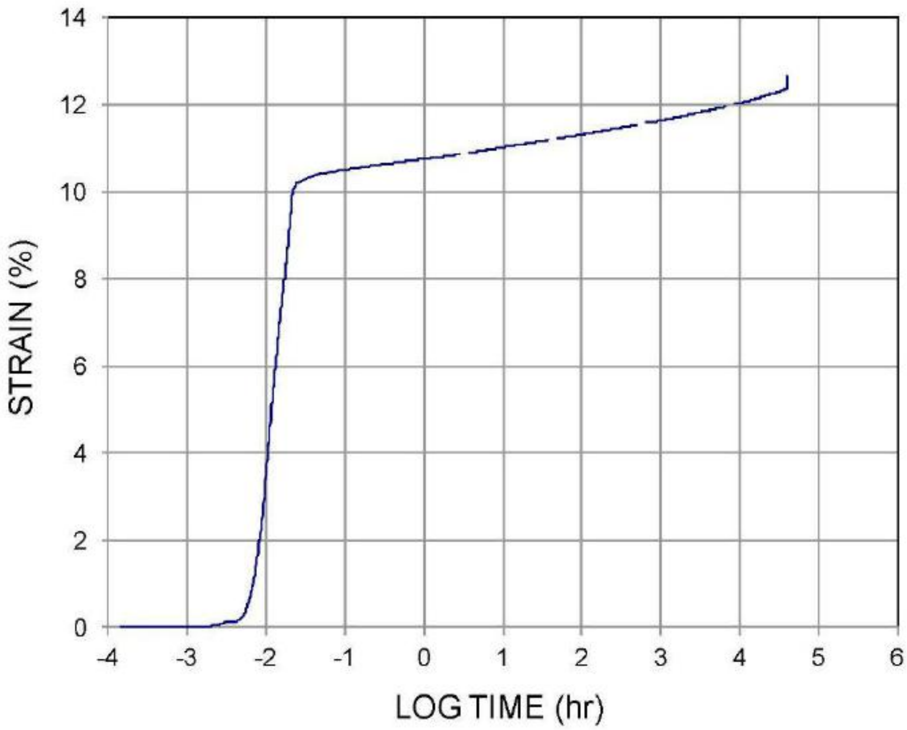

Figure F-18. SIM/Creep data/curve for 24XT at load level of 74.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 24XT

Specimen: 27463n2m-24XT-sim Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 22210 lb/ft %UTS: 78.00
Ultimate Tensile Strength: 28474 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$\log A_T$	Temp	$\log A_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	8900	10020	1120	0.1	0.9503	34.1	0.0657
3	18800	20010	1210	0.1	0.9617	48.5	0.0668
4	28900	30000	1100	0.1	1.0066	63.1	0.0692
5							
6							
						AVG	0.0672

Summary	Initial	Final	Units	@20C refT
lab time	84.0	39960	sec	-
$\log A_T(t-t')$	1.9242	6.9625	log hours	3.3838
$A_T(t-t')$	-	0.29	years	0.28
Strain	11.05	13.252	%	-
Modulus	202348.6	167584.4	lb/ft	-

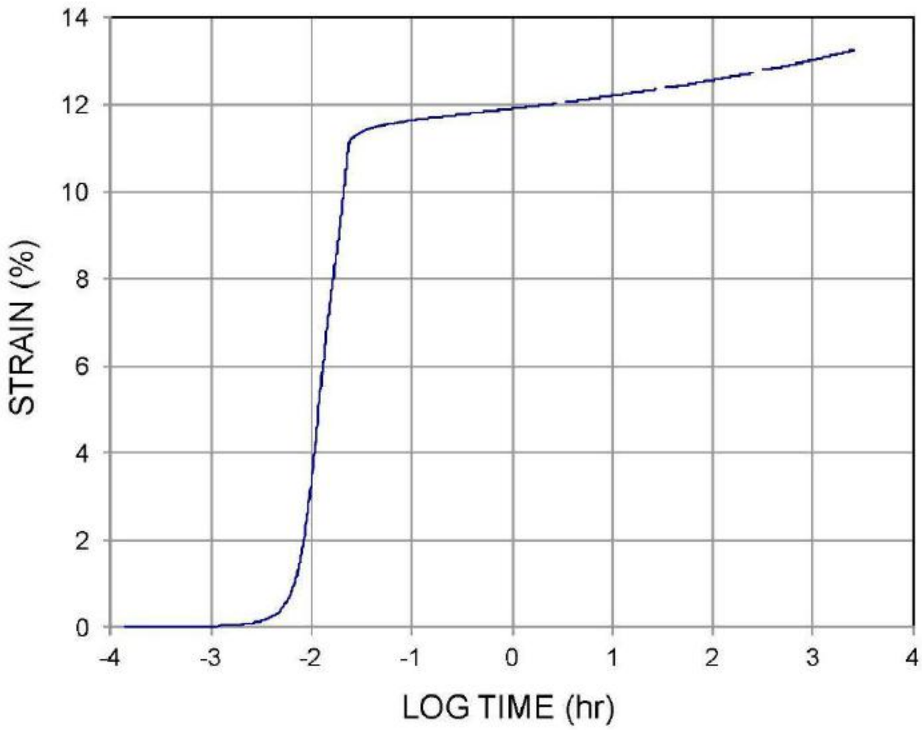

Figure F-19. SIM/Creep data/curve for 24XT at load level of 78.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 24XT

Specimen: 27463n2m-24XT-sim Test Date: June 2017 Method: SIM (10^4s, 14C),single rib, machine dir.

Average Creep Stress: 23349 lb/ft %UTS: 82.00
Ultimate Tensile Strength: 28474 lb/ft Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	$logA_T$	Temp	$logA_T/T$
1	0	0.5	0.5	-	-	19.7	-
2	9300	10020	720	0.09	1.1424	34.1	0.0790
3							
4							
5							
6							

Summary	Initial	Final	Units	@20C refT
lab time	77.5	19980	sec	-
$logA_T(t-t')$	1.8893	5.1709	log hours	1.5877
$A_T(t-t')$	-	0.00	years	0.00
Strain	11.25	13.143	%	-
Modulus	195516.6	177608.3	lb/ft	-

AVG 0.0790

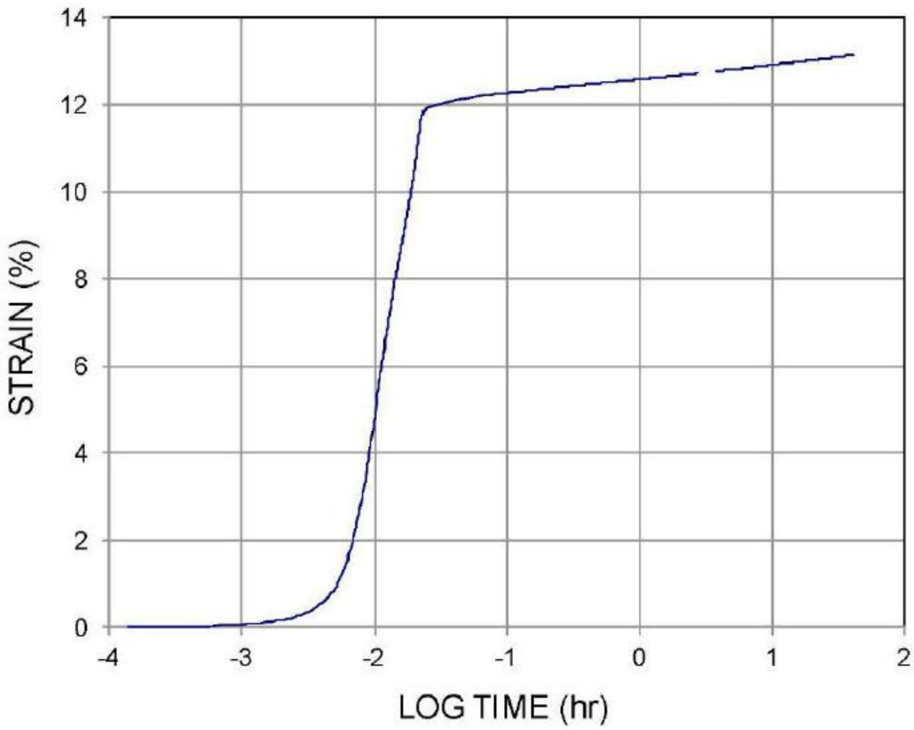

Figure F-20. SIM/Creep data/curve for 24XT at load level of 82.0% UTS.

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REGEO-2016-01-[TenCate-Miragrid XT]

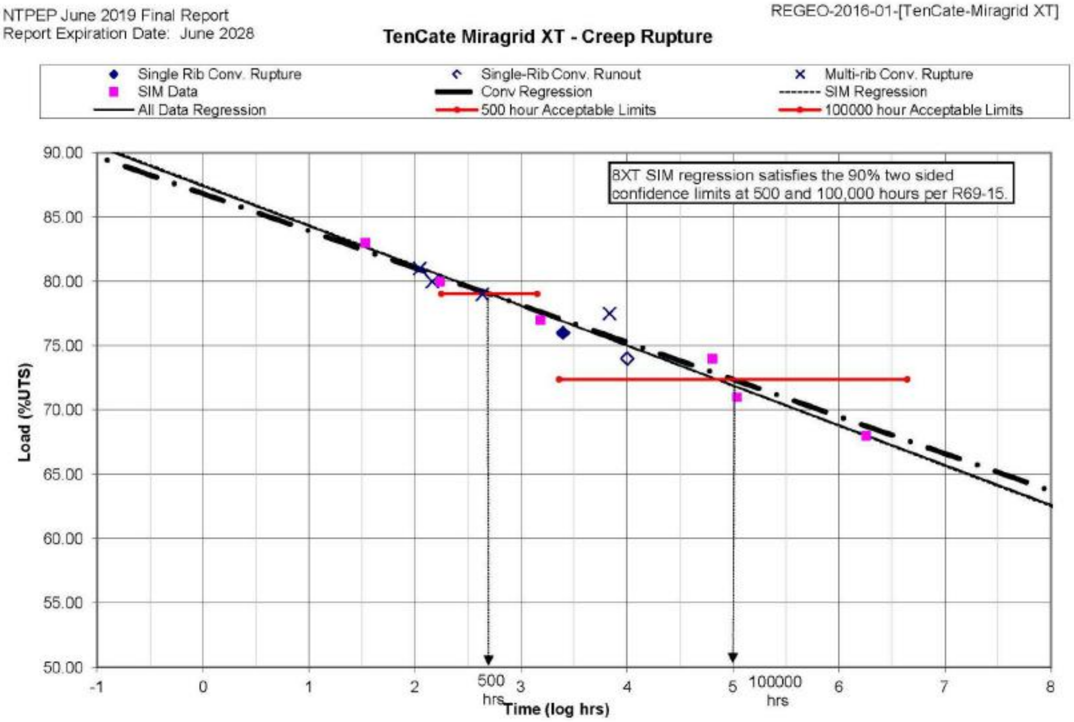

Figure F-21. Statistical evaluation results for determining validity of using SIM to extend TenCate Miragrid XT geogrid conventional creep rupture data, and to compare single-rib to multi-rib data.

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Table F-2. Computation table to determine statistical validity of using SIM to extend TenCate Miragrid XT geogrid conventional creep data.

SIM

Test Report	Product	time, log hrs	%UTS	Rupture	Runout
	8XT	6.2648	68.00	68.00	
	8XT	5.0359	71.00	71.00	
	8XT	4.8030	74.00	74.00	
	8XT	3.1833	77.00	77.00	
	8XT	2.2342	80.00	80.00	
	8XT	1.5275	83.00	83.00	

Conventional

Test Report	Product	time, log hrs	%UTS	Rupture	Runout	logti-logtbar	(logti-logtbar)2	Pi - Pbar	(Pi-Pbar)2	K*L
	8XT	2.0423	81.00	81.00		-0.77	0.5935	2.30	5.29	-1.77187
	8XT	2.1602	80.00	80.00		-0.65	0.4258	1.30	1.69	-0.84828
	8XT	2.6325	79.00	79.00		-0.18	0.0325	0.30	0.09	-0.05407
	8XT	3.8328	77.50	77.50		1.02	1.0408	-1.20	1.44	-1.2241
	8XT	3.3958	76.00	76.00		0.58	0.3400	-2.70	7.29	-1.57432
	8XT	4.0000	74.00		74.00					
	Sum	14.0636	393.50		Sum	0.00	2.4324	0.00	15.8	-5.47272
	Mean	2.8127	78.70							

student's t =	2.353	(90% 2-sided prediction limit)	
n-sim =	6		
n-conv =	5	d-o-f	9
treg =	2.699		
treg =	5.000		
P500 =	79.0283		
P100000 =	72.3852		
sigma squared =	0.1789		
sigma =	0.4230		

Conv - 500 hrs (log 2.699)		
log tL - lower =	2.26	79.0283
log tL - upper =	3.15	79.0283
SIM - logtL @ Load =	**2.71 OK**	

Conv - 100000 hrs (log 5.000)		
log tL - lower =	3.36	72.3852
log tL - upper =	6.64	72.3852
SIM - logtL @ Load =	**4.84 OK**	

80% 2-sided conf. limit	
df	student's t
2	2.92
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.86
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761

SIM - All Points
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.32058	-3.11931
intercept	28.04386	87.47747
R squared	0.878279	0.878279
	-2	93.71609
	10	56.28438
2.6990	79.05846	= 500 hr intercept
5.0000	71.88093	= 100000 hr intercept

Conventional - All Points
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.34637	-2.88705
intercept	30.07241	86.82045
R squared	0.779332	0.779332
	-2	92.59455
	10	57.94998
2.6990	79.02831	= 500 hr intercept
5.0000	72.38522	= 100000 hr intercept

All Creep Data (conv & SIM)
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.32266	-3.09923
intercept	28.20314	87.40805
R squared	0.958555	0.958555
	-2	93.60652
	10	56.41575
2.6990	79.04323	= 500 hr intercept
5.0000	71.9119	= 100000 hr intercept

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REGEO-2016-01-[TenCate-Miragrid XT]

TenCate Miragrid 8XT - 2XT - 24XT - Creep Rupture

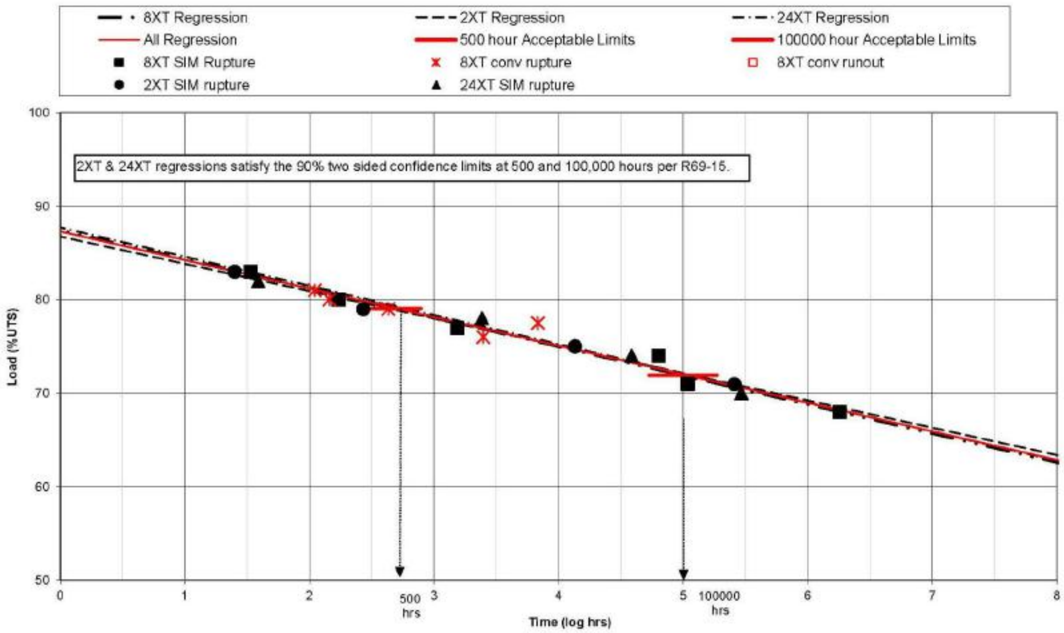

Figure F-22. Statistical evaluation results for determining validity of creating composite creep rupture envelope for the TenCate Miragrid XT geogrid product line.

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Table F-3. Computation table to determine statistical validity of creating composite creep rupture envelope for the TenCate Miragrid XT geogrid product line - 2XT and 8XT comparision.

Miragrid 2XT Creep Data Evaluation

SIM Tests on 2XT

Test Report	Product	Expected time, log hrs	%UTS	Rupture
	2XT	5.4100	70.90	70.90
	2XT	4.1304	75.00	75.00
	2XT	2.4319	79.00	79.00
	2XT	1.3981	83.00	83.00

student's t = 1.833 (90% 2-sided prediction limit)
n-2XT = 4
n-8XT = 11 d-o-f 9
treg = 2.6990
treg = 4.6990
P500 = 78.0432
P100000 = 71.9119
sigma squared = 0.1006
sigma = 0.3172

90% 2-sided conf. limit	
df	student's t
2	2.92
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.86
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761

SIM & Conventional Tests on 8XT

Test Report	Product	time, log hrs	%UTS	Rupture	Runout	logti-logtbar	(logti-logtbar)2	Pi - Pbar	(Pi-Pbar)2	K * L	
	8XT	6.2548	68.00	68.00		2.88	8.3051	-8.95	80.18388	-25.8058	SIM
	8XT	5.0359	71.00	71.00		1.66	2.7654	-5.95	35.45661	-9.90219	SIM
	8XT	4.8030	74.00	74.00		1.43	2.0461	-2.95	8.720339	-4.22519	SIM
	8XT	3.1833	77.00	77.00		-0.19	0.0380	0.05	0.002066	-0.00862	SIM
	8XT	2.2342	80.00	80.00		-1.14	1.2967	3.05	9.274783	-3.46797	SIM
	8XT	1.5275	83.00	83.00		-1.85	3.4056	6.05	36.54752	-11.1565	SIM
	8XT										SIM
	8XT										SIM
	8XT	2.0423	81.00	81.00		-1.33	1.7706	4.05	16.3657	-5.38303	Conv
	8XT	2.1602	80.00	80.00		-1.21	1.4707	3.05	9.274783	-3.69333	Conv
	8XT	2.6325	79.00	79.00		-0.74	0.5482	2.05	4.183884	-1.51463	Conv
	8XT	3.8329	77.50	77.50		0.46	0.2115	0.55	0.297521	0.250836	Conv
	8XT	3.3958	76.00	76.00		0.02	0.0005	-0.95	0.911157	-0.02182	Conv
	8XT										Conv
	8XT										Conv
	8XT										Conv
	8XT										Conv
	8XT										Conv
	Sum	37.1023	846.50		Sum	0.00	21.8556	0.00	201.2273	-84.9281	
	Mean	3.3728	76.95								

* runout plotting below the regression line is not included in the regression

8XT - 500 hrs (log 2.699)			8XT - 100000 hrs (log 5.000)		
log tL - lower =	2.50	78.0432	log tL - lower =	4.73	71.9118
log tL - upper =	2.89	78.0432	log tL - upper =	5.27	71.9118

2XT - logtL @ Load = 2.64 **OK** **2XT - logtL @ Load =** 5.08 **OK**

2XT- All Points
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.34233	-2.92116
intercept	29.69866	88.75427
R squared	0.992248	0.992248
	-2	92.5066
	10	57.54266
2.6990	78.87006 = 500 hr intercept	
5.0000	72.14847 = 100000 hr intercept	

8XT - All Points
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.32286	-3.09923
intercept	28.20314	87.40805
R squared	0.968566	0.968566
	-2	93.60652
	10	56.41575
2.6990	78.04323 = 500 hr intercept	
5.0000	71.9118 = 100000 hr intercept	

All Creep Data 8XT & 2XT (conv & SIM)
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.32934	-3.0364
intercept	28.73243	87.24317
R squared	0.970822	0.970822
	-2	93.31597
	10	56.87916
5.8178	69.5786 = 75-yr intercept	
5.9425	69.19938 = 100-yr intercept	

Table F-4. Computation table to determine statistical validity of creating composite creep rupture envelope for the TenCate Miragrid XT geogrid product line - 24XT and 8XT comparision.

Miragrid 24XT Creep Data Evaluation

SIM Tests on 24XT

Test Report	Product	Expected time, log hrs	%UTS	Rupture
	24XT	5.4648	70.00	70.00
	24XT	4.5842	74.00	74.00
	24XT	3.3839	78.00	78.00
	24XT	1.5877	82.00	82.00

student's t = 1.833 (90% 2-sided prediction limit)
n-24XT = 4
n-8XT = 11 d-o-f 9
treg = 2.6990
treg = 4.6990
P500 = 79.0432
P100000 = 71.9119
sigma squared = 0.1006
sigma = 0.3172

90% 2-sided conf. limit	
df	student's t
2	2.92
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.86
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761

SIM & Conventional Tests on 8XT

Test Report	Product	time, log hrs	%UTS	Rupture	Runout	logti-logtbar	(logti-logtbar)2	Pi - Pbar	(Pi-Pbar)2	K * L	
	8XT	6.2548	68.00	68.00		2.88	8.3051	-8.95	80.18388	-25.8058	SIM
	8XT	5.0359	71.00	71.00		1.66	2.7654	-5.95	35.45661	-9.90219	SIM
	8XT	4.8030	74.00	74.00		1.43	2.0451	-2.95	8.729339	-4.22519	SIM
	8XT	3.1833	77.00	77.00		-0.19	0.0360	0.05	0.002066	-0.00862	SIM
	8XT	2.2342	80.00	80.00		-1.14	1.2967	3.05	9.274793	-3.46797	SIM
	8XT	1.5275	83.00	83.00		-1.85	3.4056	6.05	36.54752	-11.1565	SIM
	8XT										SIM
	8XT										SIM
	8XT	2.0423	81.00	81.00		-1.33	1.7708	4.05	16.3657	-5.38303	Conv
	8XT	2.1602	80.00	80.00		-1.21	1.4707	3.05	9.274793	-3.69333	Conv
	8XT	2.6325	79.00	79.00		-0.74	0.5482	2.05	4.183884	-1.51453	Conv
	8XT	3.8328	77.50	77.50		0.46	0.2115	0.55	0.297521	0.250835	Conv
	8XT	3.3958	76.00	76.00		0.02	0.0005	-0.95	0.911157	-0.02182	Conv
	8XT										Conv
	8XT										Conv
	8XT										Conv
	8XT										Conv
	8XT										Conv
	Sum	37.1023	846.50		Sum	0.00	21.8556	0.00	201.2273	-64.9281	
	Mean	3.3729	76.95								

* runout plotting below the regression line is not included in the regression

8XT - 500 hrs (log 2.699)			8XT - 100000 hrs (log 5.000)		
log tL - lower =	2.50	79.0432	log tL - lower =	4.73	71.9119
log tL - upper =	2.89	79.0432	log tL - upper =	5.27	71.9119
24XT - logtL @ Load =	2.78	OK	**24XT - logtL @ Load =**	5.07	OK

24XT - All Points
time is dependent variable

	if time were the y axis	but time is the x axis
slope	-0.32079	-3.11728
intercept	28.13536	87.70578
R squared	0.97474	0.97474
	-2	93.94034
	10	56.53298
2.6990	78.29224 = 500 hr intercept	
5.0000	72.11938 = 100000 hr intercept	

8XT - All Points
time is dependent variable

	if time were the y axis	but time is the x axis
slope	-0.32288	-3.08823
intercept	28.20314	87.40805
R squared	0.958555	0.958555
	-2	93.60852
	10	56.41575
2.6990	79.04323 = 500 hr intercept	
5.0000	71.9119 = 100000 hr intercept	

All Creep Data 8XT & 24XT (conv & SIM)
time is dependent variable

	if time were the y axis	but time is the x axis
slope	-0.32027	-3.12234
intercept	28.06057	87.58337
R squared	0.976551	0.976551
	-2	93.82805
	10	56.35998
5.8176	69.41986 = 75-yr intercept	
5.9425	69.02887 = 100-yr intercept	

Table F-5. Computation table for composite creep rupture envelope for the TenCate Miragrid XT geogrid product line.

		data for regression calculation	Stress, % of UTS								
product:		loghrs	all	2XT	24XT	8XT	sim rupture	rt rupture	conv'l rupture	sim runout*	conv'l runout*
SIM DATA:	2XT	5.4100	70.96	70.96			70.96				
	2XT	4.1304	75.00	75.00			75.00				
	2XT	2.4319	79.00	79.00			79.00				
	2XT	1.3981	83.00	83.00			83.00				
	24XT	5.4648	70.00		70.00		70.00				
	24XT	4.5842	74.00		74.00		74.00				
	24XT	3.3838	78.00		78.00		78.00				
	24XT	1.5877	82.00		82.00		82.00				
	8XT	6.2548	68.00			68.00	68.00				
	8XT	5.0359	71.00			71.00	71.00				
	8XT	4.8030	74.00			74.00	74.00				
	8XT	3.1833	77.00			77.00	77.00				
	8XT	2.2342	80.00			80.00	80.00				
	8XT	1.5275	83.00			83.00	83.00				
CONV DATA:	8XT	2.0423	81.00			81.00			81.00		
	8XT	2.1602	80.00			80.00			80.00		
	8XT	2.6325	79.00			79.00			79.00		
	8XT	3.8328	77.50			77.50			77.50		
	8XT	3.3958	76.00			76.00			76.00		
	8XT	4.0000				74.00					74.00

NOTE: Don't include runouts in the regression calculation unless the points lie above the line

SIM & Conventional - 2XT
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.34233	-2.9212
intercept	29.69856	86.7543
R squared	0.992249	0.99225
	-2	92.5966
	10	57.5427
6	69.22731 = 114 Year intercept	
5.817863	69.75936 = 75 Year intercept	

SIM & Conventional - 24XT
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.320793	-3.1173
intercept	28.13536	87.7058
R squared	0.97474	0.97474
	-2	93.9403
	10	56.533
6	69.0021 = 114 Year intercept	
5.817863	69.56987 = 75 Year intercept	

SIM Only - 8XT
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.320584	-3.1193
intercept	28.04386	87.4775
R squared	0.978279	0.97828
	-2	93.7161
	10	56.2844
5.999706	68.76253 = 114 Year intercept	
5.817863	69.32976 = 75 Year intercept	

SIM & Conventional - 8XT
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.318438	-3.1403
intercept	27.85201	87.4646
R squared	0.955004	0.955
	-2	93.7452
	10	56.0612
5.999706	68.6235 = 114 Year intercept	
5.817863	69.19455 = 75 Year intercept	

SIM Only - All
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.3263348	-3.064338
intercept	28.497362	87.325548
R squared	0.9802268	0.9802268
	-2	93.464224
	10	56.682168
6.000	68.94 = 114 Year intercept	
5.943	69.11 = 100 Year intercept	
5.818	69.50 = 75 Year intercept	
4.420	73.78 = 3 Year intercept	

SIM & Conventional - All
time is dependent variable:

	if time were the y axis	but time is the x axis
slope	-0.3272588	-3.0557
intercept	28.567742	87.2940
R squared	0.9692884	0.9693
	-2	93.405404
	10	56.737178
6.000	68.96 = 114 Year intercept	
5.943	69.13 = 100 Year intercept	
5.818	69.52 = 75 Year intercept	
4.420	73.79 = 3 Year intercept	

The regression for the conventional creep tests produced at log 2.699 hr (500 hrs) and log 5.000 hr (100,000 hrs) intercepts at 79.03% and 72.39% UTS, respectively. The regression for the accelerated creep tests (SIM) produced log 2.71 and log 4.84, respectively, for the same %UTS. This was within the 90% confidence limits of log 2.25 to log 3.15 and log 3.36 to log 6.64 associated with those %UTS. This evaluation is summarized in Table F-6. Thus, the conventional and accelerated data may be used together to construct the characteristic creep rupture curve of the primary product. Confidence limits satisfied per R69-15.

Table F-6. Summary of statistical comparison between SIM and conventional creep rupture envelopes.

Product	Intercept at log 2.699 & 5.000 hrs, %UTS	Intercept at same % UTS, log hrs	90% Confidence Limits @ Higher %UTS, log hrs	90% Confidence Limits @ Lower %UTS, log hrs
8XT	79.03 & 72.39	2.699 & 5.000	-	-
8XT SIM	-	2.71 & 4.84	2.25 to 3.15	3.36 to 6.64

The regression for the all creep tests on the primary product (8XT) produced log 2.699 hr (500 hrs) and log 5.000 hr (100,000 hrs) intercepts at 79.04% and 71.91% UTS, respectively. The regression for the creep tests on 2XT & 24XT produced log time intercepts for the same %UTS within the 90% confidence limits of log 2.50 to log 2.89 and log 4.73 to log 5.27 associated with those %UTS. This evaluation is summarized in Table F-7. Thus, the primary, 8XT, and secondary products, 2XT & 24XT, data may be used together to construct the characteristic creep rupture curve of the family of products. Confidence limits satisfied per R69-15.

Table F-7. Summary of statistical comparison between rupture envelopes for all tested Miragrid geogrid products, to test validity of composite creep rupture envelope for product line.

Product	Intercept at log 2.699 & 5.000 hrs, %UTS	Intercept at same % UTS, log hrs	90% Confidence Limits @ Higher %UTS, log hrs	90% Confidence Limits @ Lower %UTS, log hrs
8XT	79.04 & 71.91	2.699 & 5.000	-	-
2XT		2.64 & 5.08	2.50 to 2.89	4.73 to 5.27
24XT	-	2.78 & 5.07	2.50 to 2.89	4.73 to 5.27

Appendix G: Durability Detailed Test Results

Table G-1. Yarn test results to evaluate susceptibility to hydrolysis

Material: Polyester Yarn
Product Identification: Yarn used to produce Miragrid XT Geogrids

PARAMETER	TEST REPLICATE NUMBER 1	2	3	MEAN	STD. DEV.
Carboxyl End Group (CEG) Count (Test Method: GRI GG7)					
mmol/Kg	15.7	16.1	15.8	**15.9**	0.2
Molecular Weight (Test Method: GRI GG8)					
Mn (Number average molecular weight)	35,109	29,455	33,786	**32,783**	2,957

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table G-2. UV resistance test results of TenCate Miragrid 2XT geogrid.

PARAMETER	TEST REPLICATE NUMBER 1	2	3	4	5	MEAN	STD. DEV.	PERCENT RETAINED
UV Resistance (ASTM D 4355) Strength Retained measured via single strip tensile (ASTM D 6637, Method A)								
MD - Number of Ribs per foot:	10.80							
MD - Tensile Strength (lbs) - B	246.4	246.6	245.5	243.0	249.4	**246**	2	
MD - Tensile Strength (lb/ft) - B	2661	2663	2651	2624	2694	**2659**	25	
MD - Tensile Strength (kN/m) - B	38.9	38.9	38.7	38.3	39.3	**38.8**	0.4	
MD - Tensile Strength (lbs) - E	233.6	222.8	236.7	233.9	234.1	**232**	5	
MD - Tensile Strength (lb/ft) - E	2523	2406	2556	2526	2528	**2508**	58	**94**
MD - Tensile Strength (kN/m) - E	36.8	35.1	37.3	36.9	36.9	**36.6**	0.9	
MD - Elong. @ Max. Load (%) - B	9.53	9.22	9.06	8.94	9.58	**9.27**	0.28	
MD - Elong. @ Max. Load (%) - E	9.22	8.69	9.53	9.50	9.40	**9.27**	0.35	**100**

B - Baseline Unexposed
E - Exposed for 500 hours of ASTM D 4355 Cycle

MD - Machine Direction TD - Transverse/Cross Machine Direction

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested.

Table G-3. Summary of UV resistance test results for Miragrid 2XT geogrid.

Miragrid XT Series Style	Mean Baseline Tensile Strength (lb/ft)	Standard Deviation (lb/ft)	Mean Exposed Tensile Strength (lb/ft)	Standard Deviation (lb/ft)	% Strength Retained
2XT	2,659	25	2,508	58	94

(Conversion: 1 lb/ft = 0.0146 kN/m)

Appendix H: Creep Stiffness Detailed Test Results

Low Strain Ramp and Hold Test Results
Product: 2XT

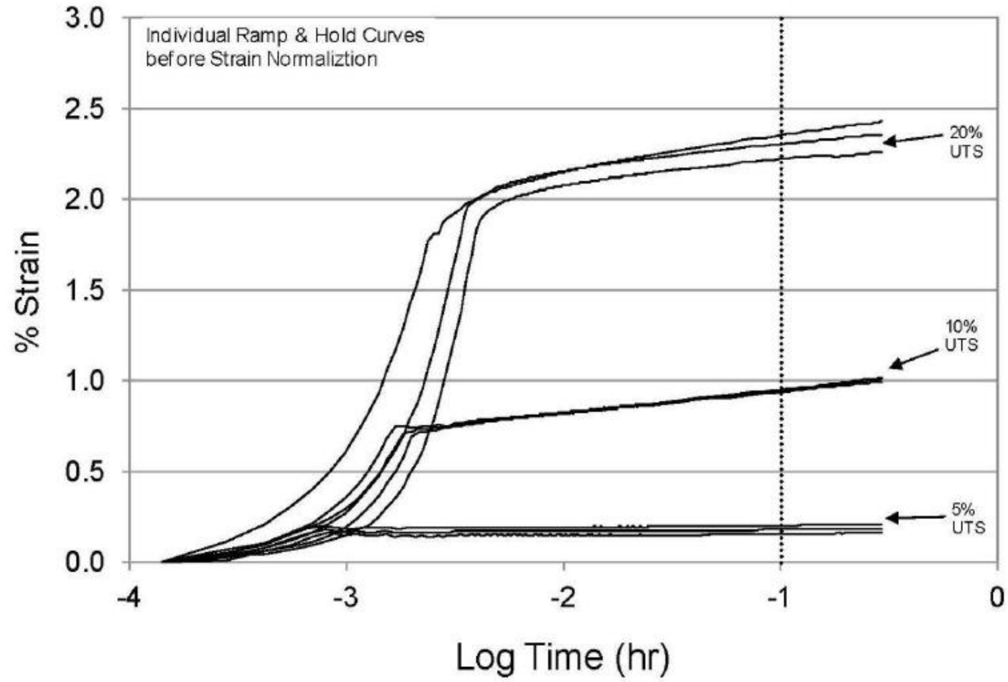

Figure H-1. Low strain ramp and hold tests for 2XT, before strain normalization.

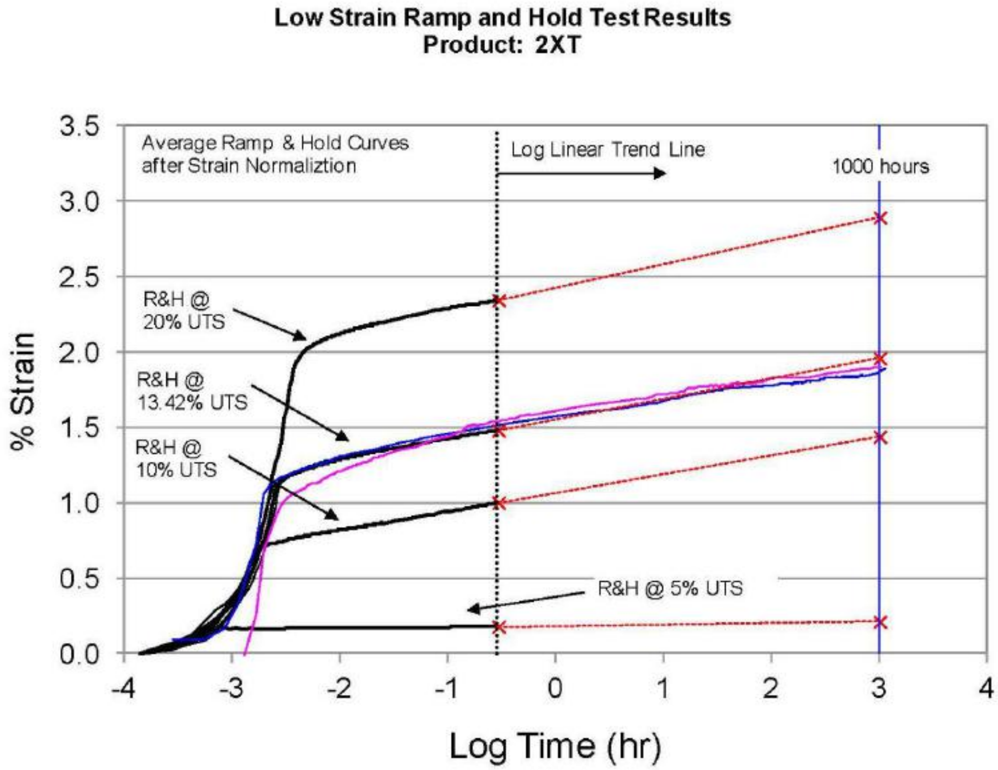

Figure H-2. Low strain ramp and hold tests for 2XT, after strain normalization, with 1000 hour low strain creep tests.

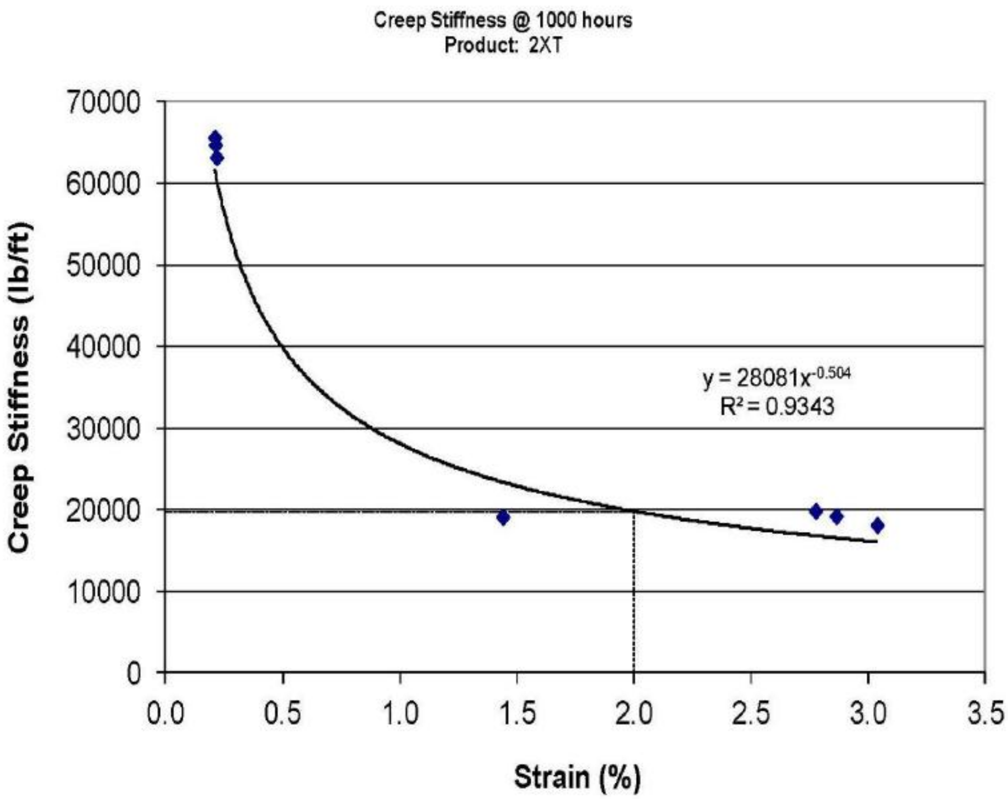

Figure H-3. Creep stiffness versus strain at 1,000 hours for 2XT.

Low Strain Ramp and Hold Test Results
Product: 8XT

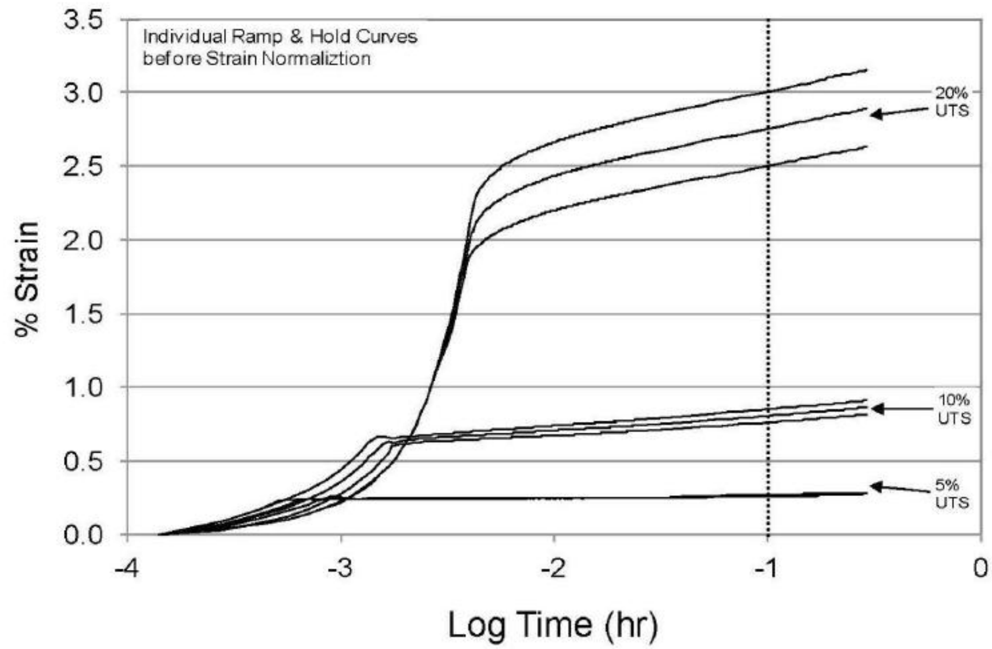

Figure H-4. Low strain ramp and hold tests for 8XT, before strain normalization.

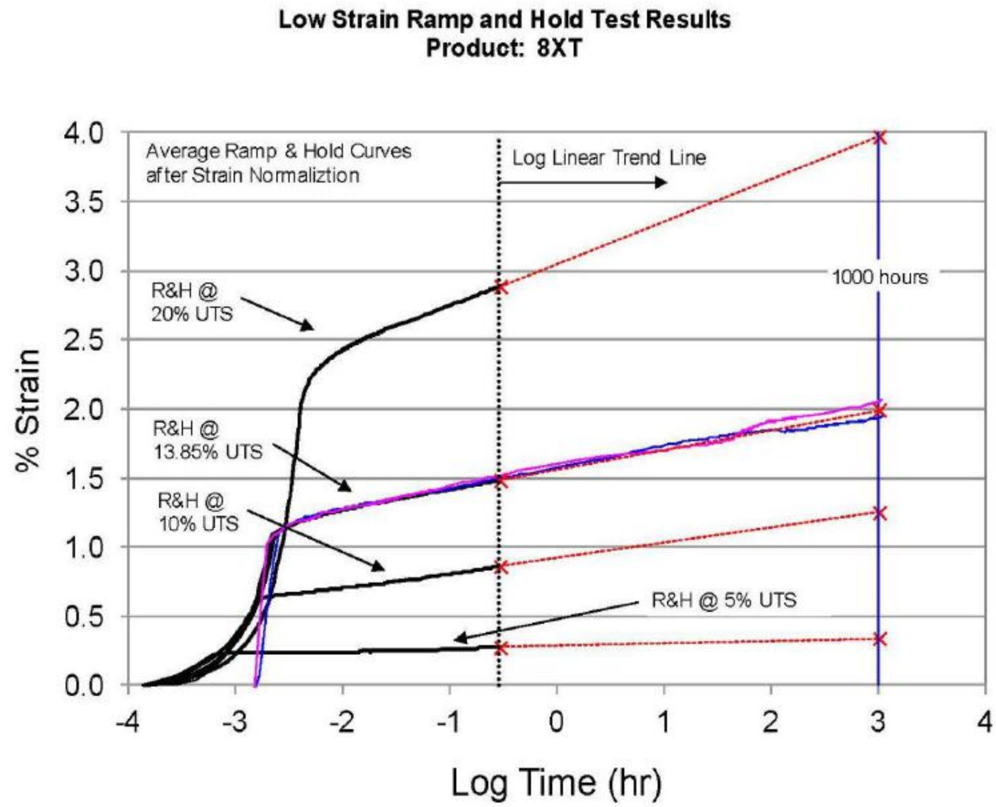

Figure H-5. Low strain ramp and hold tests for 8XT, after strain normalization, with 1000 hour low strain creep tests.

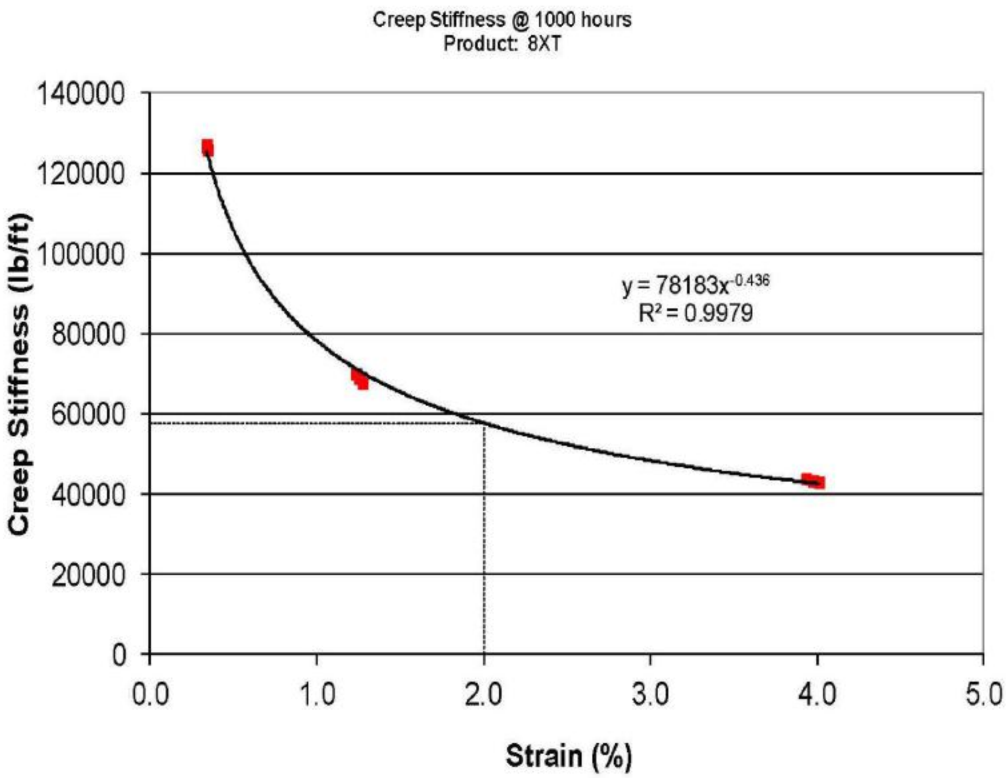

Figure H-6. Creep stiffness versus strain at 1,000 hours for 8XT.

Low Strain Ramp and Hold Test Results
Product: 24XT

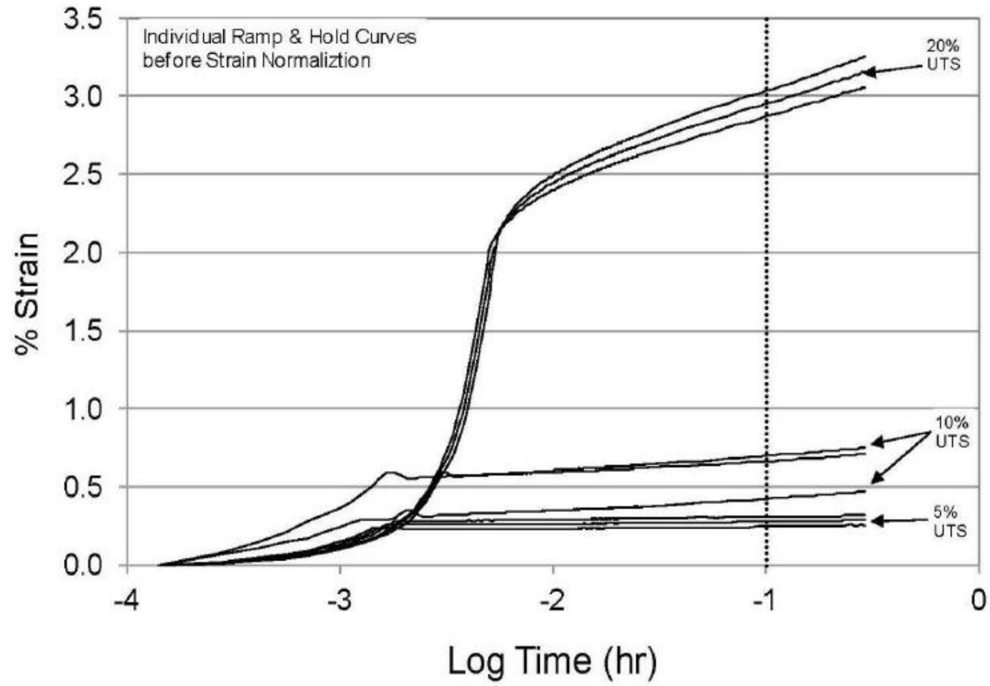

Figure H-7. Low strain ramp and hold tests for 24XT, before strain normalization.

Low Strain Ramp and Hold Test Results
Product: 24XT

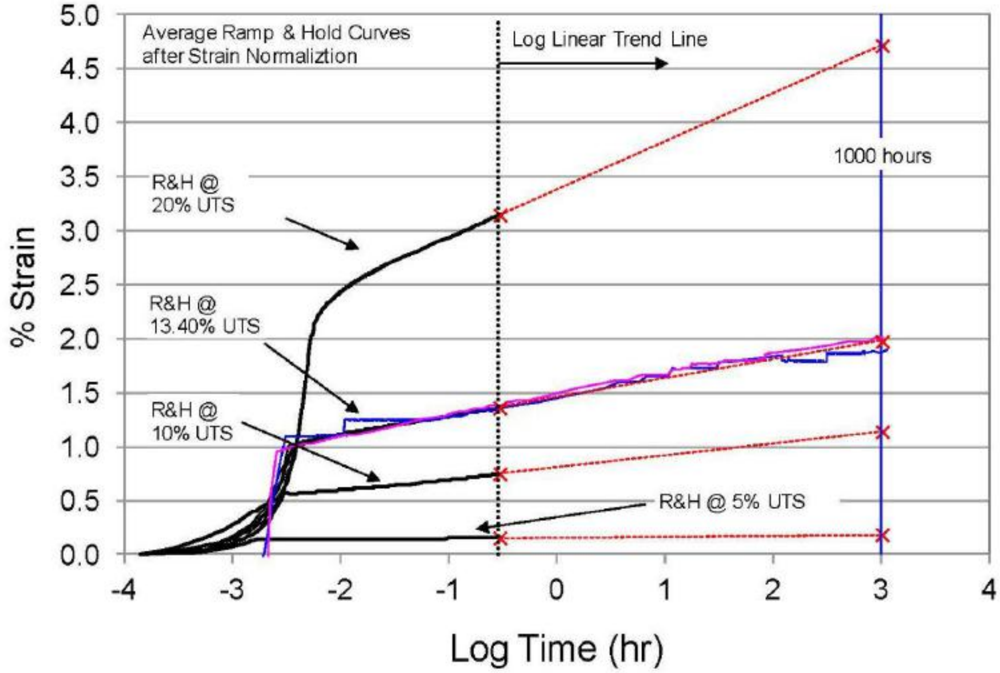

Figure H-8. Low strain ramp and hold tests for 24XT, after strain normalization, with 1000 hour low strain creep tests.

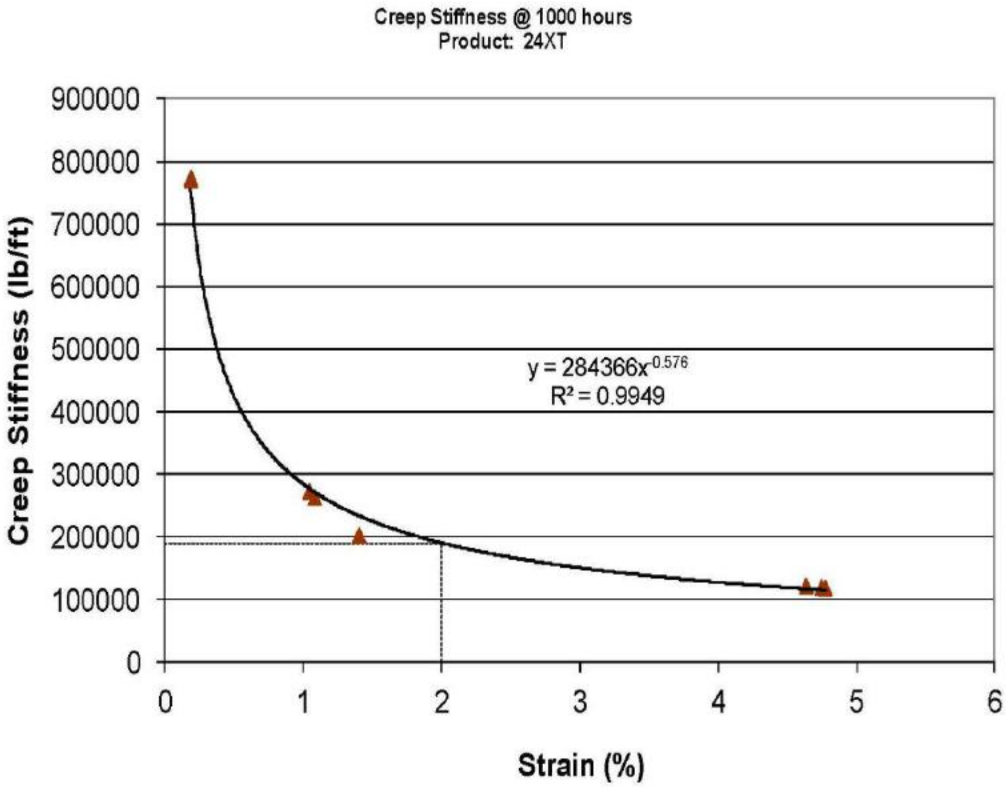

Figure H-9. Creep stiffness versus strain at 1,000 hours for 24XT.

"The National Transportation Product Evaluation Program (NTPEP) was established by the American Association of State Highway and Transportation Officials (AASHTO) in early 1994. The program pools the professional and physical resources of the AASHTO member departments in order to test materials, products and devices of common interest. The primary goals of the program are to provide cost-effective evaluations for the states by eliminating duplication of routine testing by the states; and to reduce duplication of effort by the manufacturers who produce and market commonly used proprietary, engineered products." **NTPEP**

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APPENDIX: 1.2.6A UNIT-GEOGRID CONNECTION TEST REPORT

REDI-ROCK

GEOGRID CONNECTION DESIGN PARAMETERS

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Test Methods:	ASTM D6638 & NCMA SRWU-1	Test Facility:	Bathurst, Clarabut Geotechnical Testing, Inc.
Geogrid Type:	Miragrid 5XT	Test Date:	February 17, 2011
Block Type:	Positive Connection (PC) Block		

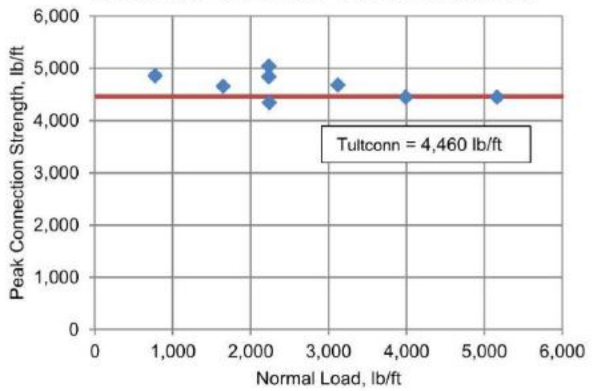
CONNECTION STRENGTH TEST DATA[a]

Test No.	Normal Load, lb/ft	Peak Connection, lb/ft	Observed Failure
1	2,236	5,040	Rupture
2	775	4,860	Rupture
3	5,165	4,444	Rupture
4	2,242	4,343	Rupture
5	1,649	4,658	Rupture
6	3,123	4,680	Rupture
7	2,236	4,838	Rupture
8	3,991	4,444	Rupture

Peak Connection $_{(average)}$ = 4,663 lb/ft

Peak Connection $_{(95\%\ confidence\ level)}$ = 4,460 lb/ft[b]

MIRAGRID 5XT CONNECTION STRENGTH



CONNECTION DESIGN DATA

for use with AASHTO LRFD Bridge Design Specifications, 6th Edition (2012)

Miragrid 5XT Ultimate Tensile Strength (MARV)	T_{ult} =	4,700 lb/ft
Ultimate Connection Strength	$T_{ultconn}$ =	4,460 lb/ft
Ultimate Tensile Strength of Geosynthetic Test Sample	T_{lot} =	5,334 lb/ft
Connection Strength / Sample Strength	$T_{ultconn} / T_{lot}$ =	0.84
Short-term Ultimate Connection Strength Reduction Factor[c]	CR_u =	0.84
Creep Reduction Factor		
75-Year Design	$RF_{CR(75)}$ =	1.44
100-Year Design	$RF_{CR(100)}$ =	1.45
Durability Reduction Factor[d]	RF_D =	1.15
Long-term Connection Strength Reduction Factor		
75-Year Design	$CR_{cr(75)}$ =	0.58
100-Year Design	$CR_{cr(100)}$ =	0.58
Nominal Long-term Geosynthetic Connection Strength		
75-Year Design	$T_{ac(75)}$ =	2,384 lb/ft
100-Year Design	$T_{ac(100)}$ =	2,368 lb/ft

(a) Tested with 3/4" clean crushed stone lightly compacted in the vertical core slot in accordance with Redi-Rock's typical installation recommendations.
(b) Because the geogrid connection is not normal load dependent and an expression of peak connection for use in design cannot be reliably determined through linear regression, the peak connection results are analyzed as continuous random variables. The average value or sample mean is reported for the test sample as well as a reduction based upon a 95% confidence interval calculated from the Student's t-test for n-1 degrees of freedom.
(c) Recommended CRu for design is based on a statistical best fit analysis of Tultconn / Tlot values across all geogrid types tested.
(d) Recommended value for $5 < pH < 8$. RF_D value of 1.3 recommended for $4.5 \le pH \le 5$ and $8 \le pH \le 9$.

REPORT

RESULTS OF REDI-ROCK POSITIVE CONNECTION (PC) BLOCK AND MIRAGRID 5XT GEOGRID CONNECTION CAPACITY TESTING

submitted to

REDI-ROCK INTERNATIONAL

CONFIDENTIAL

Distribution:

2 copies	REDI-ROCK International LLC. 05481 US 31 South Charlevoix, Michigan 49720 USA
2 copies	Bathurst, Clarabut Geotechnical Testing, Inc. 1167 Clyde Court, Kingston, Ontario K7P 2E4 CANADA

Introduction

This report gives the results of a connection testing program carried out to evaluate the mechanical/frictional performance of the connection between Redi-Rock Positive Connection (PC)™ Block modular concrete units manufactured by Redi-Rock International, LLC and Miragrid 5XT® geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Jack Bergmann of Redi-Rock International, LLC, received 20 December 2010.

The tests were carried out at the laboratories of Bathurst, Clarabut Geotechnical Testing, Inc. in Kingston, Ontario, under the supervision of Mr. Peter Clarabut.

Objectives of test program

The facing-geogrid connection between Redi-Rock concrete block units and Miragrid 5XT geogrid was investigated using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the frictional/mechanical performance of these connections. A second objective was to make preliminary recommendations for the selection of long-term tensile connection capacities to be used in the design and analysis of geogrid-reinforced soil wall systems that employ Redi-Rock blocks in combination with Miragrid 5XT geogrid.

Materials

The Redi-Rock Positive Connection (PC) Block units used in this investigation are solid concrete blocks. The nominal dimensions of the blocks are 28 inches (toe to heel) by 18 inches high by 46 inches long and weigh approximately 1625 lb per unit. Construction alignment and wall batter is achieved by means of two dome-shaped concrete shear keys cast into the top surface of the units. The Redi-Rock block system employs a rectangular hole in the block to mechanically attach the geogrid reinforcement. The rectangular hole is centrally located across the block length and located 10 inches from the back of the block. The blocks used in this series of tests were supplied by Redi-Rock International and were received at our laboratory on 4 February 2010 and designated as BIC-10-007.

Miragrid 5XT is a coated bi-directional grid composed of 100% polyester multifilament yarn with a tensile strength of 4700 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 2 February 2011). The geogrid specimens used in this series of testing were cut from roll/lot # 031119212/10121-1-1147 received at our laboratory on 24 June 2010. The index strength of roll/lot # 031119212/10121-1-1147 was 5334 lb/ft (test data supplied by TC Mirafi).

Apparatus and general test procedure

The method of test used in this investigation follows that reported by Bathurst and Simac (1993) and recommended by the NCMA (Simac et al. 1993) and ASTM D 6638. A brief de-

scription of the apparatus and test methodology is presented here. The test apparatus used to perform the tests is illustrated in **Figure 1**. The test apparatus allows tensile loads of up to 35,000 pounds to be applied to the geogrid while it is confined between two block layers. The facing blocks were laterally restrained and surcharged vertically. A strip of geogrid reinforcement 12 inches wide (11 longitudinal strands) was passed through the block and both ends were attached to roller clamps. The connection detail and roller clamp arrangement is illustrated in **Figure 2**. A photograph of the Redi-Rock Positive Connection (PC) Block system and the recommended geogrid connection configuration is shown in **Figure 3**. The hollow slot portion of the block was infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 4** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the lower grid to measure grid displacement at the back of the block. Wall heights were simulated by placing one block over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. Gum rubber mats were placed over the top block to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inch/minute) using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and the LVDT(s) were recorded continuously during the test by a microcomputer/data acquisition system. All blocks used in the tests were visually inspected to confirm that they were free of defects. Each test was continued until there was a sustained loss in connection load due to grid rupture. Following each test, the blocks were removed and the grid examined to confirm failure modes. A virgin specimen of grid was used for each test.

The only variable in this series of connection tests was the magnitude of surcharge load.

Test program

The surcharge loads used in the test program are given in **Table 1**. Also tabulated are the failure loads observed for each test.

Test results

A summary of tensile loads at peak capacity is given in **Figure 5**.

The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 5XT for walls between 775 and 5165 lb/ft normal load, ranged between 81 and 94% of the index tensile strength of the specimen of Miragrid 5XT used in this investigation (5334 lb/ft - value reported by manufacturer for material used in this nvestigation).

Two repeat tests were performed and results in **Figure 5** illustrate that there is variability in connection capacity between nominal identical tests. The variability is 8.4% and hence within the ± 10% of the mean peak load criterion required by the NCMA. This variability is likely the result of small differences in the setting up of the blocks and laying out of the geogrid reinforcement. The trend in data for peak connection loads has been plotted using a linear curve.

All tests ended in rupture of one or more longitudinal geogrid members. There was evidence of slippage of the grid within the concrete block-grid interface in all tests. Grid straining and slippage caused abrasion of longitudinal members and junction failure as the geogrid was pulled across the concrete surfaces.

Implications to Redi-Rock Positive Connection (PC) Block design and construction with Miragrid 5XT geogrid

The long-term design connection capacity in the field must be less than the peak capacity envelope determined in this test series for the same method and quality of construction. The NCMA Segmental Retaining Wall Design Manual (First Edition, 1993) recommends that the design connection capacity at a given surcharge load for a critical wall structure be the lesser of the peak capacity divided by a minimum factor of safety (not less than 1.5) or the capacity based on a 3/4 inch displacement criterion. The *design* curve in **Figure 6** has been selected based on peak capacity load data only.

The design capacity envelope illustrated in **Figure 6** should be used with caution. The actual design capacity envelope should be lower if the quality of construction in the field is less than that adopted in this controlled laboratory investigation and/or lower quality concrete is used in the manufacture of the blocks. For example, the interface concrete surfaces should be free of debris before placement of grid and blocks in order to minimize abrasion to the grid and to maximize the frictional resistance that is developed at the concrete block-grid interface.

It is very important that production blocks have uniform dimensions so that there is no stepping at the block joints that can lead to non-uniform frictional resistance at the block-grid interface, pinching of the grid at the block edges and possibly fracture of the concrete units.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional connection performance of Redi-Rock modular block facing units in combination with Miragrid 5XT. The following conclusions can be drawn:

1. The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 5XT geogrid for walls between 775 and 5165 lb/ft normal load, ranged between 81 and 94% of the index tensile strength of the specimen of Miragrid 5XT used in this investigation (5334 lb/ft - value reported by manufacturer for material used in this nvestigation).
2. The trend in data for peak connection loads has been plotted using a linear curve. In addition, some variability in strength values was observed between nominal identical tests due to small differences in setting up of the blocks and laying out of the geogrid reinforcement.
3. Care must be taken during the installation of Redi-Rock Positive Connection (PC) Block units in order to prevent accumulation of soil and rock debris at the concrete block-grid

interface surfaces. This debris may significantly reduce the capacity of the Redi-Rock facing unit-grid system.

4. The design envelope in **Figure 6** is based on an interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual (First Edition, 1993). The choice of design connection strengths may vary from site to site and quality of construction in the field may require lower design values than those taken from **Figure 6**.

R. J. Bathurst, Ph.D., P. Eng.

P. Clarabut

REFERENCES

ASTM D 6638-01. Standard Test Method for Determining Connection Strength between Geosynthetic Reinforcement and Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Bathurst, R.J. and Simac, M.R., 1993. Laboratory Testing of Modular Unit/Geogrid Facing Connections, *ASTM Symposium on Geosynthetic Soil Reinforcement Testing Procedures*, San Antonio, 19 January 1993.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. *NCMA Segmental Retaining Wall Design Manual (First Edition)*, National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406.

Table 1:

Test Program:

Redi-Rock Positive Connection (PC) Block unit - Miragrid 5XT polyester geogrid connection

Test number	normal load (lb/ft)	peak horz. load (lb/block)	peak tensile capacity per single strip (lb/ft) (note 2)	observed failure mode
1	2236	10080	5040	Rupture
2	775	9720	4860	Rupture
3	5165	8888	4444	Rupture
4	2242	8685	4343	Rupture
5	1649	9315	4658	Rupture
6	3123	9360	4680	Rupture
7	2236	9675	4838	Rupture
8	3991	8888	4444	Rupture

Note: 1) The geogrid specimens used in this series of testing were cut from roll/lot # 031119212/10121-1-1147 received at our laboratory on 24 June 2010. The index strength of roll/lot # 031119212/10121-1-1147 was 5334 lb/ft (test data supplied by TC Mirafi)

2) The load recorded at the actuator is twice the value shown here.

Redi-Rock Positive Connection (PC) Block and Miragrid 5XT

Project # BCGT210050
Series BCGT3041

LEGEND

1	Redi-Rock Block	6	guide rail	11	platform
2	geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamps	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

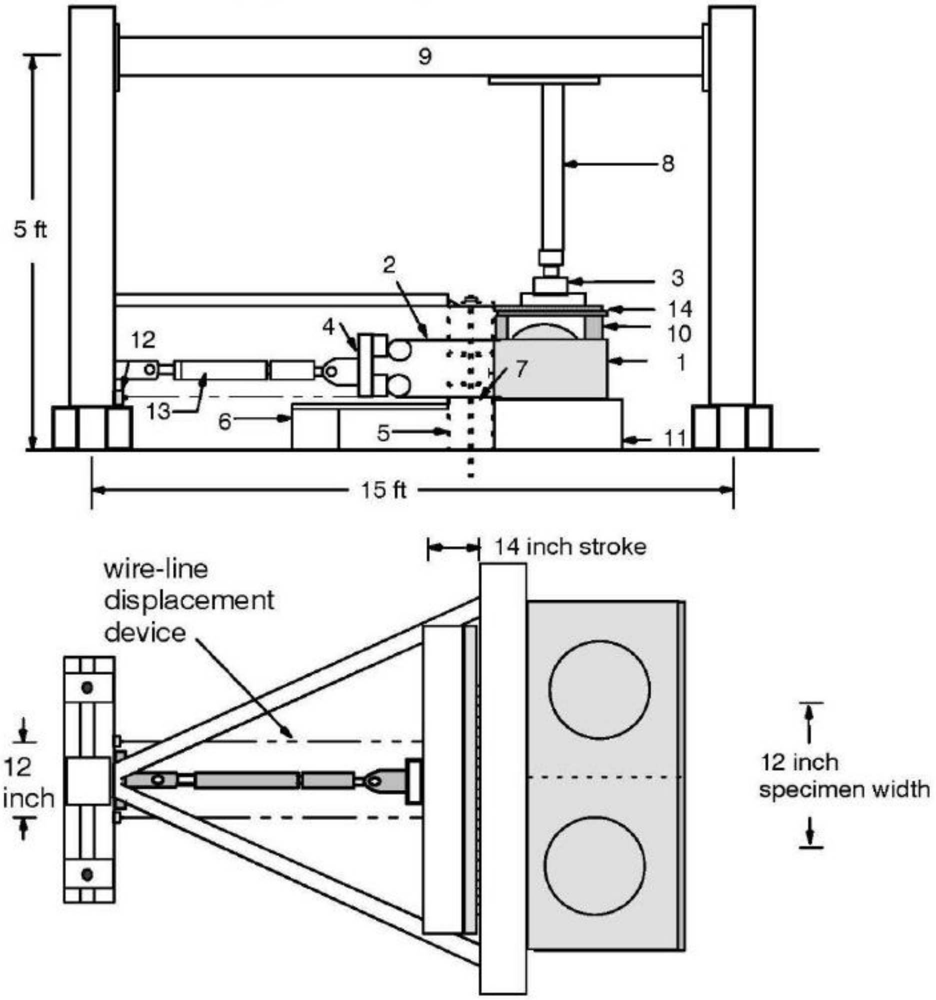


Figure 1: Schematic of connection test apparatus showing Redi-Rock Positive Connection (PC) Block units and Mirafi geogrid

Bathurst, Clarabut Geotechnical Testing, Inc. 17 February 2011

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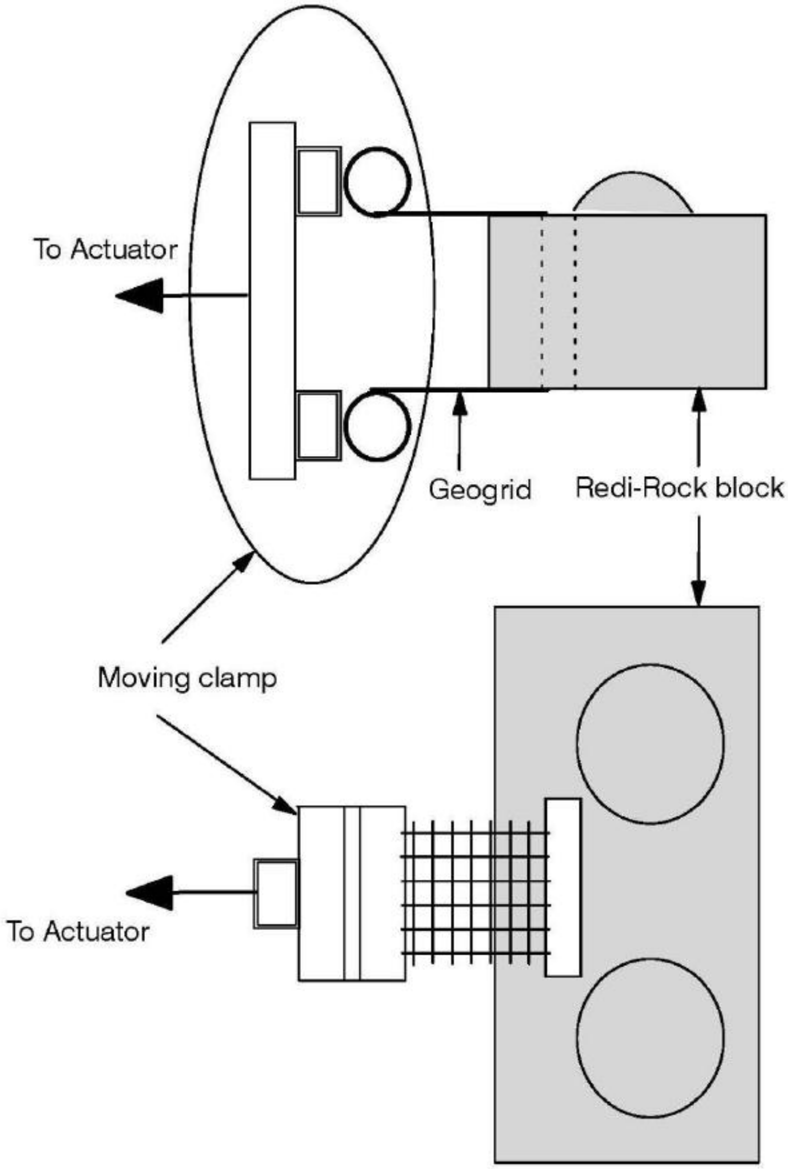

Figure 2: Schematic of connection detail and clamp arrangement

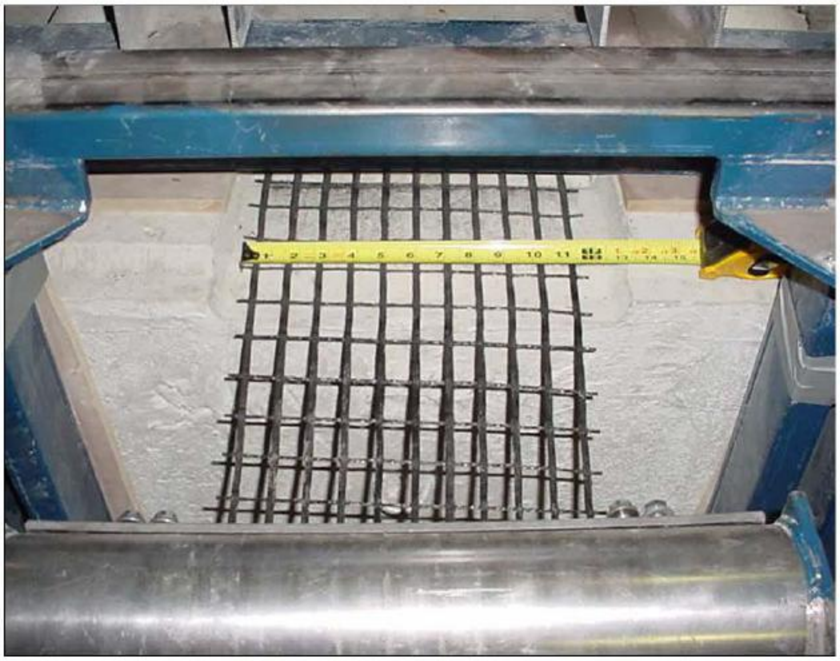

Figure 3: Photograph of the Redi-Rock Positive Connection (PC) Block system and Miragrid 5XT geogrid

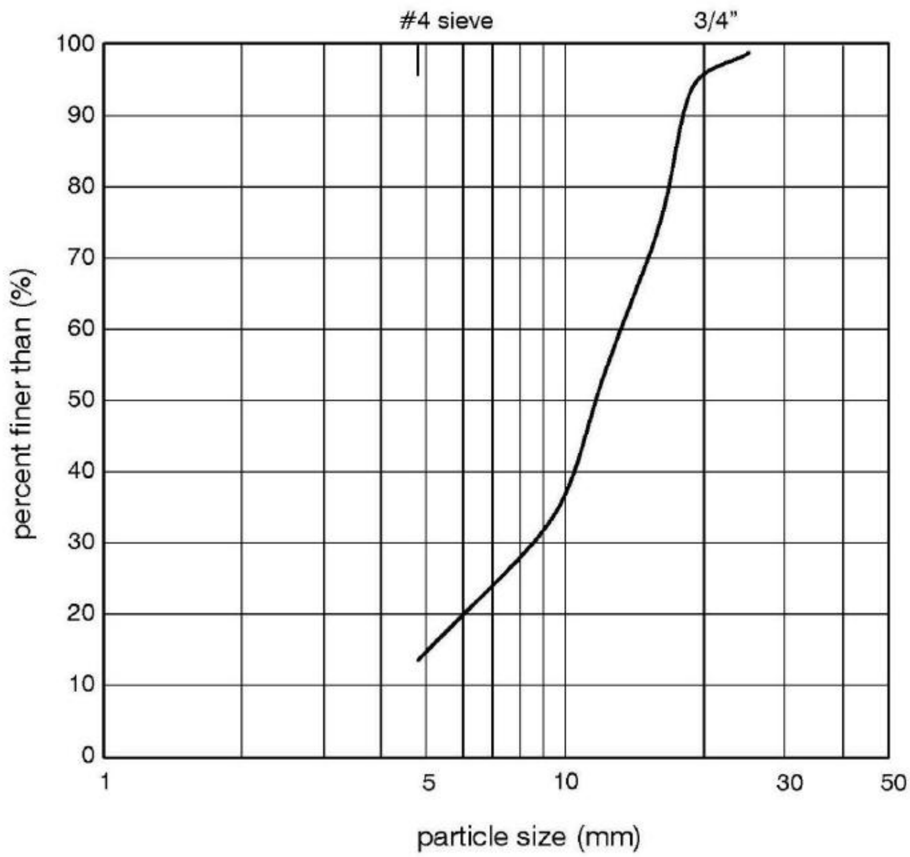

Figure 4: Particle size distribution for 100% crushed granular stone used in Redi-Rock Positive Connection (PC) Block tests

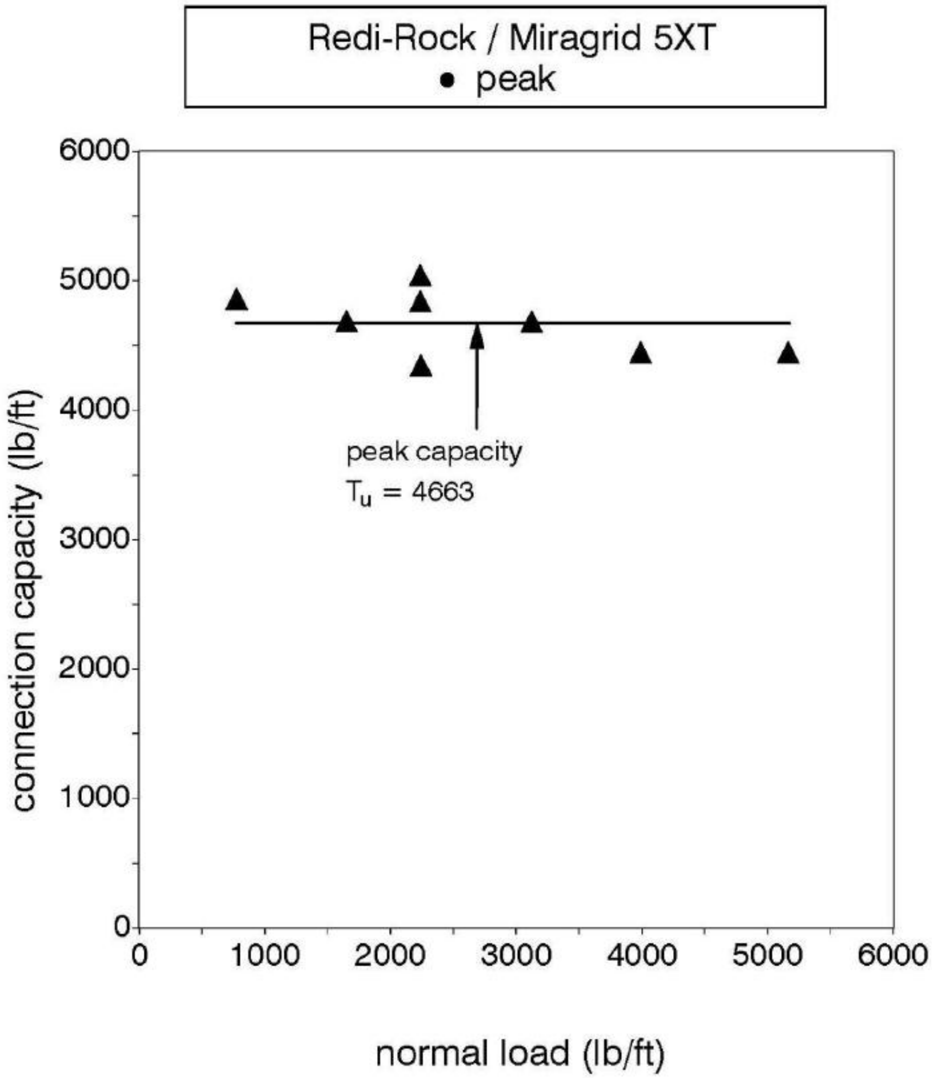

Figure 5: Connection capacity versus normal load for Redi-Rock Positive Connection (PC) Block with Miragrid 5XT based on a 12 inch wide strip of geogrid

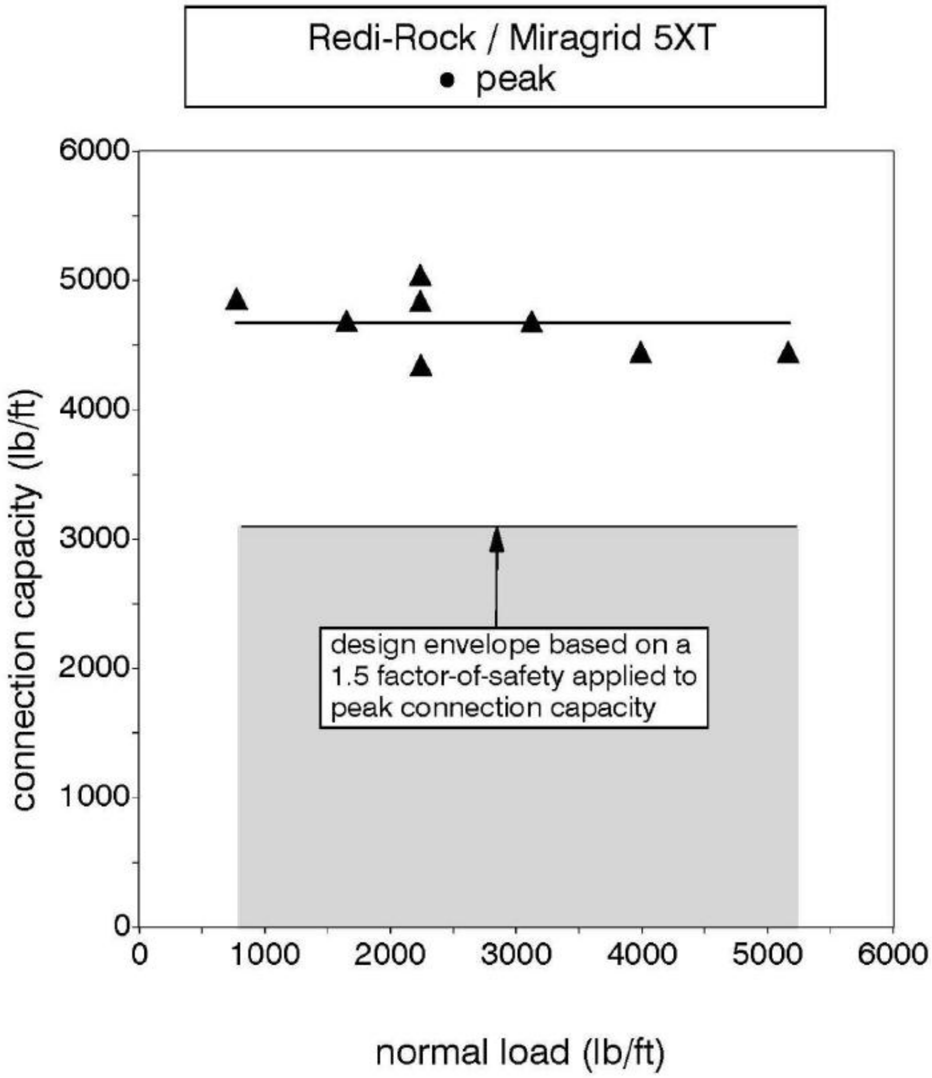

Figure 6: Preliminary design capacity envelope for Redi-Rock Positive Connection (PC) Block units with Miragrid 5XT geogrid based on a 12 wide inch strip of geogrid

REDI-ROCK

GEOGRID CONNECTION DESIGN PARAMETERS

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Test Methods:	ASTM D6638 & NCMA SRWU-1	Test Facility:	Bathurst, Clarabut Geotechnical Testing, Inc.
Geogrid Type:	Miragrid 8XT	Test Date:	December 16, 2011
Block Type:	Positive Connection (PC) Block		

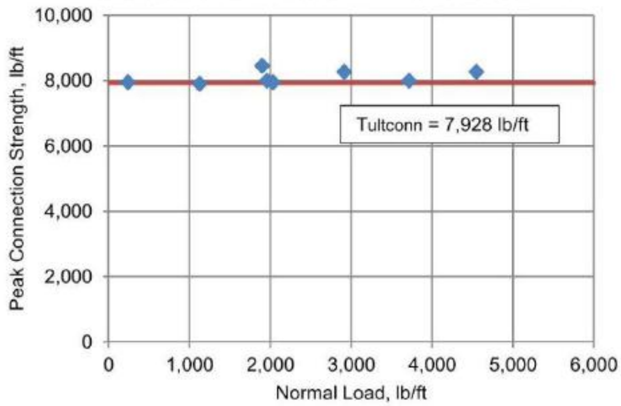
CONNECTION STRENGTH TEST DATA[(a)]

Test No.	Normal Load, lb/ft	Peak Connection, lb/ft	Observed Failure
1	1,960	7,995	Rupture
2	241	7,949	Rupture
3	1,125	7,904	Rupture
4	2,036	7,949	Rupture
5	2,914	8,269	Rupture
6	3,715	7,995	Rupture
7	1,900	8,452	Rupture
8	4,551	8,269	Rupture

Peak Connection (average) = 8,098 lb/ft

Peak Connection (95% confidence level) = 7,928 lb/ft [(b)]

MIRAGRID 8XT CONNECTION STRENGTH



CONNECTION DESIGN DATA

for use with AASHTO LRFD Bridge Design Specifications, 6th Edition (2012)

Miragrid 8XT Ultimate Tensile Strength (MARV)	T_{ult} =	7,400 lb/ft
Ultimate Connection Strength	$T_{ultconn}$ =	7,928 lb/ft
Ultimate Tensile Strength of Geosynthetic Test Sample	T_{lot} =	8,055 lb/ft
Connection Strength / Sample Strength	$T_{ultconn} / T_{lot}$ =	0.98
Short-term Ultimate Connection Strength Reduction Factor [(c)]	CR_u =	0.84
Creep Reduction Factor		
75-Year Design	$RF_{CR(75)}$ =	1.44
100-Year Design	$RF_{CR(100)}$ =	1.45
Durability Reduction Factor [(d)]	RF_D =	1.15
Long-term Connection Strength Reduction Factor		
75-Year Design	$CR_{cr(75)}$ =	0.58
100-Year Design	$CR_{cr(100)}$ =	0.58
Nominal Long-term Geosynthetic Connection Strength		
75-Year Design	$T_{ac(75)}$ =	3,754 lb/ft
100-Year Design	$T_{ac(100)}$ =	3,728 lb/ft

(a) Tested with 3/4" clean crushed stone lightly compacted in the vertical core slot in accordance with Redi-Rock's typical installation recommendations.
(b) Because the geogrid connection is not normal load dependent and an expression of peak connection for use in design cannot be reliably determined through linear regression, the peak connection results are analyzed as continuous random variables. The average value or sample mean is reported for the test sample as well as a reduction based upon a 95% confidence interval calculated from the Student's t-test for n-1 degrees of freedom.
(c) Recommended CRu for design is based on a statistical best fit analysis of Tultconn / Tlot values across all geogrid types tested.
(d) Recommended value for 5 < pH < 8. RF_D value of 1.3 recommended for $4.5 \le pH \le 5$ and $8 \le pH \le 9$.

REPORT

RESULTS OF

REDI-ROCK POSITIVE CONNECTION (PC) BLOCK AND MIRAGRID 8XT GEOGRID CONNECTION CAPACITY TESTING

submitted to

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Introduction

This report gives the results of a connection testing program carried out to evaluate the mechanical/frictional performance of the connection between Redi-Rock Positive Connection (PC)™ Block modular concrete units manufactured by Redi-Rock International, LLC and Miragrid 8XT® geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Jamie Johnson of Redi-Rock International, LLC received 29 November 2011.

The tests were carried out at the laboratories of Bathurst, Clarabut Geotechnical Testing, Inc. in Kingston, Ontario, under the supervision of Mr. Peter Clarabut.

Objectives of test program

The facing-geogrid connection between Redi-Rock concrete block units and Miragrid 8XT geogrid was investigated using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the frictional/mechanical performance of these connections. A second objective was to make preliminary recommendations for the selection of long-term tensile connection capacities to be used in the design and analysis of geogrid-reinforced soil wall systems that employ Redi-Rock blocks in combination with Miragrid 8XT geogrid.

Materials

The Redi-Rock Positive Connection (PC) Block units used in this investigation are solid concrete blocks. The nominal dimensions of the blocks are 28 inches (toe to heel) by 18 inches high by 46 inches long and weigh approximately 1625 lb per unit. Construction alignment and wall batter is achieved by means of two dome-shaped concrete shear keys cast into the top surface of the units. The Redi-Rock block system employs a rectangular hole in the block to mechanically attach the geogrid reinforcement. The rectangular hole is centrally located across the block length and located 10 inches from the back of the block. The blocks used in this series of tests were supplied by Redi-Rock International and were received at our laboratory on 9 August 2011 and designated as BIC-11-025.

Miragrid 8XT is a coated bi-directional grid composed of 100% polyester multifilament yarn with a tensile strength of 7400 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 28 November 2011). The geogrid used in this series of testing was delivered as 12 inch wide (11 strands), specimens from roll/lot # 031140138 received at our laboratory on 17 November 2011. The index strength of roll/lot # 031140138 was 8,055 lb/ft (test data supplied by TC Mirafi).

Apparatus and general test procedure

The method of test used in this investigation follows that reported by Bathurst and Simac (1993) and recommended by the NCMA (Simac et al. 1993) and ASTM D 6638. A brief de-

scription of the apparatus and test methodology is presented here. The test apparatus used to perform the tests is illustrated in **Figure 1**. The test apparatus allows tensile loads of up to 35,000 pounds to be applied to the geogrid while it is confined between two block layers. The facing block was laterally restrained and surcharged vertically. A strip of geogrid reinforcement 12 inches wide (11 longitudinal strands) was passed through the block and both ends were attached to roller clamps. The connection detail and roller clamp arrangement is illustrated in **Figure 2**. A photograph of the Redi-Rock Positive Connection (PC) Block system and the recommended geogrid connection configuration is shown in **Figure 3**. The hollow slot portion of the block was infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 4** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the lower grid to measure grid displacement at the back of the block. Wall heights were simulated by placing one block over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. Gum rubber mats were placed over the top block to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inch/minute) using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and the LVDT(s) were recorded continuously during the test by a microcomputer/data acquisition system. All blocks used in the tests were visually inspected to confirm that they were free of defects. Each test was continued until there was a sustained loss in connection load due to grid rupture. Following each test, the block was removed and the grid examined to confirm failure modes. A virgin specimen of grid was used for each test.

The only variable in this series of connection tests was the magnitude of surcharge load.

Test program

The surcharge loads used in the test program are given in **Table 1**. Also tabulated are the failure loads observed for each test.

Test results

A summary of tensile loads at peak capacity is given in **Figure 5**.

The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 8XT for walls between 241 and 4551 lb/ft normal load, ranged between 100 and 109% of the index tensile strength of the specimen of Miragrid 8XT used in this investigation (8,055 lb/ft - value reported by manufacturer for material used in this investigation).

Two repeat tests were performed and results in **Figure 5** illustrate that there is some variability in connection capacity between nominal identical tests. The variability is 3.9% and hence within the ± 10% of the mean peak load criterion required by the NCMA. This variability is likely the result of small differences in the setting up of the blocks and laying out of the geogrid reinforcement. The trend in data for peak connection loads has been plotted using a linear curve.

All tests ended in rupture of one or more longitudinal geogrid members. There was evidence of slippage of the grid within the concrete block-grid interface in all tests. Grid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces.

Implications to Redi-Rock Positive Connection (PC) Block design and construction with Miragrid 8XT geogrid

The long-term design connection capacity in the field must be less than the peak capacity envelope determined in this test series for the same method and quality of construction. The NCMA Segmental Retaining Wall Design Manual (First Edition, 1993) recommends that the design connection capacity at a given surcharge load for a critical wall structure be the lesser of the peak capacity divided by a minimum factor of safety (not less than 1.5) or the capacity based on a 3/4 inch displacement criterion. The *design* curve in **Figure 6** has been selected based on peak capacity load data only.

The design capacity envelope illustrated in **Figure 6** should be used with caution. The actual design capacity envelope should be lower if the quality of construction in the field is less than that adopted in this controlled laboratory investigation and/or lower quality concrete is used in the manufacture of the blocks. For example, the interface concrete surfaces should be free of debris before placement of grid and blocks in order to minimize abrasion to the grid and to maximize the frictional resistance that is developed at the concrete block-grid interface.

It is very important that production blocks have uniform dimensions so that there is no stepping at the block joints that can lead to non-uniform frictional resistance at the block-grid interface, pinching of the grid at the block edges and possibly fracture of the concrete units.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional connection performance of Redi-Rock modular block facing units in combination with Miragrid 8XT. The following conclusions can be drawn:

1. The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 8XT geogrid for walls between 241 and 4551 lb/ft normal load, ranged between 100 and 109% of the index tensile strength of the specimen of Miragrid 8XT used in this investigation (8,055 lb/ft - value reported by manufacturer for material used in this investigation).
2. The trend in data for peak connection loads has been plotted using a linear curve. In addition, some variability in strength values was observed between nominal identical tests due to small differences in setting up of the blocks and laying out of the geogrid reinforcement.
3. Care must be taken during the installation of Redi-Rock Positive Connection (PC) Block units in order to prevent accumulation of soil and rock debris at the concrete block-grid

interface surfaces. This debris may significantly reduce the capacity of the Redi-Rock facing unit-grid system.

4. The design envelope in **Figure 6** is based on an interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual (First Edition, 1993). The choice of design connection strengths may vary from site to site and quality of construction in the field may require lower design values than those taken from **Figure 6.**

P. Clarabut

REFERENCES

ASTM D 6638-01. Standard Test Method for Determining Connection Strength between Geosynthetic Reinforcement and Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Bathurst, R.J. and Simac, M.R., 1993. Laboratory Testing of Modular Unit/Geogrid Facing Connections, *ASTM Symposium on Geosynthetic Soil Reinforcement Testing Procedures*, San Antonio, 19 January 1993.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. *NCMA Segmental Retaining Wall Design Manual (First Edition),* National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406.

Table 1:

Test Program:

Redi-Rock Positive Connection (PC) Block unit - Miragrid 8XT polyester geogrid connection

Test number	normal load (lb/ft)	peak horz. load (lb/block)	peak tensile capacity per single strip (lb/ft) (note 1)	observed failure mode
1	1960	15990	7995	Rupture
2	241	15898	7949	Rupture
3	1125	15807	7904	Rupture
4	2036	15898	7949	Rupture
5	2914	16538	8269	Rupture
6	3715	15990	7995	Rupture
7	1900	16903	8452	Rupture
8	4551	16538	8269	Rupture

Note: 1) The load recorded at the actuator is twice the value shown here.

Redi-Rock Positive Connection (PC) Block and Miragrid 8XT

Project # BCGT211035
Series BCGT3138

LEGEND

1	Redi-Rock block	6	guide rail	11	platform
2	geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamps	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

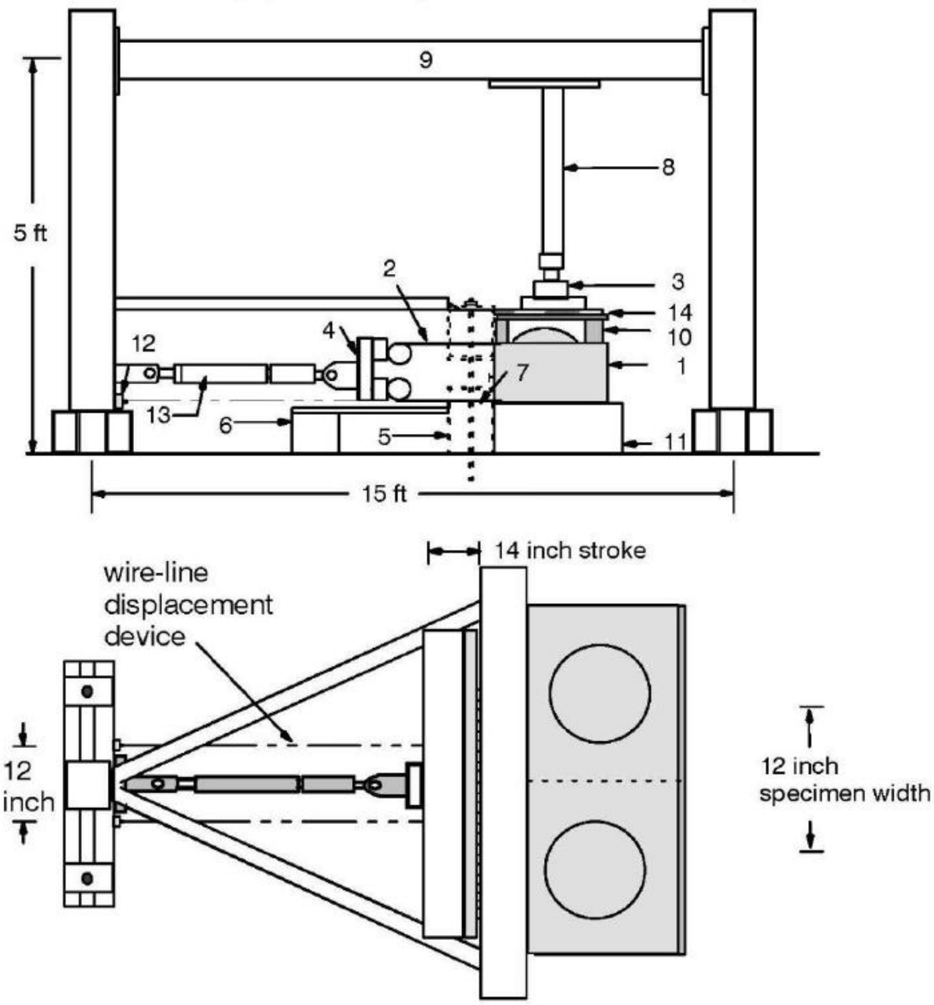

Figure 1: Schematic of connection test apparatus showing Redi-Rock Positive Connection (PC) Block units and Mirafi geogrid

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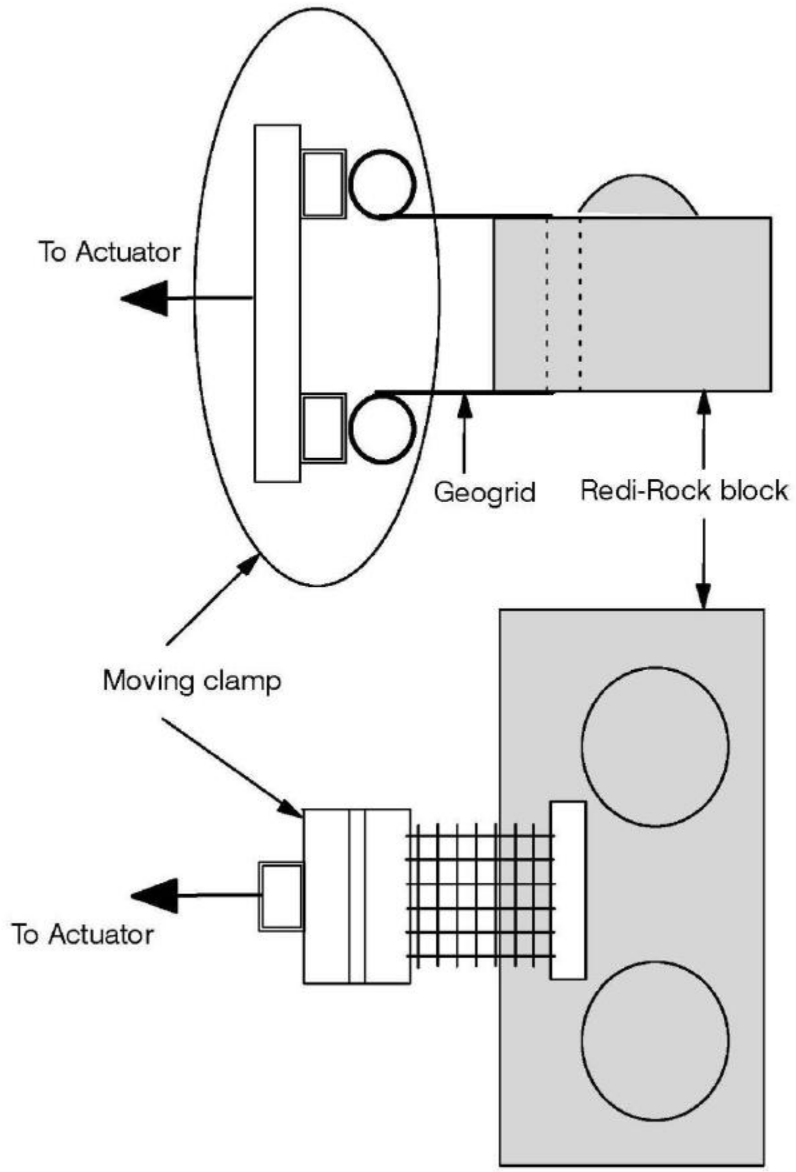

Figure 2: Schematic of connection detail and clamp arrangement

Figure 3: Photograph of the Redi-Rock Positive Connection (PC) Block system and Miragrid 8XT geogrid

Redi-Rock Positive Connection (PC) Block and Miragrid 8XT

Project # BCGT211035

Series BCGT3138

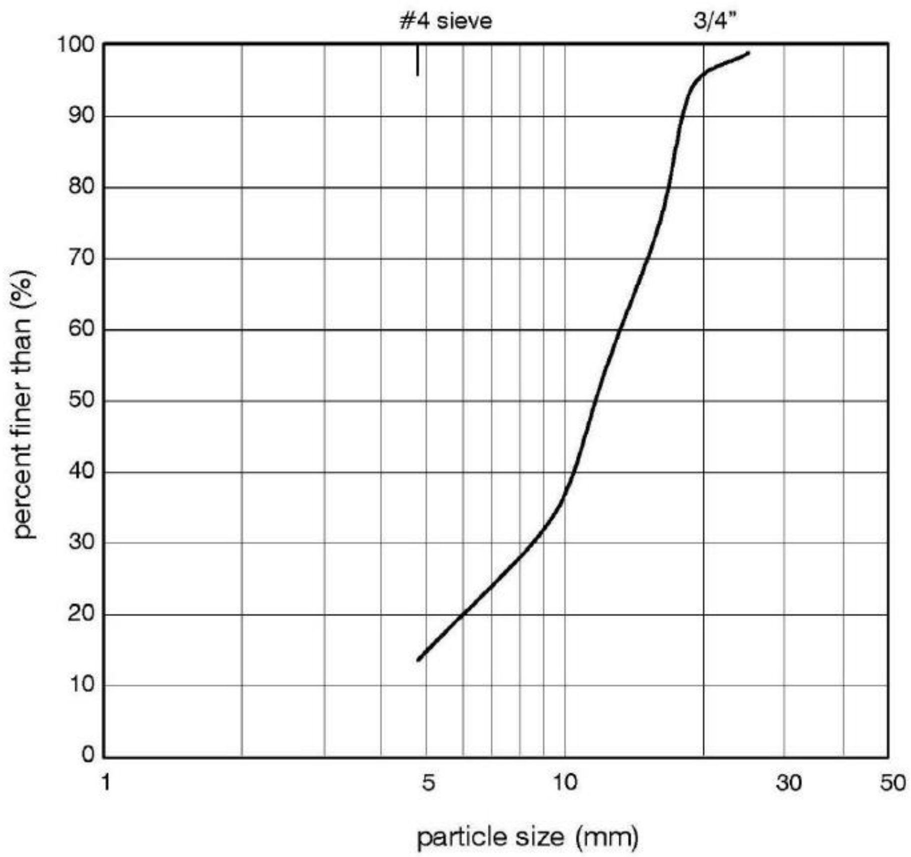

Figure 4: Particle size distribution for 100% crushed granular stone used in Redi-Rock Positive Connection (PC) Block tests

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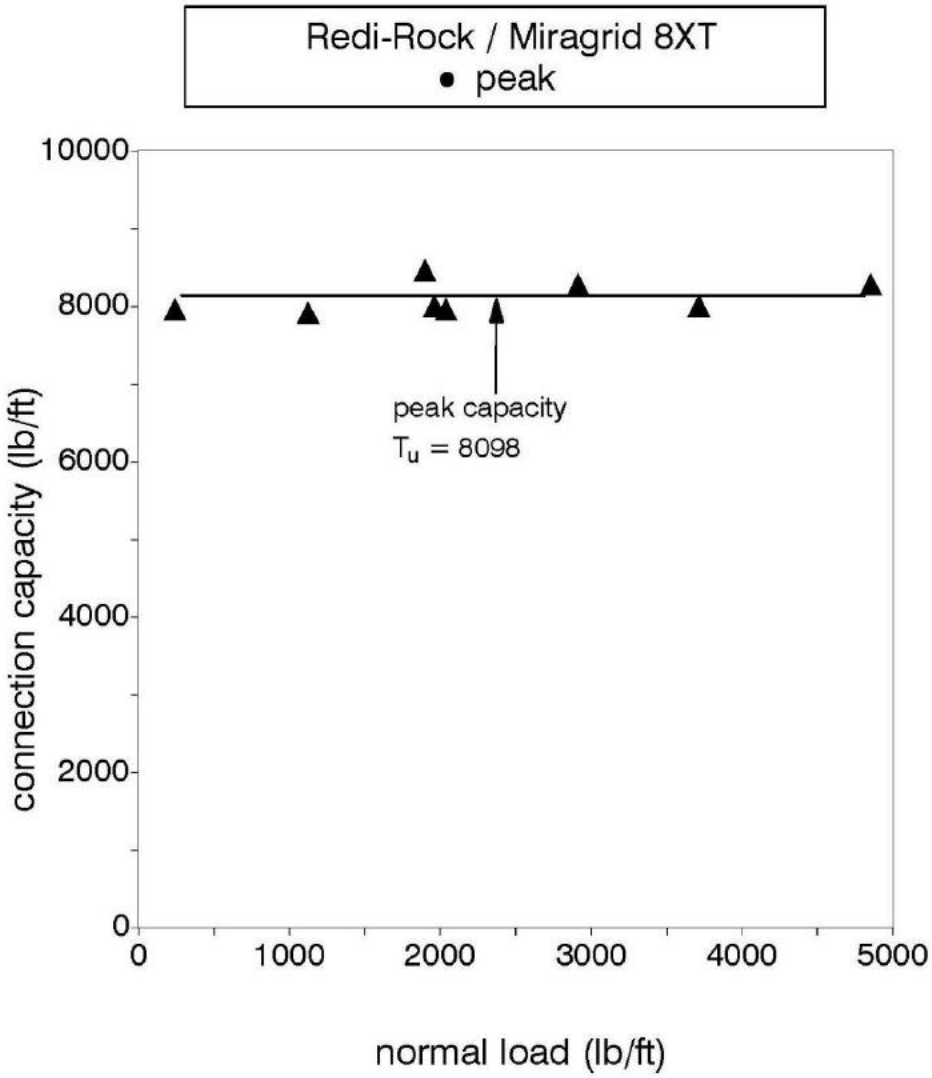

Figure 5: Connection capacity versus normal load for Redi-Rock Positive Connection (PC) Block with Miragrid 8XT based on a 12 inch wide strip of geogrid

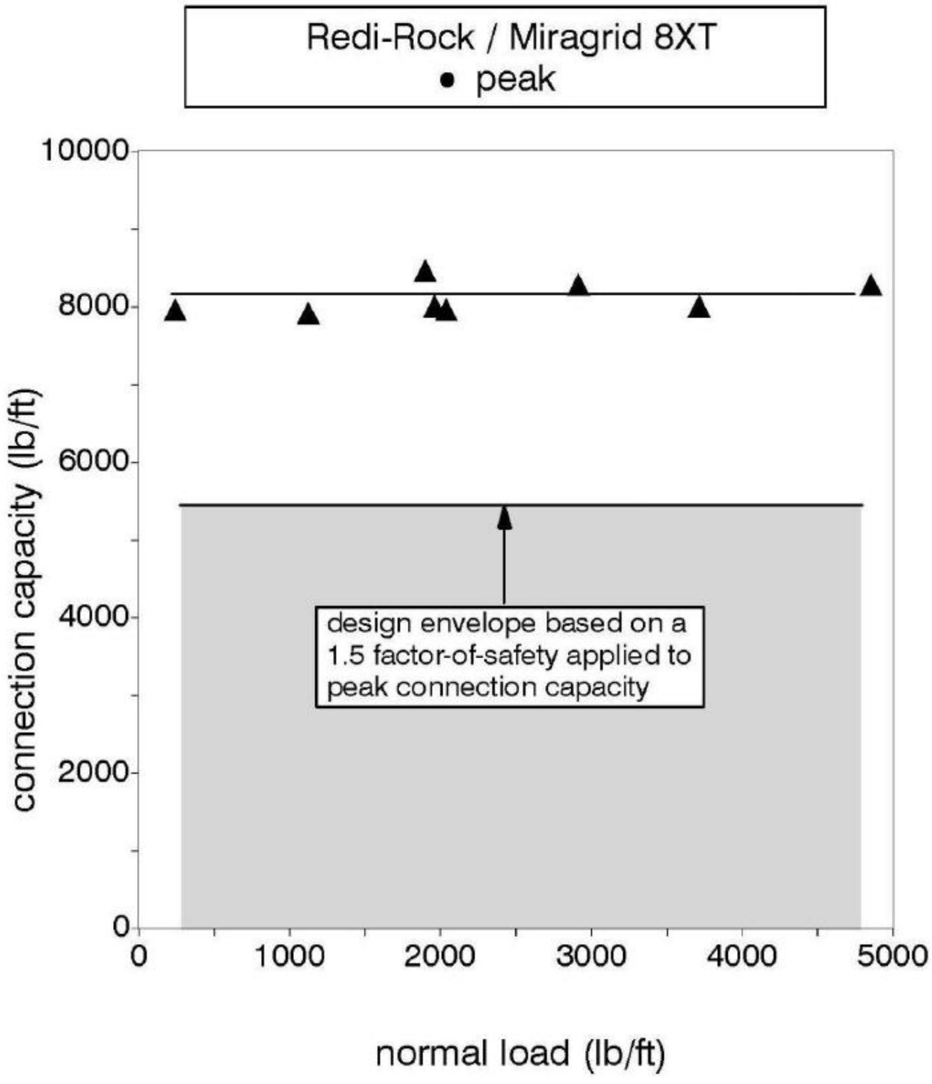

Figure 6: Preliminary design capacity envelope for Redi-Rock Positive Connection (PC) Block units with Miragrid 8XT geogrid based on a 12 wide inch strip of geogrid

REDI-ROCK

GEOGRID CONNECTION DESIGN PARAMETERS

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Test Methods:	ASTM D6638 & NCMA SRWU-1	Test Facility:	Bathurst, Clarabut Geotechnical Testing, Inc.
Geogrid Type:	Miragrid 10XT	Test Date:	November 28, 2011
Block Type:	Positive Connection (PC) Block		

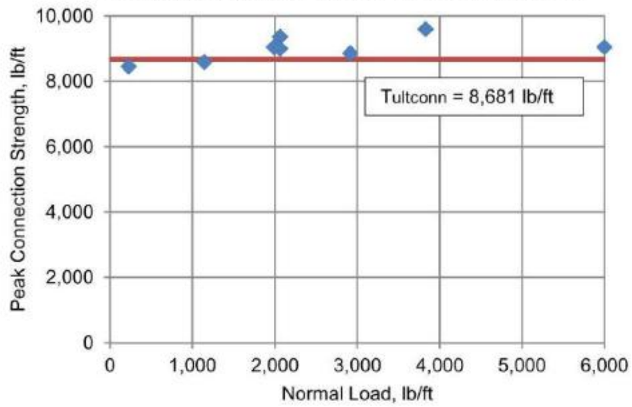
CONNECTION STRENGTH TEST DATA[a]

Test No.	Normal Load, lb/ft	Peak Connection, lb/ft	Observed Failure
1	1,990	9,046	Rupture
2	228	8,452	Rupture
3	1,147	8,589	Rupture
4	2,067	9,365	Rupture
5	2,918	8,863	Rupture
6	3,830	9,594	Rupture
7	2,067	9,000	Rupture
8	6,000	9,046	Rupture

Peak Connection $_{(average)}$ = 8,994 lb/ft

Peak Connection $_{(95\%\ confidence\ level)}$ = 8,681 lb/ft [b]

MIRAGRID 10XT CONNECTION STRENGTH



CONNECTION DESIGN DATA

for use with AASHTO LRFD Bridge Design Specifications, 6th Edition (2012)

Miragrid 10XT Ultimate Tensile Strength (MARV)	T_{ult} =	9,500 lb/ft
Ultimate Connection Strength	$T_{ultconn}$ =	8,681 lb/ft
Ultimate Tensile Strength of Geosynthetic Test Sample	T_{lot} =	10,635 lb/ft
Connection Strength / Sample Strength	$T_{ultconn} / T_{lot}$ =	0.82
Short-term Ultimate Connection Strength Reduction Factor [c]	CR_u =	0.82
Creep Reduction Factor		
75-Year Design	$RF_{CR(75)}$ =	1.44
100-Year Design	$RF_{CR(100)}$ =	1.45
Durability Reduction Factor [d]	RF_D =	1.15
Long-term Connection Strength Reduction Factor		
75-Year Design	$CR_{cr(75)}$ =	0.57
100-Year Design	$CR_{cr(100)}$ =	0.57
Nominal Long-term Geosynthetic Connection Strength		
75-Year Design	$T_{ac(75)}$ =	4,704 lb/ft
100-Year Design	$T_{ac(100)}$ =	4,672 lb/ft

(a) Tested with 3/4" clean crushed stone lightly compacted in the vertical core slot in accordance with Redi-Rock's typical installation recommendations.
(b) Because the geogrid connection is not normal load dependent and an expression of peak connection for use in design cannot be reliably determined through linear regression, the peak connection results are analyzed as continuous random variables. The average value or sample mean is reported for the test sample as well as a reduction based upon a 95% confidence interval calculated from the Student's t-test for n-1 degrees of freedom.
(c) Recommended CRu for design is based on a statistical best fit analysis of Tultconn / Tlot values across all geogrid types tested.
(d) Recommended value for 5 < pH < 8. RF_D value of 1.3 recommended for 4.5 ≤ pH ≤ 5 and 8 ≤ pH ≤ 9.

REPORT

RESULTS OF

REDI-ROCK POSITIVE CONNECTION (PC) BLOCK AND MIRAGRID 10XT GEOGRID CONNECTION CAPACITY TESTING

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Introduction

This report gives the results of a connection testing program carried out to evaluate the mechanical/frictional performance of the connection between Redi-Rock Positive Connection (PC)™ Block modular concrete units manufactured by Redi-Rock International, LLC and Miragrid 10XT® geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Jamie Johnson of Redi-Rock International, LLC received 9 August 2011.

The tests were carried out at the laboratories of Bathurst, Clarabut Geotechnical Testing, Inc. in Kingston, Ontario, under the supervision of Mr. Peter Clarabut.

Objectives of test program

The facing-geogrid connection between Redi-Rock concrete block units and Miragrid 10XT geogrid was investigated using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the frictional/mechanical performance of these connections. A second objective was to make preliminary recommendations for the selection of long-term tensile connection capacities to be used in the design and analysis of geogrid-reinforced soil wall systems that employ Redi-Rock blocks in combination with Miragrid 10XT geogrid.

Materials

The Redi-Rock Positive Connection (PC) Block units used in this investigation are solid concrete blocks. The nominal dimensions of the blocks are 28 inches (toe to heel) by 18 inches high by 46 inches long and weigh approximately 1625 lb per unit. Construction alignment and wall batter is achieved by means of two dome-shaped concrete shear keys cast into the top surface of the units. The Redi-Rock block system employs a rectangular hole in the block to mechanically attach the geogrid reinforcement. The rectangular hole is centrally located across the block length and located 10 inches from the back of the block. The blocks used in this series of tests were supplied by Redi-Rock International and were received at our laboratory on 9 August 2011 and designated as BIC-11-025.

Miragrid 10XT is a coated bi-directional grid composed of 100% polyester multifilament yarn with a tensile strength of 9500 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 28 November 2011). The geogrid used in this series of testing was delivered as 12 inch wide (11 strands), specimens from roll/lot # 000235307 received at our laboratory on 11 August 2011. The index strength of roll/lot # 000235307 was 10,635 lb/ft (test data supplied by TC Mirafi).

Apparatus and general test procedure

The method of test used in this investigation follows that reported by Bathurst and Simac (1993) and recommended by the NCMA (Simac et al. 1993) and ASTM D 6638. A brief de-

scription of the apparatus and test methodology is presented here. The test apparatus used to perform the tests is illustrated in **Figure 1**. The test apparatus allows tensile loads of up to 35,000 pounds to be applied to the geogrid while it is confined between two block layers. The facing block was laterally restrained and surcharged vertically. A strip of geogrid reinforcement 12 inches wide (11 longitudinal strands) was passed through the block and both ends were attached to roller clamps. The connection detail and roller clamp arrangement is illustrated in **Figure 2**. A photograph of the Redi-Rock Positive Connection (PC) Block system and the recommended geogrid connection configuration is shown in **Figure 3**. The hollow slot portion of the block was infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 4** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the lower grid to measure grid displacement at the back of the block. Wall heights were simulated by placing one block over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. Gum rubber mats were placed over the top block to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inch/minute) using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and the LVDT(s) were recorded continuously during the test by a microcomputer/data acquisition system. All blocks used in the tests were visually inspected to confirm that they were free of defects. Each test was continued until there was a sustained loss in connection load due to grid rupture. Following each test, the block was removed and the grid examined to confirm failure modes. A virgin specimen of grid was used for each test.

The only variable in this series of connection tests was the magnitude of surcharge load.

Test program

The surcharge loads used in the test program are given in **Table 1**. Also tabulated are the failure loads observed for each test.

Test results

A summary of tensile loads at peak capacity is given in **Figure 5**.

The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 10XT for walls between 228 and 4707 lb/ft normal load, ranged between 79 and 90% of the index tensile strength of the specimen of Miragrid 10XT used in this investigation (10,635 lb/ft - value reported by manufacturer for material used in this investigation).

Two repeat tests were performed and results in **Figure 5** illustrate that there is minor variability in connection capacity between nominal identical tests. The variability is 2.5% and hence within the $\pm 10\%$ of the mean peak load criterion required by the NCMA. This variability is likely the result of small differences in the setting up of the blocks and laying out of the geogrid reinforcement. The trend in data for peak connection loads has been plotted using a linear curve.

All tests ended in rupture of one or more longitudinal geogrid members. There was evidence of slippage of the grid within the concrete block-grid interface in all tests. Grid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces.

Implications to Redi-Rock Positive Connection (PC) Block design and construction with Miragrid 10XT geogrid

The long-term design connection capacity in the field must be less than the peak capacity envelope determined in this test series for the same method and quality of construction. The NCMA Segmental Retaining Wall Design Manual (First Edition, 1993) recommends that the design connection capacity at a given surcharge load for a critical wall structure be the lesser of the peak capacity divided by a minimum factor of safety (not less than 1.5) or the capacity based on a 3/4 inch displacement criterion. The *design* curve in **Figure 6** has been selected based on peak capacity load data only.

The design capacity envelope illustrated in **Figure 6** should be used with caution. The actual design capacity envelope should be lower if the quality of construction in the field is less than that adopted in this controlled laboratory investigation and/or lower quality concrete is used in the manufacture of the blocks. For example, the interface concrete surfaces should be free of debris before placement of grid and blocks in order to minimize abrasion to the grid and to maximize the frictional resistance that is developed at the concrete block-grid interface.

It is very important that production blocks have uniform dimensions so that there is no stepping at the block joints that can lead to non-uniform frictional resistance at the block-grid interface, pinching of the grid at the block edges and possibly fracture of the concrete units.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional connection performance of Redi-Rock modular block facing units in combination with Miragrid 10XT. The following conclusions can be drawn:

1. The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 10XT geogrid for walls between 228 and 4707 lb/ft normal load, ranged between 79 and 90% of the index tensile strength of the specimen of Miragrid 10XT used in this investigation (10,635 lb/ft - value reported by manufacturer for material used in this investigation).
2. The trend in data for peak connection loads has been plotted using a linear curve. In addition, some variability in strength values was observed between nominal identical tests due to small differences in setting up of the blocks and laying out of the geogrid reinforcement.
3. Care must be taken during the installation of Redi-Rock Positive Connection (PC) Block units in order to prevent accumulation of soil and rock debris at the concrete block-grid

interface surfaces. This debris may significantly reduce the capacity of the Redi-Rock facing unit-grid system.

4. The design envelope in **Figure 6** is based on an interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual (First Edition, 1993). The choice of design connection strengths may vary from site to site and quality of construction in the field may require lower design values than those taken from **Figure 6**.

P. Clarabut

REFERENCES

ASTM D 6638-01. Standard Test Method for Determining Connection Strength between Geosynthetic Reinforcement and Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Bathurst, R.J. and Simac, M.R., 1993. Laboratory Testing of Modular Unit/Geogrid Facing Connections, *ASTM Symposium on Geosynthetic Soil Reinforcement Testing Procedures*, San Antonio, 19 January 1993.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. *NCMA Segmental Retaining Wall Design Manual (First Edition)*, National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406.

Table 1:

Test Program:

Redi-Rock Positive Connection (PC) Block unit - Miragrid 10XT polyester geogrid connection

Test number	normal load (lb/ft)	peak horz. load (lb/block)	peak tensile capacity per single strip (lb/ft) (note 2)	observed failure mode
1	1990	18091	9046	Rupture
2	228	16903	8452	Rupture
3	1147	17178	8589	Rupture
4	2067	18731	9365	Rupture
5	2918	17726	8863	Rupture
6	3830	19188	9594	Rupture
7	2067	18000	9000	Rupture
8	4707	18091	9046	Rupture

Note: 1) The geogrid used in this series of testing were delivered as pre-cut. 12 inch wide (11 strands), specimens from roll/lot # 000235307 received at our laboratory on 11 August 2011. The index strength of roll/lot # 000235307 was 10,635 lb/ft (test data supplied by TC Mirafi).

2) The load recorded at the actuator is twice the value shown here.

Redi-Rock Positive Connection (PC) Block and Miragrid 10XT

Project # BCGT211021

Series BCGT3108

LEGEND

1	Redi-Rock block	6	guide rail	11	platform
2	geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamps	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

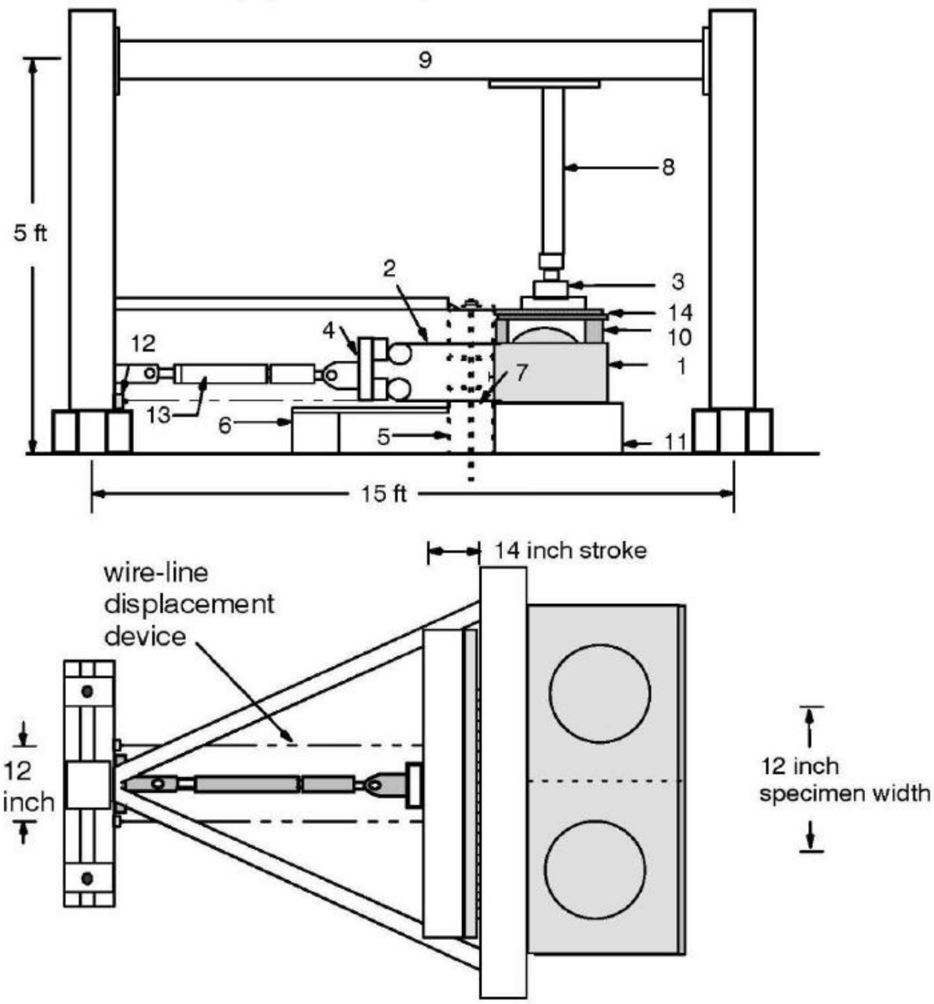

Figure 1: Schematic of connection test apparatus showing Redi-Rock Positive Connection (PC) Block units and Mirafi geogrid

Bathurst, Clarabut Geotechnical Testing, Inc. 28 November 2011

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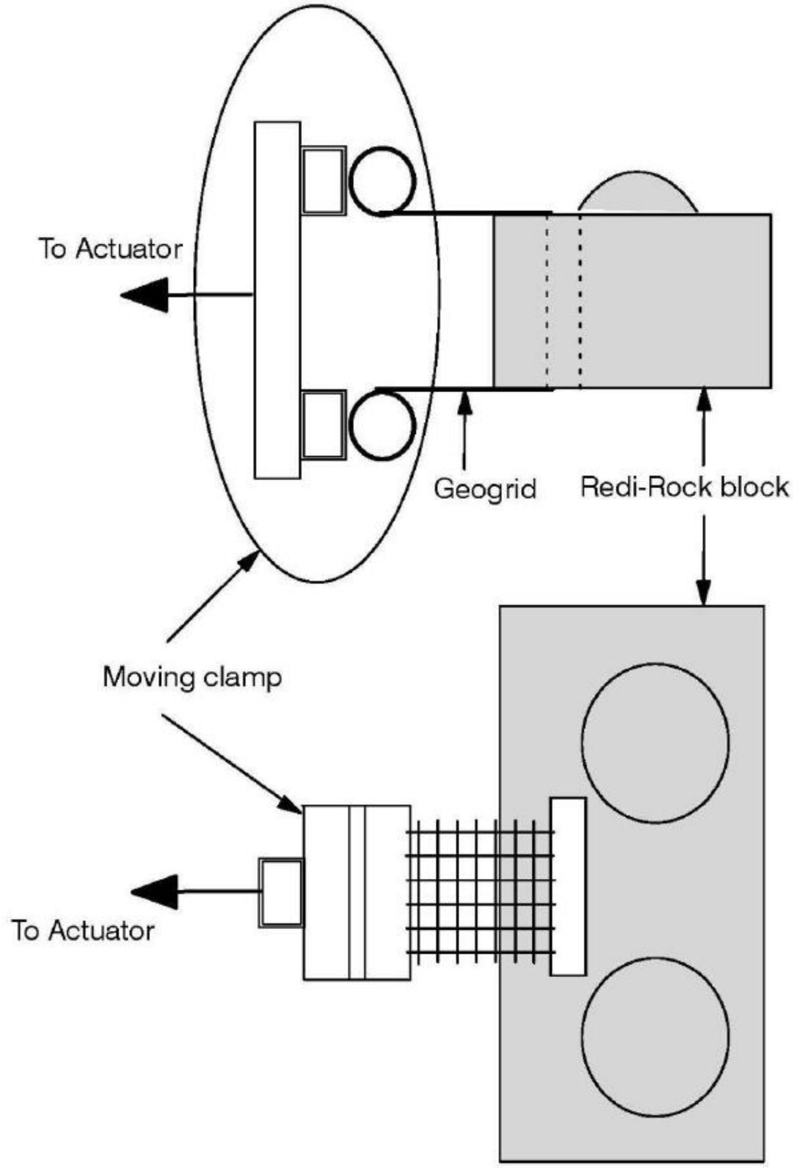

Figure 2: Schematic of connection detail and clamp arrangement

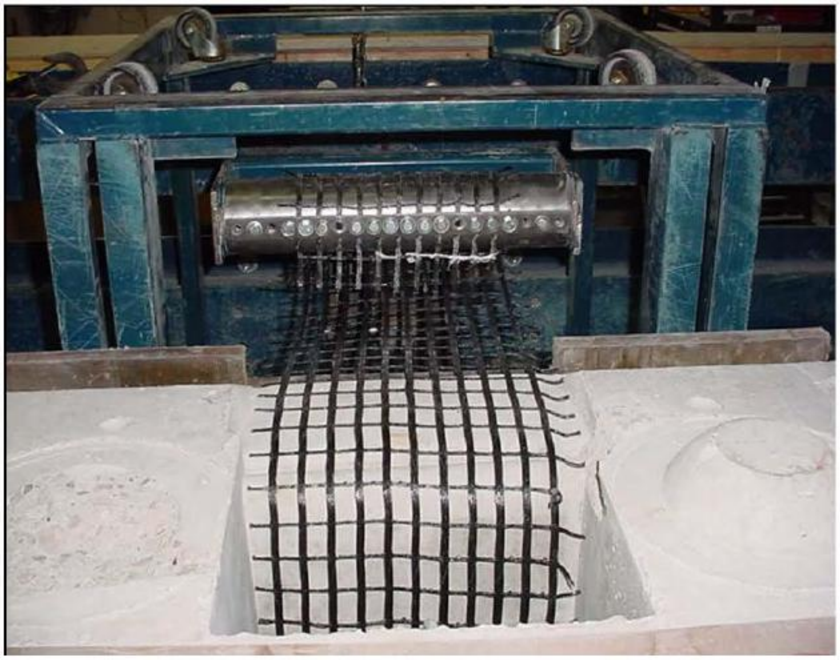

Figure 3: Photograph of the Redi-Rock Positive Connection (PC) Block system and Miragrid 10XT geogrid

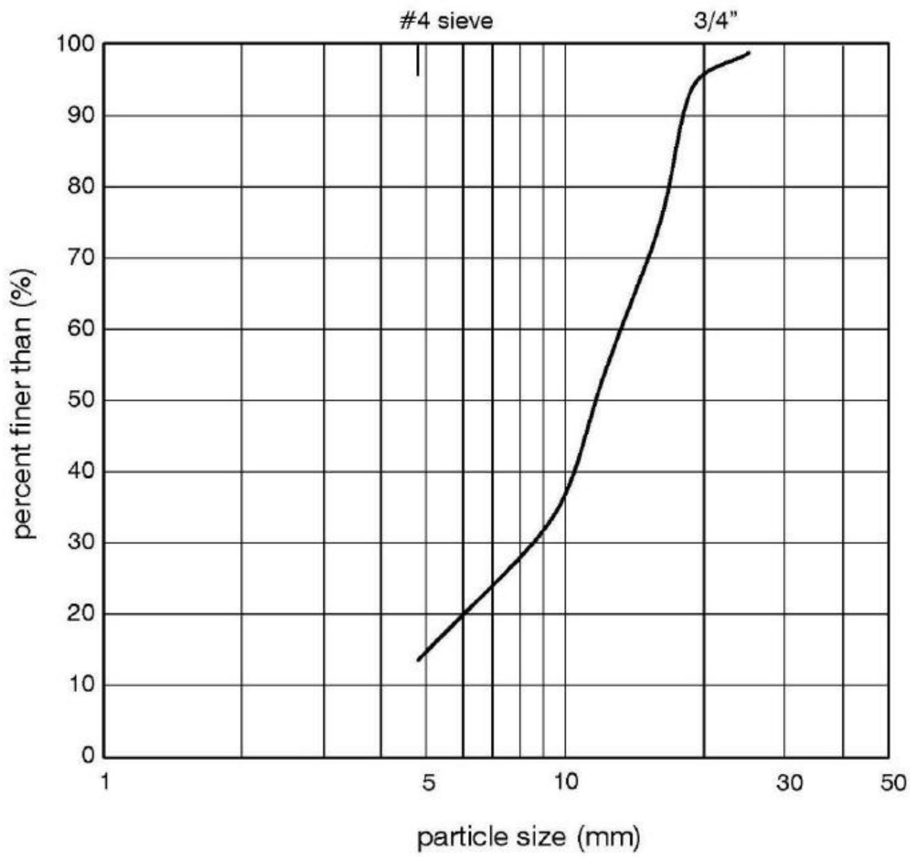

Figure 4: Particle size distribution for 100% crushed granular stone used in Redi-Rock Positive Connection (PC) Block tests

Redi-Rock Positive Connection (PC) Block
and Miragrid 10XT

Project # BCGT211021
Series BCGT3108

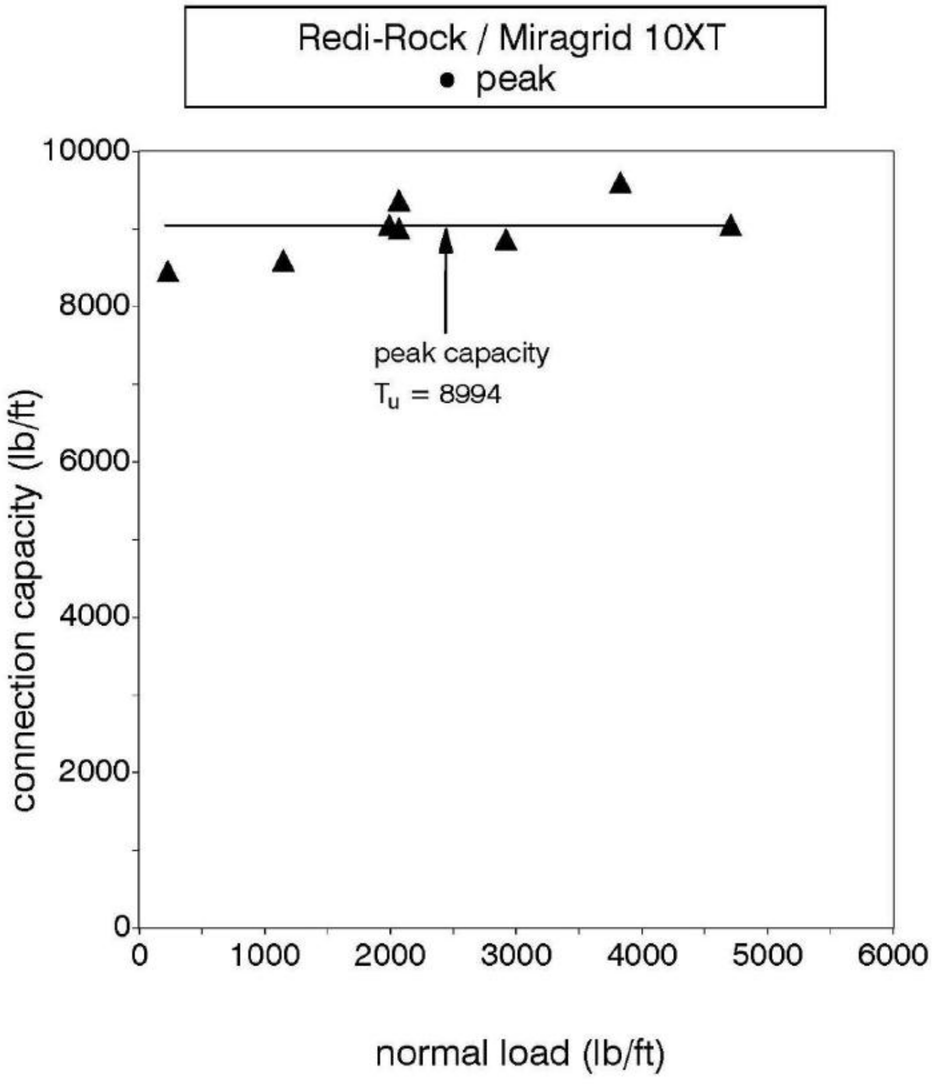

Figure 5: Connection capacity versus normal load for Redi-Rock Positive Connection (PC) Block with Miragrid 10XT based on a 12 inch wide strip of geogrid

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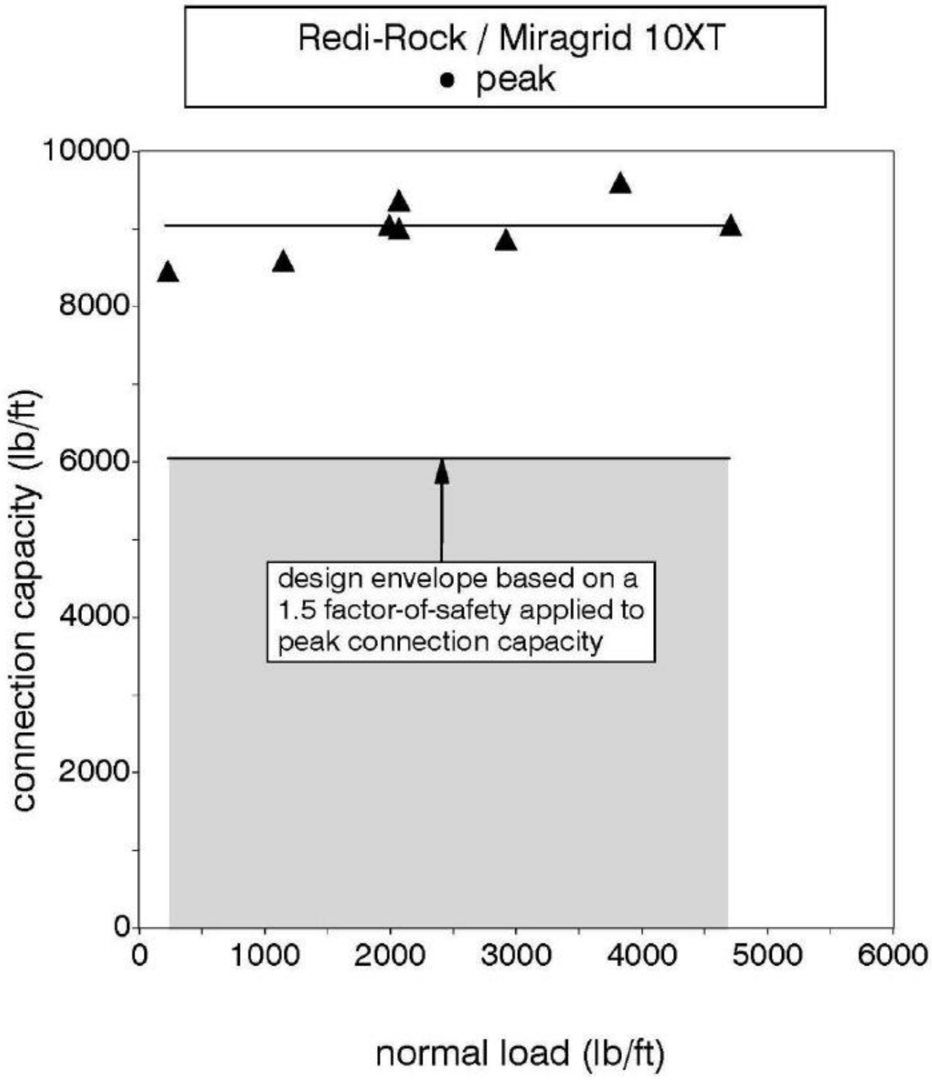

Figure 6: Preliminary design capacity envelope for Redi-Rock Positive Connection (PC) Block units with Miragrid 10XT geogrid based on a 12 wide inch strip of geogrid

REDI-ROCK

GEOGRID CONNECTION DESIGN PARAMETERS

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Test Methods:	ASTM D6638 & NCMA SRWU-1	Test Facility:	Bathurst, Clarabut Geotechnical Testing, Inc.
Geogrid Type:	Miragrid 20XT	Test Date:	December 16, 2011
Block Type:	Positive Connection (PC) Block		

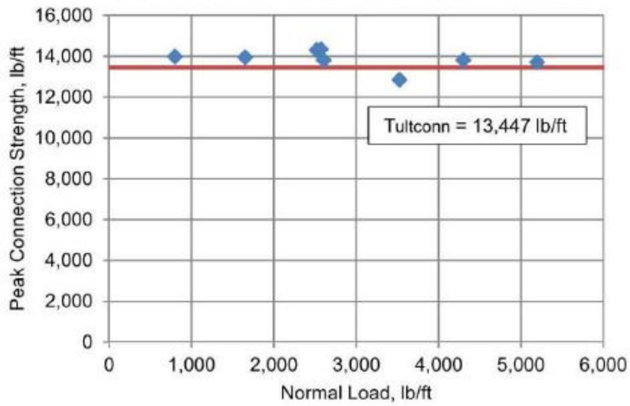
CONNECTION STRENGTH TEST DATA[a]

Test No.	Normal Load, lb/ft	Peak Connection, lb/ft	Observed Failure
1	2,608	13,797	Rupture
2	802	13,980	Rupture
3	1,654	13,934	Rupture
4	2,521	14,299	Rupture
5	3,527	12,837	Rupture
6	4,302	13,797	Rupture
7	2,573	14,345	Rupture
8	5,196	13,706	Rupture

Peak Connection (average) = 13,837 lb/ft

Peak Connection (95% confidence level) = 13,447 lb/ft [b]

MIRAGRID 20XT CONNECTION STRENGTH



CONNECTION DESIGN DATA

for use with AASHTO LRFD Bridge Design Specifications, 6th Edition (2012)

Miragrid 20XT Ultimate Tensile Strength (MARV)	T_{ult} =	13,705 lb/ft
Ultimate Connection Strength	$T_{ultconn}$ =	13,447 lb/ft
Ultimate Tensile Strength of Geosynthetic Test Sample	T_{lot} =	16,397 lb/ft
Connection Strength / Sample Strength	$T_{ultconn} / T_{lot}$ =	0.82
Short-term Ultimate Connection Strength Reduction Factor [c]	CR_u =	0.80
Creep Reduction Factor		
75-Year Design	$RF_{CR(75)}$ =	1.44
100-Year Design	$RF_{CR(100)}$ =	1.45
Durability Reduction Factor [d]	RF_D =	1.15
Long-term Connection Strength Reduction Factor		
75-Year Design	$CR_{cr(75)}$ =	0.56
100-Year Design	$CR_{cr(100)}$ =	0.55
Nominal Long-term Geosynthetic Connection Strength		
75-Year Design	$T_{ac(75)}$ =	6,621 lb/ft
100-Year Design	$T_{ac(100)}$ =	6,575 lb/ft

(a) Tested with 3/4" clean crushed stone lightly compacted in the vertical core slot in accordance with Redi-Rock's typical installation recommendations.
(b) Because the geogrid connection is not normal load dependent and an expression of peak connection for use in design cannot be reliably determined through linear regression, the peak connection results are analyzed as continuous random variables. The average value or sample mean is reported for the test sample as well as a reduction based upon a 95% confidence interval calculated from the Student's t-test for n-1 degrees of freedom.
(c) Recommended CRu for design is based on a statistical best fit analysis of Tultconn / Tlot values across all geogrid types tested.
(d) Recommended value for 5 < pH < 8. RF_D value of 1.3 recommended for 4.5 ≤ pH ≤ 5 and 8 ≤ pH ≤ 9.

REPORT

RESULTS OF REDI-ROCK POSITIVE CONNECTION (PC) BLOCK AND MIRAGRID 20XT GEOGRID CONNECTION CAPACITY TESTING

submitted to

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Introduction

This report gives the results of a connection testing program carried out to evaluate the mechanical/frictional performance of the connection between Redi-Rock Positive Connection (PC)™ modular concrete block units manufactured by Redi-Rock International, LLC and Miragrid 20XT® geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Jamie Johnson of Redi-Rock International, LLC received 29 November 2011.

The tests were carried out at the laboratories of Bathurst, Clarabut Geotechnical Testing, Inc. in Kingston, Ontario, under the supervision of Mr. Peter Clarabut.

Objectives of test program

The facing-geogrid connection between Redi-Rock concrete block units and Miragrid 20XT geogrid was investigated using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the frictional/mechanical performance of these connections. A second objective was to make preliminary recommendations for the selection of long-term tensile connection capacities to be used in the design and analysis of geogrid-reinforced soil wall systems that employ Redi-Rock blocks in combination with Miragrid 20XT geogrid.

Materials

The Redi-Rock Positive Connection (PC) Block units used in this investigation are solid concrete blocks. The nominal dimensions of the blocks are 28 inches (toe to heel) by 18 inches high by 46 inches long and weigh approximately 1625 lb per unit. Construction alignment and wall batter is achieved by means of two dome-shaped concrete shear keys cast into the top surface of the units. The Redi-Rock block system employs a rectangular hole in the block to mechanically attach the geogrid reinforcement. The rectangular hole is centrally located across the block length and located 10 inches from the back of the block. The blocks used in this series of tests were supplied by Redi-Rock International and were received at our laboratory on 9 August 2011 and designated as BIC-11-025.

Miragrid 20XT is a coated bi-directional grid composed of 100% polyester multifilament yarn with a tensile strength of 13,705 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 28 November 2011). The geogrid used in this series of testing was delivered as 12 inch wide (12 strands), specimens from roll/lot # 31136431 received at our laboratory on 17 November 2011. The index strength of roll/lot # 31136431 was 16,397 lb/ft (test data supplied by TC Mirafi).

Apparatus and general test procedure

The method of test used in this investigation follows that reported by Bathurst and Simac (1993) and recommended by the NCMA (Simac et al. 1993) and ASTM D 6638. A brief de-

scription of the apparatus and test methodology is presented here. The test apparatus used to perform the tests is illustrated in **Figure 1**. The test apparatus allows tensile loads of up to 35,000 pounds to be applied to the geogrid while it is confined between two block layers. The facing block was laterally restrained and surcharged vertically. A strip of geogrid reinforcement 12 inches wide (11 longitudinal strands) was passed through the block and both ends were attached to roller clamps. The connection detail and roller clamp arrangement is illustrated in **Figure 2**. A photograph of the Redi-Rock Positive Connection (PC) Block system and the recommended geogrid connection configuration is shown in **Figure 3**. The hollow slot portion of the block was infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 4** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the lower grid to measure grid displacement at the back of the block. Wall heights were simulated by placing one block over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. Gum rubber mats were placed over the top block to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inch/minute) using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and the LVDT(s) were recorded continuously during the test by a microcomputer/data acquisition system. All blocks used in the tests were visually inspected to confirm that they were free of defects. Each test was continued until there was a sustained loss in connection load due to grid rupture. Following each test, the block was removed and the grid examined to confirm failure modes. A virgin specimen of grid was used for each test.

The only variable in this series of connection tests was the magnitude of surcharge load.

Test program

The surcharge loads used in the test program are given in **Table 1**. Also tabulated are the failure loads observed for each test.

Test results

A summary of tensile loads at peak capacity is given in **Figure 5**.

The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 20XT for walls between 802 and 5196 lb/ft normal load, ranged between 78 and 87% of the index tensile strength of the specimen of Miragrid 20XT used in this investigation (16,397 lb/ft - value reported by manufacturer for material used in this investigation).

Two repeat tests were performed and results in **Figure 5** illustrate that there is minor variability in connection capacity between nominal identical tests. The variability is 2.5% and hence within the ±10% of the mean peak load criterion required by the NCMA. This variability is likely the result of small differences in the setting up of the blocks and laying out of the geogrid reinforcement. The trend in data for peak connection loads has been plotted using a linear curve.

All tests ended in rupture of one or more longitudinal geogrid members. There was evidence of slippage of the grid within the concrete block-grid interface in all tests. Grid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces.

Implications to Redi-Rock Positive Connection (PC) Block design and construction with Miragrid 20XT geogrid

The long-term design connection capacity in the field must be less than the peak capacity envelope determined in this test series for the same method and quality of construction. The NCMA Segmental Retaining Wall Design Manual (First Edition, 1993) recommends that the design connection capacity at a given surcharge load for a critical wall structure be the lesser of the peak capacity divided by a minimum factor of safety (not less than 1.5) or the capacity based on a 3/4 inch displacement criterion. The *design* curve in **Figure 6** has been selected based on peak capacity load data only.

The design capacity envelope illustrated in **Figure 6** should be used with caution. The actual design capacity envelope should be lower if the quality of construction in the field is less than that adopted in this controlled laboratory investigation and/or lower quality concrete is used in the manufacture of the blocks. For example, the interface concrete surfaces should be free of debris before placement of grid and blocks in order to minimize abrasion to the grid and to maximize the frictional resistance that is developed at the concrete block-grid interface.

It is very important that production blocks have uniform dimensions so that there is no stepping at the block joints that can lead to non-uniform frictional resistance at the block-grid interface, pinching of the grid at the block edges and possibly fracture of the concrete units.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional connection performance of Redi-Rock modular block facing units in combination with Miragrid 20XT. The following conclusions can be drawn:

1. The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 20XT geogrid for walls between 802 and 5196 lb/ft normal load, ranged between 100 and 109% of the index tensile strength of the specimen of Miragrid 20XT used in this investigation (16,397 lb/ft - value reported by manufacturer for material used in this investigation).
2. The trend in data for peak connection loads has been plotted using a linear curve. In addition, some variability in strength values was observed between nominal identical tests due to small differences in setting up of the blocks and laying out of the geogrid reinforcement.
3. Care must be taken during the installation of Redi-Rock Positive Connection (PC) Block units in order to prevent accumulation of soil and rock debris at the concrete block-grid

interface surfaces. This debris may significantly reduce the capacity of the Redi-Rock facing unit-grid system.

4. The design envelope in **Figure 6** is based on an interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual (First Edition, 1993). The choice of design connection strengths may vary from site to site and quality of construction in the field may require lower design values than those taken from **Figure 6**.

P. Clarabut

REFERENCES

ASTM D 6638-01. Standard Test Method for Determining Connection Strength between Geosynthetic Reinforcement and Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Bathurst, R.J. and Simac, M.R., 1993. Laboratory Testing of Modular Unit/Geogrid Facing Connections, *ASTM Symposium on Geosynthetic Soil Reinforcement Testing Procedures*, San Antonio, 19 January 1993.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. *NCMA Segmental Retaining Wall Design Manual (First Edition)*, National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406.

Table 1:

Test Program:

Redi-Rock Positive Connection (PC) Block unit - Miragrid 20XT polyester geogrid connection

Test number	normal load (lb/ft)	peak horz. load (lb/block)	peak tensile capacity per single strip (lb/ft) (note 2)	observed failure mode
1	2608	27594	13797	Rupture
2	802	27959	13980	Rupture
3	1654	27868	13934	Rupture
4	2521	28599	14299	Rupture
5	3527	25675	12837	Rupture
6	4302	27594	13797	Rupture
7	2573	28690	14345	Rupture
8	5196	27411	13706	Rupture

Redi-Rock Positive Connection (PC) Block and Miragrid 20XT

Project # BCGT211035

Series BCGT3139

LEGEND

1	Redi-Rock block	6	guide rail	11	platform
2	geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamps	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

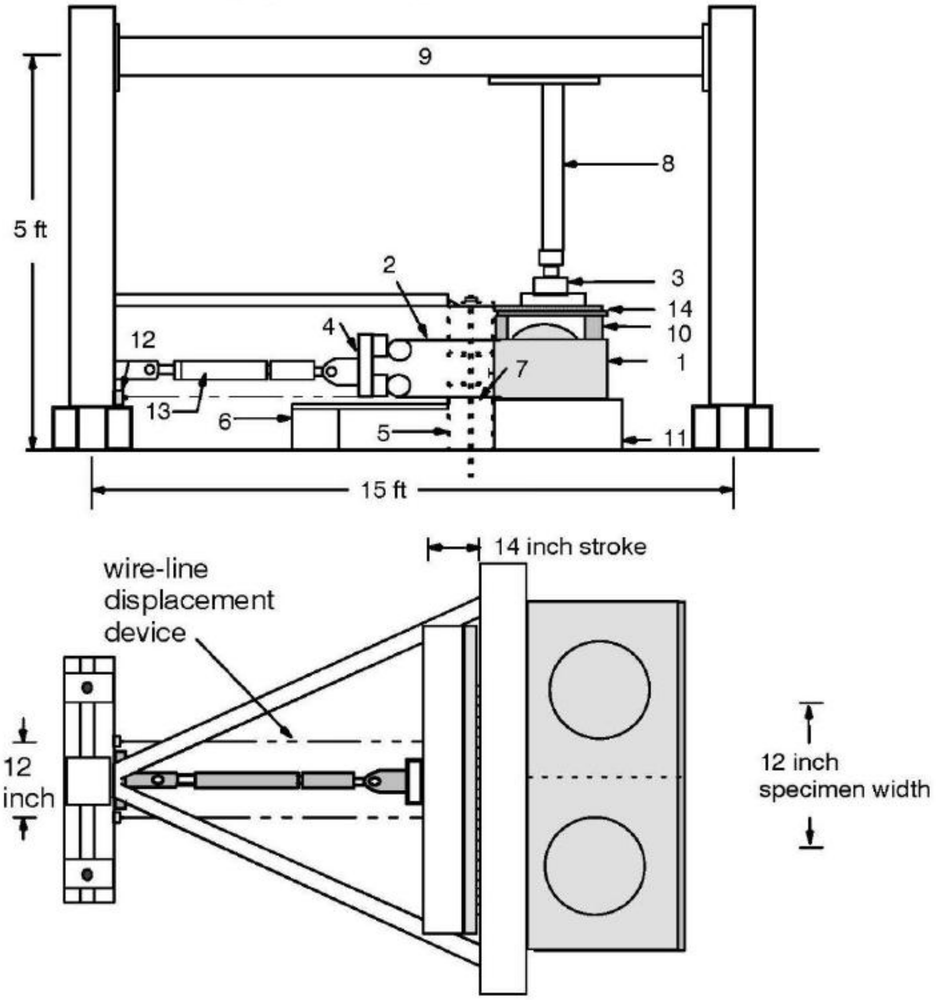

Figure 1: Schematic of connection test apparatus showing Redi-Rock Positive Connection (PC) Block units and Mirafi geogrid

Bathurst, Clarabut Geotechnical Testing, Inc.

16 December 2011

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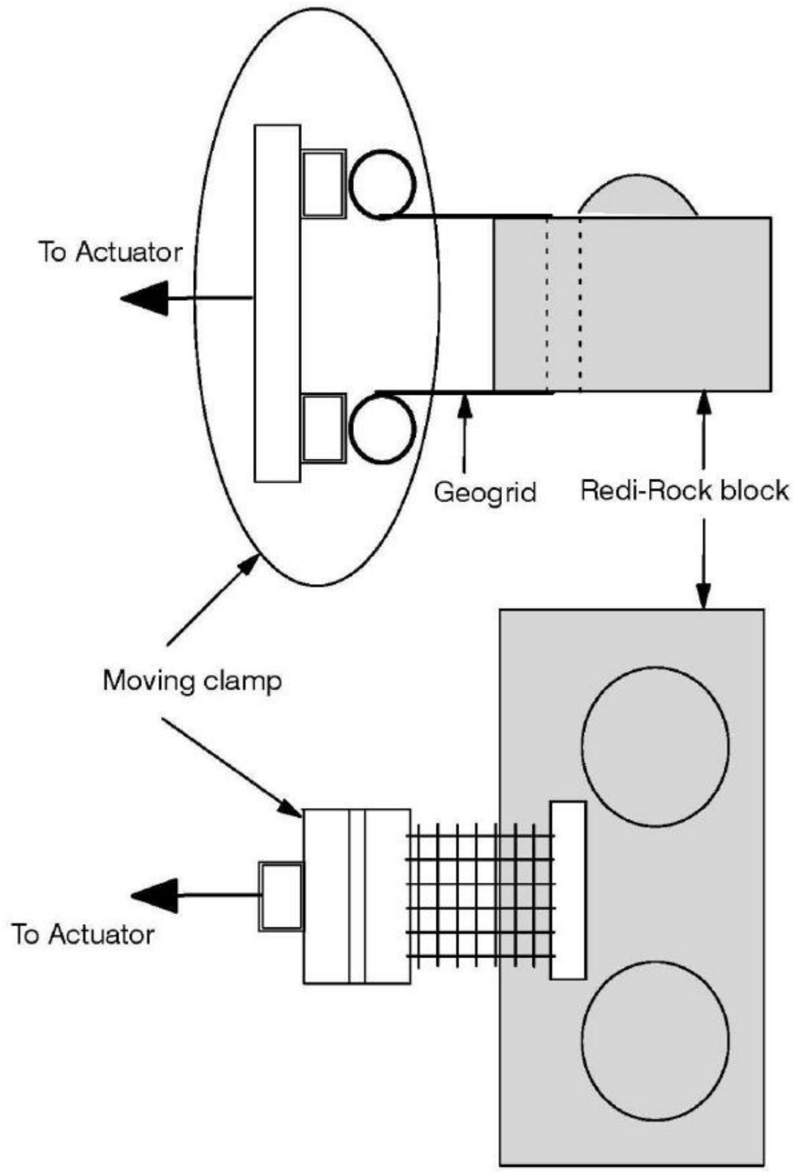

Figure 2: Schematic of connection detail and clamp arrangement

Figure 3: Photograph of the Redi-Rock Positive Connection (PC) Block system and Miragrid 20XT geogrid

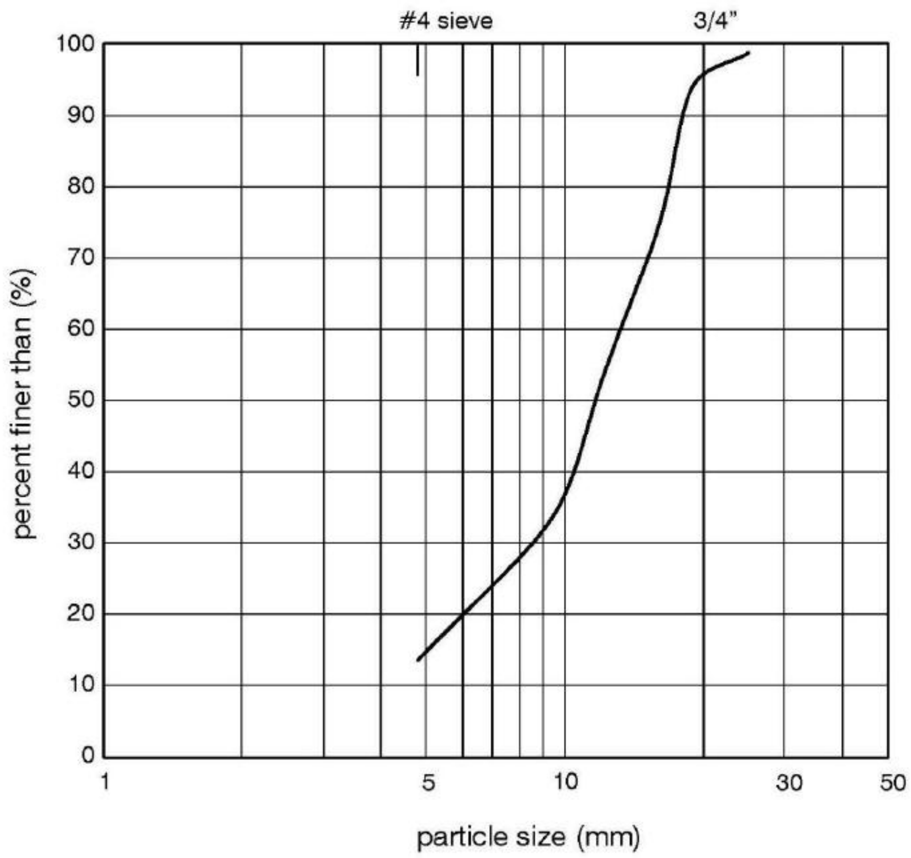

Figure 4: Particle size distribution for 100% crushed granular stone used in Redi-Rock Positive Connection (PC) Block tests

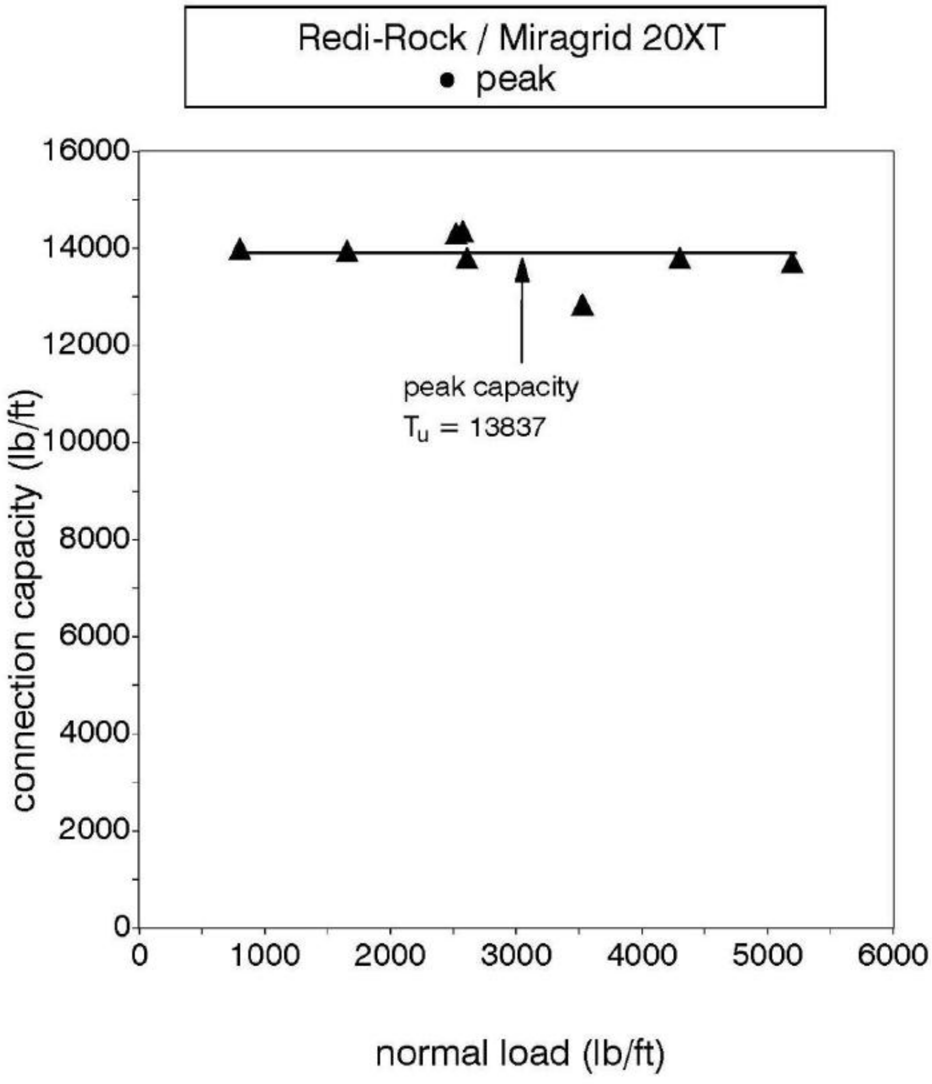

Figure 5: Connection capacity versus normal load for Redi-Rock Positive Connection (PC) Block with Miragrid 20XT based on a 12 inch wide strip of geogrid

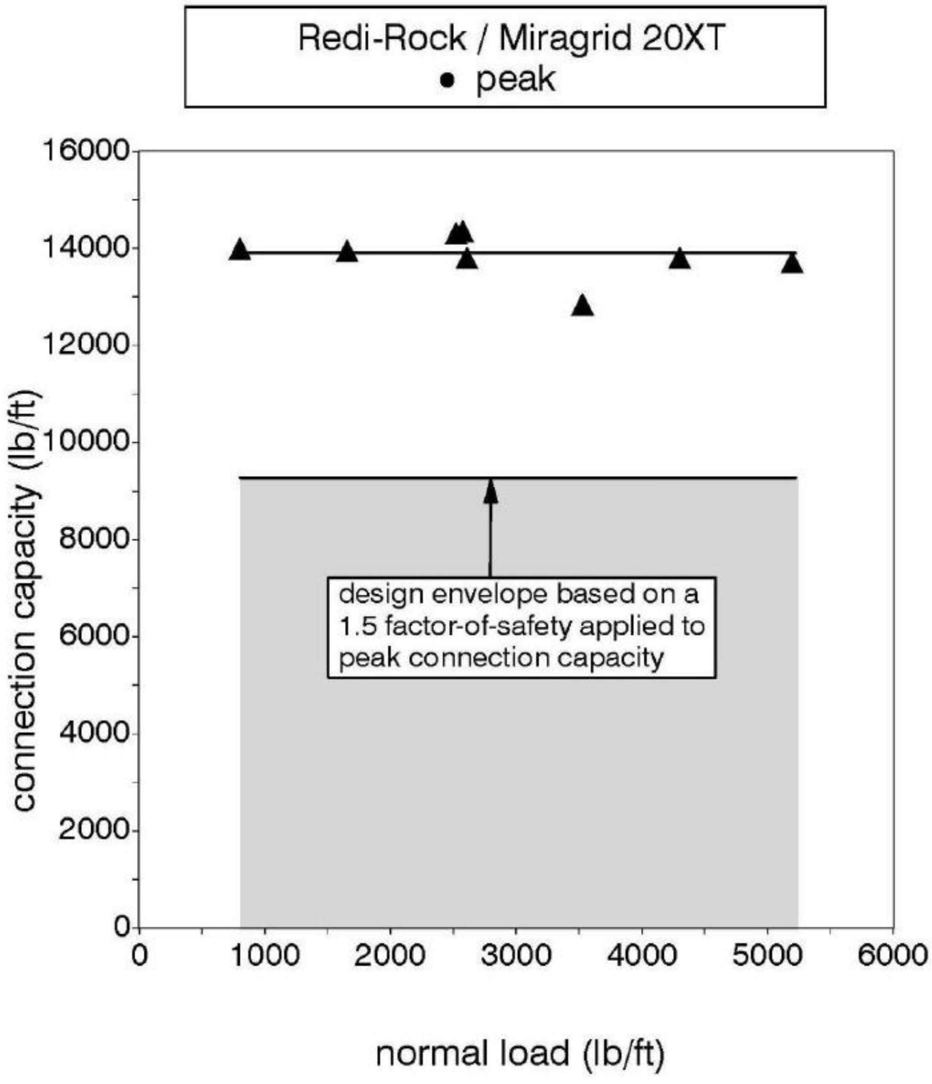

Figure 6: Preliminary design capacity envelope for Redi-Rock Positive Connection (PC) Block units with Miragrid 20XT geogrid based on a 12 wide inch strip of geogrid

REDI-ROCK

GEOGRID CONNECTION DESIGN PARAMETERS

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Test Methods:	ASTM D6638 & NCMA SRWU-1	Test Facility:	Bathurst, Clarabut Geotechnical Testing, Inc.
Geogrid Type:	Miragrid 24XT	Test Date:	February 29, 2012
Block Type:	Positive Connection (PC) Block		

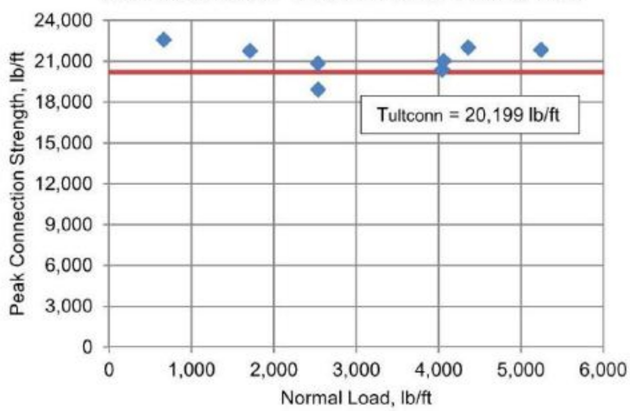
CONNECTION STRENGTH TEST DATA[a]

Test No.	Normal Load, lb/ft	Peak Connection, lb/ft	Observed Failure
1	4,046	20,375	Grid Rupture
2	4,362	22,020	Grid Rupture
3	665	22,568	Grid Rupture
4	2,538	20,832	Grid Rupture
5	1,713	21,746	Grid Rupture
6	5,248	21,837	Block & Grid
7	2,539	18,913	Grid Rupture
8	4,063	21,015	BlockRupture

Peak Connection $_{(average)}$ = 21,163 lb/ft

Peak Connection $_{(95\%\ confidence\ level)}$ = 20,199 lb/ft [b]

MIRAGRID 24XT CONNECTION STRENGTH



CONNECTION DESIGN DATA

for use with AASHTO LRFD Bridge Design Specifications, 6th Edition (2012)

Miragrid 24XT Ultimate Tensile Strength (MARV)	T_{ult} =	27,415 lb/ft
Ultimate Connection Strength	$T_{ultconn}$ =	20,199 lb/ft
Ultimate Tensile Strength of Geosynthetic Test Sample	T_{lot} =	29,130 lb/ft
Connection Strength / Sample Strength	$T_{ultconn} / T_{lot}$ =	0.69
Short-term Ultimate Connection Strength Reduction Factor [c]	CR_u =	0.69
Creep Reduction Factor		
75-Year Design	$RF_{CR(75)}$ =	1.44
100-Year Design	$RF_{CR(100)}$ =	1.45
Durability Reduction Factor [d]	RF_D =	1.15
Long-term Connection Strength Reduction Factor		
75-Year Design	$CR_{cr(75)}$ =	0.48
100-Year Design	$CR_{cr(100)}$ =	0.48
Nominal Long-term Geosynthetic Connection Strength		
75-Year Design	$T_{ac(75)}$ =	11,423 lb/ft
100-Year Design	$T_{ac(100)}$ =	11,344 lb/ft

(a) Tested with 3/4" clean crushed stone lightly compacted in the vertical core slot in accordance with Redi-Rock's typical installation recommendations.
(b) Because the geogrid connection is not normal load dependent and an expression of peak connection for use in design cannot be reliably determined through linear regression, the peak connection results are analyzed as continuous random variables. The average value or sample mean is reported for the test sample as well as a reduction based upon a 95% confidence interval calculated from the Student's t-test for n-1 degrees of freedom.
(c) Recommended CRu for design is based on a statistical best fit analysis of Tultconn / Tlot values across all geogrid types tested.
(d) Recommended value for 5 < pH < 8. RF_D value of 1.3 recommended for 4.5 ≤ pH ≤ 5 and 8 ≤ pH ≤ 9.

REPORT

RESULTS OF
REDI-ROCK POSITIVE CONNECTION (PC) BLOCK AND MIRAGRID 24XT GEOGRID CONNECTION CAPACITY TESTING

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Introduction

This report gives the results of a connection testing program carried out to evaluate the mechanical/frictional performance of the connection between Redi-Rock Positive Connection (PC)® modular concrete block units manufactured by Redi-Rock International, LLC and Miragrid 24XT® geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Jamie Johnson of Redi-Rock International, LLC received 9 August 2011.

The tests were carried out at the laboratories of Bathurst, Clarabut Geotechnical Testing, Inc. in Kingston, Ontario, under the supervision of Mr. Peter Clarabut.

Objectives of test program

The facing-geogrid connection between Redi-Rock concrete block units and Miragrid 24XT geogrid was investigated using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the frictional/mechanical performance of these connections. A second objective was to make preliminary recommendations for the selection of long-term tensile connection capacities to be used in the design and analysis of geogrid-reinforced soil wall systems that employ Redi-Rock blocks in combination with Miragrid 24XT geogrid.

Materials

The Redi-Rock Positive Connection (PC) Block units used in this investigation are solid concrete blocks. The nominal dimensions of the blocks are 28 inches (toe to heel) by 18 inches high by 46 inches long and weigh approximately 1625 lb per unit. Construction alignment and wall batter is achieved by means of two dome-shaped concrete shear keys cast into the top surface of the units. The Redi-Rock block system employs a rectangular hole in the block to mechanically attach the geogrid reinforcement. The rectangular hole is centrally located across the block length and located 10 inches from the back of the block. The bottom blocks used in this series of tests were supplied by Redi-Rock International and were received at our laboratory on 9 August 2011 and designated as BIC-11-026 and BIC-11-027.

Miragrid 24XT is a coated bi-directional grid composed of 100% polyester multifilament yarn with a tensile strength of 27,415 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 8 January 2012). The geogrid used in this series of testing was delivered as 12 inch wide (12 strands), specimens from roll/lot # 031116222 received at our laboratory on 25 August 2011. The index strength of roll/lot # 031116222 was 29,130 lb/ft (test data supplied by TC Mirafi).

Apparatus and general test procedure

The method of test used in this investigation follows that reported by Bathurst and Simac (1993) and recommended by the NCMA (Simac et al. 1993) and ASTM D 6638. A brief de-

scription of the apparatus and test methodology is presented here. The test apparatus used to perform the tests is illustrated in **Figure 1**. The test apparatus allows tensile loads of up to 70,000 pounds to be applied to the geogrid while it is confined between two block layers. The facing block was laterally restrained and surcharged vertically. A strip of geogrid reinforcement 12 inches wide (11 longitudinal strands) was passed through the block and both ends were attached to roller clamps. The connection detail and roller clamp arrangement is illustrated in **Figure 2**. A photograph of the Redi-Rock Positive Connection (PC) Block system and the recommended geogrid connection configuration is shown in **Figure 3**. The hollow slot portion of the block was infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 4** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the lower grid to measure grid displacement at the back of the block. Wall heights were simulated by placing one block over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. Gum rubber mats were placed over the top block to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inch/minute) using a computer-controlled hydraulic actuator. The load and displacements measured by the actuator and the LVDT(s) were recorded continuously during the test by a microcomputer/data acquisition system. All blocks used in the tests were visually inspected to confirm that they were free of defects. Each test was continued until there was a sustained loss in connection load due to grid rupture or concrete failure. Following each test, the block was removed and the grid examined to confirm failure modes. A virgin specimen of grid was used for each test.

The only variable in this series of connection tests was the magnitude of surcharge load.

Test program

The surcharge loads used in the test program are given in **Table 1**. Also tabulated are the failure loads observed for each test.

Test results

A summary of tensile loads at peak capacity is given in **Figure 5**.

The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 24XT for walls between 665 and 5248 lb/ft normal load, ranged between 68 and 77% of the index tensile strength of the specimen of Miragrid 24XT used in this investigation (29,130 lb/ft - value reported by manufacturer for material used in this investigation). The trend in data for peak connection loads has been plotted using a linear curve.

Two repeat tests were performed and results in **Figure 5** illustrate that there is some variability in connection capacity between nominal identical tests. The variability is 6.5% and hence within the ± 10% of the mean peak load criterion required by the NCMA. This variability is likely the result of small differences in the setting up of the blocks and laying out of the geogrid reinforcement. The trend in data for peak connection loads has been plotted using a linear curve. The reduced connection capacity at lower surcharge loads may be due to the combined effect of lower surcharge pressure and more geogrid slippage.

Tests 6 and **8** ended in failure of the concrete blocks, all other tests ended in failure of the geogrid reinforcement. There was evidence of slippage of the grid within the concrete block-grid interface in all tests. Grid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces.

Implications to Redi-Rock Positive Connection (PC) Block design and construction with Miragrid 24XT geogrid

The long-term design connection capacity in the field must be less than the peak capacity envelope determined in this test series for the same method and quality of construction. The NCMA Segmental Retaining Wall Design Manual (First Edition, 1993) recommends that the design connection capacity at a given surcharge load for a critical wall structure be the lesser of the peak capacity divided by a minimum factor of safety (not less than 1.5) or the capacity based on a 3/4 inch displacement criterion. The *design* curve in **Figure 6** has been selected based on peak capacity load data only.

The design capacity envelope illustrated in **Figure 6** should be used with caution. The actual design capacity envelope should be lower if the quality of construction in the field is less than that adopted in this controlled laboratory investigation and/or lower quality concrete is used in the manufacture of the blocks. For example, the interface concrete surfaces should be free of debris before placement of grid and blocks in order to minimize abrasion to the grid and to maximize the frictional resistance that is developed at the concrete block-grid interface.

It is very important that production blocks have uniform dimensions so that there is no stepping at the block joints that can lead to non-uniform frictional resistance at the block-grid interface, pinching of the grid at the block edges and possibly fracture of the concrete units.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional connection performance of Redi-Rock modular block facing units in combination with Miragrid 24XT. The following conclusions can be drawn:

1. The peak connection capacity between Redi-Rock Positive Connection (PC) Block units and Miragrid 24XT geogrid for walls between 665 and 5248 lb/ft normal load, ranged between 68 and 77% of the index tensile strength of the specimen of Miragrid 24XT used in this investigation (29,130 lb/ft - value reported by manufacturer for material used in this investigation).
2. The trend in data for peak connection loads has been plotted using a linear curve. In addition, some variability in strength values was observed between nominal identical tests due to small differences in setting up of the blocks and laying out of the geogrid reinforcement.

3. Care must be taken during the installation of Redi-Rock Positive Connection (PC) Block units in order to prevent accumulation of soil and rock debris at the concrete block-grid interface surfaces. This debris may significantly reduce the capacity of the Redi-Rock facing unit-grid system.

4. The design envelope in **Figure 6** is based on an interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual (First Edition, 1993). The choice of design connection strengths may vary from site to site and quality of construction in the field may require lower design values than those taken from **Figure 6**.

P. Clarabut

REFERENCES

ASTM D 6638-01. Standard Test Method for Determining Connection Strength between Geosynthetic Reinforcement and Segmental Concrete Units (Modular Concrete Blocks), American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

Bathurst, R.J. and Simac, M.R., 1993. Laboratory Testing of Modular Unit/Geogrid Facing Connections, *ASTM Symposium on Geosynthetic Soil Reinforcement Testing Procedures*, San Antonio, 19 January 1993.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., 1993. *NCMA Segmental Retaining Wall Design Manual (First Edition),* National Concrete Masonry Association, 2302 Horse Pen Road, Herndon, VA 22071-3406.

Table 1:

Test Program:

Redi-Rock Positive Connection (PC) Block unit - Miragrid 24XT polyester geogrid connection

Test number	normal load (lb/ft)	peak horz. load (lb/block)	peak tensile capacity per single strip (lb/ft) (note 2)	observed failure mode
1	4046	40751	20375	Grid Rupture
2	4362	44040	22020	Grid Rupture
3	665	45137	22568	Grid Rupture
4	2538	41665	20832	Grid Rupture
5	1713	43492	21746	Grid Rupture
6	5248	43675	21837	Grid and Block Rupture
7	2539	37827	19914	Grid Rupture
8	4063	42030	21015	Block Rupture

Redi-Rock Positive Connection (PC) block and Miragrid 24XT

Project # BCGT211031
Series BCGT3132B

LEGEND

1	Redi-Rock (PC) Block	6	guide rail	11	platform
2	geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamps	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

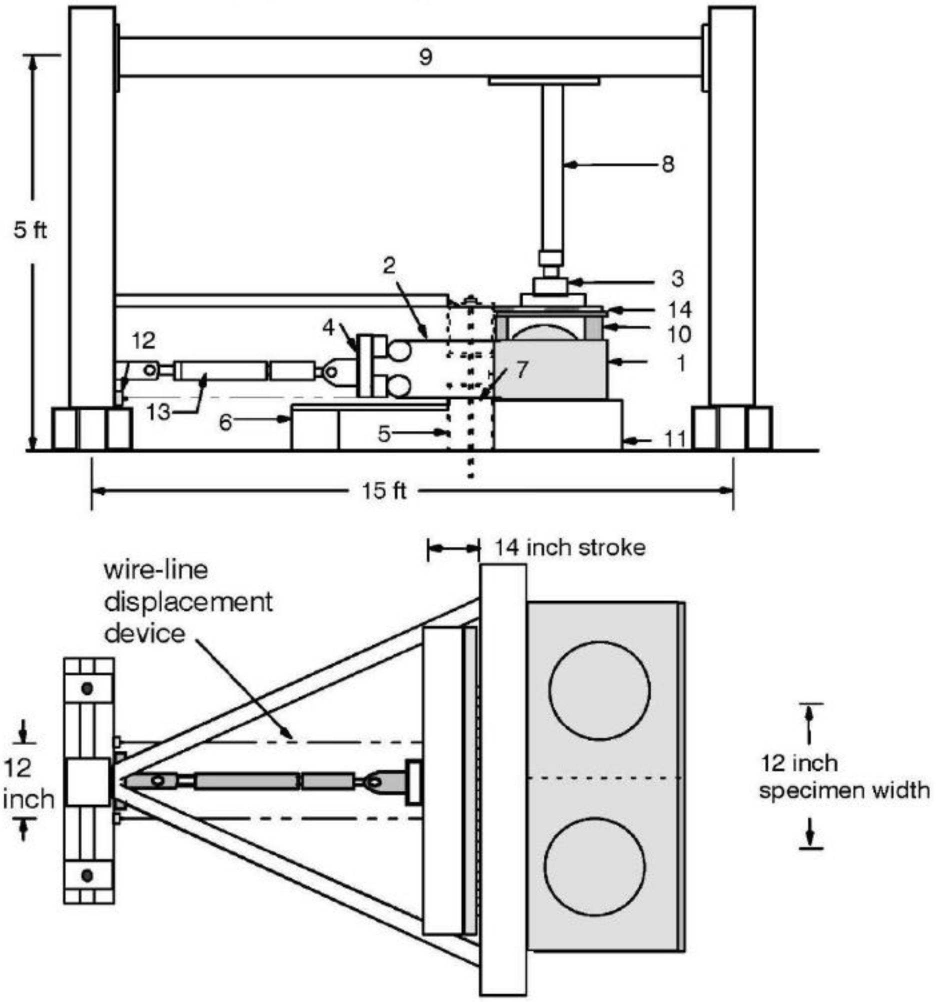

Figure 1: Schematic of connection test apparatus showing Redi-Rock Positive Connection (PC) Block units and Mirafi geogrid

Bathurst, Clarabut Geotechnical Testing, Inc. 29 February 2012

Telephone: (613) 384 6363 Email: petebcgt@kos.net 7 of 12

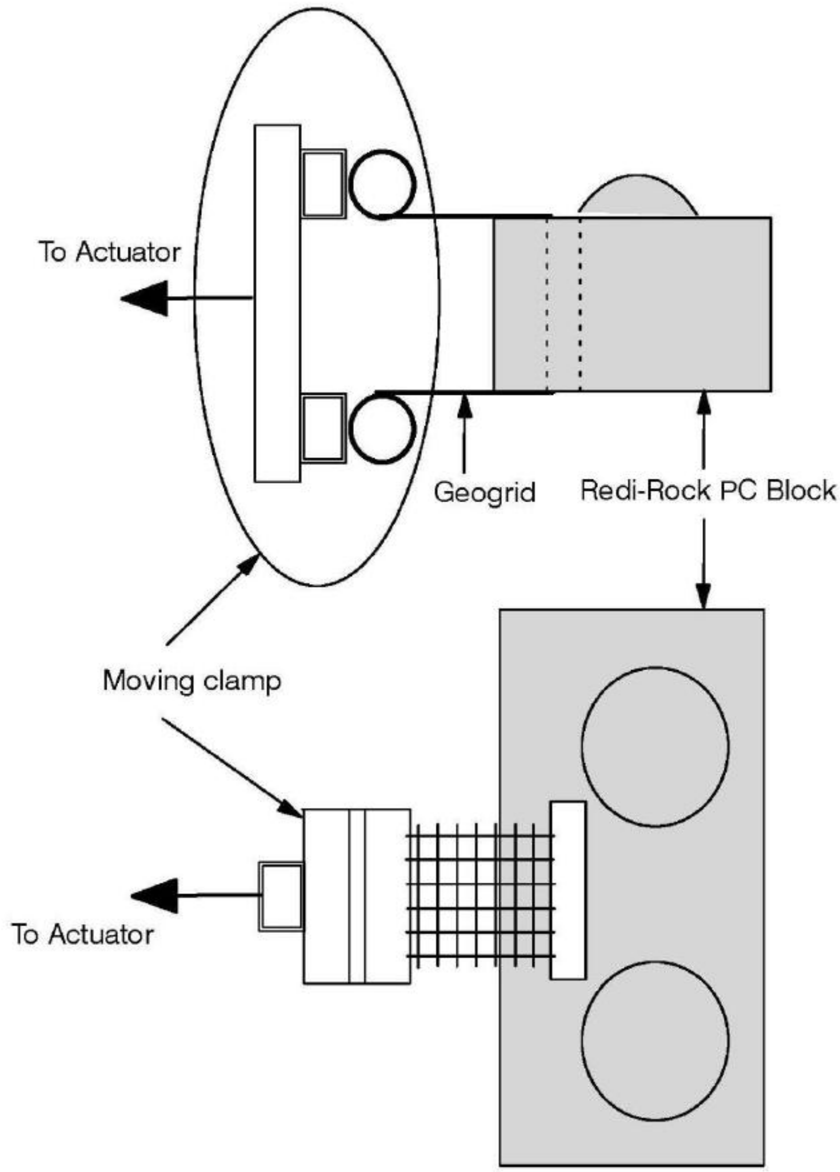

Figure 2: Schematic of connection detail and clamp arrangement

Figure 3: Photograph of the Redi-Rock Positive Connection (PC) Block system and Miragrid 24XT geogrid

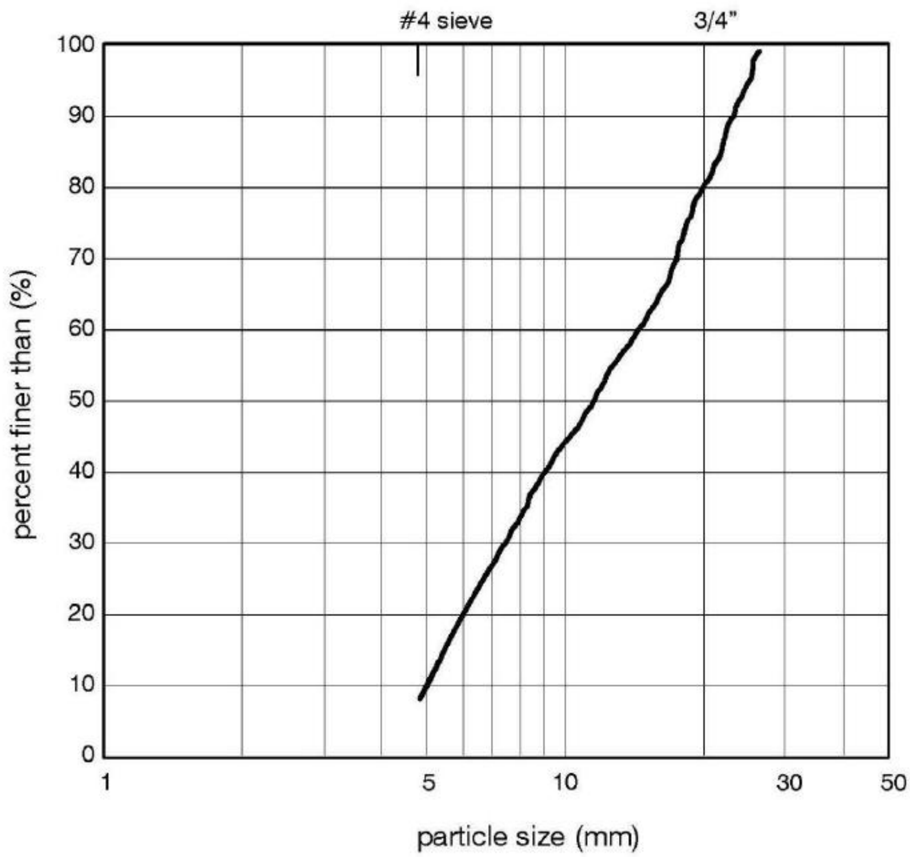

Figure 4: Particle size distribution for 100% crushed granular stone used in Redi-Rock Positive Connection (PC) Block tests

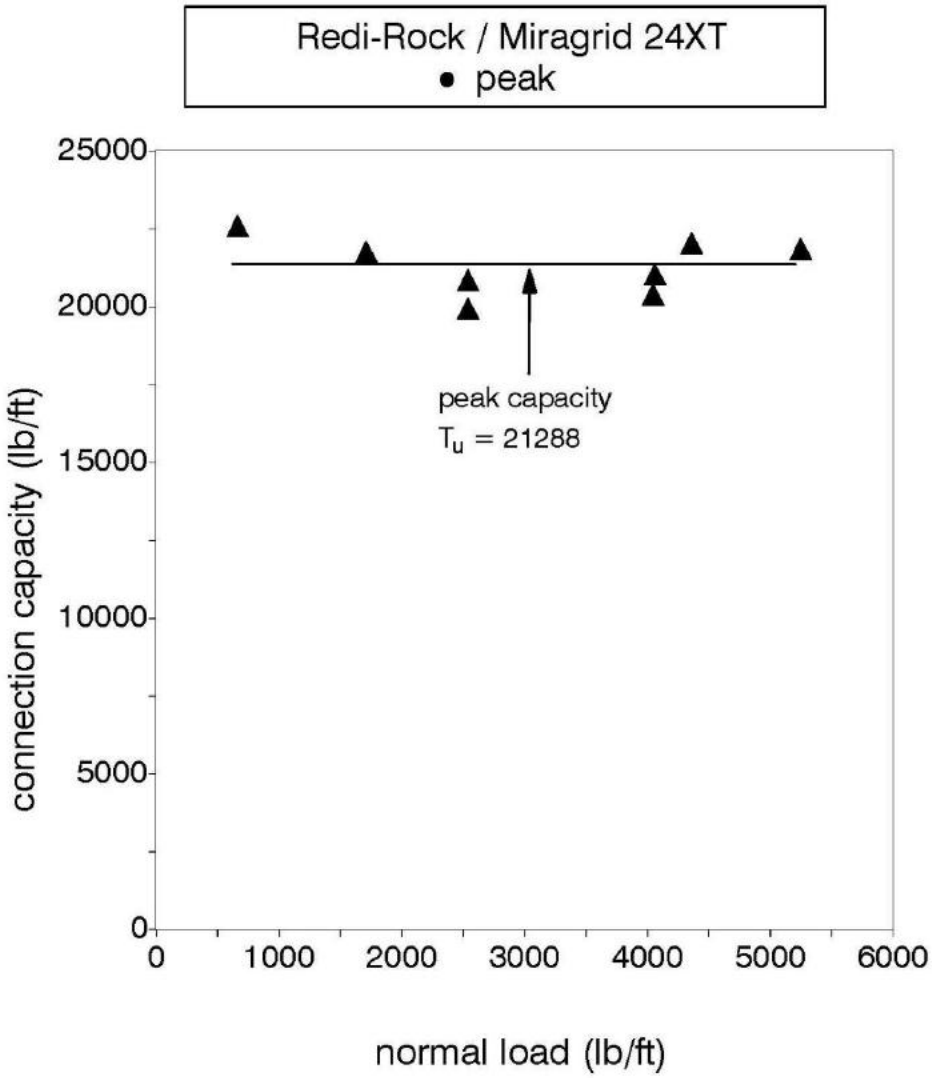

Figure 5: Connection capacity versus normal load for Redi-Rock Positive Connection (PC) Block with Miragrid 24XT based on a 12 inch wide strip of geogrid

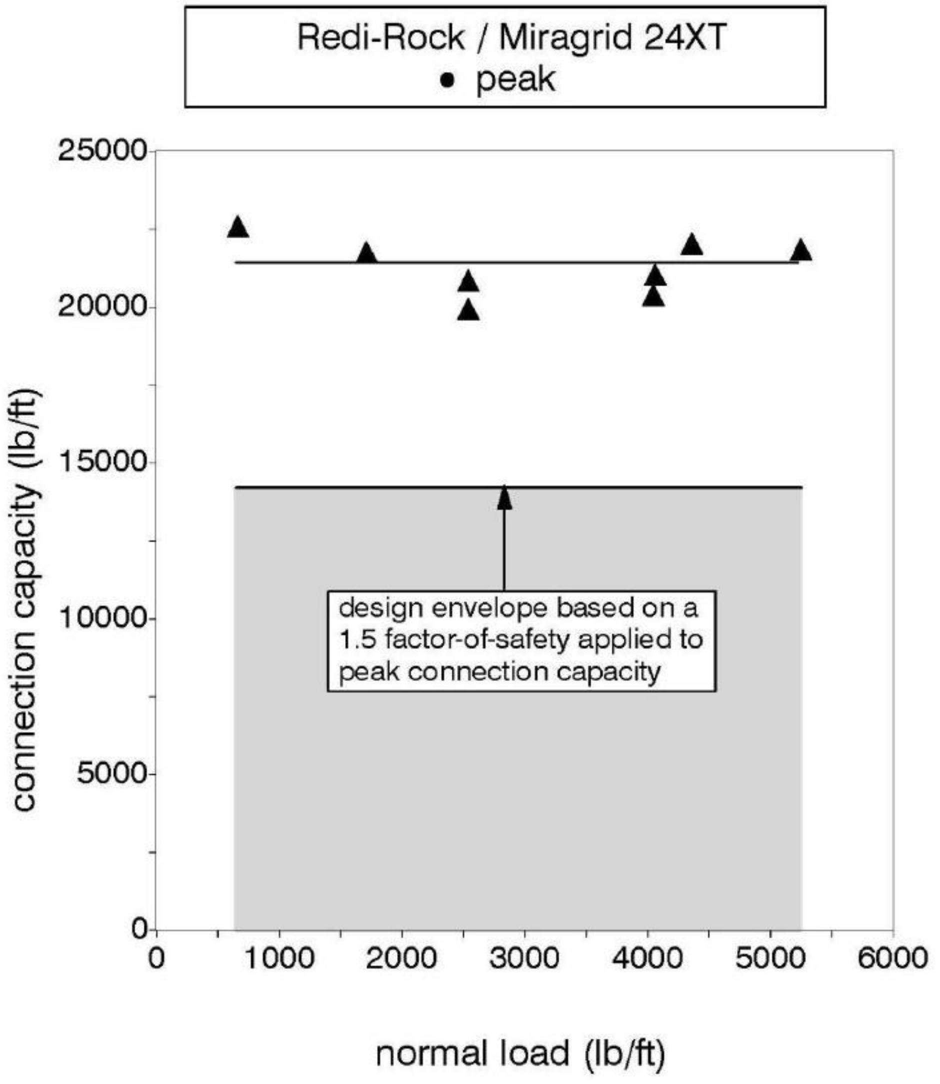

Figure 6: Preliminary design capacity envelope for Redi-Rock Positive Connection (PC) Block units with Miragrid 24XT geogrid based on a 12 wide inch strip of geogrid

APPENDIX: 1.2.6B IN-BLOCK INSTALLATION DAMAGE REPORT

REDI-ROCK POSITIVE CONNECTION (PC) SERIES BLOCKS

AND MIRAFI XT GEOGRID STRIPS

IN-BLOCK INSTALLATION DAMAGE TESTING REPORT

PREPARED BY:
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05481 US 31 SOUTH
CHARLEVOIX, MI 49720
(866) 222-8400

DATE:
MAY 6, 2013

INTRODUCTION

This report summarizes the test procedure used to evaluate installation damage to Mirafi XT geogrid strips when installed in a Redi-Rock Positive Connection (PC) block.

The Redi-Rock Positive Connection block is a precast concrete segmental retaining wall block that can be used to design and construct gravity or mechanically stabilized earth (MSE) retaining walls. When used for a MSE wall, a 12" wide strip of geogrid is passed through a vertical core slot in the PC block. The geogrid strip extends horizontally into the reinforced zone on both the top and bottom of the block. (**Figure 1**) Following installation of the geogrid strip through the PC block, the vertical core slot in the block is filled with stone backfill. Hand tamping is used to compact and consolidate the stone in the slot.

Figure 1 - PC Block with Geogrid Strip

For this testing, a procedure was developed to quantify damage to the geogrid strips due to compaction of the stone core fill in the PC block. Any in-block installation damage to the geogrid will reduce the connection strength of the geogrid strip and the Redi-Rock PC block.

A series of tests was performed at the Redi-Rock International equipment manufacturing facility in Charlevoix, MI where strips of Mirafi geogrid were installed in PC blocks. Crushed stone core fill was placed in the vertical core slot of the PC blocks. The stone was then consolidated with standard, heavy, or very heavy compaction effort. Following compaction of the stone, the geogrid strip samples were exhumed, labeled, and sent to TenCate Geosynthetics for wide width testing at their materials lab in Cornelia, GA.

A comparison of the wide width tests from geogrid strips installed in the block and undamaged control strips is used to quantify a reduction in strength of the geogrid due to the installation and compaction of the crushed stone core fill in the PC block.

MATERIALS

Redi-Rock Positive Connection (PC) blocks were used in these tests. The blocks are 18" high. They measure 46.125" along the face (widest part of the block), and are 28" from the outside of the face texture to the back of the block. (**Figure 2**)

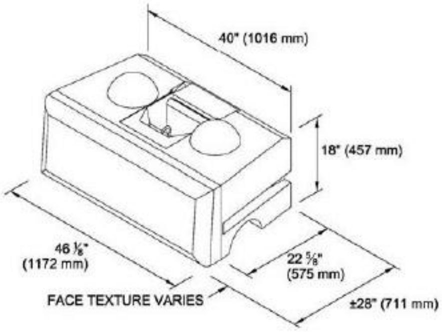


Figure 2 - PC Block Dimensions

The geogrid reinforcement used in these tests was Miragrid 5XT, 10XT, and 20XT manufactured by TenCate Geosynthetics. The geogrid is factory cut into 12" wide strips for use with the Redi-Rock PC System. The Miragrid 5XT was from lot 031142599... The Miragrid 10XT was from lot 031142157, test roll 000254429 with a reported tensile strength of 10,505 lb/ft (153.3 kN/m) ultimate and 4,180 lb/ft (61.0 kN/m) at 5%. The Miragrid 20XT was from lot 031143300...

The stone used for infill was crushed limestone. It was visually graded as angular material with a soil classification of GP (poorly graded gravel). The LA Abrasion testing for this material demonstrated a 27% loss. Full details are provided in **Appendix A**.

The compactor used for the very heavy installation compaction tests was a Stone Model S52 vibratory plate compactor rated to deliver 5,100 lb (22.70 kN) eccentric force and operate at 5,400 Hz.

Tests were performed in a steel test frame. The frame measures 54" (1.37 m) wide and 64" (1.62 m) long and is 24" (0.6 m) deep. The sides and ends of the frame are removable. (**Figure 3**)

Figure 3 - Test Frame and Plate Compactor

TEST DESCRIPTIONS

Tests were performed on different geogrid materials and with different levels of compaction effort.

In the first series of tests, 10XT geogrid was installed in a Redi-Rock PC block, the vertical core slot was filled with crushed limestone, and heavy compaction effort was applied. The heavy compaction effort is assumed to be equivalent to the maximum amount of compaction which would be encountered in a field installation. The heavy compaction effort exceeds the amount recommended by Redi-Rock for proper installation.

Crushed stone was placed in the bottom 4" (100 mm) of the test frame. Two Redi-Rock PC blocks were placed along one side of the frame. A strip of Mirafi 10XT geogrid was installed in each block. Crushed stone core fill was then placed in the slot behind the geogrid. One block was filled approximately 9" (230 mm) with stone. The stone was compacted with 20 medium blows with a large steel "spud" bar. These are the odd numbered test specimens in Appendix B. The second block was filled with 12" (300 mm) with stone. The stone was compacted with 12 medium blows with a large steel "spud" bar. **(Figure 4)** These are the even numbered test specimens in Appendix B. The stone in both blocks consolidated approximately 0.75" (19 mm) during the compaction with the steel bar. The blocks were filled the rest of the way with stone. The stone was compacted with 15 medium blows with a wood post. **(Figure 5)** The stone consolidated approximately 1" (25 mm) during the compaction with the wood post.

Figure 4 - Compaction with "Spud" Bar

Figure 5 - Compaction with Wood Post

Following compaction of the stone the geogrid sample was exhumed. The top 4" (100 mm) of stone was removed by hand. A hook and chain was attached to the lifting ring in the top of the PC block and a forklift was used to lift the block out of the test frame. (**Figure 6**) With the block suspended in the air, it only took a small amount of effort to dislodge the stone and cause it to fall freely from the slot in the block. The geogrid sample was then removed from the block, labeled, and set aside for wide width tensile testing. A separate control specimen was taken from the geogrid roll after every set of tests for baseline measurements of geogrid strength.

Figure 6 – Exhuming Geogrid from Block

In the second series of tests, 5XT geogrid was installed in a Redi-Rock PC block, the vertical core was filled with crushed limestone, and standard compaction effort was applied. The standard compaction effort is assumed to be equivalent to the compaction which would be encountered in a field installation.

Crushed stone was placed in the bottom 4" (100 mm) of the test frame. Two Redi-Rock PC blocks were placed along one side of the frame. A strip of Mirafi 5XT geogrid was installed in each block. A 6" (150 mm) thick layer of crushed stone was then placed in the vertical core slot. The stone was compacted with 10 medium blows with a large steel "spud" bar. The stone consolidated approximately 1" (25 mm) due to the compaction. A second layer of stone 6" (150 mm) thick was placed in the vertical core slot and then compacted with 10 medium blows with a large steel "spud" bar. The second lift of stone consolidated approximately 0.5" (13 mm) due to the compaction. A third layer of stone 6" (150 mm) thick was placed in the vertical core slot and then compacted with 10 medium blows with a large steel "spud" bar. The third lift of stone consolidated approximately 1.5" (38 mm) due to the compaction.

Following compaction of the stone, the geogrid sample was exhumed following the same procedure used for the first series of 10XT tests. A separate control specimen was taken from the geogrid roll after every set of tests for baseline measurements of geogrid strength.

In the third series of tests, 20XT geogrid was installed in a Redi-Rock PC block, the vertical core was filled with crushed limestone, and standard compaction effort was applied. The tests for the 20XT geogrid were performed following the same procedure as used for the 5XT tests. The stone lifts, compaction effort, and visually identified consolidation were the same as the 5XT tests.

In the fourth series of tests, 10XT geogrid was installed in a Redi-Rock PC block, the vertical core was filled with crushed limestone, and very heavy compaction effort was applied. The very heavy compaction effort is assumed to be greater than any compaction which would be encountered in a field installation. The results from these tests are intended to provide an indication of the upper boundary of installation damage to geogrid strips from compaction of stone in the PC block.

Crushed stone was placed in the bottom 4" (100 mm) of the test frame. Two Redi-Rock PC blocks were placed along one side of the frame. A strip of Mirafi 10XT geogrid was installed in each block. Crushed stone was then placed in the slot behind the geogrid. The blocks were filled approximately 12" (300 mm) with stone. The stone was compacted with 40 very heavy blows with a large steel "spud" bar. The blocks were then filled the remaining 8" (200 mm) with stone. The stone was compacted with 15 very heavy blows with a sledgehammer. (**Figure 6**) The stone was further compacted with 6 passes of a vibratory plate compactor on the top of the PC blocks. (**Figure 7**) Note: it was very difficult to maneuver the plate compactor between the knobs on the top of the PC block. (**Figure 8**) Consequently, this compaction is not expected in field installations.

Figure 7 - Compaction with Sledgehammer

Figure 8 - Compaction with Plate Compactor

Figure 9 - Limited Maneuvering Room on Top of Block

Following compaction of the stone, the geogrid sample was exhumed following the same procedure used for the first series of 10XT tests. A separate control specimen was taken from the geogrid roll after every set of tests for baseline measurements of geogrid strength.

RESULTS

Wide width tensile tests were performed on the geogrid test specimens at the TenCate materials laboratory in Cornelia, GA. Tests were performed in accordance with ASTM D6637 (Method B). The detailed results are included in **Appendix B**. The results are summarized in **Table 1**.

Table 1 – Wide Width Tensile Testing Summary Results

Geogrid	Baseline Samples Maximum Load (lb/ft)	Compaction Effort	Installed Samples Maximum Load (lb/ft)	Percent of Strength Retained Installed/Baseline Samples	Reduction Factor for In-Block Installation Damage, $RF_{IN\text{-}BLOCK\ ID}$
5XT	4,992	Standard	4,964	0.994	1.006
10XT	10,322	Heavy	9,882	0.957	1.045
10XT	10,276	Very Heavy	9,125	0.888	1.126
20XT	15,988	Standard	15,086	0.944	1.060

Tests with standard compaction effort consistent with Redi-Rock's installation recommendations show a strength reduction from less than 1% to 6%. Based on this testing, a reduction factor from 1.01 to 1.06 should be applied to connection test results which were performed without the inclusion of stone core fill in the vertical core slot in the PC block. This reduction factor will account for the reduction in strength of the geogrid due to in-block installation damage. Note: connection tests which include stone core fill already incorporate the impact of this strength reduction in the test results.

Tests with heavy and very heavy compaction effort show a strength reduction of 4.5% to 12.6%. Based on this testing, an upper boundary for the reduction factor for the inclusion of stone core fill in the vertical core slot should range between 1.10 and 1.15.

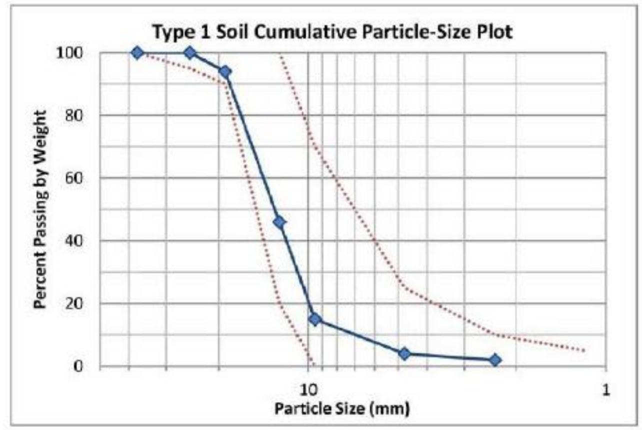
If a Redi-Rock PC System wall is proposed using a stone core fill material or compaction effort which is different from that used in the existing Redi-Rock connection tests, in-block damage testing similar to the procedure used in this report should be considered to determine appropriate installation damage reduction factors. The resulting reduction factors should be applied to connection tests for the geogrid and Redi-Rock PC block which were performed without the inclusion of stone core fill in the vertical core slot.

APPENDIX A

CRUSHED STONE PROPERTIES

Crushed Limestone Used for PC System In-Block Installation Damage Testing

US Sieve No.	Sieve Size (mm)	% Passing by Weight Type 1 (Coarse Gravel)
1.5-in	37.5	100
1-in	25	100
3/4-in	19	94
1/2-in	12.5	46
3/8-in	9.5	15
No. 4	4.75	4
No. 8	2.36	2
Loss by Washing		1
D_{50} (mm)	13.0	
LA Abrasion (% Loss)	27	
Angularity (ASTM D2488)	Angular (Visual)	
Soil Classification (ASTM D2487)	GP (Poorly Graded Gravel)	



D_{10} (mm)	7.3	$C_U = D_{60} / D_{10}$	1.97
D_{30} (mm)	11.0		
D_{60} (mm)	14.4	$C_C = D_{30}^2 / (D_{10} * D_{60})$	1.15

APPENDIX B

WIDE WIDTH TENSILE TESTS

Redi-Rock Positive Connection In-Block Connection Installation Damage Wide Width Tensile Test Results
Custom Installation Damage Testing Procedure
Wide Width Tensile Testing (ASTM D6637, Method B)

Installation Testing:	March 25, 2013	Geogrid Testing:	April 13, 2013
Location:	Redi-Rock International, Charlevoix, MI 49720	Location:	TenCate, Cornelia, GA 30531
Geogrid Type:	Miragrid 5XT	Specimen Width (in):	7.77
Installation:	Standard Compaction	Number of Ribs Tested:	7

Machine Direction

Sample Identification	Specimen Number	Maximum Load *(lb/ft)*	Maximum Load *(kN/m)*	Elongation at Break *(%)*	Load at 2% *(lb/ft)*	Load at 2% *(kN/m)*	Load at 5% *(lb/ft)*	Load at 5% *(kN/m)*	Load at 10% *(lb/ft)*	Load at 10% *(kN/m)*
5 XT Strips (Baseline Measurements)	1	5,046	73.6	10.6	1,121	16.4	2,199	32.1	4,898	71.5
	2	4,971	72.5	9.9	1,124	16.4	2,264	33.0		
	3	4,998	72.9	10.5	1,096	16.0	2,173	31.7	4,861	70.9
	4	5,021	73.3	11.0	1,033	15.1	2,081	30.4	4,783	69.8
	5	4,922	71.8	10.3	1,073	15.7	2,153	31.4	4,857	70.9
Average		4,992	73	10.5	1,089	16	2,174	32	4,850	71
Standard Deviation		48	1	0.40	38	1	67	1	48	1
Specification		4,700	68.6	10.0	1,060	15.5	1,740	25.4	4,225	61.7
COV		1.0%	1.0%	3.9%	3.5%	3.5%	3.1%	3.1%	1.0%	1.0%

Machine Direction

Sample Identification	Specimen Number	Maximum Load *(lb/ft)*	Maximum Load *(kN/m)*	Elongation at Break *(%)*	Load at 2% *(lb/ft)*	Load at 2% *(kN/m)*	Load at 5% *(lb/ft)*	Load at 5% *(kN/m)*	Load at 10% *(lb/ft)*	Load at 10% *(kN/m)*
5 XT Strips (Standard Installation Compaction Tests)	1	4,991	72.8	10.8	1,067	15.6	2,134	31.1	4,813	70.2
	2	4,715	68.8	10.2	1,065	15.5	2,098	30.6	4,685	68.4
	3	5,040	73.6	10.4	1,155	16.9	2,244	32.7	4,961	72.4
	4	4,855	70.9	9.8	1,104	16.1	2,195	32.0		
	5	4,961	72.4	10.5	1,040	15.2	2,110	30.8	4,832	70.5
	6	5,044	73.6	10.5	1,068	15.6	2,158	31.5	4,916	71.7
	7	5,054	73.8	10.9	1,097	16.0	2,127	31.0	4,793	70.0
	8	5,013	73.2	10.3	1,153	16.8	2,231	32.6	4,926	71.9
	9	5,007	73.1	10.7	1,124	16.4	2,198	32.1	4,839	70.6
	10	4,960	72.4	10.5	1,055	15.4	2,101	30.7	4,830	70.5
Average		4,964	72	10.5	1,093	15.9	2,160	31.5	4,844	70.7
Standard Deviation		105	2	0.32	41	0.59	54	0.79	83	1.21
COV		2.1%	2.1%	3.0%	3.7%	3.7%	2.5%	2.5%	1.7%	1.7%
Percent Retained		99.4%	99.4%	100.0%	100.3%	100.3%	99.3%	99.3%	99.9%	99.9%
RF_{ID}		1.006	1.006							

Redi-Rock Positive Connection In-Block Connection Installation Damage Wide Width Tensile Test Results
Custom Installation Damage Testing Procedure
Wide Width Tensile Testing (ASTM D6637, Method B)

Installation Testing:	February 28 - March 4, 2013	Geogrid Testing:	March 11 - 15, 2013
Location:	Redi-Rock International, Charlevoix, MI 49720	Location:	TenCate, Cornelia, GA 30531
Geogrid Type:	Miragrid 10XT	Specimen Width (in):	7.75
Installation:	Heavy Compaction	Number of Ribs Tested:	7

Machine Direction

Sample Identification	Specimen Number	Maximum Load *(lb/ft)*	Maximum Load *(kN/m)*	Elongation at Break *(%)*	Load at 2% *(lb/ft)*	Load at 2% *(kN/m)*	Load at 5% *(lb/ft)*	Load at 5% *(kN/m)*	Load at 10% *(lb/ft)*	Load at 10% *(kN/m)*
10 XT Strips (Baseline Measurements)	1	10,128	147.8	11.3	2,197	32.1	3,837	56.0	9,133	133.3
	2	10,535	153.8	11.9	2,188	31.9	3,929	57.3	9,330	136.2
	3	10,596	154.6	12.7	2,131	31.1	3,734	54.5	8,849	129.1
	4	10,109	147.5	11.1	2,176	31.8	4,145	60.5	9,495	138.6
	5	10,242	149.5	12.6	2,049	29.9	3,180	46.4	7,944	115.9
Average		10,322	151	11.9	2,148	31	3,765	55	8,950	131
Standard Deviation		229	3	0.73	61	1	360	5	612	9
Specification		9,500	138.6	10.0	1,300	19.0	3,120	45.5	7,000	102.2
COV		2.2%	2.2%	6.1%	2.8%	2.8%	9.6%	9.6%	6.8%	6.8%

Machine Direction

Sample Identification	Specimen Number	Maximum Load *(lb/ft)*	Maximum Load *(kN/m)*	Elongation at Break *(%)*	Load at 2% *(lb/ft)*	Load at 2% *(kN/m)*	Load at 5% *(lb/ft)*	Load at 5% *(kN/m)*	Load at 10% *(lb/ft)*	Load at 10% *(kN/m)*
10 XT Strips (Heavy Installation Compaction Tests)	1	10,053	146.7	11.2	2,238	32.7	3,971	58.0	9,383	136.9
	2a	10,139	148.0	11.3	2,156	31.5	3,781	55.2	9,214	134.5
	2b	9,647	140.8	10.2	2,276	33.2	4,020	58.7	9,497	138.6
	3a	10,250	149.6	11.1	2,359	34.4	4,158	60.7	9,564	139.6
	3b	9,276	135.4	12.8	868	12.7	2,671	39.0	6,365	92.9
	4	10,102	147.4	11.6	2,165	31.6	3,772	55.0	8,864	129.4
	5	10,153	148.2	12.3	2,057	30.0	3,615	52.8	8,648	126.2
	6	9,816	143.3	10.9	2,254	32.9	3,910	57.1	9,078	132.5
	7	9,691	141.4	10.5	2,278	33.2	4,141	60.4	9,469	138.2
	8	9,971	145.5	10.9	2,318	33.8	4,144	60.5	9,497	138.6
	9	9,915	144.7	14.3	1,828	26.7	2,634	38.4	5,840	85.2
	10	9,566	139.6	16.7	1,793	26.2	2,272	33.2	3,694	53.9
Average		9,882	144	12.0	2,049	29.9	3,591	52.4	8,259	120.5
Standard Deviation		290	4	1.86	414	6.04	670	9.77	1,904	27.79
COV		2.9%	2.9%	15.5%	20.2%	20.2%	18.6%	18.6%	23.1%	23.1%

Percent Retained	95.7%	95.7%	100.5%	95.4%	95.4%	95.4%	95.4%	92.3%	92.3%
RF_{ID}	1.045	1.045							

Redi-Rock Positive Connection In-Block Connection Installation Damage Wide Width Tensile Test Results
Custom Installation Damage Testing Procedure
Wide Width Tensile Testing (ASTM D6637, Method B)

Installation Testing:	February 28 - March 4, 2013	Geogrid Testing:	March 11 - 15, 2013
Location:	Redi-Rock International, Charlevoix, MI 49720	Location:	TenCate, Cornelia, GA 30531
Geogrid Type:	Miragrid 10XT	Specimen Width (in):	7.75
Installation:	Very Heavy Compaction	Number of Ribs Tested:	7

Machine Direction

Sample Identification	Specimen Number	Maximum Load (lb/ft)	Maximum Load (kN/m)	Elongation at Break (%)	Load at 2% (lb/ft)	Load at 2% (kN/m)	Load at 5% (lb/ft)	Load at 5% (kN/m)	Load at 10% (lb/ft)	Load at 10% (kN/m)
10 XT Strips (Baseline Measurements)	6	10,343	150.9	12.9	2,038	29.7	3,171	46.3	8,117	118.5
	7	10,239	149.4	11.5	2,207	32.2	3,829	55.9	9,153	133.6
	8	10,032	146.4	11.3	2,201	32.1	3,850	56.2	9,250	135.0
	9	10,444	152.4	12.1	2,173	31.7	3,748	54.7	9,005	131.4
	10	10,324	150.7	11.7	2,265	33.1	3,905	57.0	9,121	133.1
Average		10,276	150	12	2,177	32	3,701	54	8,929	130
Standard Deviation		155	2	1	84	1	301	4	462	7
Specification		9,500	138.6	10	1,300	19.0	3,120	45.5	7,000	102.2
COV		1.5%	1.5%	5.3%	3.9%	3.9%	8.1%	8.1%	5.2%	5.2%

Machine Direction

Sample Identification	Specimen Number	Maximum Load (lb/ft)	Maximum Load (kN/m)	Elongation at Break (%)	Load at 2% (lb/ft)	Load at 2% (kN/m)	Load at 5% (lb/ft)	Load at 5% (kN/m)	Load at 10% (lb/ft)	Load at 10% (kN/m)
10 XT Strips (Very Heavy Installation Compaction Tests)	1	9,697	141.5	12.1	2,093	30.5	3,653	53.3	8,993	131.2
	2a	8,474	123.7	7	2,296	33.5	3,992	58.3		
	2b	8,179	119.4	8.4	2,625	38.3	4,629	67.6		
	3a	9,088	132.6	9.7	2,308	33.7	3,939	57.5		
	3b	9,526	139.0	9.1	2,806	41.0	4,925	71.9		
	4	8,325	121.5	10.2	2,330	34.0	4,076	59.5	8,212	119.8
	5	9,217	134.5	10.6	2,122	31.0	3,770	55.0	9,024	131.7
	6	9,392	137.1	10.6	2,249	32.8	3,894	56.8	8,957	130.7
	7	9,664	141.0	9.5	2,404	35.1	4,185	61.1		
	8	9,645	140.8	10.3	2,260	33.0	3,927	57.3	9,427	137.6
	9	9,139	133.4	8.3	2,760	40.3	4,924	71.9		
	10	9,158	133.7	9.5	2,307	33.7	4,097	59.8		
Average		9,125	133	9.6	2,380	34.7	4,168	60.8	8,923	130.2
Standard Deviation		530	8	1.32	231	3.37	428	6.24	440	6.43
COV		5.8%	5.8%	13.8%	9.7%	9.7%	10.3%	10.3%	4.9%	4.9%

Percent Retained	88.8%	88.8%	80.7%	109.3%	109.3%	112.6%	112.6%	99.9%	99.9%
RF_{ID}	1.126	1.126							

Redi-Rock Positive Connection In-Block Connection Installation Damage Wide Width Tensile Test Results
Custom Installation Damage Testing Procedure
Wide Width Tensile Testing (ASTM D6637, Method B)

Installation Testing:	March 25, 2013	Geogrid Testing:	April 12, 2013
Location:	Redi-Rock International, Charlevoix, MI 49720	Location:	TenCate, Cornelia, GA 30531
Geogrid Type:	Miragrid 20XT	Specimen Width (in):	7.92
Installation:	Standard Compaction	Number of Ribs Tested:	8

Machine Direction

Sample Identification	Specimen Number	Maximum Load *(lb/ft)*	Maximum Load *(kN/m)*	Elongation at Break *(%)*	Load at 2% *(lb/ft)*	Load at 2% *(kN/m)*	Load at 5% *(lb/ft)*	Load at 5% *(kN/m)*	Load at 10% *(lb/ft)*	Load at 10% *(kN/m)*
20XT Strips (Baseline Measurements)	1	16,427	239.7	12.9	3,378	49.3	5,644	82.4	13,208	192.8
	2	16,064	234.4	12.6	3,105	45.3	5,307	77.5	12,761	186.2
	3	15,688	229.0	11.8	3,435	50.1	5,650	82.5	13,417	195.8
	4	15,811	230.8	12.1	3,486	50.9	5,716	83.4	13,390	195.4
	5	15,951	232.8	12.4	3,452	50.4	5,693	83.1	13,324	194.5
Average		15,988	233	12.4	3,371	49	5,602	82	13,220	193
Standard Deviation		283	4	0.43	154	2	168	2	269	4
Specification		4,700	68.6	10.0	1,060	15.5	1,740	25.4	4,225	61.7
COV		1.8%	1.8%	3.5%	4.6%	4.6%	3.0%	3.0%	2.0%	2.0%

Machine Direction

Sample Identification	Specimen Number	Maximum Load *(lb/ft)*	Maximum Load *(kN/m)*	Elongation at Break *(%)*	Load at 2% *(lb/ft)*	Load at 2% *(kN/m)*	Load at 5% *(lb/ft)*	Load at 5% *(kN/m)*	Load at 10% *(lb/ft)*	Load at 10% *(kN/m)*
20XT Strips (Standard Installation Compaction Tests)	1	15,503	226.3	11.6	3,367	49.1	5,558	81.1	13,349	194.8
	2	14,693	214.4	10.8	3,425	50.0	5,660	82.6	13,494	196.9
	3	14,850	216.7	11.2	3,399	49.6	5,594	81.6	13,223	193.0
	4	15,671	228.7	12.8	3,236	47.2	5,395	78.7	12,752	186.1
	5	15,166	221.3	10.8					13,583	198.2
	6	15,387	224.6	12.4	3,220	47.0	5,375	78.4	12,748	186.0
	7	15,105	220.4	11.1	3,409	49.8	5,694	83.1	13,708	200.1
	8	14,313	208.9	10.7	3,331	48.6	5,546	80.9	13,316	194.3
	9	15,432	225.2	11.9	3,266	47.7	5,497	80.2	13,134	191.7
	10	14,739	215.1	10.2	3,596	52.5	5,945	86.8	14,144	206.4
Average		15,086	220	11.4	3,361	49.1	5,585	81.5	13,345	194.8
Standard Deviation		430	6	0.82	116	1.70	172	2.51	424	6.19
COV		2.8%	2.8%	7.2%	3.5%	3.5%	3.1%	3.1%	3.2%	3.2%
Percent Retained		94.4%	94.4%	91.8%	99.7%	99.7%	99.7%	99.7%	100.9%	100.9%
RF_{ID}		1.060	1.060							

APPENDIX: 1.2.7 REINFORCEMENT PULL-OUT TEST REPORT

Prepared for:

TenCate Geosynthetics
365 South Holland Drive
Pendergrass, Georgia 30567

FINAL REPORT

PULLOUT TESTING MIRAGRID 3XT, 8XT, 10XT AND 20XT GEOGRIDS IN SILTY SAND AND AASHTO #57 STONE

Prepared by:

SGI TESTING SERVICES, LLC

4405 International Blvd., Suite B-117
Norcross, GA 30093

Project Number SGI19008

20 November 2019

CAVEAT

The reported results apply only to the materials and test conditions used in the laboratory testing program. The results do not necessarily apply to other materials or test conditions. The test results should not be used in engineering analysis unless the test conditions model the anticipated field conditions. The testing was performed in accordance with general engineering testing standards and requirements. This testing report is submitted for the exclusive use of the client to whom it is addressed.

1. INTRODUCTION

SGI Testing Services, LLC (SGI) conducted a laboratory testing program to evaluate the pullout resistance of four Miragrid geogrids in two types of soils. The sample preparation procedures and testing conditions used in the testing program were specified by Dr. Laura Spencer, P.E. of TenCate Geosynthetics. All of the pullout tests were conducted at SGI located in Norcross, Georgia, United States.

2. TEST MATERIALS

Two types of materials were used in this testing program. Descriptions of these materials are given below:

- *Reinforcement Material:* Miragrid 3XT, 8XT, 10XT, and 20XT geogrids; and
- *Soil Material*: silty sand and AASHTO #57 stone. Particle size analysis, compaction, and direct shear testing were conducted on the two soil materials and the test results are presented in Appendix A.

Miragrid 3XT, 8XT, 10XT, and 20XT geogrid samples were provided by TenCate Geosynthetics. Silty sand and AASHTO #57 stone were provided by SGI.

3. PULLOUT TEST EQUIPMENT

The pullout testing device used in this testing program had plan dimensions of 2 ft by 5 ft and an overall depth of 12 inch. Normal (vertical) stresses were applied to the testing specimen by using dead weight for low normal stress tests or six hydraulic cylinders for high normal stress tests, and pullout (horizontal) loads were applied to the test specimen through two hydraulic cylinders. The schematic diagrams of the pullout testing device are shown in Figures 1 and 2.

4. TEST METHOD AND PROCEDURES

The pullout tests were performed in accordance with the ASTM D 6706, "*Measuring Geosynthetic Pullout Resistance in Soil*". For each pullout test, the test specimen was set up in accordance with the following procedures and tested under the specific conditions as described below:

- For test series #1 to 4, AASHTO #57 stone was placed in the lower half of the pullout box and nominally compacted under dry conditions to form a 6-inch (150-mm) thick layer. For test series #5 to 8, silty sand was placed in the lower half of the pullout box and compacted by hand tamping to form a 6-inch (150-mm) thick layer. The silty sand was compacted to approximately 95% of the maximum dry unit weight at optimum moisture content (OMC);
- For each pullout test, a geogrid specimen was placed on top of the compacted soil as shown in Figures 3 and 4. The front end of the geogrid specimen was connected to the pullout loading harness;
- Two "tell-tale" wire gages were connected at selected locations. Displacements of the geogrid specimen at these tell-tale locations were measured by using LVDTs;
- For test series #1 to 4, AASHTO #57 stone was placed in the upper half of the pullout box and nominally compacted under dry conditions to form a 6-inch (150-mm) thick layer. For test series #5 to 8, silty sand was placed in the upper half of the pullout box and compacted by hand tamping to form a 6-inch (150-mm) thick layer. The silty sand was compacted to approximately 95% of the maximum dry unit weight at optimum moisture content (OMC);
- A load cell was then attached to the pullout loading harness to measure the pullout load of the test specimen at the specimen clamp. An LVDT was fixed to the specimen clamp to measure the total pullout displacement at the specimen clamp.

- A specific normal stress was then applied to the test specimen through dead weight (steel plates) for low normal stress testing or hydraulic cylinders for high normal stress testing; and

- After application of the normal stress, the geogrid specimen was subjected to pullout loading by displacing it at a constant displacement rate of 0.04 inch/min (1 mm/min) as measured at the specimen clamp. The geogrid specimen was pulled until the pullout failure occurred.

Completed pullout test setups are shown in Figures 5 and 6 (normal stress applied by using dead weight) and Figure 7 (normal stress applied by using hydraulic cylinders).

5. PULLOUT TEST RESULTS

Eight series of pullout tests were performed in this testing program. For each pullout test series, the test conditions and test results are presented on a summary page in Appendix C. The summary page includes:

- Pullout force versus displacement figure;
- Pullout resistance versus normal stress figure; and
- A table that summarizes test conditions, maximum pullout resistance, coefficient of interaction (C_i), and failure mode.

The maximum pullout resistance is defined as maximum pullout load divided by the initial width of a geogrid test specimen as follows:

$$P_{max} = \frac{F_{max}}{W} \qquad (1)$$

where:

P_{max} = maximum pullout resistance (lbs/ft);
F_{max} = maximum pullout load (lbs); and
W = initial width of the geogrid specimen (ft).

The coefficient of interaction (C_i) was calculated using the equation as follows:

$$C_i = \frac{F_{max}}{2(L_e W)(\sigma_n \tan\phi + c)} \quad (2)$$

where:

F_{max}	=	maximum pullout load;
L_e	=	initial embedded length of the geogrid specimen;
W	=	initial width of the geogrid specimen;
σ_n	=	total normal stress applied to the geogrid specimen;
ϕ	=	residual total-stress friction angle of soil; and
c	=	residual total-stress cohesion of soil.

The residual shear strength parameters (ϕ and c) of the silty sand and AASHTO # 57 stone used in calculating direct sliding coefficients were determined from direct shear testing, and are presented in Appendix A.

For each pullout test, the geogrid specimen was pulled until the pullout failure or tensile failure (rupture) occurred. The geogrid specimen was considered to be in the pullout failure mode when the tell-tale gage attached to the rear end of the geogrid specimen displaced at least 0.5 inch (12.5 mm) at the completion of the test, and pullout load decreased or remained constant with increasing pullout displacement.

6. CLOSURE

SGI appreciates the opportunity to provide laboratory testing services to TenCate Geosynthetics. Should you have any questions regarding this report, or if you require additional information, please do not hesitate to contact the undersigned.

Sincerely,

Zehong Yuan, Ph.D., P.E.
Laboratory Manager

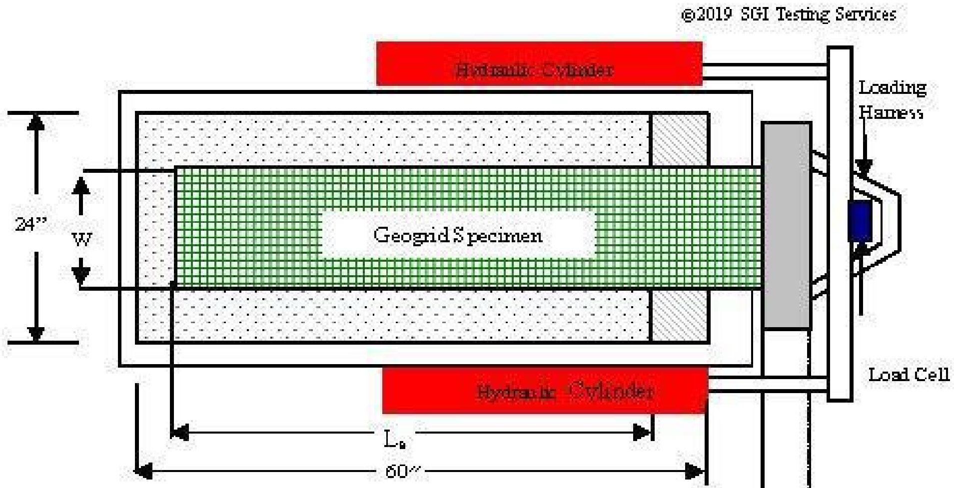


Figure 1. Plan view of pull out test setup (Note: not to scale).

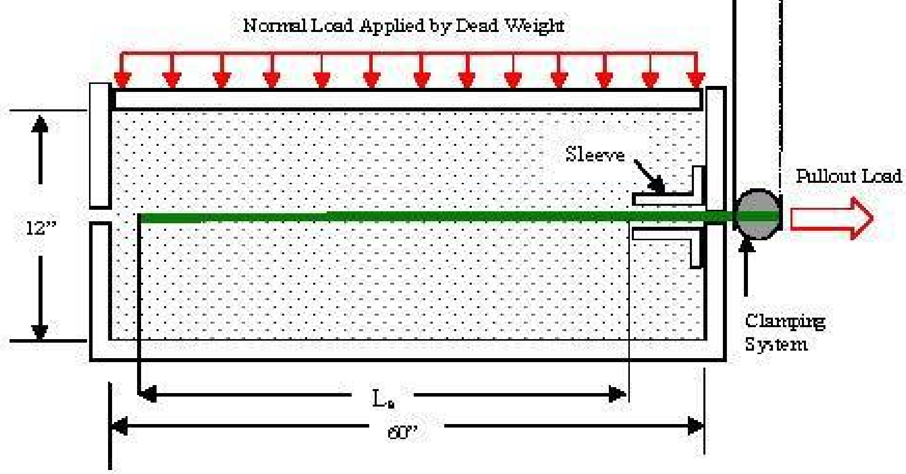


Figure 2. Cross-section of pull out test setup (Note: not to scale).

Figure 3. Miragrid 3XT geogrid placed on compacted silty sand.

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Figure 4. Miragrid 8XT geogrid placed on compacted AASHTO #57 stone.

Figure 5. A completed setup of pullout test at low normal stress (150 psf) by using dead weight.

Figure 6. A completed setup of pullout test at low normal stress (250 psf) by using dead weight.

Figure 7. A completed setup of pullout test at high normal stress by using six hydraulic cylinders.

Figure 8. Abrasion and rupture of 10XT geogrid ribs at the completion of pullout test # 3C at 1200 psf.

Figure 9. Abrasion damage to 20XT geogrid MD and CMD ribs and junction failure (i.e., rupture of CMD ribs) at the completion of pullout test # 4C at 1250 psf.

APPENDIX A

SUMMARY OF
SOIL PROPERTY TEST RESULTS

SGI Testing Services, LLC

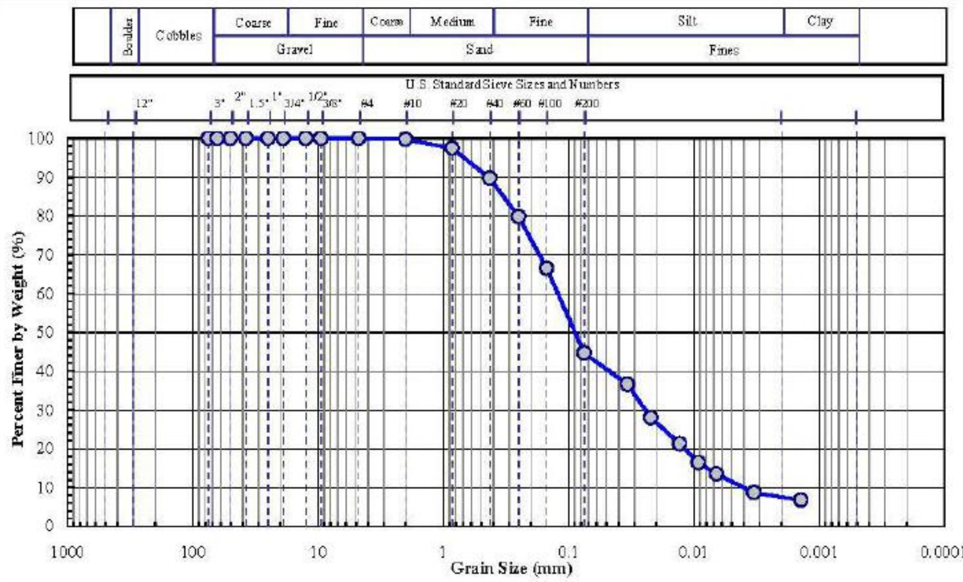
4405 International Blvd., Suite B-117, Norcross, GA 30093
Ph: (770) 931-8222 Fax: (770) 931-8240

Project Name:	Pullout
Project No:	SGI17008
Client Sample ID:	Silty Sand
Lab Sample No:	S15970

ASTM D 2216, D 1140, D 422, C 136, D 4318, D 2487

SOIL INDEX PROPERTIES

Moisture Content, Grain Size, Atterberg Limits, Classification

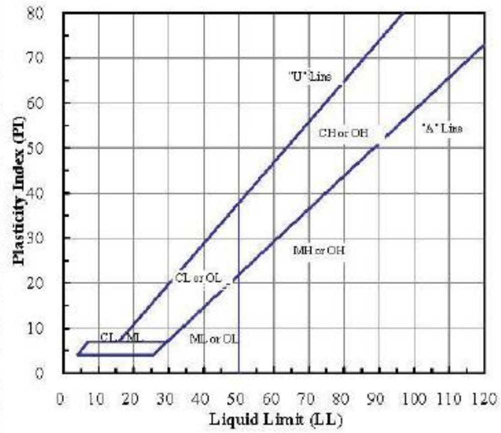


Sieve No.	Size (mm)	% Finer
3"	75	100.0
2"	50	100.0
1.5"	37.5	100.0
1"	25	100.0
3/4"	19	100.0
1/2"	12.5	100.0
3/8"	9.5	100.0
#4	4.75	100.0
#10	2.00	99.7
#20	0.850	97.4
#40	0.425	89.7
#60	0.250	79.8
#100	0.150	66.4
#200	0.075	44.6

Hydrometer Particle Diameter (mm)	% Finer
0.0340	36.6
0.0220	27.9
0.0066	13.5
0.0033	8.7
0.0014	6.7

Gravel (%):	0
Sand (%):	55.4
Fines (%):	44.6
Silt (%):	
Clay (%):	

Coeff. Unif. (Cu):	
Coeff. Curv. (Cc):	



Client Sample ID	Lab Sample No	Moisture Content (%)	Fines Content < No. 200 (%)	Atterberg Limits LL (%)	PL (%)	PI (-)	Engineering Classification
Silty Sand	S15970		44.6				SM

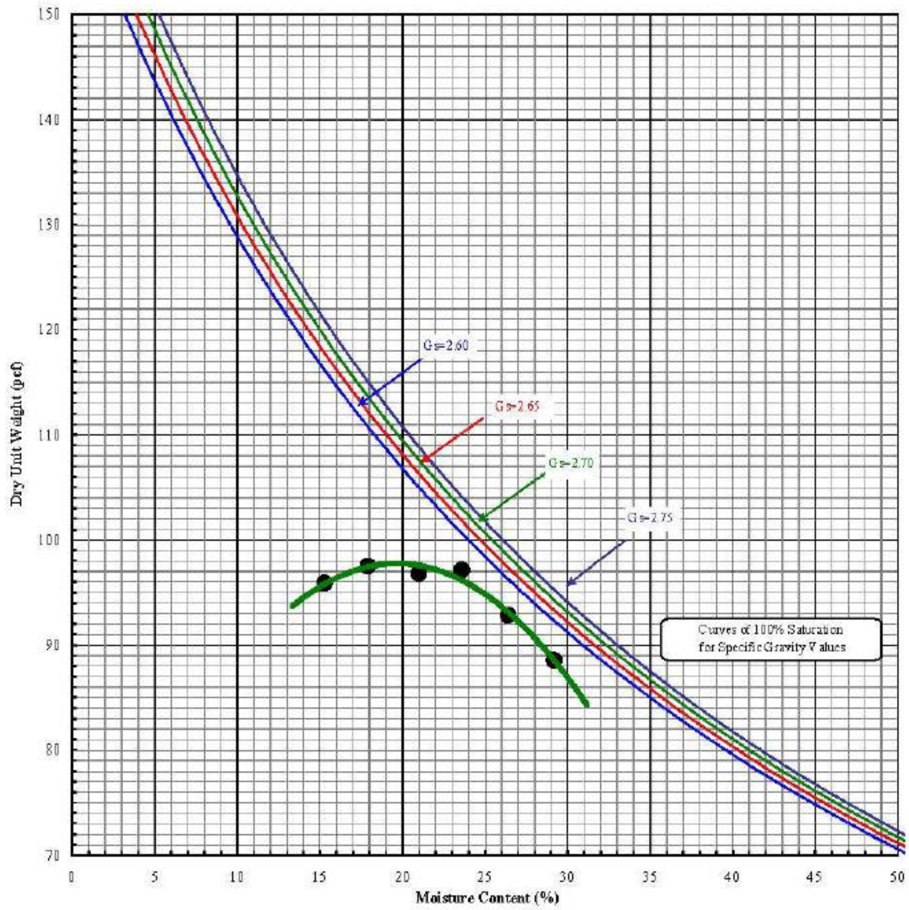
S15970 index.xls

SGI Testing Services, LLC

4405 International Blvd., Suite B-117, Norcross, GA 30093
Ph: (770) 931 8222 Fax: (770) 931 8240

Project Name:	Pullout
Project No:	SGI17008
Client Sample ID:	Silty Sand
Lab Sample No:	S15970

ASTM D698 **COMPACTION MOISTURE-DENSITY RELATIONSHIP** Standard - Method A



Client Sample ID	SGI Sample ID NO.	Compaction Data		Maximum Dry Unit Weight and Optimum Moisture Content			
				Measured		Corrected	
		ω_t (%)	γ_d (pcf)	ω_{om} (%)	γ_{dmax} (pcf)	ω_{om} (%)	γ_{dmax} (pcf)
Silty Sand	S15970	15.3	95.9	20.0	98.0		
		17.9	97.5				
		21.0	96.8				
		23.6	97.1				
		26.4	92.8				
		29.2	88.5				

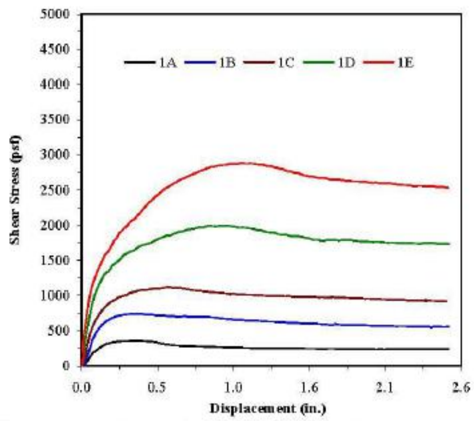
% Retained on #4 Sieve:
% Retained on #3/8" Sieve:
% Retained on 3/4" Sieve:
% Retained on 2.0" Sieve:

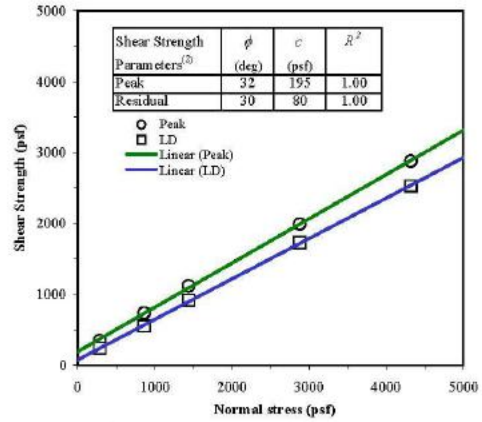
S15970 Compaction.xls

SGI TESTING SERVICES, LLC

DIRECT SHEAR TESTING (ASTM D 3080)

TEST SERIES NO. 1: Internal shear strength of silty sand compacted to approximately 95% of max standard Proctor dry density at OMC
(γ_{dmax} = 98 pcf, OMC = 20%, ASTM D 698)





Test No.	Shear Box Size	Normal Stress	Shear Rate	Soaking		Consolidation						Soil Compaction			Shear Strength		Failure Mode
						Step 1		Step 2		Step 3		γ_d	ω_i	ω_f	τ_P	τ_R	
	(in. x in.)	(psf)	(in./min)	(psf)	(hour)	(psf)	(hour)	(psf)	(hour)	(psf)	(hour)	(pcf)	(%)	(%)	(psf)	(psf)	
1A	12 x 12	288	0.04	-	-	288	1.0	-	-	-	-	92.9	20.3		350	240	(1)
1B	12 x 12	864	0.04	-	-	864	1.0	-	-	-	-	93.5	19.5		739	555	
1C	12 x 12	1440	0.04	-	-	1440	1.0	-	-	-	-	93.7	19.2		1120	916	
1D	12 x 12	2880	0.04	-	-	2880	1.0	-	-	-	-	93.3	19.8		1994	1735	
1E	12 x 12	4320	0.04	-	-	4320	1.0	-	-	-	-	93.0	20.1		2882	2531	

NOTES:
(1) Shear failure was forced to occur internally through the soil specimen at the predetermined plane between the upper and lower shear box during each test.
(2) The reported total-stress parameters of friction angle and cohesion were determined from a best-fit line drawn through the test data. The residual shear strength was calculated using the shear force measured at the end of the test.

DATE REPORTED:	3/30/2017
FIGURE NO.	A-3
PROJECT NO.	SGI17008
DOCUMENT NO.	
FILE NO.	

SGI TESTING SERVICES, LLC

SGI.SM2017.DS.xls

SGI Testing Services, LLC

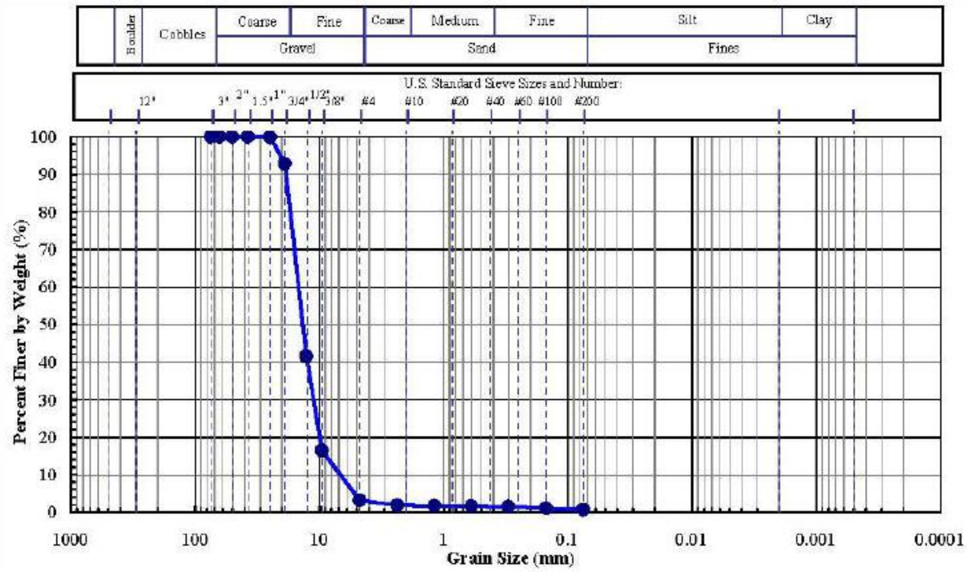
4405 International Blvd., Suite B-117, Norcross, GA 30093
Ph: (770) 931-8222 Fax: (770) 931-8240

Project Name:	Pullout
Project No:	
Client Sample ID:	AASHTO #57 Stone
Lab Sample No:	S21598

ASTM D 2216, D 1140, D 422, C 136, D 4318, D 2487

SOIL INDEX PROPERTIES

Moisture Content, Grain Size, Atterberg Limits, Classification

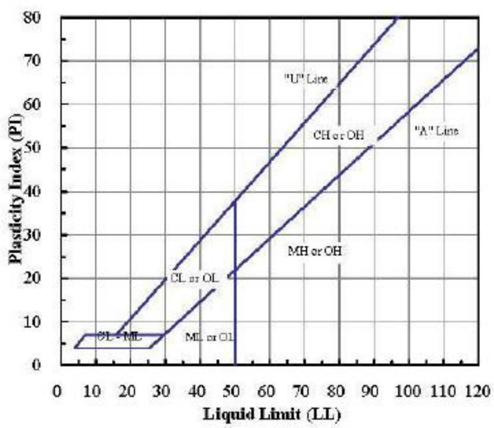


Sieve No.	Size (mm)	% Finer
3"	75	100.0
2"	50	100.0
1.5"	37.5	100.0
1"	25	100.0
3/4"	19	92.8
1/2"	12.5	41.5
3/8"	9.5	16.4
#4	4.75	3.1
#8	2.36	1.9
#16	1.180	1.7
#30	0.600	1.6
#50	0.300	1.4
#100	0.150	1.0
#200	0.075	0.6

Hydrometer Particle Diameter (mm)	% Finer
0.0340	
0.0220	
0.0064	
0.0032	
0.0013	

Gravel (%):	96.9
Sand (%):	2.5
Fines (%):	0.6
Silt (%):	
Clay (%):	

Coeff. Unif. (Cu):	2.2
Coeff. Curv. (Cc):	1.2

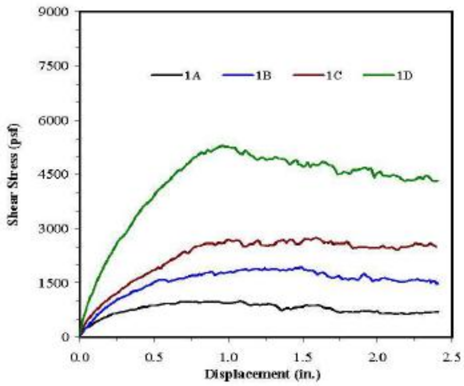


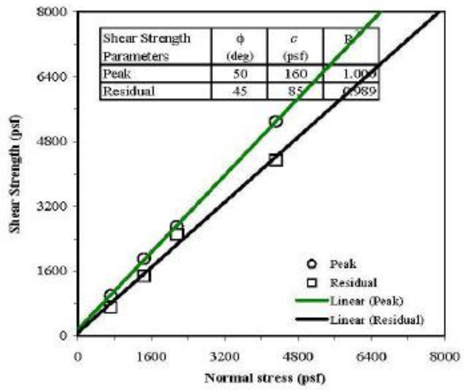
Client Sample ID.	Lab Sample No:	Moisture Content (%)	Fines Content < No. 200 (%)	Atterberg Limits LL (%)	PL (%)	PI (-)	Engineering Classification
AASHTO #57 Stone	S21598		0.6				GP

S21598.GrainSizeRange.xls

SGI TESTING SERVICES, LLC
DIRECT SHEAR TESTING (ASTM D 3080)

AASHTO No. 57 aggregate nominally compacted under dry condition





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in./min)	Soaking		Consolidation		Initial				After		Shear Strength		Failure Mode
				Stress (psf)	Time (hour)	Stress (psf)	Time (hour)	γ_d (pcf)	RD (%)	ω_i (%)	Gap (mm)	γ_d (pcf)	ω_f (%)	τ_P (psf)	τ_R (psf)	
1A	12 x 12	720	0.04	-	-	720	0.5							996	702	(1)
1B	12 x 12	1440	0.04	-	-	1440	0.5							1905	1475	(1)
1C	12 x 12	2160	0.04	-	-	2160	0.5							2705	2502	(1)
1D	12 x 12	4320	0.04	-	-	4320	0.5							5290	4335	(1)

NOTES:
(1) Sliding (i.e., shear failure) was forced to occur along the shear plane between the upper and lower shear box.
(2) The reported total-stress parameters of friction angle and cohesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The residual shear strength was calculated using the shear force measured at the end of the test.

SGI TESTING SERVICES, LLC

DATE OF REPORT:	6/26/2019
FIGURE NO.	A-5
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

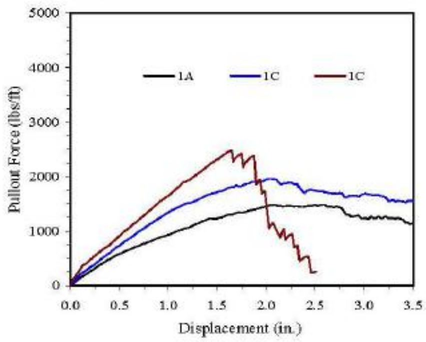
S19028-05R ds.xls

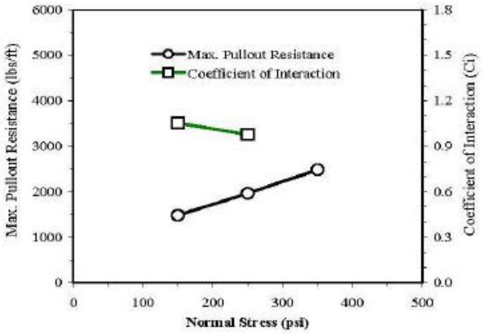
APPENDIX B

SUMMARY OF PULLOUT TEST RESULTS

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 1: Miragrid 3XT geogrid (Lot # 20190331-3-2) in MD within AASHTO #57 stone nominally compacted under dry conditions





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction: Initial Dry Unit Weight (pcf)	Soil Compaction: Initial Moisture Content (%)	Residual Soil Shear Strength: ϕ (degree)	Residual Soil Shear Strength: c (psf)	Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction(2) $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode(1)
1A	15.0	36.0	150	0.04			45	85	1484	1.05	Pullout
1B	15.0	36.0	250	0.04			45	85	1964	0.98	Pullout
1C	15.0	36.0	350	0.04			45	85	2484		Rupture

NOTES:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.
(2) C_i not calculated when the test geogrid specimen ruptured instead of pullout.

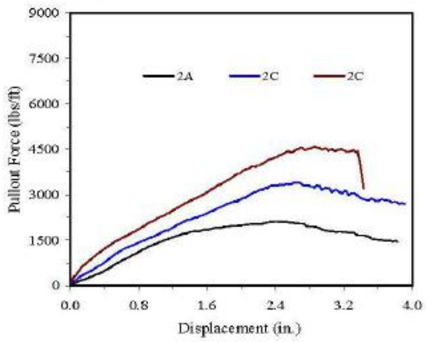
SGI TESTING SERVICES, LLC

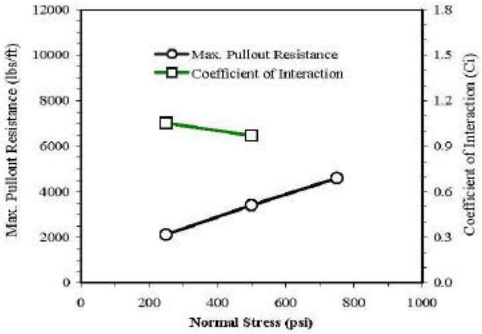
DATE REPORTED:	10/28/2019
FIGURE NO.	1
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

P19008-01R pullout.xls

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 2: Miragrid 8XT geogrid (Lot # 20190808-1-2) in MD within AASHTO #57 stone nominally compacted under dry conditions





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction: Initial Dry Unit Weight (pcf)	Soil Compaction: Initial Moisture Content (%)	Residual Soil Shear Strength: ϕ (degree)	Residual Soil Shear Strength: c (psf)	Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction[2] $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode[1]
2A	15.0	36.0	250	0.04			45	85	2116	1.05	Pullout
2B	15.0	36.0	500	0.04			45	85	3406	0.97	Pullout
2C	15.0	36.0	750	0.04			45	85	4592		Rupture

NOTES:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.
(2) C_i not calculated when the test geogrid specimen ruptured instead of pullout.

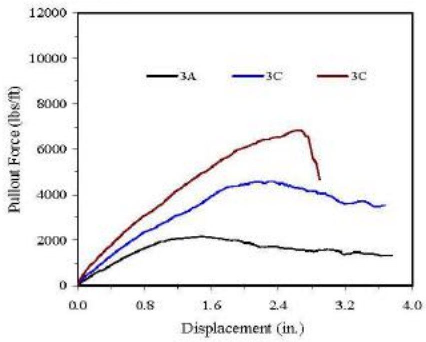
SGI TESTING SERVICES, LLC

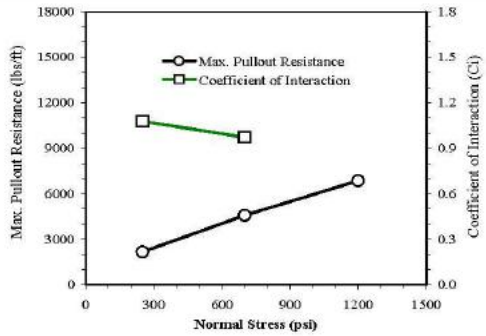
DATE REPORTED:	10/28/2019
FIGURE NO.	2
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

P19008-02R pullout.xls

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 3: Miragrid 10XT geogrid (Lot # 20190429-2-1) in MD within AASHTO #57 stone nominally compacted under dry conditions





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction: Initial Dry Unit Weight (pcf)	Soil Compaction: Initial Moisture Content (%)	Residual Soil Shear Strength: ϕ (degree)	Residual Soil Shear Strength: c (psf)	Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction[(2)] $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode[(1)]
3A	15.0	36.0	250	0.04			45	85	2166	1.08	Pullout
3B	15.0	36.0	700	0.04			45	85	4580	0.97	Pullout
3C	15.0	36.0	1200	0.04			45	85	6851		Rupture

NOTES:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.
(2) C_i not calculated when the test geogrid specimen ruptured instead of pullout.

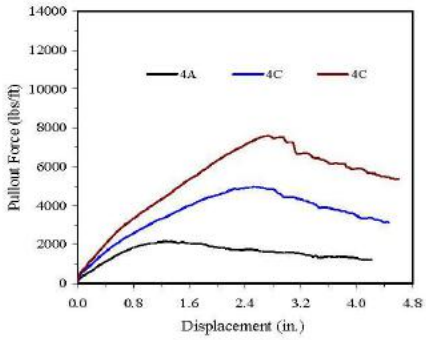
SGI TESTING SERVICES, LLC

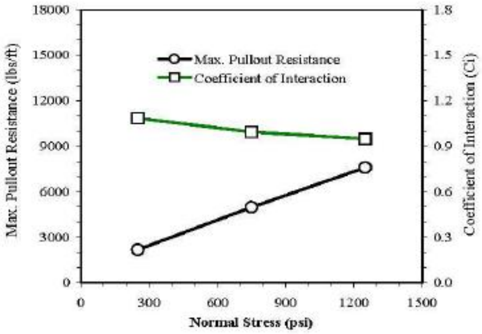
DATE REPORTED:	10/28/2019
FIGURE NO.	3
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

P19008-03R pullout.xls

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 4: Miragrid 20XT geogrid (Lot # 20190220-1-2) in MD within AASHTO #57 stone nominally compacted under dry conditions





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction: Initial Dry Unit Weight (pcf)	Soil Compaction: Initial Moisture Content (%)	Residual Soil Shear Strength: ϕ (degree)	Residual Soil Shear Strength: c (psf)	Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode[(1)]
4A	15.0	36.0	250	0.04			45	85	2180	1.08	Pullout
4B	15.0	36.0	750	0.04			45	85	4980	0.99	Pullout
4C	15.0	36.0	1250	0.04			45	85	7606	0.95	Pullout

NOTE:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.

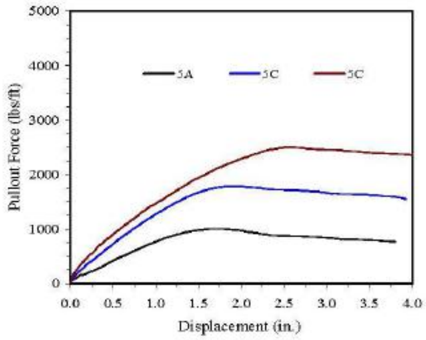
SGI TESTING SERVICES, LLC

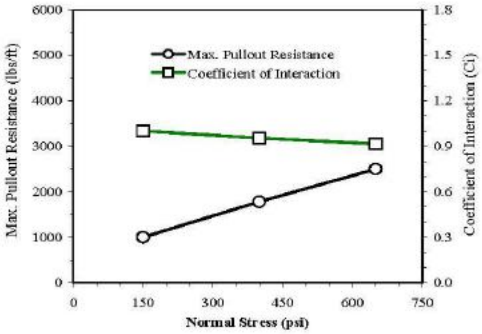
DATE REPORTED:	10/28/2019
FIGURE NO.	4
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

P19008-04R pullout.xls

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 5: Miragrid 3XT geogrid (Lot # 20190331-3-2) in MD within silty sand compacted to approximately 95% of max standard Proctor density at OMC +/- 2% (γ_{max} = 98 pcf, OMC = 20%)





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction: Initial Dry Unit Weight (pcf)	Soil Compaction: Initial Moisture Content (%)	Residual Soil Shear Strength: ϕ (degree)	Residual Soil Shear Strength: c (psf)	Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode(1)
5A	15.0	36.0	150	0.04	92.7	19.5	30	80	1001	1.00	Pullout
5B	15.0	36.0	400	0.04	93.5	18.5	30	80	1780	0.95	Pullout
5C	15.0	36.0	650	0.04	93.4	18.6	30	80	2501	0.92	Pullout

NOTE:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.

SGI TESTING SERVICES, LLC

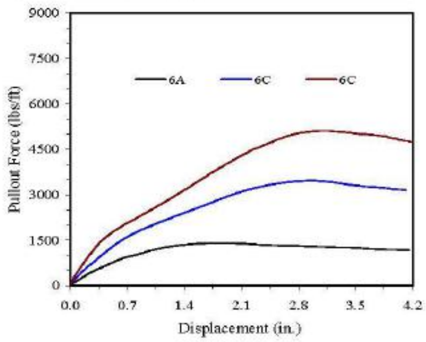
DATE REPORTED:	10/28/2019
FIGURE NO.	5
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

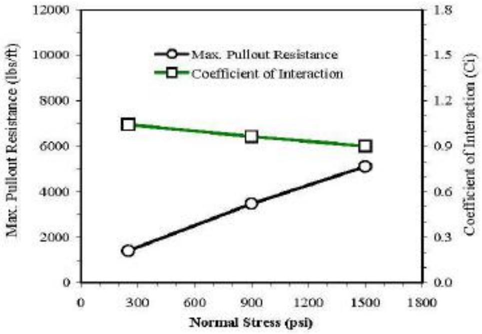
P19008-05RR.pullout.xls

REDI-ROCK

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 6: Miragrid 8XT geogrid (Lot # 20190808-1-2) in MD within silty sand compacted to approximately 95% of max standard Proctor density at OMC +/- 2% (γ_{max} = 98 pcf, OMC = 20%)





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction: Initial Dry Unit Weight (pcf)	Soil Compaction: Initial Moisture Content (%)	Residual Soil Shear Strength: ϕ (degree)	Residual Soil Shear Strength: c (psf)	Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode(1)
6A	15.0	36.0	250	0.04	93.7	18.3	30	80	1403	1.04	Pullout
6B	15.0	36.0	900	0.04	93.3	18.7	30	80	3467	0.96	Pullout
6C	15.0	36.0	1500	0.04	92.9	19.2	30	80	5116	0.90	Pullout

NOTE:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.

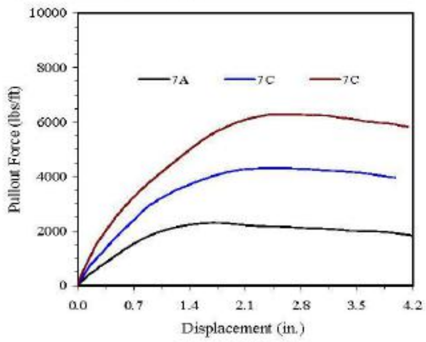
DATE REPORTED:	10/28/2019
FIGURE NO.	6
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

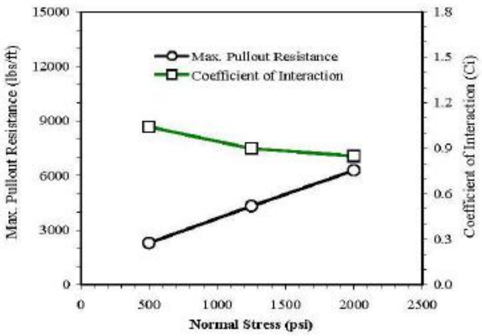
SGI TESTING SERVICES, LLC

P19008-06R pullout.xls

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 7: Miragrid 10XT geogrid (Lot # 20190429-2-1) in MD within silty sand compacted to approximately 95% of max standard Proctor density at OMC +/- 2% (γ_{max} = 98 pcf, OMC = 20%)





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction: Initial Dry Unit Weight (pcf)	Soil Compaction: Initial Moisture Content (%)	Residual Soil Shear Strength: ϕ (degree)	Residual Soil Shear Strength: c (psf)	Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode(1)
7A	15.0	36.0	500	0.04	93.5	18.5	30	80	2304	1.04	Pullout
7B	15.0	36.0	1250	0.04	93.2	18.9	30	80	4318	0.90	Pullout
7C	15.0	36.0	2000	0.04	92.7	19.5	30	80	6285	0.85	Pullout

NOTE:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.

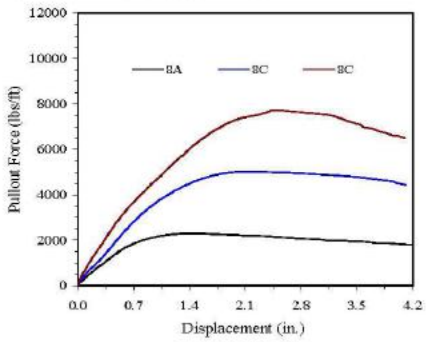
SGI TESTING SERVICES, LLC

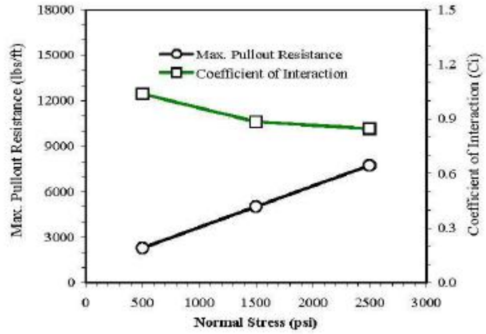
DATE REPORTED:	10/28/2019
FIGURE NO.	7
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

P19008-07RR pullout.xls

TENCATE GEOSYNTHETICS
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. 8: Miragrid 20XT geogrid (Lot # 20190220-1-2) in MD within silty sand compacted to approximately 95% of max standard Proctor density at OMC +/- 2% (γ_{max} = 98 pcf, OMC = 20%)





Test No.	Test Specimen Width W (in.)	Embedment Length L (in.)	Normal Stress σ_n (psf)	Pullout Rate (in./min)	Soil Compaction		Residual Soil Shear Strength		Max. Pullout Resistance P_{max} (lbs/ft)	Coefficient of Interaction $C_i = \frac{P_{max}}{2L(\sigma_n \tan\phi + c)}$ (-)	Failure Mode[1]
					Initial Dry Unit Weight (pcf)	Initial Moisture Content (%)	ϕ (degree)	c (psf)			
8A	15.0	36.0	500	0.04	93.6	18.4	30	80	2296	1.04	Pullout
8B	15.0	36.0	1500	0.04	93.5	18.5	30	80	5019	0.88	Pullout
8C	15.0	36.0	2500	0.04	93.3	18.8	30	80	7733	0.85	Pullout

NOTE:
(1) Failure Mode: Pullout failure as indicated by a minimum displacement of 0.5" in measured at the rear end of the geogrid specimen at the completion of the test.

DATE REPORTED:	10/28/2019
FIGURE NO.	8
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

SGI TESTING SERVICES, LLC

PI9008-08R pullout.xls

APPENDIX: 1.2.8 SOIL-GEOSYNTHETIC INTERFACE SHEAR TEST REPORT

Prepared for:

TenCate Geosynthetics
365 South Holland Drive
Pendergrass, Georgia 30567

FINAL REPORT

INTERFACE DIRECT SHEAR TESTING SILTY SAND AND AASHTO #57 STONE AGAINST MIRAGRID 3XT, 8XT, 10XT, AND 20XT GEOGRIDS

Prepared by:

SGI TESTING SERVICES, LLC

4405 International Blvd., Suite B-117
Norcross, GA 30093

Project Number SGI19007

20 November 2019

CAVEAT

The reported results apply only to the materials and test conditions used in the laboratory testing program. The results do not necessarily apply to other materials or test conditions. The test results should not be used in engineering analysis unless the test conditions model the anticipated field conditions. The testing was performed in accordance with general engineering testing standards and requirements. This testing report is submitted for the exclusive use of the client to whom it is addressed.

1. INTRODUCTION

SGI Testing Services, LLC (SGI) conducted a laboratory testing program to evaluate the shear strength of interfaces between four Miragrid geogrids and two types of soils. The sample preparation procedures and testing conditions used in the testing program were specified by Dr. Laura Spencer, P.E. of TenCate Geosynthetics. All of the interface direct shear tests were conducted at SGI located in Norcross, Georgia, United States.

2. TEST MATERIALS

Two types of materials were used in this testing program. Descriptions of these materials are given below:

- *Reinforcement Material:* Miragrid 3XT, 8XT, 10XT, and 20XT geogrids; and
- *Soil Material*: silty sand and AASHTO #57 stone. Particle size analysis, compaction, and direct shear testing were conducted on the two soil materials and the test results are presented in Appendix A.

Miragrid 3XT, 8XT, 10XT, and 20XT geogrid samples were provided by TenCate Geosynthetics. Silty sand and AASHTO #57 stone were provided by SGI.

3. INTERFACE DIRECT SHEAR TEST EQUIPMENT

The interface direct testing device used in this testing consisted of an upper and lower shear box. The upper shear box measured 300 mm by 300 mm (12 in. by 12 in.) in plan and 75 mm (3 in.) in depth. The lower shear box measured 300 mm by 350 mm (12 in. by 14 in.) in plan and 75 mm (3 in.) in depth. Normal (vertical) stresses were applied to the testing specimen by using dead weight for low normal stress tests or an air bladder system for high normal stress tests, and shear loads were applied to the test specimen through an automatically-controlled motor system.

4. TEST METHOD AND PROCEDURES

The interface direct shear tests were performed in accordance with the ASTM Standard Test Method D 5321, *"Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"*. For each interface direct shear test, the test specimen was set up in accordance with the following procedures and tested under the specific conditions as described below:

- For test series #1 to 4, silty sand was compacted into the lower shear box by hand tamping to approximately 95% of maximum standard Proctor dry unit weight at optimum moisture content. For test series #5 to 8, AASHTO #57 stone was nominally compacted in the lower shear box under dry conditions;

- A geogrid specimen was trimmed from the as-received geogrid sample and placed on the compacted soil and attached to the lower shear box. The geogrid specimen was oriented so that the direction of shearing was parallel to the machine direction of the geogrid specimen;

- For test series #1 to 4, silty sand was then placed on top of the geogrid into the upper shear box, and compacted by hand tamping to approximately 95% of maximum standard Proctor dry unit weight at optimum moisture content. For test series #5 to 8, AASHTO #57 stone was nominally compacted in the upper shear box under dry conditions;

- A specific normal stress was applied to the test specimen by using dead weight for low normal stress tests (500 psf), or through an air bladder system for high normal stress tests; and

- After the application of the normal stress, the test specimen was sheared at a constant shear displacement rate of 1 mm/min. (0.04 in/min.). Shearing was continued until a minimum total shear displacement of 64 mm (2.5 in.) was achieved.

5. INTERFACE DIRECT SHEAR TEST RESULTS

Eight series of interface direct shear tests were performed in this testing program. For each test series, the test results are presented in a summary page in Appendix B. The summary page includes:

- Shear force versus displacement figure;
- Shear strength versus normal stress figure; and
- A table that summarizes test conditions, peak and residual shear strengths, and direct sliding coefficients at peak and residual shear strengths.

The coefficient of direct sliding (C_{DS}) was calculated using the equation as follows:

$$C_{DS} = \frac{\tau_i}{\sigma_n \tan\phi + c}$$

where:

τ_i	=	peak or residual interface shear strength at σ_n;
σ_n	=	total normal stress applied to the test interface;
ϕ	=	peak or residual total-stress friction angle of soil; and
c	=	peak or residual total-stress cohesion of soil.

The shear strength parameters (ϕ and c) of the silty sand and AASHTO # 57 stone used in calculating direct sliding coefficients were determined from direct shear testing, and are presented in Appendix A.

6. CLOSURE

SGI appreciates the opportunity to provide laboratory testing services to TenCate Geosynthetics. Should you have any questions regarding this report, or if you require additional information, please do not hesitate to contact the undersigned.

Sincerely,

Zehong Yuan, Ph.D., P.E.
Laboratory Manager

Figure 1. 10XT geogrid placed on top of compacted silty sand.

Figure 2. Silty sand placed in the upper shear box on 10XT geogrid.

Figure 3. Silty sand/Miragrid 10XT geogrid contact surface at the compaction of a shear test with geogrid "bonded" to silty sand and "geogrid prints" on silty sand.

APPENDIX A

SUMMARY OF
SOIL PROPERTY TEST RESULTS

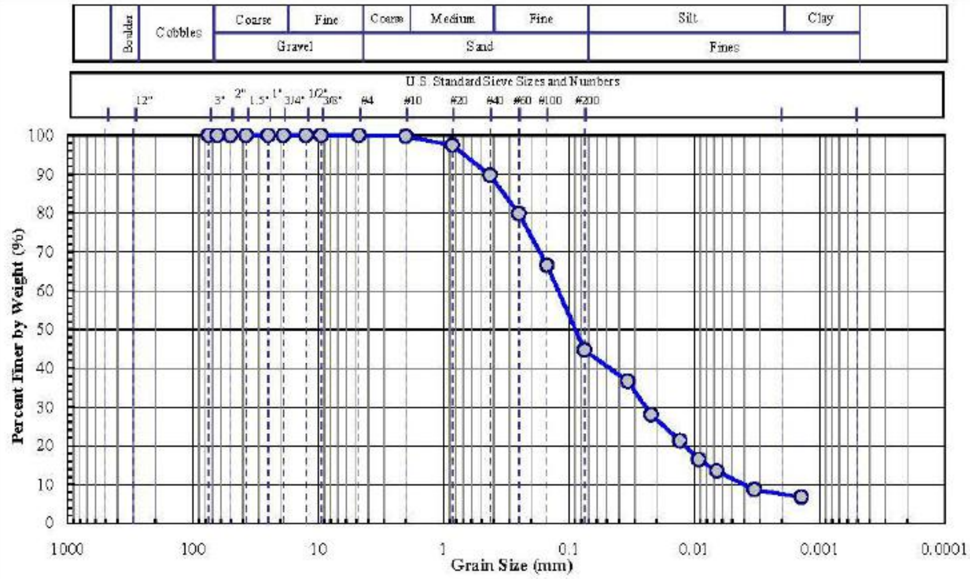
SGI Testing Services, LLC
4405 International Blvd., Suite B-117, Norcross, GA 30093
Ph: (770) 931-8222 Fax: (770) 931-8240

Project Name:	Pullout
Project No:	SGI17008
Client Sample ID:	Silty Sand
Lab Sample No:	S15970

ASTM D 2216, D 1140, D 422, C 136, D 4318, D 2487

SOIL INDEX PROPERTIES

Moisture Content, Grain Size, Atterberg Limits, Classification

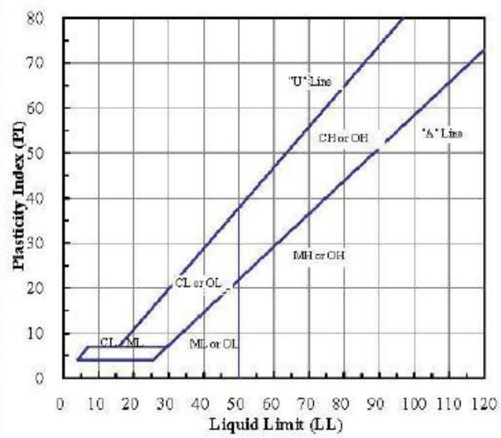


Sieve No.	Size (mm)	% Finer
3"	75	100.0
2"	50	100.0
1.5"	37.5	100.0
1"	25	100.0
3/4"	19	100.0
1/2"	12.5	100.0
3/8"	9.5	100.0
#4	4.75	100.0
#10	2.00	99.7
#20	0.850	97.4
#40	0.425	89.7
#60	0.250	79.8
#100	0.150	66.4
#200	0.075	44.6

Hydrometer Particle Diameter (mm)	% Finer
0.0340	36.6
0.0220	27.9
0.0066	13.5
0.0033	8.7
0.0014	6.7

Gravel (%):	0
Sand (%):	55.4
Fines (%):	44.6
Silt (%):	
Clay (%):	

Coeff. Unif. (Cu):	
Coeff. Curv. (Cc):	



Client Sample ID	Lab Sample No:	Moisture Content (%)	Fines Content < No. 200 (%)	Atterberg Limits LL (%)	Atterberg Limits PL (%)	Atterberg Limits PI (-)	Engineering Classification
Silty Sand	S15970		44.6				SM

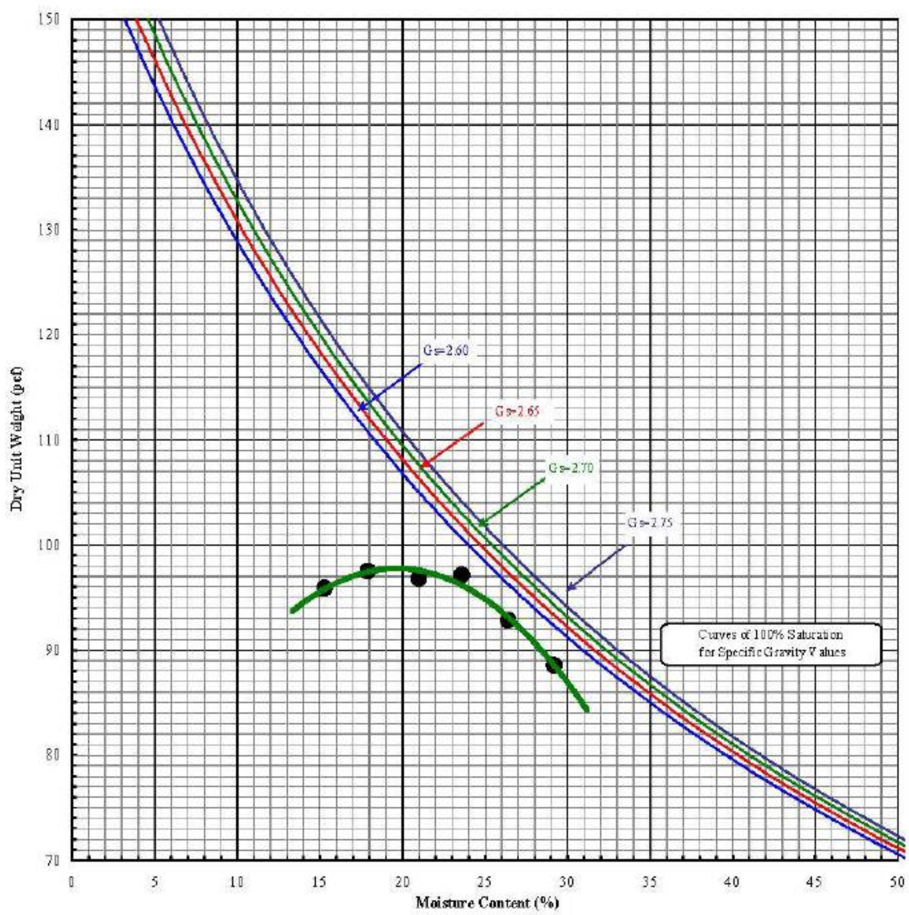
S15970 index.xls

SGI Testing Services, LLC

4405 International Blvd., Suite B-117, Norcross, GA 30093
Ph: (770) 931 8222 Fax: (770) 931 8240

Project Name:	Pullout
Project No:	SGI17008
Client Sample ID:	Silty Sand
Lab Sample No:	S15970

ASTM D698 **COMPACTION MOISTURE-DENSITY RELATIONSHIP** Standard - Method A



Client Sample ID	SGI Sample ID NO.	Compaction Data		Maximum Dry Unit Weight and Optimum Moisture Content			
				Measured		Corrected	
		ω_t (%)	γ_d (pcf)	ω_{om} (%)	γ_{dmax} (pcf)	ω_{om} (%)	γ_{dmax} (pcf)
Silty Sand	S15970	15.3	95.9	20.0	98.0		
		17.9	97.5				
		21.0	96.8				
		23.6	97.1				
		26.4	92.8				
		29.2	88.5				

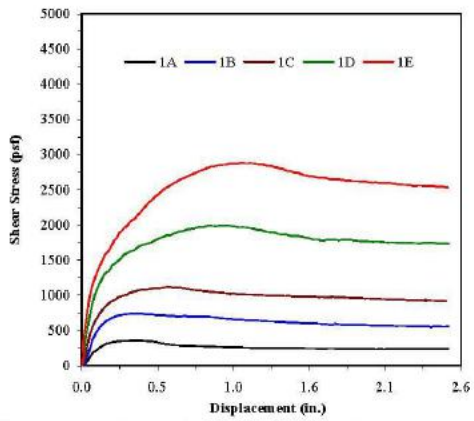
% Retained on #4 Sieve:
% Retained on #3/8" Sieve:
% Retained on 3/4" Sieve:
% Retained on 2.0" Sieve:

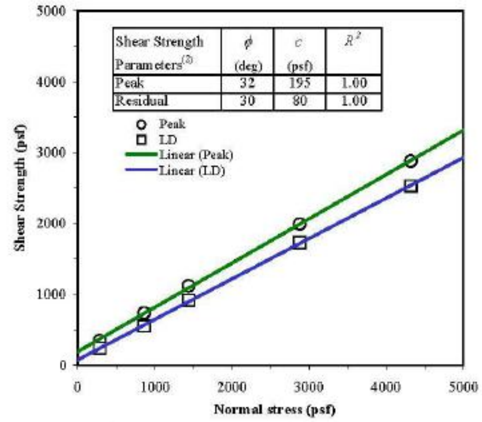
S15970 Compaction.xls

SGI TESTING SERVICES, LLC

DIRECT SHEAR TESTING (ASTM D 3080)

TEST SERIES NO. 1: Internal shear strength of silty sand compacted to approximately 95% of max standard Proctor dry density at OMC (γ_{dmax} = 98 pcf, OMC = 20%, ASTM D 698)





Test No.	Shear Box Size (in. x in.)	Normal Stress (psf)	Shear Rate (in./min)	Soaking (psf)	Soaking (hour)	Consolidation Step 1 (psf)	Step 1 (hour)	Step 2 (psf)	Step 2 (hour)	Step 3 (psf)	Step 3 (hour)	Soil Compaction γ_d (pcf)	ω_i (%)	ω_f (%)	Shear Strength τ_P (psf)	τ_R (psf)	Failure Mode
1A	12 x 12	288	0.04	-	-	288	1.0	-	-	-	-	92.9	20.3		350	240	(1)
1B	12 x 12	864	0.04	-	-	864	1.0	-	-	-	-	93.5	19.5		739	555	
1C	12 x 12	1440	0.04	-	-	1440	1.0	-	-	-	-	93.7	19.2		1120	916	
1D	12 x 12	2880	0.04	-	-	2880	1.0	-	-	-	-	93.3	19.8		1994	1735	
1E	12 x 12	4320	0.04	-	-	4320	1.0	-	-	-	-	93.0	20.1		2882	2531	

NOTES:

(1) Shear failure was forced to occur internally through the soil specimen at the predetermined plane between the upper and lower shear box during each test

(2) The reported total-stress parameters of friction angle and cohesion were determined from a best-fit line drawn through the test data. The residual shear strength was calculated using the shear force measured at the end of the test.

DATE REPORTED:	3/30/2017
FIGURE NO.	A-3
PROJECT NO.	SGI17008
DOCUMENT NO.	
FILE NO.	

SGI TESTING SERVICES, LLC

SGI SM2017.DS.xls

SGI Testing Services, LLC

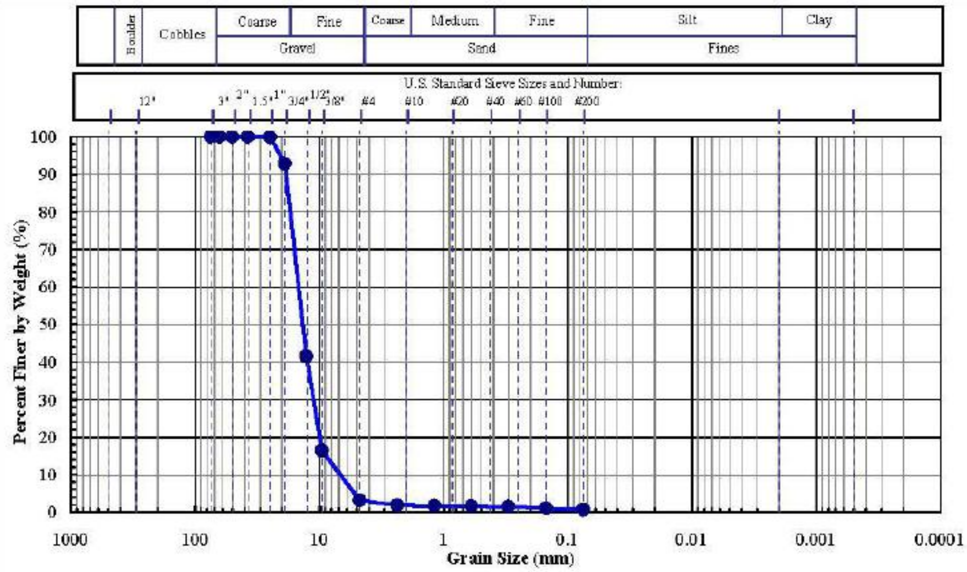
4405 International Blvd., Suite B-117, Norcross, GA 30093
Ph: (770) 931-8222 Fax: (770) 931-8240

Project Name:	Pullout
Project No:	
Client Sample ID:	AASHTO #57 Stone
Lab Sample No:	S21598

ASTM D 2216, D 1140, D 422, C 136, D 4318, D 2487

SOIL INDEX PROPERTIES

Moisture Content, Grain Size, Atterberg Limits, Classification

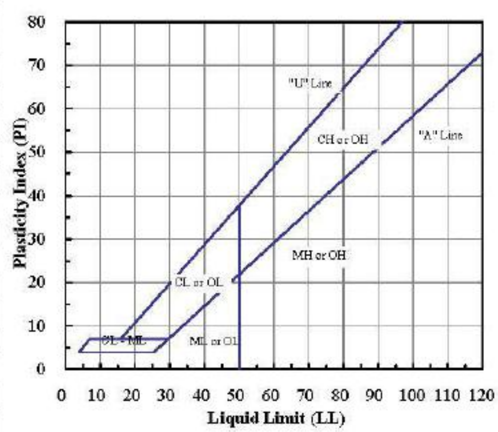


Sieve No.	Size (mm)	% Finer
3"	75	100.0
2"	50	100.0
1.5"	37.5	100.0
1"	25	100.0
3/4"	19	92.8
1/2"	12.5	41.5
3/8"	9.5	16.4
#4	4.75	3.1
#8	2.36	1.9
#16	1.180	1.7
#30	0.600	1.6
#50	0.300	1.4
#100	0.150	1.0
#200	0.075	0.6

Hydrometer Particle Diameter (mm)	% Finer
0.0340	
0.0220	
0.0064	
0.0032	
0.0013	

Gravel (%):	96.9
Sand (%):	2.5
Fines (%):	0.6
Silt (%):	
Clay (%):	

Coeff. Unif. (Cu):	2.2
Coeff. Curv. (Cc):	1.2

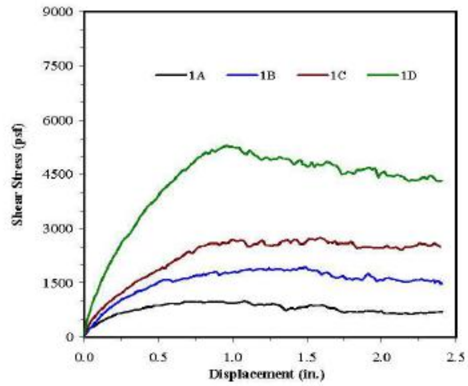


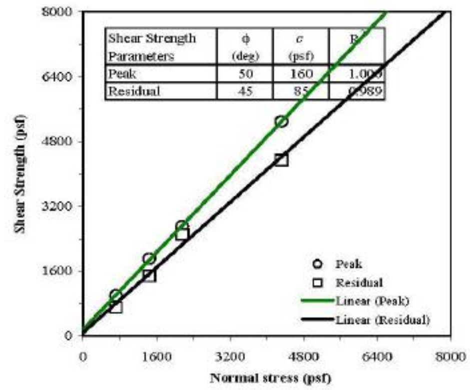
Client Sample ID.	Lab Sample No:	Moisture Content (%)	Fines Content < No. 200 (%)	Atterberg Limits LL (%)	PL (%)	PI (-)	Engineering Classification
AASHTO #57 Stone	S21598		0.6				GP

S21598.GrainSizeRange.xls

SGI TESTING SERVICES, LLC
DIRECT SHEAR TESTING (ASTM D 3080)

AASHTO No. 57 aggregate nominally compacted under dry condition





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in./min)	Soaking Stress (psf)	Soaking Time (hour)	Consolidation Stress (psf)	Consolidation Time (hour)	Initial γ_d (pcf)	Initial RD (%)	Initial ω_i (%)	Initial Gap (mm)	After γ_d (pcf)	After ω_f (%)	Shear Strength τ_P (psf)	Shear Strength τ_R (psf)	Failure Mode
1A	12 x 12	720	0.04	-	-	720	0.5							996	702	(1)
1B	12 x 12	1440	0.04	-	-	1440	0.5							1905	1475	(1)
1C	12 x 12	2160	0.04	-	-	2160	0.5							2705	2502	(1)
1D	12 x 12	4320	0.04	-	-	4320	0.5							5290	4335	(1)

NOTES:
(1) Sliding (i.e., shear failure) was forced to occur along the shear plane between the upper and lower shear box.
(2) The reported total-stress parameters of friction angle and cohesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The residual shear strength was calculated using the shear force measured at the end of the test.

DATE OF REPORT:	6/26/2019
FIGURE NO.	A-5
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

SGI TESTING SERVICES, LLC

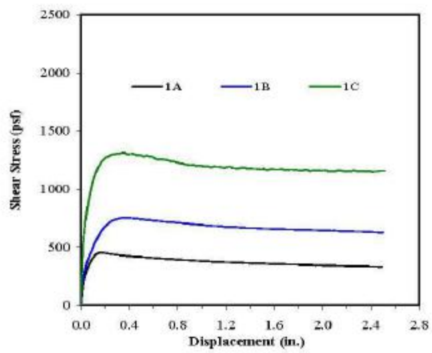
S19028-05R ds.xls

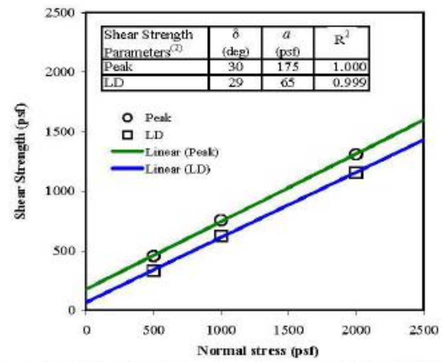
APPENDIX B

SUMMARY OF
INTERFACE DIRECT SHEAR TEST RESULTS

TENCATE GEOSYNTHETICS
INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 3XT geogrid in MD (Lot # 20190331-3-2, direction of shearing parallel to MD) against
Lower Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking		Consolidation		Soil Compaction			Soil Shear Strength Parameters				Shear Strength(1)		Coefficient of Direct Sliding	
				Stress (psf)	Time (hrs)	Stress (psf)	Time (hrs)	γ_d (pcf)	ω_i (%)	ω_f (%)	ϕ_P (deg)	c_P (psf)	ϕ_R (deg)	c_R (psf)	τ_P (psf)	τ_R (psf)	C_{DSP}	C_{DSR}
1A	12 x 12	500	0.04	-	-	500	24	92.9	20.3	-	32	195	30	80	455	332	0.90	0.90
1B	12 x 12	1000	0.04	-	-	1000	24	93.5	19.5	-					755	625	0.92	0.95
1C	12 x 12	2000	0.04	-	-	2000	24	93.6	19.3	-					1311	1155	0.91	0.94

NOTE:
(1) Sliding (i.e., shear failure) occurred at the soil-geogrid interface in each test.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

SGI TESTING SERVICES, LLC

DATE OF REPORT:	10/24/2019
FIGURE NO.	B-1
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

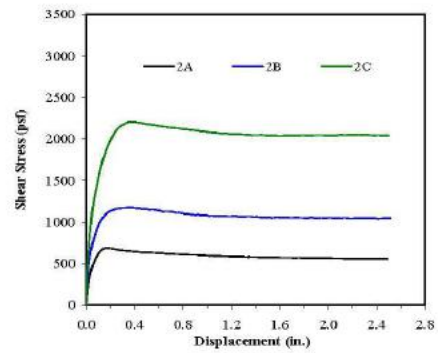
SGI19008-1RR.ds.xls

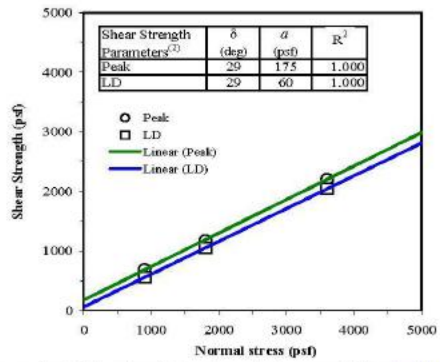
TENCATE GEOSYNTHETICS

INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 8XT geogrid in MD (Lot # 20190808-1-2, direction of shearing parallel to MD) against

Lower Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size	Normal Stress	Shear Rate	Soaking		Consolidation		Soil Compaction			Soil Shear Strength Parameters				Shear Strength[1]		Coefficient of Direct Sliding	
				Stress	Time	Stress	Time	γ_d	ω_i	ω_f	ϕ_P	c_P	ϕ_R	c_R	τ_P	τ_R		
	(in x in)	(psf)	(in/min)	(psf)	(hrs)	(psf)	(hrs)	(pcf)	(%)	(%)	(deg)	(psf)	(deg)	(psf)	(psf)	(psf)	C_{DSP}	C_{DSR}
2A	12 x 12	900	0.04	-	-	900	24	93.6	19.4	-					690	556	0.91	0.93
2B	12 x 12	1800	0.04	-	-	1800	24	93.2	19.9	-	32	195	30	80	1176	1050	0.89	0.94
2C	12 x 12	3600	0.04	-	-	3600	24	93.0	20.1	-					2205	2042	0.90	0.95

NOTE:

(1) Sliding (i.e., shear failure) occurred at the soil-geogrid interface in each test.

(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

SGI TESTING SERVICES, LLC

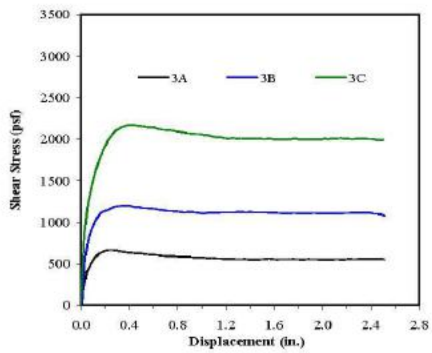
DATE OF REPORT:	10/24/2019
FIGURE NO.	B-2
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

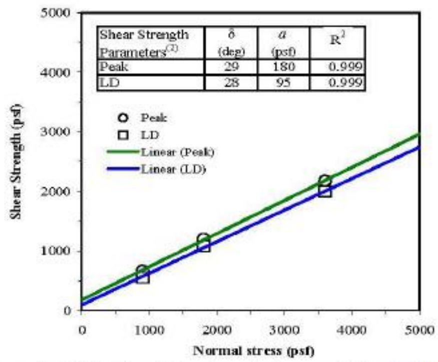
SGI19008-2RR.ds.xls

TENCATE GEOSYNTHETICS

INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 10XT geogrid in MD (Lot # 20190429-2-1, direction of shearing parallel to MD) against
Lower Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking Stress (psf)	Soaking Time (hrs)	Consolidation Stress (psf)	Consolidation Time (hrs)	Soil Compaction γ_d (pcf)	Soil Compaction ω_i (%)	Soil Compaction ω_f (%)	Soil Shear Strength Parameters ϕ_P (deg)	c_P (psf)	ϕ_R (deg)	c_R (psf)	Shear Strength(1) τ_P (psf)	τ_R (psf)	Coefficient of Direct Sliding C_{DSP}	C_{DSR}
3A	12 x 12	900	0.04	-	-	900	24	93.0	20.1	-	32	195	30	80	665	555	0.88	0.93
3B	12 x 12	1800	0.04	-	-	1800	24	92.8	20.4	-					1201	1079	0.91	0.96
3C	12 x 12	3600	0.04	-	-	3600	24	93.5	19.5	-					2175	1995	0.89	0.92

NOTE:
(1) Sliding (i.e., shear failure) occurred at the soil-geogrid interface in each test.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

DATE OF REPORT:	10/24/2019
FIGURE NO.	B-3
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

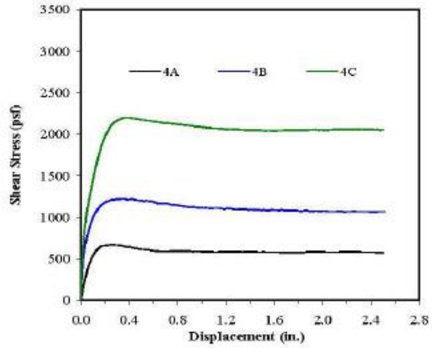
SGI TESTING SERVICES, LLC

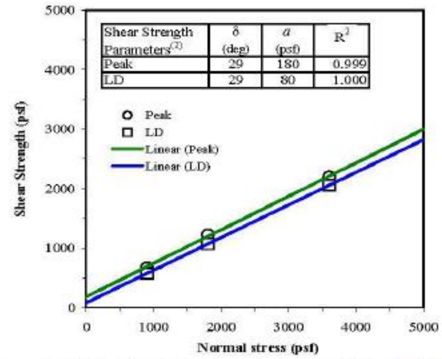
SGI19008-3RR.ds.xls

TENCATE GEOSYNTHETICS

INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 20XT geogrid in MD (Lot # 20190220-1-2, direction of shearing parallel to MD) against
Lower Shear Box: Silty sand compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking Stress (psf)	Soaking Time (hrs)	Consolidation Stress (psf)	Consolidation Time (hrs)	Soil Compaction γ_d (pcf)	Soil Compaction ω_i (%)	Soil Compaction ω_f (%)	Soil Shear Strength Parameters ϕ_P (deg)	c_P (psf)	ϕ_R (deg)	c_R (psf)	Shear Strength[1] τ_P (psf)	τ_R (psf)	Coefficient of Direct Sliding C_{DSP}	C_{DSR}
4A	12 x 12	900	0.04	-	-	900	24	93.7	19.2	-	32	195	30	80	670	572	0.89	0.95
4B	12 x 12	1800	0.04	-	-	1800	24	94.0	18.9	-					1224	1070	0.93	0.96
4C	12 x 12	3600	0.04	-	-	3600	24	93.4	19.6	-					2200	2055	0.90	0.95

NOTE:
(1) Sliding (i.e., shear failure) occurred at the soil-geogrid interface in each test.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

SGI TESTING SERVICES, LLC

DATE OF REPORT:	10/24/2019
FIGURE NO.	B-4
PROJECT NO.	SGI19008
DOCUMENT NO.	
FILE NO.	

SGI19008-4RR.ds.xls

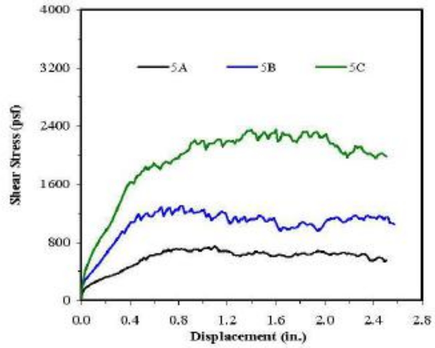
REDI-ROCK

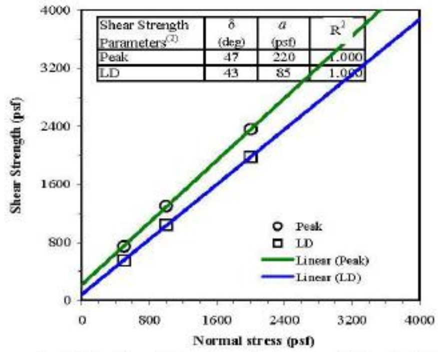
TENCATE GEOSYNTHETICS

INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 3XT geogrid (Lot # 20190331-3-2, direction of shearing parallel to MD) against

Lower Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking Stress (psf)	Soaking Time (hrs)	Consolidation Stress (psf)	Consolidation Time (hrs)	Soil Compaction γ_d (pcf)	Soil Compaction ω_i (%)	Soil Compaction ω_f (%)	Soil Shear Strength Parameters ϕ_P (deg)	c_P (psf)	ϕ_R (deg)	c_R (psf)	Shear Strength(1) τ_P (psf)	τ_R (psf)	Coefficient of Direct Sliding C_{DSP}	C_{DSR}
5A	12 x 12	500	0.04	-	-	500	0.5			-	50	160	45	85	745	550	0.99	0.94
5B	12 x 12	1000	0.04	-	-	1000	0.5			-					1300	1042	0.96	0.96
5C	12 x 12	2000	0.04	-	-	2000	0.5			-					2355	1975	0.93	0.95

NOTE:

(1) Sliding (i.e., shear failure) occurred at the gravel-geogrid interface in each test.

(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

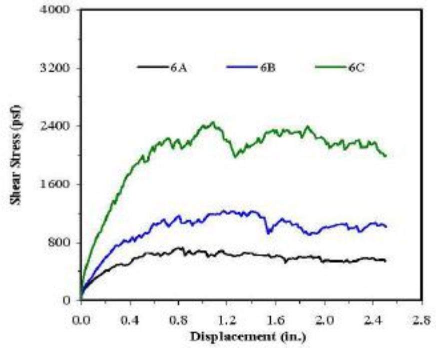
SGI TESTING SERVICES, LLC

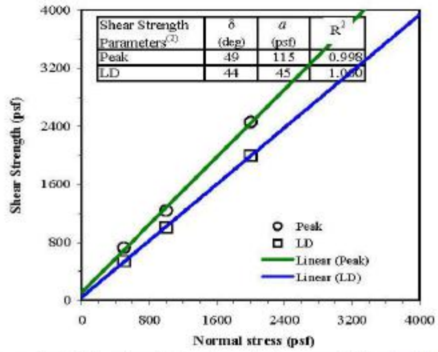
DATE OF REPORT:	10/24/2019
FIGURE NO.	B-5
PROJECT NO.	SGI19007
DOCUMENT NO.	
FILE NO.	

SGI19008-5 RR.ds.xls

TENCATE GEOSYNTHETICS
INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 8XT geogrid (Lot # 20190808-1-2, direction of shearing parallel to MD) against
Lower Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking Stress (psf)	Soaking Time (hrs)	Consolidation Stress (psf)	Consolidation Time (hrs)	Soil Compaction γ_d (pcf)	Soil Compaction ω_i (%)	Soil Compaction ω_f (%)	Soil Shear Strength Parameters ϕ_P (deg)	c_P (psf)	ϕ_R (deg)	c_R (psf)	Shear Strength(1) τ_P (psf)	τ_R (psf)	Coefficient of Direct Sliding C_{DSP}	C_{DSR}
6A	12 x 12	500	0.04	-	-	500	0.5			-	50	160	45	85	725	540	0.96	0.92
6B	12 x 12	1000	0.04	-	-	1000	0.5			-					1235	1006	0.91	0.93
6C	12 x 12	2000	0.04	-	-	2000	0.5			-					2455	1995	0.97	0.96

NOTE:
(1) Sliding (i.e., shear failure) occurred at the gravel-geogrid interface in each test.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

SGI TESTING SERVICES, LLC

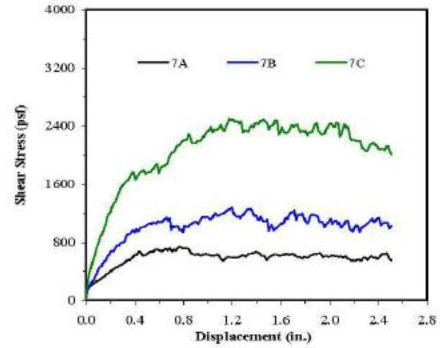
DATE OF REPORT:	10/24/2019
FIGURE NO.	B-6
PROJECT NO.	SGI19007
DOCUMENT NO.	
FILE NO.	

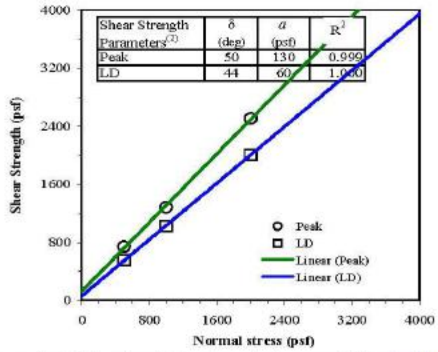
SGI19008-6RR.ds.xls

TENCATE GEOSYNTHETICS

INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 10XT geogrid (Lot # 20190429-2-1, direction of shearing parallel to MD) against
Lower Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking Stress (psf)	Soaking Time (hrs)	Consolidation Stress (psf)	Consolidation Time (hrs)	Soil Compaction γ_d (pcf)	Soil Compaction ω_i (%)	Soil Compaction ω_f (%)	Soil Shear Strength Parameters ϕ_P (deg)	c_P (psf)	ϕ_R (deg)	c_R (psf)	Shear Strength(1) τ_P (psf)	τ_R (psf)	Coefficient of Direct Sliding C_{DSP}	C_{DSR}
7A	12 x 12	500	0.04	-	-	500	0.5			-	50	160	45	85	740	552	0.98	0.94
7B	12 x 12	1000	0.04	-	-	1000	0.5			-					1281	1026	0.95	0.95
7C	12 x 12	2000	0.04	-	-	2000	0.5			-					2505	2007	0.99	0.96

NOTE:
(1) Sliding (i.e., shear failure) occurred at the gravel-geogrid interface in each test.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

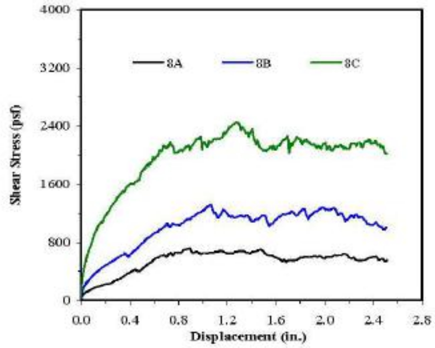
DATE OF REPORT:	10/24/2019
FIGURE NO.	B-7
PROJECT NO.	SGI19007
DOCUMENT NO.	
FILE NO.	

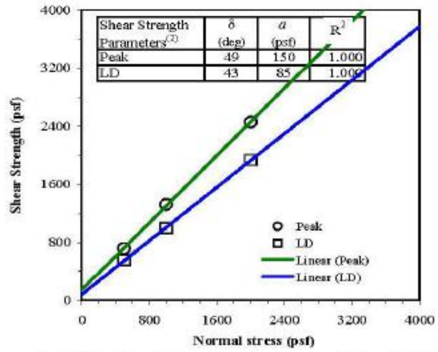
SGI TESTING SERVICES, LLC

SGI19008-7RR.ds.xls

TENCATE GEOSYNTHETICS
INTERFACE DIRECT SHEAR TESTING (ASTM D 5321)

Upper Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content against Miragrid 20XT geogrid (Lot # 20190220-1-2, direction of shearing parallel to MD) against
Lower Shear Box: AASHTO #57 stone compacted to approximately 95% of max standard Proctor density at optimum moisture content





Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking Stress (psf)	Soaking Time (hrs)	Consolidation Stress (psf)	Consolidation Time (hrs)	Soil Compaction γ_d (pcf)	Soil Compaction ω_i (%)	Soil Compaction ω_f (%)	Soil Shear Strength Parameters ϕ_P (deg)	c_P (psf)	ϕ_R (deg)	c_R (psf)	Shear Strength(1) τ_P (psf)	τ_R (psf)	Coefficient of Direct Sliding C_{DSP}	C_{DSR}
8A	12 x 12	500	0.04	-	-	500	0.5			-	50	160	45	85	715	552	0.95	0.94
8B	12 x 12	1000	0.04	-	-	1000	0.5			-					1322	1000	0.98	0.92
8C	12 x 12	2000	0.04	-	-	2000	0.5			-					2455	1933	0.97	0.93

NOTE:
(1) Sliding (i.e., shear failure) occurred at the gravel-geogrid interface in each test.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

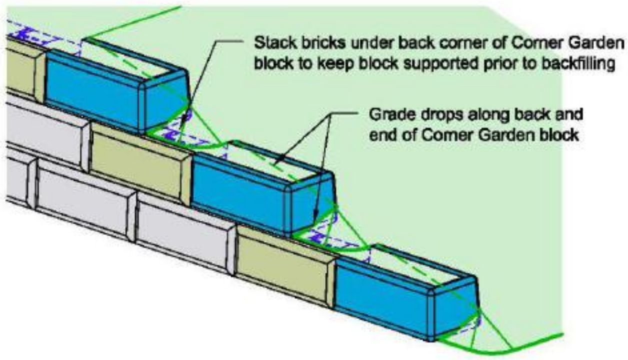
SGI TESTING SERVICES, LLC

DATE OF REPORT:	10/24/2019
FIGURE NO.	B-8
PROJECT NO.	SGI19007
DOCUMENT NO.	
FILE NO.	

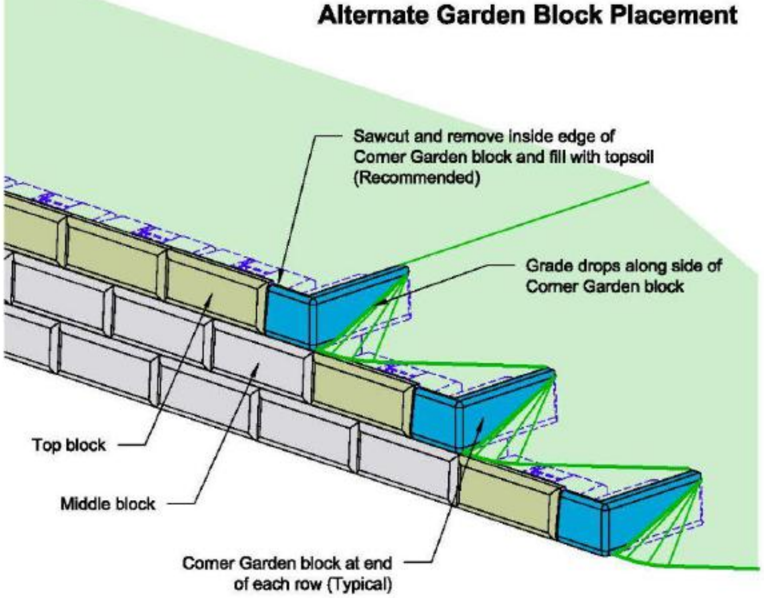
SGI19008-8RR.ds.xls

APPENDIX: 1.3.4 COPING OPTIONS

Top of Wall Step Options



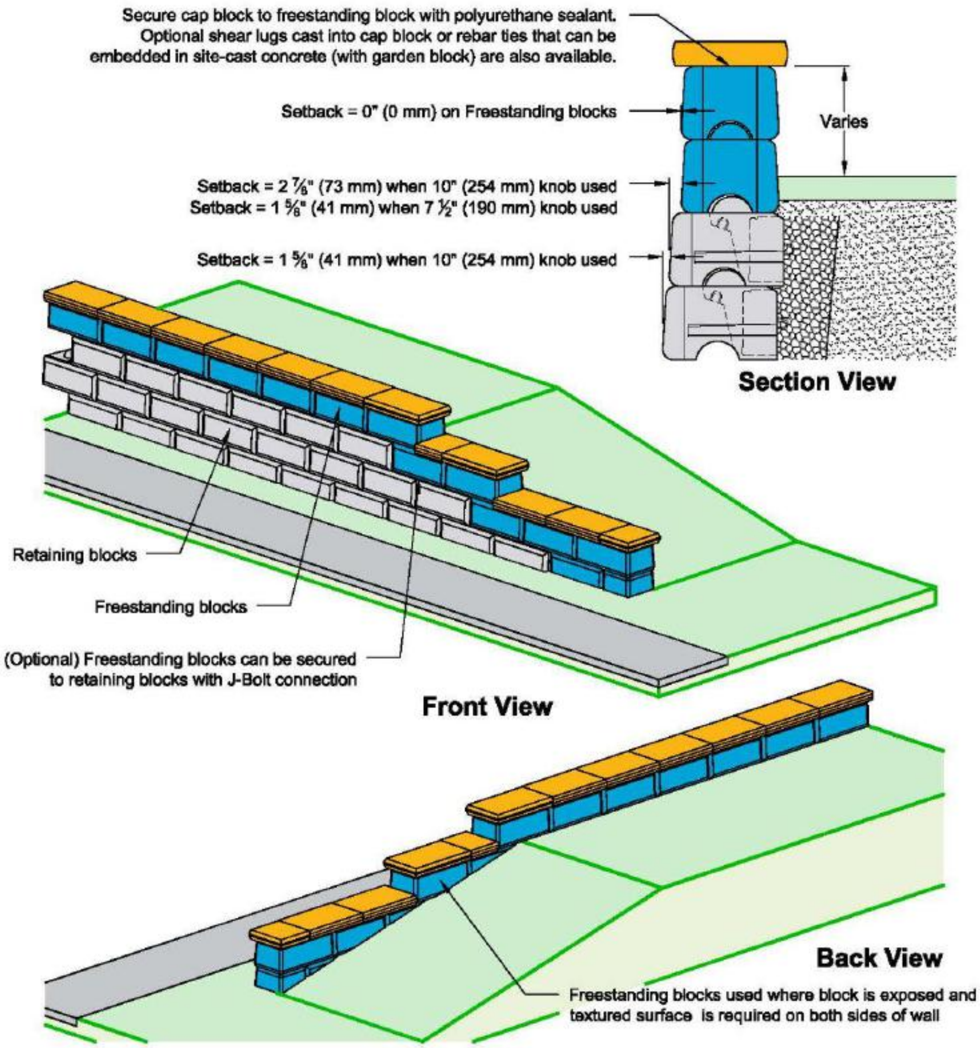
Alternate Garden Block Placement



This drawing is for reference only. Determination of the suitability and/or manner of use of any details contained in this document is the sole responsibility of the design engineer of record. Final project designs, including all construction details, shall be prepared by a licensed professional engineer using the actual conditions of the proposed site.

DRAWN BY:	JRJ	TITLE: Top of Wall Step Options	REDI-ROCK 05481 US 31 SOUTH, CHARLEVOIX, MI 49720 (866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com
APPROVED BY:	JRJ		
DATE:	06-22-2015		
SHEET:	1 of 1	FILE: 1 Top of Wall Step Options 062215.dwg	

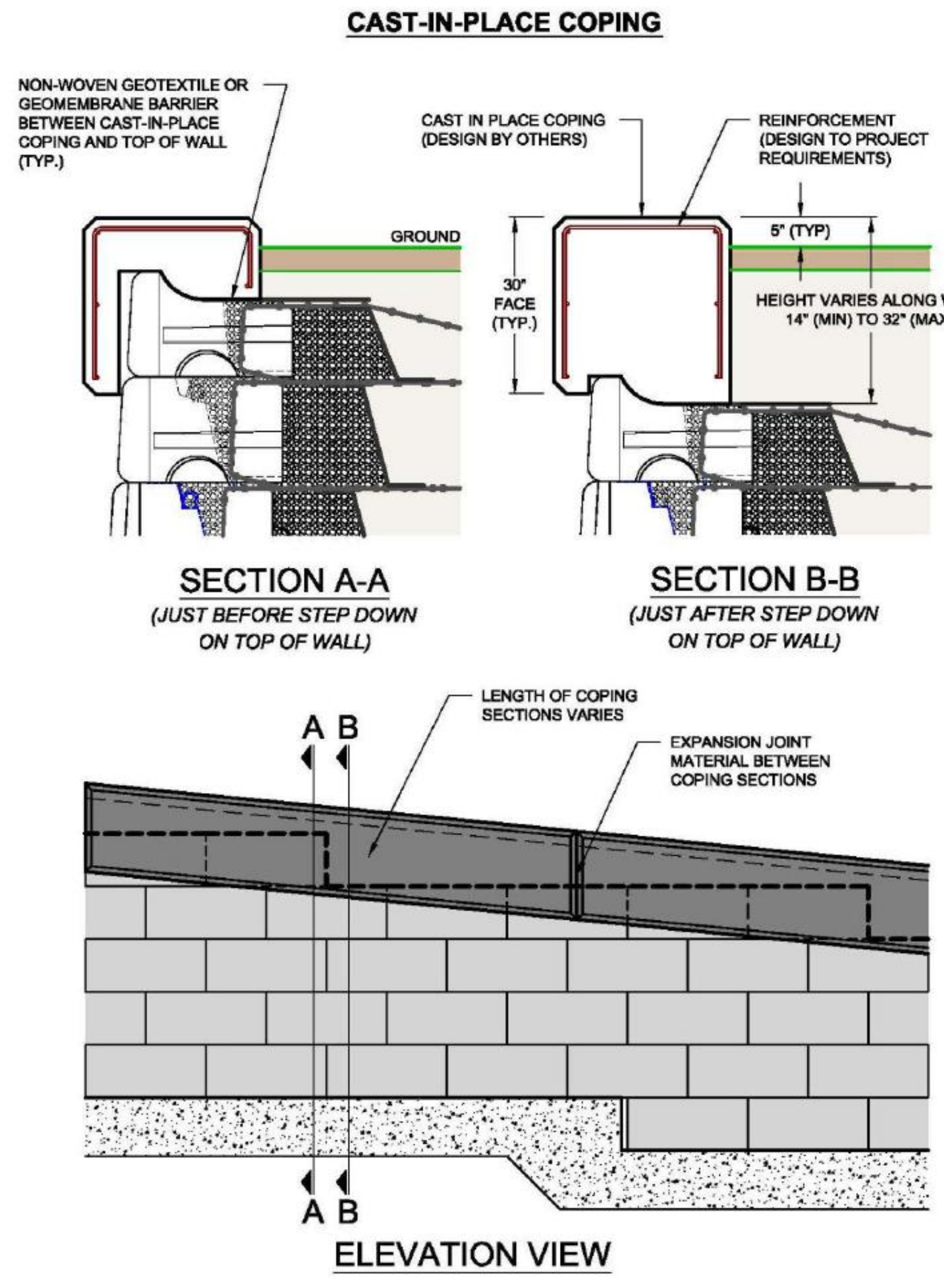
Freestanding Blocks with Cap at Top of Wall



One-component, highly flexible, non-priming, gun grade, high performance elastomeric polyurethane sealant shall have movement of plus or minus 25% per ASTM C719, tensile strength greater than 200 psi (1.4 MPa) per ASTM D412, and adhesion to peel on concrete greater than 20 PLI per ASTM C794. Apply sealant in one and one half-inch (1.5") (38 mm) diameter round "hersey kiss" shaped dollops located in two rows at the top of the Freestanding blocks at 8" (203 mm) on center.

This drawing is for reference only. Determination of the suitability and/or manner of use of any details contained in this document is the sole responsibility of the design engineer of record. Final project designs, including all construction details, shall be prepared by a licensed professional engineer using the actual conditions of the proposed site.

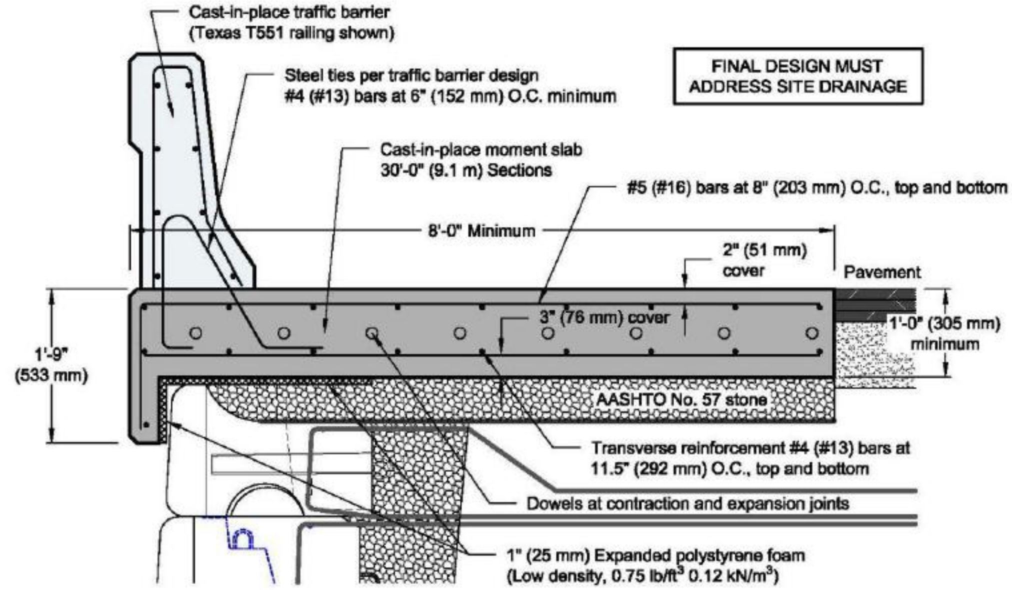
DRAWN BY:	JRJ	TITLE: Freestanding Blocks with Cap at Top of Wall	REDI-ROCK 05481 US 31 SOUTH, CHARLEVOIX, MI 49720 (866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com
APPROVED BY:	JRJ		
DATE:	06-22-2015		
SHEET:	1 of 1	FILE: 3 Freestanding Blocks with Cap at Top of Wall 062215.dwg	



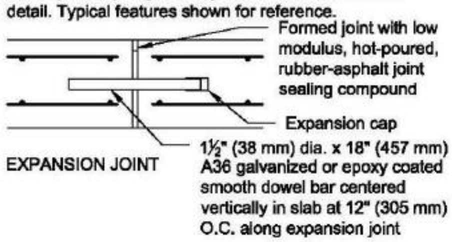
DRAWN BY:	JRJ	TITLE: Cast-In-Place Wall Coping	REDI-ROCK 05481 US 31 SOUTH, CHARLEVOIX, MI 49720 (866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com
APPROVED BY:	JRJ		
DATE:	06-22-2015		
SHEET:	1 of 1	FILE: 11 Cast-In-Place Wall Coping 062215.dwg	

APPENDIX: 1.3.5 TRAFFIC BARRIERS

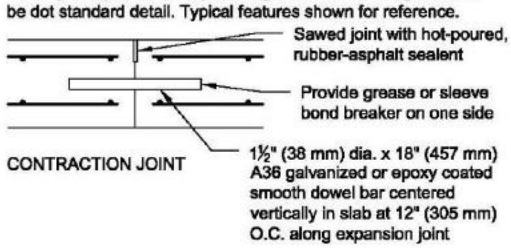
Cast-in-Place Moment Slab Traffic Barrier - Flat Grade Installation



Expansion joints shall be provided in moment slab every 90'-0" (27.4 m). Expansion joint shall be dot standard detail. Typical features shown for reference.



Contraction joints shall be provided in moment slab every 30'-0" (9.1 m) between expansion joints. Contraction joint shall be dot standard detail. Typical features shown for reference.



Materials
Concrete for cast-in-place barrier and moment slab shall be dot standard structure mix. Minimum 28 day compressive strength shall be 4,000 psi (27.6 mpa) or higher as specified. Reinforcing steel shall conform to ASTM A706 or AASHTO M31 Grade 60 (420 MPa).

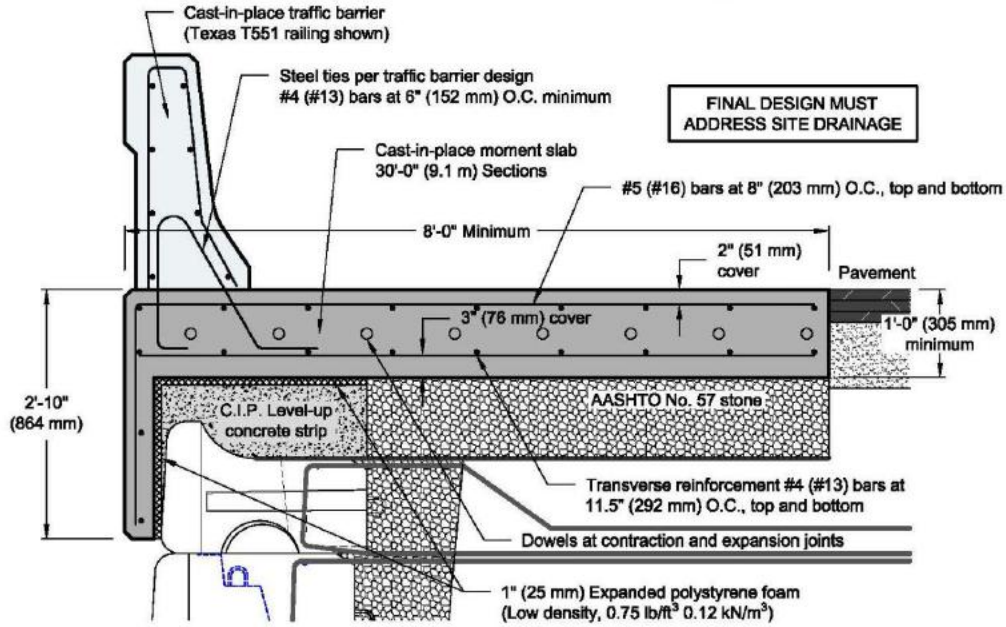
Design
Moment slab shown is dimensioned based on an equivalent static load of 10,000 lbs (44.5 kN) per NCHRP Report 663. Moment slab reinforcement shown is based on *AASHTO LRFD Bridge Design Specifications, 5th edition, 2010*, TL-4 loading detailed in Table A13.2.1.

The selection and use of this detail, while designed in accordance with generally accepted engineering principles and practices, is the sole responsibility of the registered professional engineer in charge of the project.

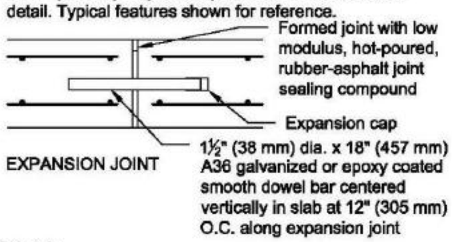
This drawing is for reference only. Determination of the suitability and/or manner of use of any details contained in this document is the sole responsibility of the design engineer of record. Final project designs, including all construction details, shall be prepared by a licensed professional engineer using the actual conditions of the proposed site.

DRAWN BY:	JRJ	TITLE: Cast-In-Place Moment Slab Traffic Barrier - Flat Grade	REDI-ROCK 05481 US 31 SOUTH, CHARLEVOIX, MI 49720 (866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com
APPROVED BY:	JRJ		
DATE:	06-22-2015		
SHEET:	1 of 1	FILE: 9 Cast-In-Place Moment Slab Traffic Barrier - Flat 062215.dwg	

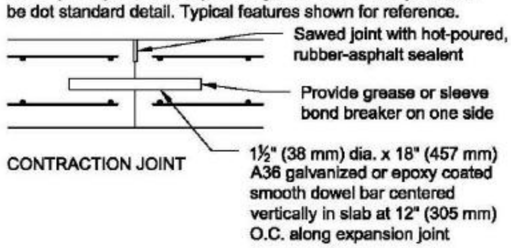
Cast-in-Place Moment Slab Traffic Barrier - Sloping Installation



Expansion joints shall be provided in moment slab every 90'-0" (27.4 m). Expansion joint shall be dot standard detail. Typical features shown for reference.



Contraction joints shall be provided in moment slab every 30'-0" (9.1 m) between expansion joints. Contraction joint shall be dot standard detail. Typical features shown for reference.



Materials

Concrete for cast-in-place barrier and moment slab shall be dot standard structure mix. Minimum 28 day compressive strength shall be 4,000 psi (27.6 mpa) or higher as specified. Cast-In-Place level up concrete shall be manufactured in accordance with ASTM C94. Minimum 28 day compressive strength shall be 3,500 psi (24.1 MPa) or higher as specified. Reinforcing steel shall conform to ASTM A706 or AASHTO M31 Grade 60 (420 MPa).

Design

Moment slab shown is dimensioned based on an equivalent static load of 10,000 lbs (44.5 kN) per NCHRP Report 663. Moment slab reinforcement shown is based on *AASHTO LRFD Bridge Design Specifications, 5th edition, 2010*, TL-4 loading detailed in Table A13.2.1.

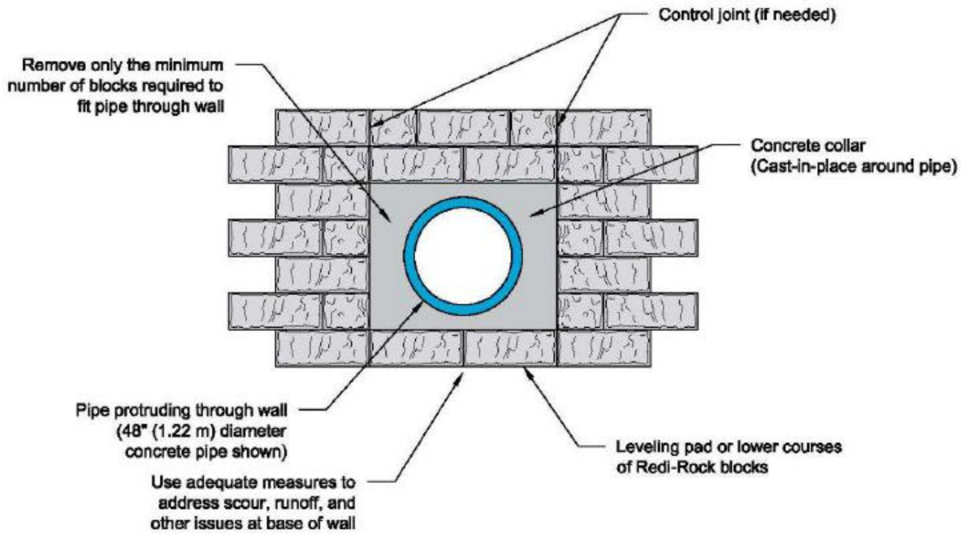
The selection and use of this detail, while designed in accordance with generally accepted engineering principles and practices, is the sole responsibility of the registered professional engineer in charge of the project.

This drawing is for reference only. Determination of the suitability and/or manner of use of any details contained in this document is the sole responsibility of the design engineer of record. Final project designs, including all construction details, shall be prepared by a licensed professional engineer using the actual conditions of the proposed site.

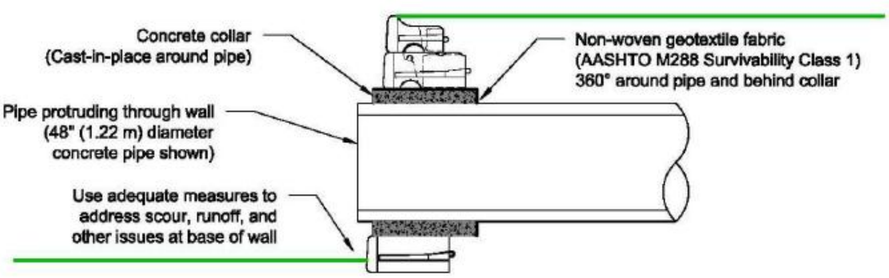
DRAWN BY:	JRJ	TITLE: Cast-In-Place Moment Slab Traffic Barrier - Sloping Grade	REDI-ROCK
APPROVED BY:	JRJ		05481 US 31 SOUTH, CHARLEVOIX, MI 49720
DATE:	06-22-2015		(866) 222-8400 ext 3010 • engineering@redi-rock.com
SHEET:	1 of 1	FILE: 10 CIP Moment Slab Traffic Barrier - Sloping 062215.dwg	www.redi-rock.com

APPENDIX: 1.3.6 SLIP JOINTS

Pipes Installed Perpendicular Through Wall



Plan View



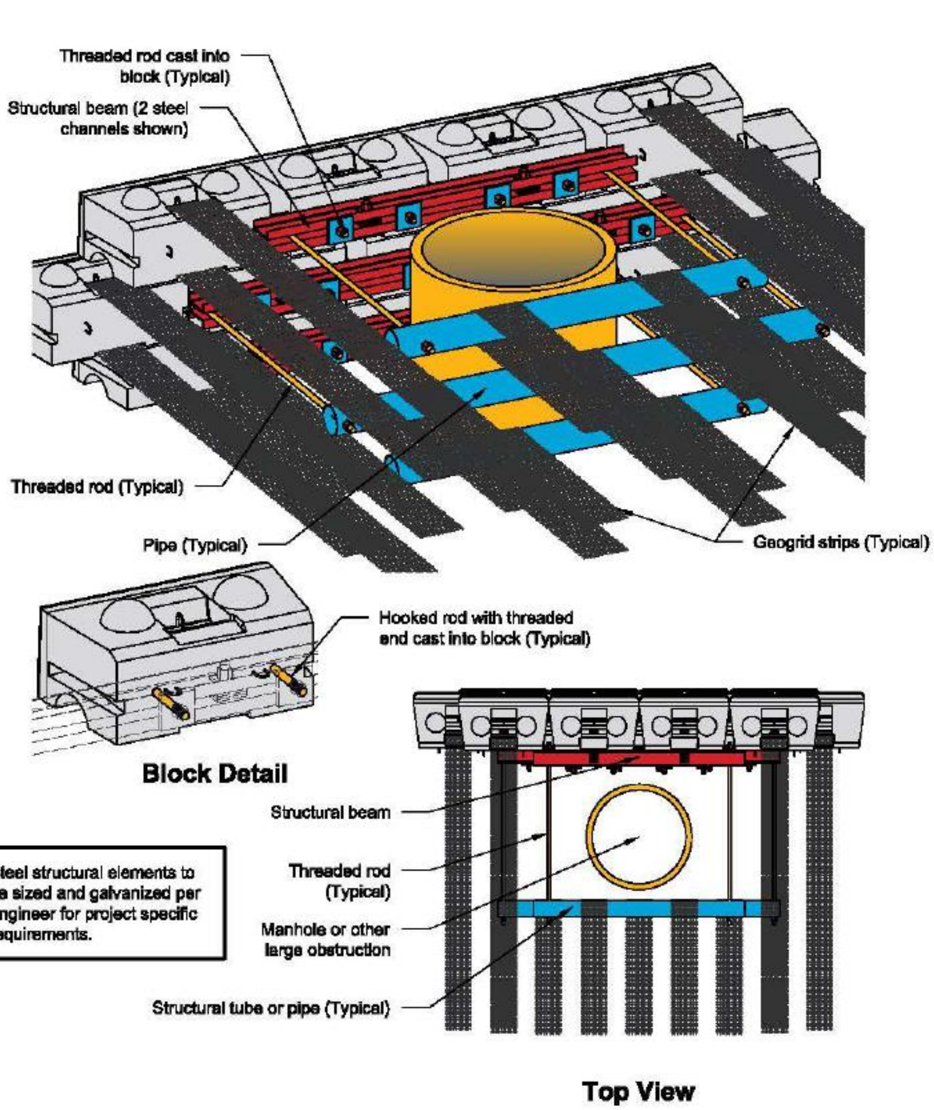
Section View

This drawing is for reference only. Determination of the suitability and/or manner of use of any details contained in this document is the sole responsibility of the design engineer of record. Final project designs, including all construction details, shall be prepared by a licensed professional engineer using the actual conditions of the proposed site.

DRAWN BY:	JRJ	TITLE: Pipes Installed Perpendicular Through Wall	REDI-ROCK 05481 US 31 SOUTH, CHARLEVOIX, MI 49720 (866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com
APPROVED BY:	JRJ		
DATE:	06-22-2015		
SHEET:	1 of 1	FILE: 1 Pipe Installed Perpendicular Through Wall 062215.dwg	

APPENDIX: 2.1.3 OBSTRUCTIONS

Manhole or Large Obstruction in Reinforced Soil Zone



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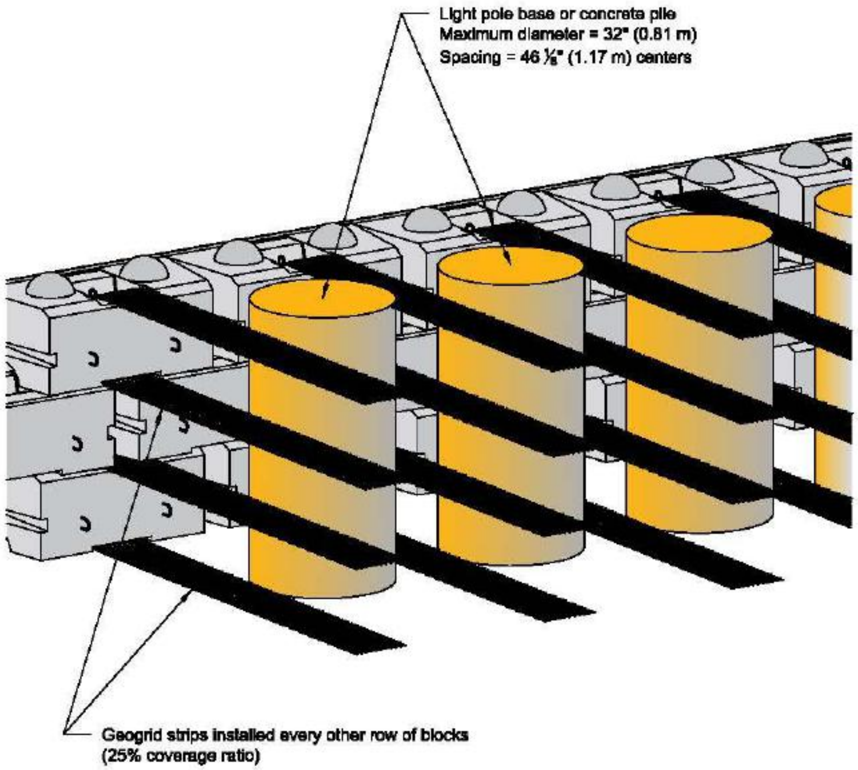
DRAWN BY:	JRJ	TITLE: Manhole or Large Obstruction in Reinforced Soil Zone	REDI-ROCK 05481 US 31 SOUTH, CHARLEVOIX, MI 49720 (866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com
APPROVED BY:	JRJ		
DATE:	06-22-2015		
SHEET:	1 of 1	FILE: 5 Manhole in Reinforced Soil Zone 062215.dwg	

Light Pole Base or Concrete Pile in Reinforced Soil Zone

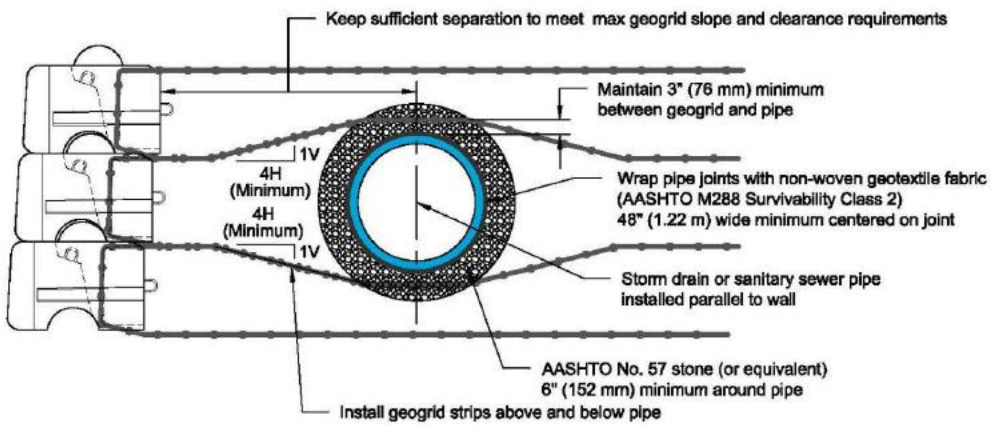


3D View from Back

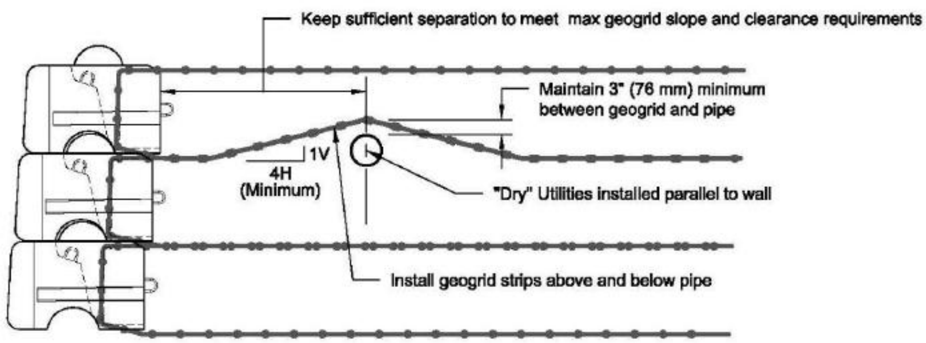
This drawing is for reference only. Determination of the suitability and/or manner of use of any details contained in this document is the sole responsibility of the design engineer of record. Final project designs, including all construction details, shall be prepared by a licensed professional engineer using the actual conditions of the proposed site.

DRAWN BY:	JRJ	TITLE: Vertical Concrete Pile in Reinforced Soil Zone	REDI-ROCK 05481 US 31 SOUTH, CHARLEVOIX, MI 49720 (866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com
APPROVED BY:	JRJ		
DATE:	06-22-2015		
SHEET:	1 of 1	FILE: 4 Vertical Concrete Pile In Reinforced Soil Zone 062215.dwg	

Utilities in the Reinforced Soil Zone



Storm or Sanitary Sewer Pipe



"Dry" Utilities (Electric, Gas, Telecommunications)

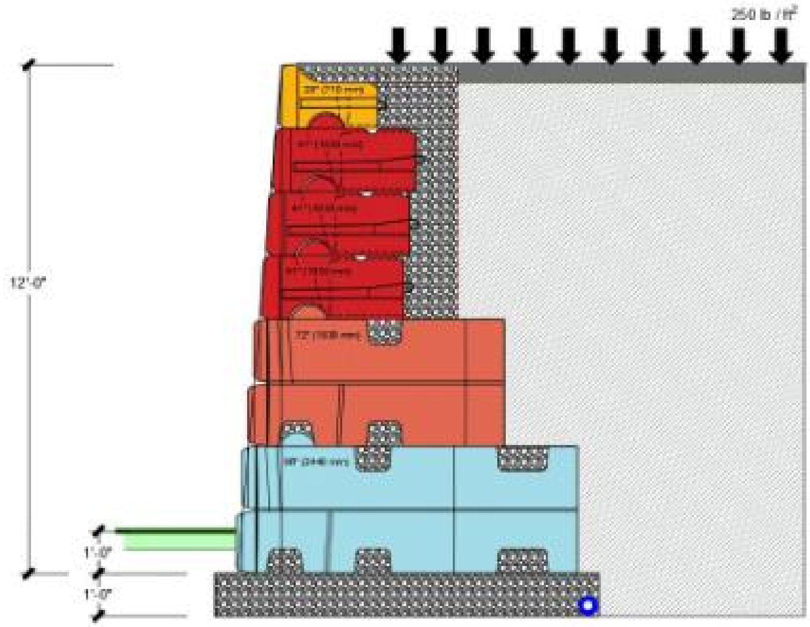
Redi-Rock International follows the recommendations of FHWA GEC 011 and discourages placing pipes or other horizontal obstructions behind the wall in the reinforced soil zone. Placing pipes in this zone could lead to maintenance problems and potential wall failure.

This drawing is for reference only. Determination of the suitability and/or manner of use of any details contained in this document is the sole responsibility of the design engineer of record. Final project designs, including all construction details, shall be prepared by a licensed professional engineer using the actual conditions of the proposed site.

DRAWN BY:	JRJ	TITLE: Utilities in Reinforced Soil Zone	REDI-ROCK
APPROVED BY:	JRJ		
DATE:	06-22-2015		05481 US 31 SOUTH, CHARLEVOIX, MI 49720
SHEET:	1 of 1	FILE: 3 Utilities in Reinforced Soil Zone 062215.dwg	(866) 222-8400 ext 3010 • engineering@redi-rock.com www.redi-rock.com

APPENDIX: 2.2.1 GRAVITY WALL EXAMPLE CALCULATIONS

IDEA PROGRAM PMB GRAVITY WALL SYSTEM SUBMITTAL SECTION 2.2
ERS DESIGN EXAMPLE
PROBLEM 1



WALL PROPERTIES

$h := 12\ ft$

$h_{emb} := 1\ ft$

$\omega := 5.14\ deg$

$\beta := 0\ deg$

LIVE LOAD SURCHARGE

$q_{LL} := 250\ \frac{lb}{ft^2}$

RETAINED SOIL

$\gamma_r := 135\ \frac{lb}{ft^3}$

$\phi_r := 34\ deg$

$\delta_r := 25.5\ deg$

$C_r := 0\ \frac{lb}{ft^2}$

FOUNDATION SOIL

$\gamma_f := 125\ \frac{lb}{ft^3}$

$\phi_f := 30\ deg$

$\delta_f := 20\ deg$

$C_f := 0\ \frac{lb}{ft^2}$

INFILL/LEVELING PAD SOIL

$\gamma_d := 100\ \frac{lb}{ft^3}$

$\phi_d := 40\ deg$

$\delta_d := 26.67\ deg$

DESIGN METHODOLOY: FHWA / AASHTO BRIDGE DESIGN MANUAL

DESIGN CONDITION: STRENGTH I

LOAD FACTORS

$\gamma_{EH\_min} := 0.9$ Horizontal Earth Pressure - Active

$\gamma_{EH\_max} := 1.5$

$\gamma_{EV\_min} := 1.0$ Vertical Earth Pressure

$\gamma_{EV\_max} := 1.35$

$\gamma_{LS} := 1.75$ Live Load Surcharge

RESISTANCE FACTORS

$\varphi_f := 0.9$ Sliding (Block on LP and LP on foundation soil.)

Overturning: Use 80% of block infill weight.

EXTERNAL STABILITY

FINDING THE WEIGHT OF THE WALL

- The weight of the wall and the location of the center of gravity is based on the average infilled unit weight for each block size.
- Although this wall will require the construction of a leveling pad from a crushed aggregate, it will not be included as part of the stability analysis. It's properties in terms of weight and internal angle of friction will not be used in the resistance components for sliding and overturning.
- The back of the wall is defined starting a the back of the first block and then drawing a line from the top back of this block to the top back of the last (top) block. This allows for some soil wedges that sit on top of the retained structure to be included in the weight calculations.

BLOCK NAME	BLOCK No.	HEIGHT (ft)	WIDTH (ft)	AREA[a] (ft^2)	INF UNIT WEIGHT[b] (pcf)	WEIGHT[c] (lb/ft)	COGx (ft)	COGz (ft)
R-28T	6	1.5	2.312	3.5	110	385	2.101	11.25
R-41M	5	1.5	3.375	5.063	123.86	627.041	2.479	9.75
R-41M	4	1.5	3.375	5.063	123.86	627.041	2.343	8.25
R-41M	3	1.5	3.375	5.063	123.86	627.041	2.208	6.75
R-7236HC	2	3	6	18	113.77	2047.86	3.209	4.5
R-9636HC	1	3	8	24	112.6	2702.4	3.964	1.5
Sum						**7016.384**		

SOIL WEDGE No.	AREA[a] (ft^2)	WEIGHT (lb/ft)	COGx (ft)	COGz (ft)
5	0.59	58.983	3.543	11
4	0.48	47.972	4.41	9.423
3	1.792	179.26	4.671	8.167
2	3.174	317.42	4.987	6.702
1	2.828	282.82	6.851	4.083
Sum		**886.453**		

For Overturning Calculations		
BLOCK NAME	80% INF UNIT WEIGHT[d] (pcf)	WEIGHT (lb/ft)
R-28T	105.16	368.06
R-41M	122.08	618.03
R-41M	122.08	618.03
R-41M	122.08	618.03
R-7236HC	103.17	1857.06
R-9636HC	100.66	2415.84
Sum		**6495.050**

a. Cross sectional area of the infilled block. It doesn't consider soil wedges located above the top block.

b. Infilled unit weight is a weighted average of the concrete and the infill aggregate's respective unit weights. The following values are used: Concrete: 143 PCF and Infill Aggregate: 100 PCF. Infill is considered to be the material in the geogrid slot-core and the sides of the blocks.

c. Weight based on the infill unit weight per unit length of wall.

d. For overturning calculations the block's infill-aggregate unit weight is taken to be 80% of 100 PCF.

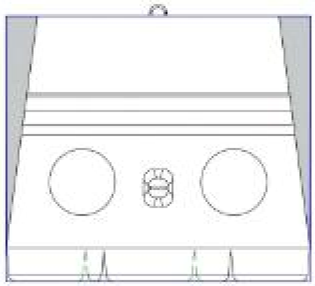
Note: COG values are measured from the front bottom of the first block. An example calculation is presented in the following pages.

EXAMPLE CALCULATIONS

Example calculation to determine the weight of the block per unit length of the block/wall

- The sample calculations are for the R-41M block.

Finding concrete to soil material ratios using volumes



$h_{R41M} := 1.50\ ft$ Block height

$w_{R41M} := 3.375\ ft$ Block width - Front to back

$l_{R41M} := 3.844\ ft$ Block front face length

$V_{Total} := h_{R41M} \cdot w_{R41M} \cdot l_{R41M} = 19.46\ ft^3$

$V_{concrete} := 15.65\ ft^3$ Average value from in-house volume tests.

$V_{soil\_wedges} := 1.724\ ft^3$ Wedges shown in gray.

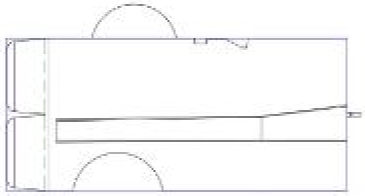
$$C := \frac{V_{concrete}}{V_{Total}} = 0.804$$

$$S := \frac{V_{soil\_wedges}}{V_{Total}} = 0.0886$$

Finding the average unit weight of the block assuming 143 PCF for concrete and 100 PCF for the infill aggregate for the soil wedges.

$$\gamma_{R41M} := \left(C \cdot 143\ \frac{lb}{ft^3}\right) + \left(S \cdot 100\ \frac{lb}{ft^3}\right) = 123.86\ \frac{lb}{ft^3}$$

Finding the weight per unit length of the wall



$A_{R41M} := h_{R41M} \cdot w_{R41M} = 5.063\ ft^2$ Cross sectional area of the block.

$L_{1\_R41M} := 1\ ft$ Unit length of the block/wall.

$W_{1\_R41M} := \gamma_{R41M} \cdot A_{R41M} \cdot L_{1\_R41M} = 627.042\ lb$

Example calculation/notes to determine the center of gravity

The Center of Gravity (COG) for each block is calculated as a weighted average using the geometric COG and the weight for each material assuming an infilled block. The geometric centers are calculated using 3D models of the block in AutoCAD.

$COG_{x\_R41M\_concrete} := 1.708\ ft$ $\qquad$ $COG_{x\_R41M\_infill} := 1.125\ ft$

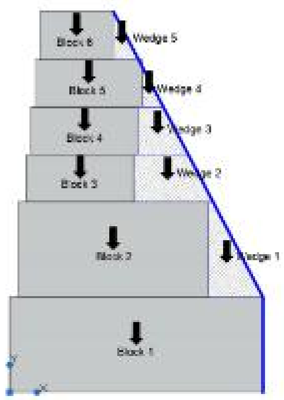
$W_{Total\_R41M\_concrete} := 2240\ lb$ $\qquad$ $W_{Total\_R41M\_infill} := 173\ lb$

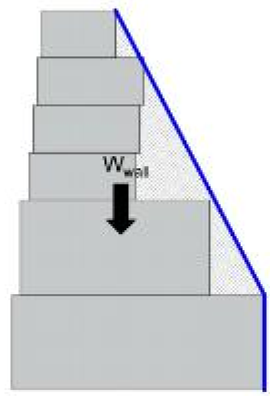
$$COG_{x\_R41M} := \frac{\left(COG_{x\_R41M\_concrete} \cdot W_{Total\_R41M\_concrete}\right) + \left(COG_{x\_R41M\_infill} \cdot W_{Total\_R41M\_infill}\right)}{W_{Total\_R41M\_concrete} + W_{Total\_R41M\_infill}} = 1.666\ ft$$

The COG for each soil wedge is the geometric COG determined using AutoCAD.

Once the COG values are determined for each block and soil wedge, the COG for the wall is calculated as a weighted average of these values. For further reference, please see the general equation below.

$$COG_{wall} := \frac{\Sigma\left(COG_{block\_1\_n} \cdot Weight_{block\_1\_n}\right) + \Sigma\left(COG_{wedge\_1\_n} \cdot Weight_{wedge\_1\_n}\right)}{Weight_{wall}}$$





Using the tables and the general equation shown in the previous pages to find the total weight of the wall and it's center of gravity.

$W_{blocks} := 7016.384\ \frac{lb}{ft}$ $\qquad$ $W_{wedges} := 886.453\ \frac{lb}{ft}$

$W_{wall} := W_{blocks} + W_{wedges} = 7902.837\ \frac{lb}{ft}$

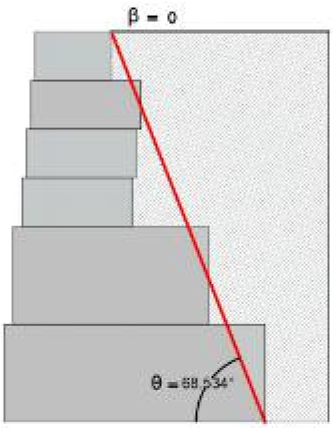
$COG_x := 3.452\ ft$

$COG_z := 4.931\ ft$

FINDING THE FORCES ACTING ON THE WALL: ACTIVE EARTH PRESSURE

- For the analysis of this example a linear back of wall is approximated in accordance with what AASHTO shows for prefabricated modular walls with irregular surfaces. (AASHTO Figure 3.11.5.9-2)
- Active earth pressure calculations are carried out using Coulomb's methods as shown in AASHTO Section 3.11.5.3

FINDING Ka



$\theta := 68.534\ deg$

$$K_a := \frac{\sin(\theta+\phi_r)^2}{\left(\sin(\theta)^2 \cdot (\sin(\theta-\delta_r))\right)\left(1+\sqrt{\frac{\sin(\phi_r+\delta_r)\cdot\sin(\phi_r-\beta)}{\sin(\theta-\delta_r)\cdot\sin(\theta+\beta)}}\right)^2} = 0.461$$

FINDING THE ACTIVE EARTH PRESSURE RESULTANT:

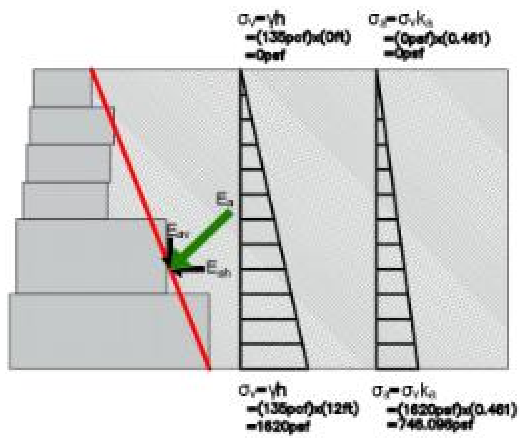
$\sigma_v := h \cdot \gamma_r = 1620\ \frac{lb}{ft^2}$

$\sigma_a := \sigma_v \cdot K_a = 746.096\ \frac{lb}{ft^2}$

$E_a := \frac{\sigma_a \cdot h}{2} = 4476.575\ \frac{lb}{ft}$

$Z_{Ea} := \left(\frac{1}{3}\right) \cdot h = 4\ ft$

$X_{Ea} := 8\ ft - (\tan(90° - \theta)) \cdot (Z_{Ea}) = 6.427\ ft$



Horizontal and Vertical Components

$E_{ah} := E_a \cdot \cos(\delta_r + 90\ deg - \theta) = 3054.959\ \frac{lb}{ft}$

$E_{av} := E_a \cdot \sin(\delta_r + 90\ deg - \theta) = 3272.148\ \frac{lb}{ft}$

FINDING THE FORCES ACTING ON THE WALL: LIVE LOAD SURCHARGE

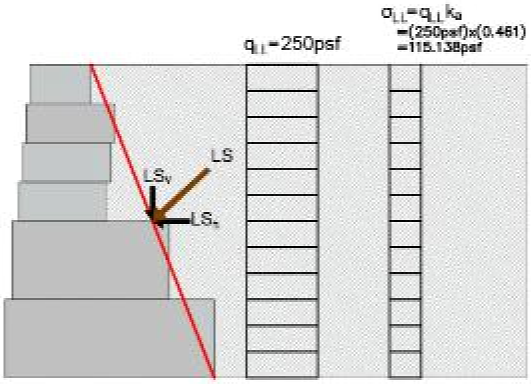
FINDING THE LIVE LOAD SURCHARGE RESULTANT:

$$\sigma_{LL} := q_{LL} \cdot K_a = 115.138 \ \frac{lb}{ft^2}$$

$$LS := \sigma_{LL} \cdot h = 1381.659 \ \frac{lb}{ft}$$

$$Z_{LS} := \left(\frac{1}{2}\right) \cdot h = 6 \ ft$$

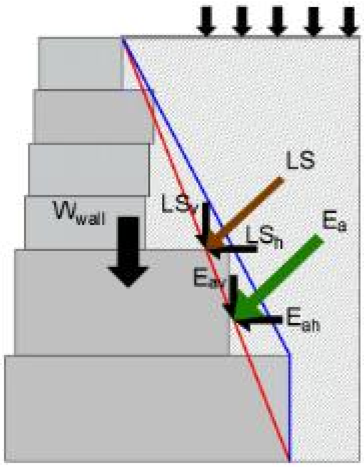
$$X_{LS} := 8 \ ft - (\tan(90° - \theta)) \cdot (Z_{LS}) = 5.641 \ ft$$



Horizontal and Vertical Components

$$LS_h := LS \cdot \cos(\delta_r + 90 \ deg - \theta) = 942.889 \ \frac{lb}{ft}$$

$$LS_v := LS \cdot \sin(\delta_r + 90 \ deg - \theta) = 1009.922 \ \frac{lb}{ft}$$



CHECKING FOR SLIDING

- For the analysis of this example the load factors used will be the maximum values from the range provided in AASHTO for loading forces and minimum values (if applicable) for resisting forces.
- Although this wall will require the construction of a leveling pad from a crushed aggregate, it will not be included as part of the stability analysis. It's properties in terms of weight and internal angle of friction will not be used in the resistance components for sliding and overturning.

Driving forces:

$$P_d := (\gamma_{EH\_max} \cdot E_{ah}) + (\gamma_{LS} \cdot LS_h) = 6232.494 \ \frac{lb}{ft}$$

Resisting forces:

- The reduction coefficient of friction is a weighted average of the two different materials used at the sliding surface. Precast concrete composes 22% of the sliding surface while aggregate core infill composes 78%.

$\mu_{con\_soil} := 0.80$ Reduction coefficient of friction for precast concrete on foundation soil

$\mu_{soil\_soil} := 1.0$ Reduction coefficient of friction for aggregate core infill on foundation soil

$\mu_{weighted} := 0.956$

$$R_r := \varphi_r \cdot ((\gamma_{EV\_min} \cdot W_{wall}) + (\gamma_{EH\_max} \cdot E_{av}) + (\gamma_{LS} \cdot LS_v)) \cdot \tan(\phi_f) \cdot \mu_{weighted} = 7241.863 \ \frac{lb}{ft}$$

Sliding Capacity Demand Ratio (CDR):

$$CDR_{SL} := \frac{R_r}{P_d} = 1.162$$ **OK**

CHEKING FOR OVERTURNING

- For overturning calculations a maximum of 80 percent soil infill weight inside the blocks will be used in the resisting forces consistent with AASHTO's guidelines in Section 11.11.4.4. AASHTO doesn't have a resistance factor for overturning so we use 1.0

Driving moments:

$$M_d := ((\gamma_{EH\_max} \cdot E_{ah}) \cdot Z_{Ea}) + ((\gamma_{LS} \cdot LS_h) \cdot Z_{LS}) = 28230.087 \ lb$$

Resisting moments:

$$W_{blocks\_reduced} := 6495.05 \ \frac{lb}{ft}$$

$$W_{wall\_reduced} := W_{blocks\_reduced} + W_{wedges} = 7381.503 \ \frac{lb}{ft}$$

$$M_r := 1.0 \cdot (((\gamma_{EV\_min} \cdot W_{wall\_reduced}) \cdot COG_x) + ((\gamma_{EH\_max} \cdot E_{av}) \cdot X_{Ea}) + ((\gamma_{LS} \cdot LS_v) \cdot X_{LS})) = 66995.654 \ lb$$

Overturning Capacity Demand Ratio (CDR):

$$CDR_{OV} := \frac{M_r}{M_d} = 2.373 \quad \underline{\textbf{OK}}$$

INTERNAL STABILITY

- Checking internal stability about the bottom of Block 2.

FINDING THE WEIGHT OF THE WALL

BLOCK NAME	BLOCK No.	HEIGHT (ft)	WIDTH (ft)	AREA[a] (ft^2)	INF UNIT WEIGHT[b] (pcf)	WEIGHT[c] (lb/ft)	COGx (ft)	COGz (ft)
R-28T	6	1.5	2.312	3.5	110	385	1.844	8.25
R-41M	5	1.5	3.375	5.063	123.86	627.041	2.229	6.75
R-41M	4	1.5	3.375	5.063	123.86	627.041	2.094	5.25
R-41M	3	1.5	3.375	5.063	123.86	627.041	1.958	3.75
R-7230HC	2	3	6	18	113.77	2047.86	3	1.5
Sum						4313.984		

SOIL WEDGE No.	AREA[a] (ft^2)	WEIGHT (lb/ft)	COGx (ft)	COGz (ft)
4	0.56	56	3.259	8
3	0.348	34.8	4.113	6.394
2	1.646	164.6	4.351	5.165
1	2.971	297.1	4.649	3.703
Sum		552.5		

BLOCK NAME	80% INF UNIT WEIGHT[d] (pcf)	WEIGHT (lb/ft)
R-28T	105.16	368.06
R-41M	122.08	618.03
R-41M	122.08	618.03
R-41M	122.08	618.03
R-7230HC	103.17	1857.06
Sum		4079.21

a. Cross sectional area of the infilled block. It doesn't consider soil wedges located above the top block.

b. Infilled unit weight is a weighted average of the concrete and the infill aggregate's respective unit weights. The following values are used: Concrete: 143 PCF and Infill Aggregate: 100 PCF. Infill is considered to be the material in the geogrid slot-core and the sides of the blocks.

c. Weight based on the infill unit weight per unit length of wall.

d. For overturning calculations the block's infill-aggregate unit weight is taken to be 80% of 100 PCF.

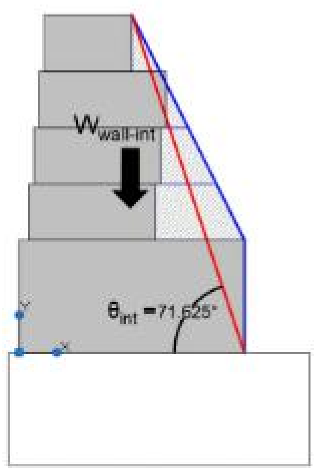
Note: COG values are measured from the front bottom of the first block.

$$W_{blocks\_int} := 4313.984\ \frac{lb}{ft} \qquad W_{wedges\_int} := 552.5\ \frac{lb}{ft}$$

$$W_{wall\_int} := W_{blocks\_int} + W_{wedges\_int} = 4866.484\ \frac{lb}{ft}$$

$$COG_{x\_int} := 2.716\ ft$$

$$COG_{z\_int} := 3.852\ ft$$



FINDING THE FORCES ACTING ON THE WALL: ACTIVE EARTH PRESSURE

$$\theta_{int} := 71.625\ deg$$

$$K_{a\_int} := \frac{\sin(\theta_{int}+\phi_r)^2}{\left(\sin(\theta_{int})^2 \cdot (\sin(\theta_{int}-\delta_r))\right)\left(1+\sqrt{\frac{\sin(\phi_r+\delta_r)\cdot\sin(\phi_r-\beta)}{\sin(\theta_{int}-\delta_r)\cdot\sin(\theta_{int}+\beta)}}\right)^2} = 0.422$$

FINDING THE ACTIVE EARTH PRESSURE RESULTANT:

- Note: The height of the wall for internal analysis is 9FT

$$h_{int} := 9\ ft$$

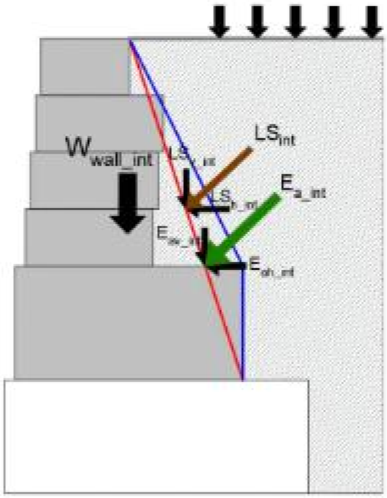
$$\sigma_{v\_int} := h_{int} \cdot \gamma_r = 1215\ \frac{lb}{ft^2}$$

$$\sigma_{a\_int} := \sigma_{v\_int} \cdot K_{a\_int} = 513.104\ \frac{lb}{ft^2}$$

$$E_{a\_int} := \frac{\sigma_{a\_int} \cdot h_{int}}{2} = 2308.967\ \frac{lb}{ft}$$

$$Z_{Ea\_int} := \left(\frac{1}{3}\right) \cdot h_{int} = 3\ ft$$

$$X_{Ea\_int} := 6\ ft - (\tan(90° - \theta_{int})) \cdot (Z_{Ea\_int}) = 5.003\ ft$$



Horizontal and Vertical Components

$$E_{ah\_int} := E_{a\_int} \cdot \cos(\delta_r + 90\ deg - \theta_{int}) = 1664.427\ \frac{lb}{ft}$$

$$E_{av\_int} := E_{a\_int} \cdot \sin(\delta_r + 90\ deg - \theta_{int}) = 1600.316\ \frac{lb}{ft}$$

FINDING THE LIVE LOAD SURCHARGE RESULTANT:

$$\sigma_{LL\_int} := q_{LL} \cdot K_{a\_int} = 105.577\ \frac{lb}{ft^2}$$

$$LS_{int} := \sigma_{LL\_int} \cdot h_{int} = 950.192\ \frac{lb}{ft}$$

$$Z_{LS\_int} := \left(\frac{1}{2}\right) \cdot h_{int} = 4.5\ ft$$

$$X_{LS\_int} := 6\ ft - (\tan(90° - \theta_{int})) \cdot (Z_{LS\_int}) = 4.505\ ft$$

Horizontal and Vertical Components

$$LS_{h\_int} := LS_{int} \cdot \cos(\delta_r + 90\ deg - \theta_{int}) = 684.95\ \frac{lb}{ft}$$

$$LS_{v\_int} := LS_{int} \cdot \sin(\delta_r + 90\ deg - \theta_{int}) = 658.566\ \frac{lb}{ft}$$

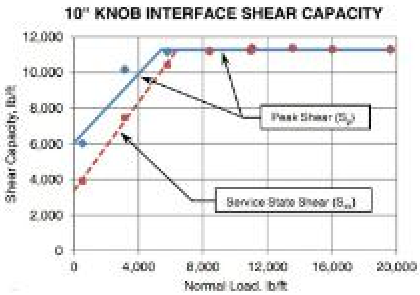
<u>CHECKING FOR SLIDING</u>

Driving forces:

$$P_{d\_int} := (\gamma_{EH\_max} \cdot E_{ah\_int}) + (\gamma_{LS} \cdot LS_{h\_int}) = 3695.303\ \frac{lb}{ft}$$

Resisting forces:

Evaluate the interface shear capacity from the curve generated from full scale blocks testing. The following are peak shear values. Since the wall section has a combination of XL Hollow Core blocks and solid blocks the lower maximum interface shear curve is used for simplicity purposes. The XL Hollow Core blocks interface shear capacity is larger making this analysis more conservative.



$S_{p\_min} := 6061\ \frac{lb}{ft}$ $\quad$ $S_{p\_max} := 11276\ \frac{lb}{ft}$

$\phi_{friction} := 44\ deg$ Angle of the first part of the curve

$$S_p := (((\gamma_{EV\_min} \cdot W_{wall\_int}) + (\gamma_{EH\_max} \cdot E_{av\_int}) + (\gamma_{LS} \cdot LS_{v\_int})) \cdot \tan(\phi_{friction})) + (S_{p\_min} \cdot \varphi_t) = 13585.467\ \frac{lb}{ft}$$

$\mu_{int} := 1$ Reduction coefficient of friction. Based on full scale lab testing of block to block interface shear.

$$R_{r\_int} := \varphi_t \cdot (S_p \cdot \mu_{int}) = 12226.921\ \frac{lb}{ft}$$

Sliding Capacity Demand Ratio (CDR):

$$CDR_{SL\_int} := \frac{R_{r\_int}}{P_{d\_int}} = 3.309$$ **<u>OK</u>**

CHECKING FOR OVERTURNING

Driving moments:

$$M_{d\_int} := \left(\left(\gamma_{EV\_max} \cdot E_{ah\_int}\right) \cdot Z_{Ea\_int}\right) + \left(\left(\gamma_{LS} \cdot LS_{h\_int}\right) \cdot Z_{LS\_int}\right) = 12134.908\ lb$$

Resisting moments:

$$W_{blocks\_reduced\_int} := 4079.21\ \frac{lb}{ft}$$

$$W_{wall\_reduced\_int} := W_{blocks\_reduced\_int} + W_{wedges\_int} = 4631.71\ \frac{lb}{ft}$$

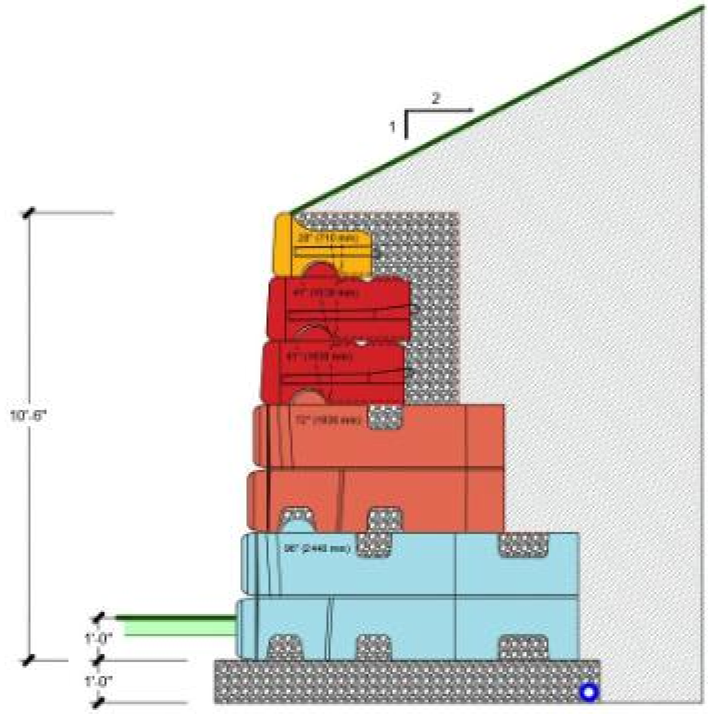
$$M_{r\_int} := 1.0 \cdot \left(\left(\left(\gamma_{EV\_min} \cdot W_{wall\_reduced\_int}\right) \cdot COG_{x\_int}\right) + \left(\left(\gamma_{EH\_max} \cdot E_{av\_int}\right) \cdot X_{Ea\_int}\right) + \left(\left(\gamma_{LS} \cdot LS_{v\_int}\right) \cdot X_{LS\_int}\right)\right) = 29782.7\ lb$$

Overturning Capacity Demand Ratio (CDR):

$$CDR_{OV} := \frac{M_{r\_int}}{M_{d\_int}} = 2.454 \quad \underline{\textbf{OK}}$$

Note:
All other interfaces should be checked for sliding and overturning. Bearing capacity and slope stability were not required in this example, but should be checked for external stability.

IDEA PROGRAM PMB GRAVITY WALL SYSTEM SUBMITTAL SECTION 2.2
ERS DESIGN EXAMPLE
PROBLEM 2



WALL PROPERTIES

$h := 10.5\ ft$

$h_{emb} := 1\ ft$

$\omega := 5.14\ deg$

$\beta := 26.565\ deg$

RETAINED SOIL	FOUNDATION SOIL	INFILL/LEVELING PAD SOIL
$\gamma_r := 135\ \frac{lb}{ft^3}$	$\gamma_f := 125\ \frac{lb}{ft^3}$	$\gamma_d := 100\ \frac{lb}{ft^3}$
$\phi_r := 34\ deg$	$\phi_f := 30\ deg$	$\phi_d := 40\ deg$
$\delta_r := 25.5\ deg$	$\delta_f := 20\ deg$	$\delta_d := 26.67\ deg$
$C_r := 0\ \frac{lb}{ft^2}$	$C_f := 0\ \frac{lb}{ft^2}$	

DESIGN METHODOLOY: FHWA/AASHTO BRIDGE DESIGN MANUAL 2020

DESIGN CONDITION: STRENGTH I

LOAD FACTORS

$\gamma_{EH\_min} := 0.9$ Horizontal Earth Pressure - Active

$\gamma_{EH\_max} := 1.5$

$\gamma_{EV\_min} := 1.0$ Vertical Earth Pressure

$\gamma_{EV\_max} := 1.35$

RESISTANCE FACTORS

$\varphi_{\tau} := 0.9$ Sliding (Block on LP and LP on foundation soil.)

Overturning: Use 80% of block infill weight.

EXTERNAL STABILITY

FINDING THE WEIGHT OF THE WALL

- The weight of the wall and the location of the center of gravity is based on the average infilled unit weight for each block size.
- Although this wall will require the construction of a leveling pad from a crushed aggregate, it will not be included as part of the stability analysis. It's properties in terms of weight and internal angle of friction will not be used in the resistance components for sliding and overturning.
- The back of the wall is defined starting a the back of the first block and then drawing a line from the top back of this block to the top slope. The location of intersection with the top slope is defined by drawing a vertical line from the back of the top block until it intersects with the top slope. This allows for some soil wedges that sit on top of the retained structure to be included in the weight calculations.

BLOCK NAME	BLOCK No.	HEIGHT (ft)	WIDTH (ft)	AREA[a] (ft^2)	INF UNIT WEIGHT[b] (pcf)	WEIGHT[c] (lb/ft)	COGx (ft)	COGz (ft)
R-28T	5	1.5	2.312	3.5	110	385	1.965	9.75
R-41M	4	1.5	3.375	5.063	123.86	627.041	2.344	8.25
R-41M	3	1.5	3.375	5.063	123.86	627.041	2.208	6.75
R-7236HC	2	3	6	18	113.77	2047.86	3.209	4.5
R-9636HC	1	3	8	24	112.6	2702.4	3.964	1.5
Sum						6389.343		

SOIL WEDGE No.	AREA[3] (ft^2)	WEIGHT (lb/ft)	COGx (ft)	COGz (ft)
5	1.742	174.2	2.586	10.889
4	1.61	161	3.71	9.652
3	1.511	151.1	4.585	8.146
2	2.974	297.4	4.923	6.697
1	2.667	266.7	6.848	4.027
Sum		1050.4		

For Overturning Calculations

BLOCK NAME	80% INF UNIT WEIGHT[d] (pcf)	WEIGHT (lb/ft)
R-28T	105.16	368.06
R-41M	122.08	618.03
R-41M	122.08	618.03
R-7236HC	103.17	1857.06
R-9636HC	100.66	2415.84
Sum		5877.02

a. Cross sectional area of the infilled block. It doesn't consider soil wedges located above the top block.

b. Infilled unit weight is a weighted average of the concrete and the infill aggregate's respective unit weights. The following values are used: Concrete: 143 PCF and Infill Aggregate: 100 PCF. Infill is considered to be the material in the geogrid slot-core and the sides of the blocks.

c. Weight based on the infill unit weight per unit length of wall.

d. For overturning calculations the block's infill-aggregate unit weight is taken to be 80% of 100 PCF.

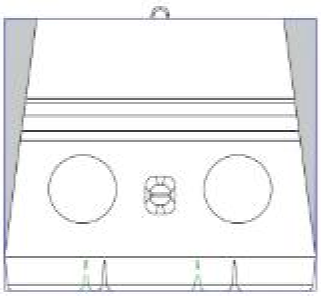
Note: COG values are measured from the front bottom of the first block. An example calculation is presented in the following pages.

EXAMPLE CALCULATIONS

Example calculation to determine the weight of the block per unit length of the block/wall

- The sample calculations are for the R-41M block.

Finding concrete to soil material ratios using volumes



$h_{R41M} := 1.50\ ft$ Block height

$w_{R41M} := 3.375\ ft$ Block width - Front to back

$l_{R41M} := 3.844\ ft$ Block front face length

$V_{Total} := h_{R41M} \cdot w_{R41M} \cdot l_{R41M} = 19.46\ ft^3$

$V_{concrete} := 15.65\ ft^3$ Average value from in-house volume tests.

$V_{soil\_wedges} := 1.724\ ft^3$ Wedges shown in gray.

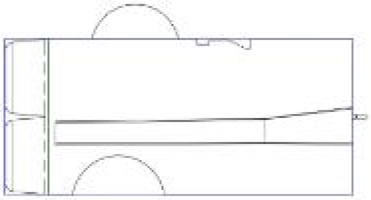
$$C := \frac{V_{concrete}}{V_{Total}} = 0.804$$

$$S := \frac{V_{soil\_wedges}}{V_{Total}} = 0.0886$$

Finding the average unit weight of the block assuming 143 PCF for concrete and 100 PCF for the infill aggregate for the soil wedges.

$$\gamma_{R41M} := \left(C \cdot 143\ \frac{lb}{ft^3}\right) + \left(S \cdot 100\ \frac{lb}{ft^3}\right) = 123.86\ \frac{lb}{ft^3}$$

Finding the weight per unit length of the wall



$A_{R41M} := h_{R41M} \cdot w_{R41M} = 5.063\ ft^2$ Cross sectional area of the block.

$L_{1\_R41M} := 1\ ft$ Unit length of the block/wall.

$W_{1\_R41M} := \gamma_{R41M} \cdot A_{R41M} \cdot L_{1\_R41M} = 627.042\ lb$

Example calculation/notes to determine the center of gravity

The Center of Gravity (COG) for each block is calculated as a weighted average using the geometric COG and the weight for each material assuming an infilled block. The geometric centers are calculated using 3D models of the block in AutoCAD.

$COG_{x\_R41M\_concrete} := 1.708\ ft$ $COG_{x\_R41M\_infill} := 1.125\ ft$

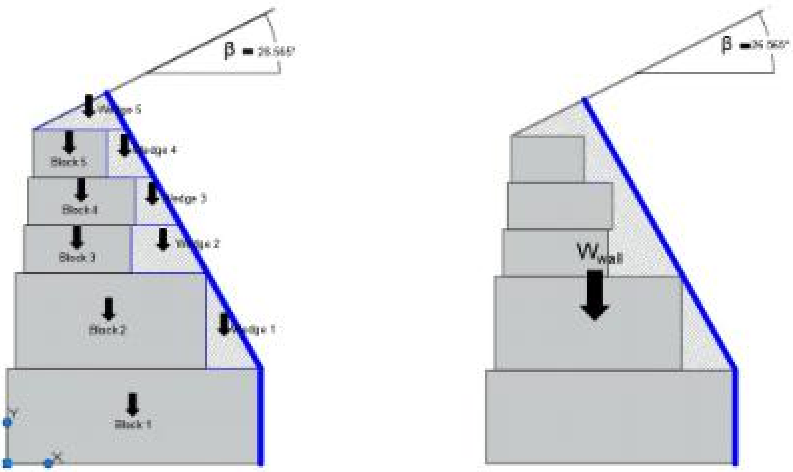
$W_{Total\_R41M\_concrete} := 2240\ lb$ $W_{Total\_R41M\_infill} := 173\ lb$

$$COG_{x\_R41M} := \frac{\left(COG_{x\_R41M\_concrete} \cdot W_{Total\_R41M\_concrete}\right) + \left(COG_{x\_R41M\_infill} \cdot W_{Total\_R41M\_infill}\right)}{W_{Total\_R41M\_concrete} + W_{Total\_R41M\_infill}} = 1.666\ ft$$

The COG for each soil wedge is the geometric COG determined using AutoCAD.

Once the COG values are determined for each block and soil wedge, the COG for the wall is calculated as a weighted average of these values. For further reference, please see the general equation below.

$$COG_{wall} := \frac{\Sigma\left(COG_{block\_1\_n} \cdot Weight_{block\_1\_n}\right) + \Sigma\left(COG_{wedge\_1\_n} \cdot Weight_{wedge\_1\_n}\right)}{Weight_{wall}}$$



Using the tables above to find the total weight of the wall and it's center of gravity.

$W_{blocks} := 6389.343\ \frac{lb}{ft}$ $W_{wedges} := 1050.4\ \frac{lb}{ft}$

$W_{wall} := W_{blocks} + W_{wedges} = 7439.743\ \frac{lb}{ft}$

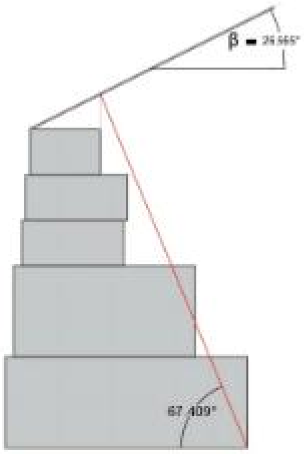
$COG_x := 3.485\ ft$

$COG_z := 4.594\ ft$

FINDING THE FORCES ACTING ON THE WALL: ACTIVE EARTH PRESSURE

- For the analysis of this example a linear back of wall is approximated in accordance with what AASHTO shows for prefabricated modular walls with irregular surfaces. (AASHTO Figure 3.11.5.9-2)
- Active earth pressure calculations are carried out using Coulomb's methods as shown in AASHTO Section 3.11.5.3

FINDING Ka



$\theta := 67.409 \ \mathbf{deg}$

$$K_a := \frac{\sin(\theta+\phi_r)^2}{\left(\sin(\theta)^2 \cdot (\sin(\theta-\delta_r))\right)\left(1+\sqrt{\frac{\sin(\phi_r+\delta_r)\cdot\sin(\phi_r-\beta)}{\sin(\theta-\delta_r)\cdot\sin(\theta+\beta)}}\right)^2} = 0.85$$

FINDING THE ACTIVE EARTH PRESSURE RESULTANT:

The retained height of soil is defined by the difference in elevation between the bottom and top of the line that defines the back of the wall. Because the wall has a top slope this height will not be the same as the total height of the wall. The variable h_r will be used to define this value, which is measured using AutoCAD.

$h_r := 11.674 \ \mathbf{ft}$

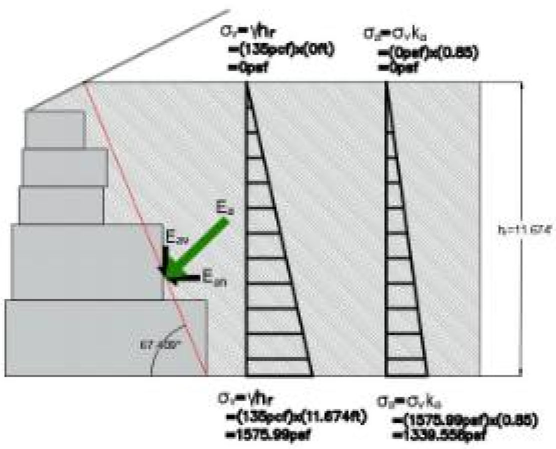
$\sigma_v := h_r \cdot \gamma_r = 1575.99 \ \frac{\mathbf{lb}}{\mathbf{ft}^2}$

$\sigma_a := \sigma_v \cdot K_a = 1339.558 \ \frac{\mathbf{lb}}{\mathbf{ft}^2}$

$E_a := \frac{\sigma_a \cdot h_r}{2} = 7819.001 \ \frac{\mathbf{lb}}{\mathbf{ft}}$

$Z_{Ea} := \left(\frac{1}{3}\right) \cdot h_r = 3.891 \ \mathbf{ft}$

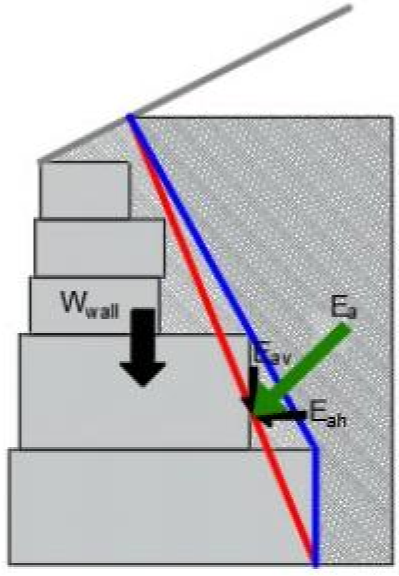
$X_{Ea} := 8 \ \mathbf{ft} - (\tan(90° - \theta)) \cdot (Z_{Ea}) = 6.381 \ \mathbf{ft}$



Horizontal and Vertical Components

$$E_{ah} := E_a \cdot \cos(\delta_r + 90\ \mathbf{deg} - \theta) = 5222.698\ \frac{lb}{ft}$$

$$E_{av} := E_a \cdot \sin(\delta_r + 90\ \mathbf{deg} - \theta) = 5818.953\ \frac{lb}{ft}$$



CHECKING FOR SLIDING

- For the analysis of this example the load factors used will be the maximum values from the range provided in AASHTO for loading forces and minimum values (if applicable) for resisting forces.
- Although this wall will require the construction of a leveling pad from a crushed aggregate, it will not be included as part of the stability analysis. It's properties in terms of weight and internal angle of friction will not be used in the resistance components for sliding and overturning.

Driving forces:

$$P_d := \gamma_{EH\_max} \cdot E_{ah} = 7834.047\ \frac{lb}{ft}$$

Resisting forces:

- The reduction coefficient of friction is a weighted average of the two different materials used at the sliding surface. Precast concrete composes 22% of the sliding surface while aggregate core infill composes 88%.

$\mu_{con\_soil} := 0.80$ Reduction coefficient of friction for precast concrete on foundation soil

$\mu_{soil\_soil} := 1.0$ Reduction coefficient of friction for aggregate core infill on foundation soil

$\mu_{weighted} := 0.956$

$$R_r := \varphi_r \cdot \left(\left(\gamma_{EV\_min} \cdot W_{wall} \right) + \left(\gamma_{EH\_max} \cdot E_{av} \right) \right) \cdot \tan\left(\phi_f \right) \cdot \mu_{weighted} = 8031.575 \ \frac{lb}{ft}$$

Sliding Capacity Demand Ratio (CDR):

$$CDR_{SL} := \frac{R_r}{P_d} = 1.025 \qquad \underline{\textbf{OK}}$$

CHECKING FOR OVERTURNING

- For overturning calculations a maximum of 80 percent soil infill weight inside the blocks will be used in the resisting forces consistent with AASHTO's guidelines in Section 11.11.4.4. AASHTO doesn't have a resistance factor for overturning so we use 1.0

Driving moments:

$$M_d := \left(\gamma_{EH\_max} \cdot E_{ah} \right) \cdot Z_{Ea} = 30484.887 \ lb$$

Resisting moments:

$$W_{blocks\_reduced} := 5877.02 \ \frac{lb}{ft}$$

$$W_{wall\_reduced} := W_{blocks\_reduced} + W_{wedges} = 6927.42 \ \frac{lb}{ft}$$

$$M_r := 1.0 \cdot \left(\left(\left(\gamma_{EV\_min} \cdot W_{wall\_reduced} \right) \cdot COG_x \right) + \left(\left(\gamma_{EH\_max} \cdot E_{av} \right) \cdot X_{Ea} \right) \right) = 79837.391 \ lb$$

Overturning Capacity Demand Ratio (CDR):

$$CDR_{OV} := \frac{M_r}{M_d} = 2.619 \qquad \underline{\textbf{OK}}$$

INTERNAL STABILITY

- Checking internal stability about the bottom of Block 2.

FINDING THE WEIGHT OF THE WALL

BLOCK NAME	BLOCK No.	HEIGHT (ft)	WIDTH (ft)	AREA[a] (ft^2)	INF UNIT WEIGHT[b] (pcf)	WEIGHT[c] (lb/ft)	COGx (ft)	COGz (ft)
R-28T	5	1.5	2.312	3.5	110	385	1.708	6.75
R-41M	4	1.5	3.375	5.063	123.86	627.041	2.073	5.25
R-41M	3	1.5	3.375	5.063	123.86	627.041	1.937	3.75
R-7236HC	2	3	6	18	113.77	2047.86	2.938	1.5
Sum						3686.943		

SOIL WEDGE No.	AREA[a] (ft^2)	WEIGHT (lb/ft)	COGx (ft)	COGz (ft)
4	1.736	173.6	2.312	7.889
3	1.585	158.5	3.43	6.652
2	1.467	146.7	4.299	5.144
1	2.911	291.1	4.631	3.697
Sum		769.9		

	For Overturning Calculations	
BLOCK NAME	80% INF UNIT WEIGHT[d] (pcf)	WEIGHT (lb/ft)
R-28T	105.16	368.06
R-41M	122.08	618.03
R-41M	122.08	618.03
R-7236HC	103.17	1857.06
Sum		3461.18

Note: COG values are measured from the front bottom of the first block.

a. Cross sectional area of the infilled block. It doesn't consider soil wedges located above the top block.

b. Infilled unit weight is a weighted average of the concrete and the infill aggregate's respective unit weights. The following values are used: Concrete: 143 PCF and Infill Aggregate: 100 PCF. Infill is considered to be the material in the geogrid slot-core and the sides of the blocks.

c. Weight based on the infill unit weight per unit length of wall.

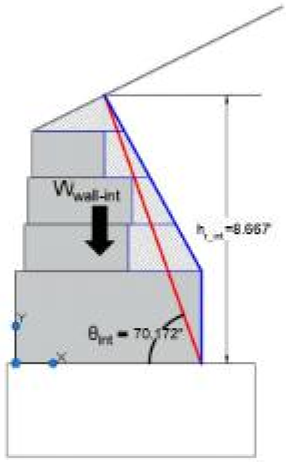
d. For overturning calculations the block's infill-aggregate unit weight is taken to be 80% of 100 PCF.

$W_{blocks\_int} := 3686.943\ \frac{lb}{ft}$ $\quad W_{wedges\_int} := 769.9\ \frac{lb}{ft}$

$W_{wall\_int} := W_{blocks\_int} + W_{wedges\_int} = 4456.843\ \frac{lb}{ft}$

$COG_{x\_int} := 2.718\ ft$

$COG_{z\_int} := 3.493\ ft$



FINDING THE FORCES ACTING ON THE WALL: ACTIVE EARTH PRESSURE

$\theta_{int} := 70.172\ deg$

$$K_{a\_int} := \frac{\sin(\theta_{int} + \phi_r)^2}{\left(\sin(\theta_{int})^2 \cdot (\sin(\theta_{int} - \delta_r))\right)\left(1 + \sqrt{\frac{\sin(\phi_r + \delta_r) \cdot \sin(\phi_r - \beta)}{\sin(\theta_{int} - \delta_r) \cdot \sin(\theta_{int} + \beta)}}\right)^2} = 0.771$$

FINDING THE ACTIVE EARTH PRESSURE RESULTANT:

- Note: The total height of retained soil is found to be 8.667FT

$h_{r\_int} := 8.667\ ft$

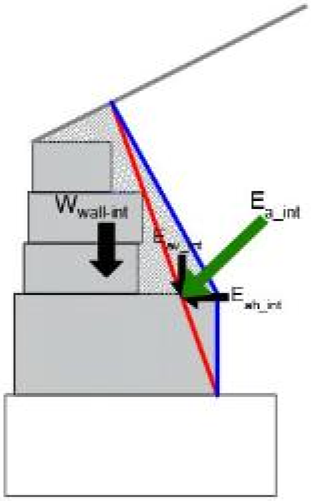
$\sigma_{v\_int} := h_{r\_int} \cdot \gamma_r = 1170.045\ \frac{lb}{ft^2}$

$\sigma_{a\_int} := \sigma_{v\_int} \cdot K_{a\_int} = 902.482\ \frac{lb}{ft^2}$

$$E_{a\_int} := \frac{\sigma_{a\_int} \cdot h_{r\_int}}{2} = 3910.905 \ \frac{lb}{ft}$$

$$Z_{Ea\_int} := \left(\frac{1}{3}\right) \cdot h_{r\_int} = 2.889 \ ft$$

$$X_{Ea\_int} := 6 \ ft - \left(\tan\left(90° - \theta_{int}\right)\right) \cdot \left(Z_{Ea\_int}\right) = 4.958 \ ft$$



Horizontal and Vertical Components

$$E_{ah\_int} := E_{a\_int} \cdot \cos\left(\delta_r + 90 \ deg - \theta_{int}\right) = 2749.551 \ \frac{lb}{ft}$$

$$E_{av\_int} := E_{a\_int} \cdot \sin\left(\delta_r + 90 \ deg - \theta_{int}\right) = 2781.213 \ \frac{lb}{ft}$$

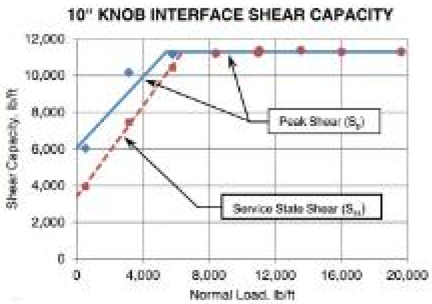
CHECKING FOR SLIDING

Driving forces:

$$P_{d\_int} := \gamma_{EH\_max} \cdot E_{ah\_int} = 4124.327 \ \frac{lb}{ft}$$

Resisting forces:

Evaluate the interface shear capacity from the curve generated from full scale blocks testing. The following are peak shear values. Since the wall section has a combination of XL Hollow Core blocks and solid blocks the lower maximum interface shear curve is used for simplicity purposes. The XL Hollow Core blocks interface shear capacity is larger making this analysis more conservative.



$$S_{p\_min} := 6061 \ \frac{lb}{ft} \qquad S_{p\_max} := 11276 \ \frac{lb}{ft}$$

$\phi_{friction} := 44 \ deg$ Angle of the first part of the curve

$$S_p := \left(\left(\left(\gamma_{EV\_min} \cdot W_{wall\_int}\right) + \left(\gamma_{EH\_max} \cdot E_{av\_int}\right)\right) \cdot \tan\left(\phi_{friction}\right)\right) + \left(S_{p\_min} \cdot \varphi_t\right) = 13787.503 \ \frac{lb}{ft}$$

$\mu_{int} := 1$ Reduction coefficient of friction. Based on full scale lab testing of block to block interface shear.

$$R_{r\_int} := \varphi_t \cdot \left(S_p \cdot \mu_{int}\right) = 12408.753 \ \frac{lb}{ft}$$

Sliding Capacity Demand Ratio (CDR):

$$CDR_{SL\_int} := \frac{R_{r\_int}}{P_{d\_int}} = 3.009 \quad \underline{\textbf{OK}}$$

CHECKING FOR OVERTURNING

Driving moments:

$$M_{d\_int} := \left(\gamma_{EH\_max} \cdot E_{ah\_int}\right) \cdot Z_{Ea\_int} = 11915.181 \ lb$$

Resisting moments:

$$W_{blocks\_reduced\_int} := 3461.18 \ \frac{lb}{ft}$$

$$W_{wall\_reduced\_int} := W_{blocks\_reduced\_int} + W_{wedges\_int} = 4231.08 \ \frac{lb}{ft}$$

$$M_{r\_int} := 1.0 \cdot \left(\left(\left(\gamma_{EV\_min} \cdot W_{wall\_reduced\_int}\right) \cdot COG_{x\_int}\right) + \left(\left(\gamma_{EH\_max} \cdot E_{av\_int}\right) \cdot X_{Ea\_int}\right)\right) = 32185.215 \ lb$$

Overturning Capacity Demand Ratio (CDR):

$$CDR_{OV} := \frac{M_{r\_int}}{M_{d\_int}} = 2.701 \quad \underline{\textbf{OK}}$$

Note:
All other interfaces should be checked for sliding and overturning. Bearing capacity and slope stability were not required in this example, but should be checked for external stability.

APPENDIX: 2.2.2 MSE WALL EXAMPLE CALCULATIONS

AASHTO 2017-2020
Example Problem 1

MSEW+: Update # 2021.14

PROJECT IDENTIFICATION

Title: Example Problem 1
Project Number:
Client: Redi-Rock International
Designer: Daniel Cerminaro
Station Number:

Description:

IDEA Submittal Example Problem 1 ERS MSE Wall with Extensible Reinforcement

Company's information:

Name: Redi-Rock International
Street: 2940 Parkview Dr

Petoskey, MI 49770
Telephone #: 616-655-1503
Fax #:
E-Mail: daniel@redi-rock.com

File path and name: C:\Users\daniel\Desktop\IDEA\MSE Wall Design Examples\P.....
.....lem 1_MS2Review.BENp

Original date and time of creating this file: Wed Aug 11 14:31:01 2021

PROGRAM MODE: ANALYSIS
of a SIMPLE STRUCTURE
using GEOGRID as reinforcing material.

SOIL DATA

REINFORCED SOIL

Unit weight, γ	135.0 lb/ft ³
Design value of internal angle of friction, ϕ	34.0 °

RETAINED SOIL

Unit weight, γ	120.0 lb/ft ³
Design value of internal angle of friction, ϕ	30.0 °

FOUNDATION SOIL (Considered as an equivalent uniform soil)

Equivalent unit weight, $\gamma_{equiv.}$	120.0 lb/ft ³
Equivalent internal angle of friction, $\phi_{equiv.}$	30.0 °
Equivalent cohesion, $c_{equiv.}$	0.0 lb/ft ²

Water table does not affect bearing capacity

LATERAL EARTH PRESSURE COEFFICIENTS

Ka (internal stability) = 0.2827 (if batter is less than 10°, Ka is calculated from eq. 15. Otherwise, eq. 38 is utilized)
Inclination of internal slip plane, ψ = 62.00° (see Fig. 28 in DEMO 82).
Ka (external stability) = 0.2973 (eq. 17 is utilized to calculate Ka for all batters)
(For external stability user specified δ = 20.00°)

BEARING CAPACITY

Bearing capacity is controlled by general shear.
Bearing capacity factors (calculated by MSEW): Nc = 30.14 N γ= 22.40

SEISMICITY

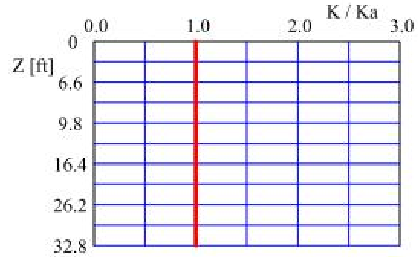
Not Applicable

**INPUT DATA: Geogrids
(Analysis)**

D A T A	Geogrid type #1	Geogrid type #2	Geogrid type #3	Geogrid type #4	Geogrid type #5
Tult [lb/ft]	9500.0	9500.0	13705.0	13705.0	
Durability reduction factor, RFd	1.15	1.15	1.15	1.15	
Installation-damage reduction factor, RFid	1.10	1.10	1.10	1.10	
Creep reduction factor, RFc	1.44	1.44	1.44	1.44	N/A
CDR for strength	N/A	N/A	N/A	N/A	
Coverage ratio, Rc	0.250	0.500	0.250	0.500	
Friction angle along geogrid-soil interface, ρ	28.35	28.35	28.35	28.35	
Pullout resistance factor, F*	0.80·tan ϕ	0.80·tan ϕ	0.80·tan ϕ	0.80·tan ϕ	N/A
Scale-effect correction factor, α	1.0	1.0	1.0	1.0	

Variation of Lateral Earth Pressure Coefficient With Depth

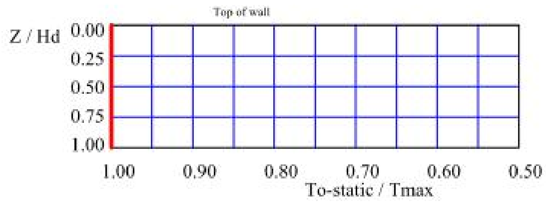
Z	K / Ka
0 ft	1.00
3.3 ft	1.00
6.6 ft	1.00
9.8 ft	1.00
13.1 ft	1.00
16.4 ft	1.00
19.7 ft	1.00



INPUT DATA: Facia and Connection (according to revised Demo 82)
(Analysis)

FACIA type: Facing enabling frictional connection of reinforcement (e.g., modular concrete blocks, gabions)
Depth/height of block is 2.33/1.50 ft. Horizontal distance to Center of Gravity of block is: 1.13 ft.
Average unit weight of block is: γ_f = 120.00 lb/ft ³

Z / Hd	To-static / Tmax
0.00	1.00
0.25	1.00
0.50	1.00
0.75	1.00
1.00	1.00



Connection strength, T-lot, is related to user specified T-lot

Geogrid Type #1		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
N-1	Tult-conn	N-2	Tult-conn	N-3	Tult-conn	N-4	Tult-conn	N-5	Tult-conn
0.0	8681.00	0.0	8681.00	0.0	13447.00	0.0	13447.00		
6000.0	8681.00	6000.0	8681.00	8448.5	13447.00	6000.0	13447.00	N/A	
10000001.	8681.00	10000001.	8681.00	10000001.	13447.00	10000001.	13447.00		
10000001.	8681.00	10000001.	8681.00	10000001.	13447.00	10000001.	13447.00		
10000001.	8681.00	10000001.	8681.00	10000001.	13447.00	10000001.	13447.00		

Geogrid Type #1		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
σ	CRu	σ	CRu	σ	CRu	σ	CRu	σ	CRu
0.0	0.82	0.0	0.82	0.0	0.82	0.0	0.82		
2575.1	0.82	2575.1	0.82	2575.1	0.82	2575.1	0.82	N/A	
4291845.9	0.82	4291845.9	0.82	4291845.9	0.82	4291845.9	0.82		
4291845.9	0.82	4291845.9	0.82	4291845.9	0.82	4291845.9	0.82		
4291845.9	0.82	4291845.9	0.82	4291845.9	0.82	4291845.9	0.82		

(1) σ = Confining stress in between stacked blocks [lb/ft ²]
(2) CRult = Tc-ult / Tult
(3) CRcr = Tcre / Tult

D A T A (for connection only)	Type #1	Type #2	Type #3	Type #4	Type #5
Product Name	10XT 25%	10XT 50%	20XT 25%	20XT 50%	N/A
Connection strength reduction factor, RFd	1.15	1.15	1.15	1.15	N/A
Creep reduction factor, RFc	N/A	N/A	N/A	N/A	N/A

INPUT DATA: Geometry and Surcharge loads (of a SIMPLE STRUCTURE)

Design height, Hd 30.00 [ft] { Embedded depth is E = 2.00 ft, and height above top of finished bottom grade is H = 28.00 ft }

Soil in front of wall is Horizontal.

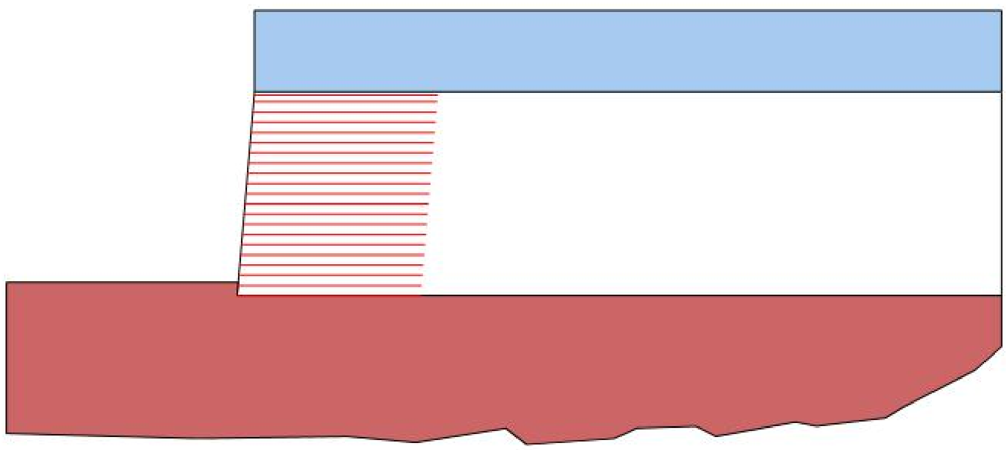
Batter, ω	5.0	[deg]
Backslope, β	0.0	[deg]
Backslope rise	0.0	[ft]

Broken back equivalent angle, I = 0.00° (see Fig. 25 in DEMO 82)

UNIFORM SURCHARGE

Uniformly distributed dead load is 0.0 [lb/ft ²], and live load is 250.0 [lb/ft ²]

ANALYZED REINFORCEMENT LAYOUT:



SCALE:

0 2 4 6 8 10[ft]

AASHTO 2017-2020 – Load and Resisting Factors

INTERNAL STABILITY

Load factor for vertical earth pressure, EV:	$\gamma_{p\text{-}EV}$	1.35	
Load factor for earthquake loads, EQ:	$\gamma_{p\text{-}EQ}$	1.00	
Load factor for live load surcharge, LS: (Same as in External Stability).	$\gamma_{p\text{-}LS}$	1.75	
Load factor for dead load surcharge, ES: (Same as in External Stability).	$\gamma_{p\text{-}ES}$	1.50	
Resistance factor for reinforcement tension	ϕ	Static	Combined static/seismic
Geogrid:		0.90	1.20
Resistance factor for reinforcement tension in connectors	ϕ	Static	Combined static/seismic
Geogrid:		0.90	1.20
Resistance factor for geosynthetic pullout	ϕ	0.90	1.20

EXTERNAL STABILITY

Load factor for vertical earth pressure, EV		Static	Combined Static/Seismic	
Sliding and Eccentricity	$\gamma_{p\text{-}EV}$	1.00	$\gamma_{p\text{-}EQ}$	1.00
Bearing Capacity	$\gamma_{p\text{-}EV}$	1.35	$\gamma_{p\text{-}EQ}$	1.35

Load factor of active lateral earth pressure, EH	$\gamma_{p\text{-}EH}$	1.50
Load factor of active lateral earth pressure during earthquake (does not multiply P_{AE} and P_{IR}):	$(\gamma_{p\text{-}EH})_{EQ}$	1.50
Load factor for earthquake loads, EQ (multiplies P_{AE} and P_{IR}):	$\gamma_{p\text{-}EQ}$	1.00

Resistance factor for shear resistance along common interfaces		Static	Combined Static/Seismic
Reinforced Soil and Foundation	ϕ_τ	1.00	1.00
Reinforced Soil and Reinforcement	ϕ_τ	1.00	1.00
Resistance factor for bearing capacity of shallow foundation		Static	Combined Static/Seismic
	ϕ_b	0.65	0.65

ANALYSIS: CALCULATED FACTORS (Static conditions)

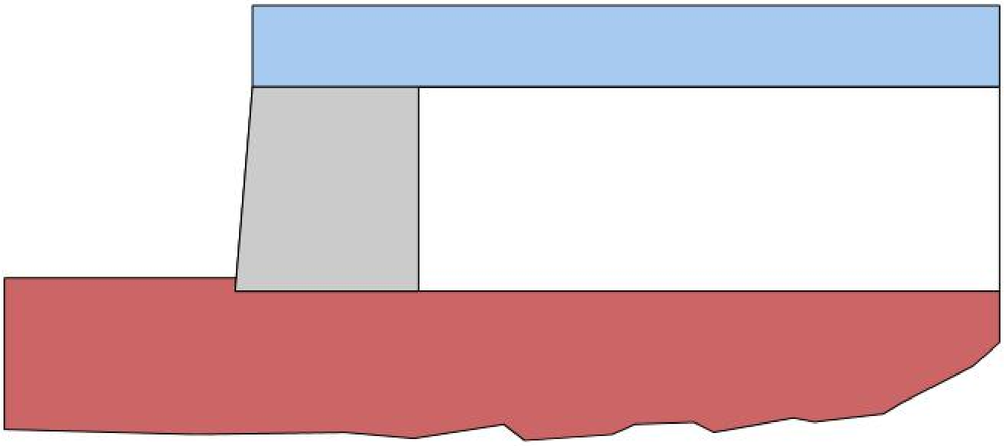
Bearing capacity, CDR = 3.79, factored bearing load = 6084 lb/ft².
Foundation Interface: Direct sliding, CDR = 2.494, Eccentricity, e/L = 0.0277, CDR-overturning = 6.15

GEOGRID #	Elevation [ft]	Length [ft]	Type #	CONNECTION CDR [connection strength]	Geogrid strength CDR	Pullout resistance CDR	Direct sliding CDR	Eccentricity e/L	Product name
1	0.00	27.00	3	1.23	1.368	20.413	2.768	0.0277	20XT 25%
2	1.50	27.00	4	1.28	1.418	20.073	2.737	0.0225	20XT 50%
3	3.00	27.00	4	1.34	1.490	19.817	2.862	0.0176	20XT 50%
4	4.50	27.00	4	1.42	1.570	19.369	3.000	0.0131	20XT 50%
5	6.00	27.00	4	1.50	1.659	18.761	3.151	0.0090	20XT 50%
6	7.50	27.00	4	1.59	1.759	18.138	3.320	0.0052	20XT 50%
7	9.00	27.00	4	1.69	1.872	17.507	3.508	0.0018	20XT 50%
8	10.50	27.00	4	1.80	2.000	16.867	3.719	-0.0012	20XT 50%
9	12.00	27.00	4	1.94	2.147	16.216	3.958	-0.0038	20XT 50%
10	13.50	27.00	4	2.09	2.318	15.552	4.230	-0.0061	20XT 50%
11	15.00	27.00	4	2.27	2.517	14.870	4.544	-0.0080	20XT 50%
12	16.50	27.00	4	2.49	2.755	14.166	4.909	-0.0095	20XT 50%
13	18.00	27.00	2	1.89	2.109	13.433	5.338	-0.0107	10XT 50%
14	19.50	27.00	2	2.11	2.354	12.661	5.852	-0.0114	10XT 50%
15	21.00	27.00	2	2.39	2.663	11.828	6.477	-0.0118	10XT 50%
16	22.50	27.00	2	2.75	3.067	10.922	7.253	-0.0118	10XT 50%
17	24.00	27.00	2	3.25	3.615	9.895	8.244	-0.0114	10XT 50%
18	25.50	27.00	2	3.95	4.400	8.666	9.553	-0.0107	10XT 50%
19	27.00	27.00	2	5.05	5.623	7.068	11.361	-0.0095	10XT 50%
20	28.50	27.00	2	8.13	9.052	5.437	14.021	-0.0080	10XT 50%
21	29.50	27.00	1	7.05	7.852	1.524	17.545	-0.0067	10XT 25%

BEARING CAPACITY for GIVEN LAYOUT – Using AASHTO 2017-2020 method

	STATIC	SEISMIC	UNITS
(Water table does not affect bearing capacity)			
Factored bearing resistance. q-n	23073	N/A	[lb/ft ²]
Factored bearing load, σ_V	6084.5	N/A	[lb/ft ²]
Eccentricity, e	0.30	N/A	[ft]
Eccentricity, e/L	0.011	N/A	
CDR calculated	3.79	N/A	
Base length	27.00	N/A	[ft]

Unfactored applied bearing pressure = (Unfactored R) / [L - 2 * (Unfactored e)] =
Unfactored R = 116382.59 [lb/ft], L = 27.00, Unfactored e = 0.20 [ft], and Sigma = 4373.86 [lb/ft ²]



SCALE:

0 2 4 6 8 10[ft]

DIRECT SLIDING for GIVEN LAYOUT (for GEOGRID reinforcements)

Along reinforced and foundation soils interface: CDR-static = 2.494

#	Geogrid Elevation [ft]	Geogrid Length [ft]	CDR Static	CDR Seismic	Geogrid Type #	Product name
1	0.00	27.00	2.768	N/A	3	20XT 25%
2	1.50	27.00	2.737	N/A	4	20XT 50%
3	3.00	27.00	2.862	N/A	4	20XT 50%
4	4.50	27.00	3.000	N/A	4	20XT 50%
5	6.00	27.00	3.151	N/A	4	20XT 50%
6	7.50	27.00	3.320	N/A	4	20XT 50%
7	9.00	27.00	3.508	N/A	4	20XT 50%
8	10.50	27.00	3.719	N/A	4	20XT 50%
9	12.00	27.00	3.958	N/A	4	20XT 50%
10	13.50	27.00	4.230	N/A	4	20XT 50%
11	15.00	27.00	4.544	N/A	4	20XT 50%
12	16.50	27.00	4.909	N/A	4	20XT 50%
13	18.00	27.00	5.338	N/A	2	10XT 50%
14	19.50	27.00	5.852	N/A	2	10XT 50%
15	21.00	27.00	6.477	N/A	2	10XT 50%
16	22.50	27.00	7.253	N/A	2	10XT 50%
17	24.00	27.00	8.244	N/A	2	10XT 50%
18	25.50	27.00	9.553	N/A	2	10XT 50%
19	27.00	27.00	11.361	N/A	2	10XT 50%
20	28.50	27.00	14.021	N/A	2	10XT 50%
21	29.50	27.00	17.545	N/A	1	10XT 25%

ECCENTRICITY for GIVEN LAYOUT

At interface with foundation: e/L static = 0.0277; Overturning: CDR-static = 6.15

#	Geogrid Elevation [ft]	Geogrid Length [ft]	e / L Static	e / L Seismic	Geogrid Type #	Product name
1	0.00	27.00	0.0277	N/A	3	20XT 25%
2	1.50	27.00	0.0225	N/A	4	20XT 50%
3	3.00	27.00	0.0176	N/A	4	20XT 50%
4	4.50	27.00	0.0131	N/A	4	20XT 50%
5	6.00	27.00	0.0090	N/A	4	20XT 50%
6	7.50	27.00	0.0052	N/A	4	20XT 50%
7	9.00	27.00	0.0018	N/A	4	20XT 50%
8	10.50	27.00	-0.0012	N/A	4	20XT 50%
9	12.00	27.00	-0.0038	N/A	4	20XT 50%
10	13.50	27.00	-0.0061	N/A	4	20XT 50%
11	15.00	27.00	-0.0080	N/A	4	20XT 50%
12	16.50	27.00	-0.0095	N/A	4	20XT 50%
13	18.00	27.00	-0.0107	N/A	2	10XT 50%
14	19.50	27.00	-0.0114	N/A	2	10XT 50%
15	21.00	27.00	-0.0118	N/A	2	10XT 50%
16	22.50	27.00	-0.0118	N/A	2	10XT 50%
17	24.00	27.00	-0.0114	N/A	2	10XT 50%
18	25.50	27.00	-0.0107	N/A	2	10XT 50%
19	27.00	27.00	-0.0095	N/A	2	10XT 50%
20	28.50	27.00	-0.0080	N/A	2	10XT 50%
21	29.50	27.00	-0.0067	N/A	1	10XT 25%

RESULTS for STRENGTH

Live Load included in calculating Tmax

#	Geogrid Elevation [ft]	Factored LTDS [lb/ft]	Factored Tmax [lb/ft]	Tmd [lb/ft]	Specified minimum CDR Static	Actual calculated CDR Static	Specified minimum CDR seismic	Actual calculated CDR seismic	Product name
1	0.00	1692.8	1237.6	N/A	N/A	1.368	N/A	N/A	20XT 25%
2	1.50	3385.6	2388.2	N/A	N/A	1.418	N/A	N/A	20XT 50%
3	3.00	3385.6	2272.3	N/A	N/A	1.490	N/A	N/A	20XT 50%
4	4.50	3385.6	2156.4	N/A	N/A	1.570	N/A	N/A	20XT 50%
5	6.00	3385.6	2040.4	N/A	N/A	1.659	N/A	N/A	20XT 50%
6	7.50	3385.6	1924.5	N/A	N/A	1.759	N/A	N/A	20XT 50%
7	9.00	3385.6	1808.6	N/A	N/A	1.872	N/A	N/A	20XT 50%
8	10.50	3385.6	1692.6	N/A	N/A	2.000	N/A	N/A	20XT 50%
9	12.00	3385.6	1576.7	N/A	N/A	2.147	N/A	N/A	20XT 50%
10	13.50	3385.6	1460.8	N/A	N/A	2.318	N/A	N/A	20XT 50%
11	15.00	3385.6	1344.8	N/A	N/A	2.517	N/A	N/A	20XT 50%
12	16.50	3385.6	1228.9	N/A	N/A	2.755	N/A	N/A	20XT 50%
13	18.00	2346.8	1113.0	N/A	N/A	2.109	N/A	N/A	10XT 50%
14	19.50	2346.8	997.0	N/A	N/A	2.354	N/A	N/A	10XT 50%
15	21.00	2346.8	881.1	N/A	N/A	2.663	N/A	N/A	10XT 50%
16	22.50	2346.8	765.2	N/A	N/A	3.067	N/A	N/A	10XT 50%
17	24.00	2346.8	649.3	N/A	N/A	3.615	N/A	N/A	10XT 50%
18	25.50	2346.8	533.3	N/A	N/A	4.400	N/A	N/A	10XT 50%
19	27.00	2346.8	417.4	N/A	N/A	5.623	N/A	N/A	10XT 50%
20	28.50	2346.8	259.3	N/A	N/A	9.052	N/A	N/A	10XT 50%
21	29.50	1173.4	149.5	N/A	N/A	7.852	N/A	N/A	10XT 25%

RESULTS for PULLOUT

Live Load included in calculating Tmax

NOTE: Live load is not included in calculating the overburden pressure used to assess pullout resistance.

#	Geogrid Elevation [ft]	Coverage Ratio	Factored: Stat./Seis. Tmax [lb/ft]	Tmd [lb/ft]	Le (see NOTE)	La [ft]	Avail.Static Pullout, Pr [lb/ft]	Specified Static CDR	Actual Static CDR	Avail.Seism. Pullout, Pr [lb/ft]	Specified seismic CDR	Actual seismic CDR
1	0.00	0.250	1237.6	N/A	27.00	0.00	25263.2	N/A	20.413	N/A	N/A	N/A
2	1.50	0.500	2388.2	N/A	26.33	0.67	47938.3	N/A	20.073	N/A	N/A	N/A
3	3.00	0.500	2272.3	N/A	25.67	1.33	45030.8	N/A	19.817	N/A	N/A	N/A
4	4.50	0.500	2156.4	N/A	25.00	2.00	41767.0	N/A	19.369	N/A	N/A	N/A
5	6.00	0.500	2040.4	N/A	24.33	2.67	38280.1	N/A	18.761	N/A	N/A	N/A
6	7.50	0.500	1924.5	N/A	23.67	3.33	34905.7	N/A	18.138	N/A	N/A	N/A
7	9.00	0.500	1808.6	N/A	23.00	4.00	31662.2	N/A	17.507	N/A	N/A	N/A
8	10.50	0.500	1692.6	N/A	22.34	4.66	28549.7	N/A	16.867	N/A	N/A	N/A
9	12.00	0.500	1576.7	N/A	21.67	5.33	25568.0	N/A	16.216	N/A	N/A	N/A
10	13.50	0.500	1460.8	N/A	21.00	6.00	22717.3	N/A	15.552	N/A	N/A	N/A
11	15.00	0.500	1344.8	N/A	20.34	6.66	19997.5	N/A	14.870	N/A	N/A	N/A
12	16.50	0.500	1228.9	N/A	19.67	7.33	17408.6	N/A	14.166	N/A	N/A	N/A
13	18.00	0.500	1113.0	N/A	19.00	8.00	14950.6	N/A	13.433	N/A	N/A	N/A
14	19.50	0.500	997.0	N/A	18.34	8.66	12623.6	N/A	12.661	N/A	N/A	N/A
15	21.00	0.500	881.1	N/A	17.67	9.33	10421.9	N/A	11.828	N/A	N/A	N/A
16	22.50	0.500	765.2	N/A	17.01	9.99	8357.6	N/A	10.922	N/A	N/A	N/A
17	24.00	0.500	649.3	N/A	16.34	10.66	6424.3	N/A	9.895	N/A	N/A	N/A
18	25.50	0.500	533.3	N/A	15.67	11.33	4621.8	N/A	8.666	N/A	N/A	N/A
19	27.00	0.500	417.4	N/A	15.01	11.99	2950.3	N/A	7.068	N/A	N/A	N/A
20	28.50	0.500	259.3	N/A	14.34	12.66	1409.7	N/A	5.437	N/A	N/A	N/A
21	29.50	0.250	149.5	N/A	13.90	13.10	227.7	N/A	1.524	N/A	N/A	N/A

RESULTS for CONNECTION (static conditions)

Live Load included in calculating Tmax

#	Geogrid Elevation [ft]	Connection force, To [lb/ft]	Reduction factor for connection (short-term strength) CRult	Reduction factor for connection (long-term strength) CRcr	Available connection strength [lb/ft]	Available Geogrid strength, Tavailable [lb/ft]	CDR connection strength Specified	CDR connection strength Actual	CDR Geogrid strength Specified	CDR Geogrid strength Actual	Product name
1	0.00	1238	0.82	0.57	6108	7524	N/A	1.23	N/A		20XT 25%
2	1.50	2388	0.82	0.57	6108	7524	N/A	1.28	N/A		20XT 50%
3	3.00	2272	0.82	0.57	6108	7524	N/A	1.34	N/A		20XT 50%
4	4.50	2156	0.82	0.57	6108	7524	N/A	1.42	N/A		20XT 50%
5	6.00	2040	0.82	0.57	6108	7524	N/A	1.50	N/A		20XT 50%
6	7.50	1924	0.82	0.57	6108	7524	N/A	1.59	N/A		20XT 50%
7	9.00	1809	0.82	0.57	6108	7524	N/A	1.69	N/A		20XT 50%
8	10.50	1693	0.82	0.57	6108	7524	N/A	1.80	N/A		20XT 50%
9	12.00	1577	0.82	0.57	6108	7524	N/A	1.94	N/A		20XT 50%
10	13.50	1461	0.82	0.57	6108	7524	N/A	2.09	N/A		20XT 50%
11	15.00	1345	0.82	0.57	6108	7524	N/A	2.27	N/A		20XT 50%
12	16.50	1229	0.82	0.57	6108	7524	N/A	2.49	N/A		20XT 50%
13	18.00	1113	0.82	0.57	4214	5215	N/A	1.89	N/A		10XT 50%
14	19.50	997	0.82	0.57	4214	5215	N/A	2.11	N/A		10XT 50%
15	21.00	881	0.82	0.57	4214	5215	N/A	2.39	N/A		10XT 50%
16	22.50	765	0.82	0.57	4214	5215	N/A	2.75	N/A		10XT 50%
17	24.00	649	0.82	0.57	4214	5215	N/A	3.25	N/A		10XT 50%
18	25.50	533	0.82	0.57	4214	5215	N/A	3.95	N/A		10XT 50%
19	27.00	417	0.82	0.57	4214	5215	N/A	5.05	N/A		10XT 50%
20	28.50	259	0.82	0.57	4214	5215	N/A	8.13	N/A		10XT 50%
21	29.50	149	0.82	0.57	4214	5215	N/A	7.05	N/A		10XT 25%

AASHTO 2017-2020
Example Problem 2

MSEW+: Update # 2021.14

PROJECT IDENTIFICATION

Title:	Example Problem 2
Project Number:	
Client:	Redi-Rock International
Designer:	Daniel Cerminaro
Station Number:	

Description:

IDEA Submittal Example Problem 1 ERS MSE Wall with Extensible Reinforcement

Company's information:

Name: Redi-Rock International
Street: 2940 Parkview Dr

Petoskey, MI 49770
Telephone #: 616-655-1503
Fax #:
E-Mail: daniel@redi-rock.com

File path and name: C:\Users\daniel\Desktop\IDEA\MSE Wall Design Examples\P.....
.....lem 2_MS2Review.BENp

Original date and time of creating this file: Wed Aug 25 14:31:01 2021

PROGRAM MODE: ANALYSIS
of a SIMPLE STRUCTURE
using GEOGRID as reinforcing material.

SOIL DATA

REINFORCED SOIL

Unit weight, γ	135.0 lb/ft ³
Design value of internal angle of friction, ϕ	34.0 °

RETAINED SOIL

Unit weight, γ	120.0 lb/ft ³
Design value of internal angle of friction, ϕ	30.0 °

FOUNDATION SOIL (Considered as an equivalent uniform soil)

Equivalent unit weight, $\gamma_{equiv.}$	120.0 lb/ft ³
Equivalent internal angle of friction, $\phi_{equiv.}$	30.0 °
Equivalent cohesion, $c_{equiv.}$	0.0 lb/ft ²

Water table does not affect bearing capacity

LATERAL EARTH PRESSURE COEFFICIENTS

Ka (internal stability) = 0.2827 (if batter is less than 10°, Ka is calculated from eq. 15. Otherwise, eq. 38 is utilized)
Inclination of internal slip plane, ψ = 62.00° (see Fig. 28 in DEMO 82).
Ka (external stability) = 0.5244 (eq. 17 is utilized to calculate Ka for all batters)
(For external stability user specified δ = 20.00°)

BEARING CAPACITY

Bearing capacity is controlled by general shear.
Bearing capacity factors (calculated by MSEW): Nc = 30.14 N γ= 22.40

SEISMICITY

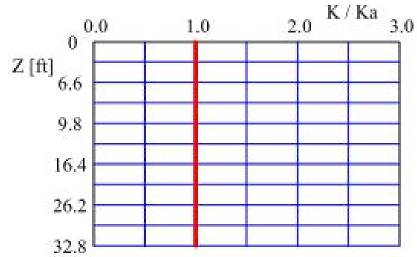
Not Applicable

INPUT DATA: Geogrids
(Analysis)

D A T A	Geogrid type #1	Geogrid type #2	Geogrid type #3	Geogrid type #4	Geogrid type #5
Tult [lb/ft]	9500.0	9500.0	13705.0	13705.0	
Durability reduction factor, RFd	1.15	1.15	1.15	1.15	
Installation-damage reduction factor, RFid	1.10	1.10	1.10	1.10	
Creep reduction factor, RFc	1.44	1.44	1.44	1.44	N/A
CDR for strength	N/A	N/A	N/A	N/A	
Coverage ratio, Rc	0.250	0.500	0.250	0.500	
Friction angle along geogrid-soil interface, ρ	28.35	28.35	28.35	28.35	
Pullout resistance factor, F*	0.80·tan ϕ	0.80·tan ϕ	0.80·tan ϕ	0.80·tan ϕ	N/A
Scale-effect correction factor, α	1.0	1.0	1.0	1.0	

Variation of Lateral Earth Pressure Coefficient With Depth

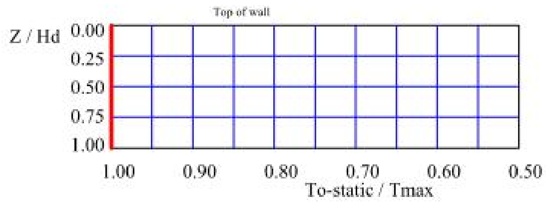
Z	K / Ka
0 ft	1.00
3.3 ft	1.00
6.6 ft	1.00
9.8 ft	1.00
13.1 ft	1.00
16.4 ft	1.00
19.7 ft	1.00



INPUT DATA: Facia and Connection (according to revised Demo 82) (Analysis)

FACIA type: Facing enabling frictional connection of reinforcement (e.g., modular concrete blocks, gabions)
Depth/height of block is 2.33/1.50 ft. Horizontal distance to Center of Gravity of block is: 1.13 ft.
Average unit weight of block is: γ_f = 120.00 lb/ft³

Z / Hd	To-static / Tmax
0.00	1.00
0.25	1.00
0.50	1.00
0.75	1.00
1.00	1.00



Connection strength, T-lot, is related to user specified T-lot

Geogrid Type #1		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
N-1	Tult-conn	N-2	Tult-conn	N-3	Tult-conn	N-4	Tult-conn	N-5	Tult-conn
0.0	8681.00	0.0	8681.00	0.0	13447.00	0.0	13447.00		
6000.0	8681.00	6000.0	8681.00	8448.5	13447.00	6000.0	13447.00	N/A	
10000001.0.00		10000001.0.00		10000001.13447.00		10000001.13447.00			
10000001.0.00		10000001.0.00		10000001.13447.00		10000001.13447.00			
10000001.0.00		10000001.0.00		10000001.13447.00		10000001.13447.00			

Geogrid Type #1		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
σ	CRu	σ	CRu	σ	CRu	σ	CRu	σ	CRu
0.0	0.82	0.0	0.82	0.0	0.82	0.0	0.82		
2575.1	0.82	2575.1	0.82	2575.1	0.82	2575.1	0.82	N/A	
4291845.90.00		4291845.90.00		4291845.90.82		4291845.90.82			
4291845.90.00		4291845.90.00		4291845.90.82		4291845.90.82			
4291845.90.00		4291845.90.00		4291845.90.82		4291845.90.82			

(1) σ = Confining stress in between stacked blocks [lb/ft²]
(2) CRult = Tc-ult / Tult
(3) CRcr = Tcrc / Tult

D A T A (for connection only)	Type #1	Type #2	Type #3	Type #4	Type #5
Product Name	Miragrid ..	Miragrid ..	Miragrid ..	Miragrid ..	N/A
Connection strength reduction factor, RFd	1.15	1.15	1.15	1.15	N/A
Creep reduction factor, RFc	N/A	N/A	N/A	N/A	N/A

INPUT DATA: Geometry and Surcharge loads (of a SIMPLE STRUCTURE)

Design height, Hd 30.00 [ft] { Embedded depth is E = 2.00 ft, and height above top of finished bottom grade is H = 28.00 ft }

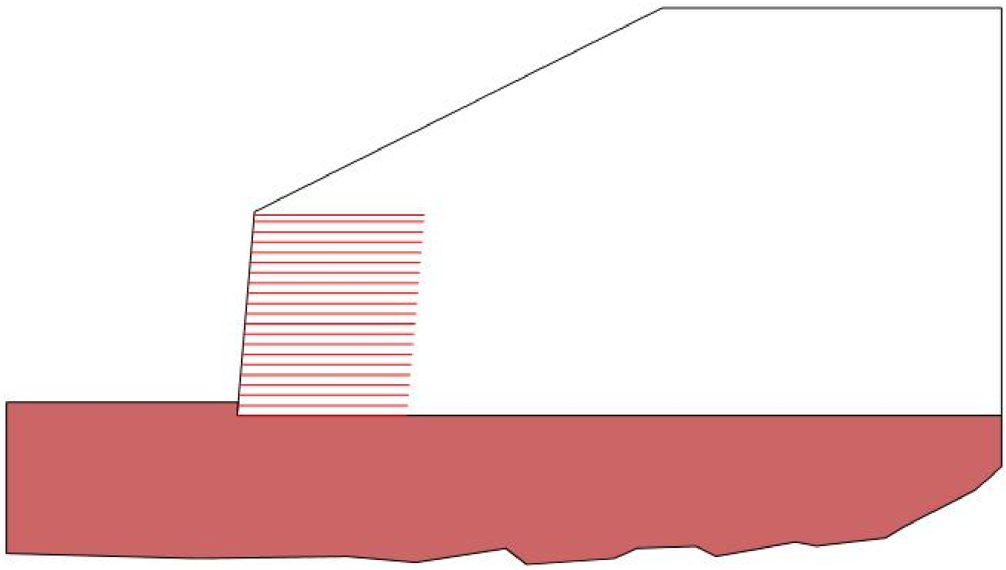
Soil in front of wall is Horizontal.

Batter, ω	5.0	[deg]	
Backslope, β	26.6	[deg]	
Backslope rise	30.0	[ft]	Broken back equivalent angle, I = 26.57° (see Fig. 25 in DEMO 82)

U N I F O R M S U R C H A R G E

Uniformly distributed dead load is 0.0 [lb/ft ²]

ANALYZED REINFORCEMENT LAYOUT:



SCALE:

0 2 4 6 8 10[ft]

AASHTO 2017-2020 – Load and Resisting Factors

INTERNAL STABILITY

Load factor for vertical earth pressure, EV:	γ_{P-EV}	1.35	
Load factor for earthquake loads, EQ:	γ_{P-EQ}	1.00	
Load factor for live load surcharge, LS: (Same as in External Stability).	γ_{P-LS}	1.75	
Load factor for dead load surcharge, ES: (Same as in External Stability).	γ_{P-ES}	1.50	
Resistance factor for reinforcement tension	ϕ	Static	Combined static/seismic
Geogrid:		0.90	1.20
Resistance factor for reinforcement tension in connectors	ϕ	Static	Combined static/seismic
Geogrid:		0.90	1.20
Resistance factor for geosynthetic pullout	ϕ	0.90	1.20

EXTERNAL STABILITY

Load factor for vertical earth pressure, EV			Static	Combined Static/Seismic	
	Sliding and Eccentricity	γ_{P-EV}	1.00	γ_{P-EQ}	1.00
	Bearing Capacity	γ_{P-EV}	1.35	γ_{P-EQ}	1.35

Load factor of active lateral earth pressure, EH	γ_{P-EH}	1.50
Load factor of active lateral earth pressure during earthquake (does not multiply P_{AE} and P_{IR}):	$(\gamma_{P-EH})_{EQ}$	1.50
Load factor for earthquake loads, EQ (multiplies P_{AE} and P_{IR}):	γ_{P-EQ}	1.00

Resistance factor for shear resistance along common interfaces			Static	Combined Static/Seismic
	Reinforced Soil and Foundation	ϕ_τ	1.00	1.00
	Reinforced Soil and Reinforcement	ϕ_τ	1.00	1.00
Resistance factor for bearing capacity of shallow foundation			Static	Combined Static/Seismic
		ϕ_b	0.65	0.65

ANALYSIS: CALCULATED FACTORS (Static conditions)

Bearing capacity, CDR = 1.85, factored bearing load = 9205 lb/ft².

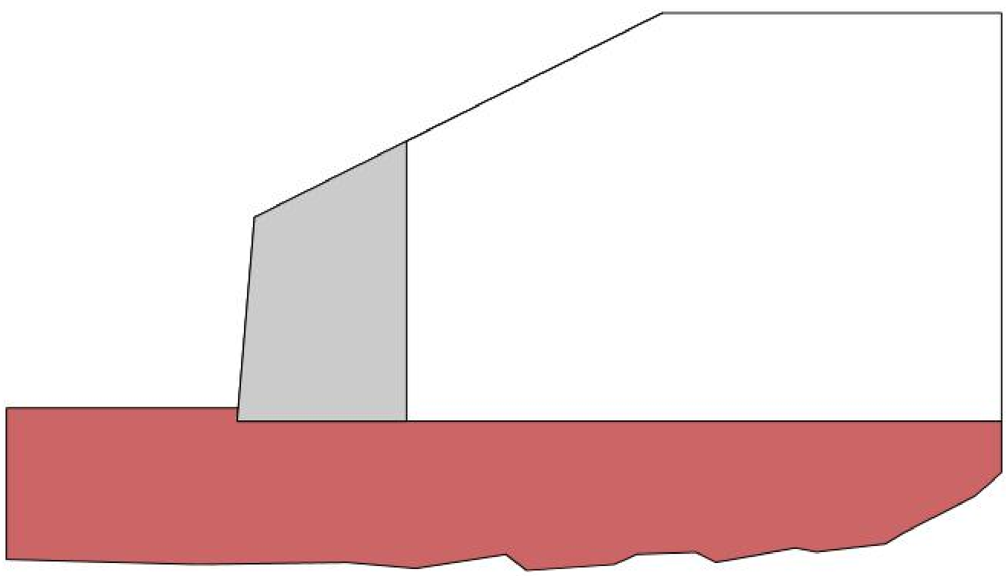
Foundation Interface: Direct sliding, CDR = 1.076, Eccentricity, e/L = 0.1551, CDR-overturning = 2.17

GEOGRID #	Elevation [ft]	Length [ft]	Type #	CONNECTION CDR [connection strength]	Geogrid strength CDR	Pullout resistance CDR	Direct sliding CDR	Eccentricity e/L	Product name
1	0.00	25.00	3	1.13	1.256	20.324	1.194	0.1551	Miragrid 2..
2	1.50	25.00	4	1.17	1.298	20.129	1.161	0.1398	Miragrid 2..
3	3.00	25.00	4	1.23	1.358	20.017	1.191	0.1250	Miragrid 2..
4	4.50	25.00	4	1.29	1.425	19.744	1.224	0.1105	Miragrid 2..
5	6.00	25.00	4	1.35	1.498	19.342	1.259	0.0965	Miragrid 2..
6	7.50	25.00	4	1.42	1.579	18.940	1.296	0.0828	Miragrid 2..
7	9.00	25.00	4	1.51	1.669	18.547	1.335	0.0694	Miragrid 2..
8	10.50	25.00	4	1.60	1.770	18.164	1.376	0.0564	Miragrid 2..
9	12.00	25.00	4	1.70	1.884	17.794	1.420	0.0436	Miragrid 2..
10	13.50	25.00	4	1.82	2.014	17.427	1.467	0.0311	Miragrid 2..
11	15.00	25.00	4	1.95	2.163	17.089	1.517	0.0187	Miragrid 2..
12	16.50	25.00	2	1.45	1.619	16.773	1.570	0.0064	Miragrid 1..
13	18.00	25.00	2	1.58	1.760	16.485	1.626	-0.0059	Miragrid 1..
14	19.50	25.00	2	1.73	1.928	16.233	1.685	-0.0183	Miragrid 1..
15	21.00	25.00	2	1.91	2.131	16.028	1.747	-0.0312	Miragrid 1..
16	22.50	25.00	2	2.14	2.382	15.887	1.812	-0.0448	Miragrid 1..
17	24.00	25.00	2	2.42	2.699	15.837	1.878	-0.0595	Miragrid 1..
18	25.50	25.00	2	2.80	3.114	15.917	1.942	-0.0760	Miragrid 1..
19	27.00	25.00	2	3.30	3.681	16.200	2.001	-0.0956	Miragrid 1..
20	28.50	25.00	2	4.76	5.300	19.818	2.048	-0.1201	Miragrid 1..
21	29.50	25.00	1	3.56	3.961	13.156	2.181	-0.1409	Miragrid 1..

BEARING CAPACITY for GIVEN LAYOUT – Using AASHTO 2017-2020 method

	STATIC	SEISMIC	UNITS
(Water table does not affect bearing capacity)			
Factored bearing resistance. q-n	17056	N/A	[lb/ft ²]
Factored bearing load, σ_V	9205.4	N/A	[lb/ft ²]
Eccentricity, e	2.74	N/A	[ft]
Eccentricity, e/L	0.110	N/A	
CDR calculated	1.85	N/A	
Base length	25.00	N/A	[ft]

Unfactored applied bearing pressure = (Unfactored R) / [L - 2 * (Unfactored e)] =
Unfactored R = 131087.95 [lb/ft], L = 25.00, Unfactored e = 2.39 [ft], and Sigma = 6483.83 [lb/ft ²]



SCALE:

0 2 4 6 8 10[ft]

DIRECT SLIDING for GIVEN LAYOUT (for GEOGRID reinforcements)

Along reinforced and foundation soils interface: CDR-static = 1.076

#	Geogrid Elevation [ft]	Geogrid Length [ft]	CDR Static	CDR Seismic	Geogrid Type #	Product name
1	0.00	25.00	1.194	N/A	3	Miragrid 20XT
2	1.50	25.00	1.161	N/A	4	Miragrid 20XT
3	3.00	25.00	1.191	N/A	4	Miragrid 20XT
4	4.50	25.00	1.224	N/A	4	Miragrid 20XT
5	6.00	25.00	1.259	N/A	4	Miragrid 20XT
6	7.50	25.00	1.296	N/A	4	Miragrid 20XT
7	9.00	25.00	1.335	N/A	4	Miragrid 20XT
8	10.50	25.00	1.376	N/A	4	Miragrid 20XT
9	12.00	25.00	1.420	N/A	4	Miragrid 20XT
10	13.50	25.00	1.467	N/A	4	Miragrid 20XT
11	15.00	25.00	1.517	N/A	4	Miragrid 20XT
12	16.50	25.00	1.570	N/A	2	Miragrid 10XT
13	18.00	25.00	1.626	N/A	2	Miragrid 10XT
14	19.50	25.00	1.685	N/A	2	Miragrid 10XT
15	21.00	25.00	1.747	N/A	2	Miragrid 10XT
16	22.50	25.00	1.812	N/A	2	Miragrid 10XT
17	24.00	25.00	1.878	N/A	2	Miragrid 10XT
18	25.50	25.00	1.942	N/A	2	Miragrid 10XT
19	27.00	25.00	2.001	N/A	2	Miragrid 10XT
20	28.50	25.00	2.048	N/A	2	Miragrid 10XT
21	29.50	25.00	2.181	N/A	1	Miragrid 10XT

ECCENTRICITY for GIVEN LAYOUT

At interface with foundation: e/L static = 0.1551; Overturning: CDR-static = 2.17

#	Geogrid Elevation [ft]	Geogrid Length [ft]	e / L Static	e / L Seismic	Geogrid Type #	Product name
1	0.00	25.00	0.1551	N/A	3	Miragrid 20XT
2	1.50	25.00	0.1398	N/A	4	Miragrid 20XT
3	3.00	25.00	0.1250	N/A	4	Miragrid 20XT
4	4.50	25.00	0.1105	N/A	4	Miragrid 20XT
5	6.00	25.00	0.0965	N/A	4	Miragrid 20XT
6	7.50	25.00	0.0828	N/A	4	Miragrid 20XT
7	9.00	25.00	0.0694	N/A	4	Miragrid 20XT
8	10.50	25.00	0.0564	N/A	4	Miragrid 20XT
9	12.00	25.00	0.0436	N/A	4	Miragrid 20XT
10	13.50	25.00	0.0311	N/A	4	Miragrid 20XT
11	15.00	25.00	0.0187	N/A	4	Miragrid 20XT
12	16.50	25.00	0.0064	N/A	2	Miragrid 10XT
13	18.00	25.00	-0.0059	N/A	2	Miragrid 10XT
14	19.50	25.00	-0.0183	N/A	2	Miragrid 10XT
15	21.00	25.00	-0.0312	N/A	2	Miragrid 10XT
16	22.50	25.00	-0.0448	N/A	2	Miragrid 10XT
17	24.00	25.00	-0.0595	N/A	2	Miragrid 10XT
18	25.50	25.00	-0.0760	N/A	2	Miragrid 10XT
19	27.00	25.00	-0.0956	N/A	2	Miragrid 10XT
20	28.50	25.00	-0.1201	N/A	2	Miragrid 10XT
21	29.50	25.00	-0.1409	N/A	1	Miragrid 10XT

RESULTS for STRENGTH

Live Load included in calculating Tmax

#	Geogrid Elevation [ft]	Factored LTDS [lb/ft]	Factored Tmax [lb/ft]	Tmd [lb/ft]	Specified minimum CDR Static	Actual calculated CDR Static	Specified minimum CDR seismic	Actual calculated CDR seismic	Product name
1	0.00	1692.8	1347.7	N/A	N/A	1.256	N/A	N/A	Miragrid 2..
2	1.50	3385.6	2608.4	N/A	N/A	1.298	N/A	N/A	Miragrid 2..
3	3.00	3385.6	2492.5	N/A	N/A	1.358	N/A	N/A	Miragrid 2..
4	4.50	3385.6	2376.6	N/A	N/A	1.425	N/A	N/A	Miragrid 2..
5	6.00	3385.6	2260.6	N/A	N/A	1.498	N/A	N/A	Miragrid 2..
6	7.50	3385.6	2144.7	N/A	N/A	1.579	N/A	N/A	Miragrid 2..
7	9.00	3385.6	2028.8	N/A	N/A	1.669	N/A	N/A	Miragrid 2..
8	10.50	3385.6	1912.9	N/A	N/A	1.770	N/A	N/A	Miragrid 2..
9	12.00	3385.6	1796.9	N/A	N/A	1.884	N/A	N/A	Miragrid 2..
10	13.50	3385.6	1681.0	N/A	N/A	2.014	N/A	N/A	Miragrid 2..
11	15.00	3385.6	1565.1	N/A	N/A	2.163	N/A	N/A	Miragrid 2..
12	16.50	2346.8	1449.1	N/A	N/A	1.619	N/A	N/A	Miragrid 1..
13	18.00	2346.8	1333.2	N/A	N/A	1.760	N/A	N/A	Miragrid 1..
14	19.50	2346.8	1217.3	N/A	N/A	1.928	N/A	N/A	Miragrid 1..
15	21.00	2346.8	1101.3	N/A	N/A	2.131	N/A	N/A	Miragrid 1..
16	22.50	2346.8	985.4	N/A	N/A	2.382	N/A	N/A	Miragrid 1..
17	24.00	2346.8	869.5	N/A	N/A	2.699	N/A	N/A	Miragrid 1..
18	25.50	2346.8	753.5	N/A	N/A	3.114	N/A	N/A	Miragrid 1..
19	27.00	2346.8	637.6	N/A	N/A	3.681	N/A	N/A	Miragrid 1..
20	28.50	2346.8	442.8	N/A	N/A	5.300	N/A	N/A	Miragrid 1..
21	29.50	1173.4	296.3	N/A	N/A	3.961	N/A	N/A	Miragrid 1..

RESULTS for PULLOUT

Live Load included in calculating Tmax

#	Geogrid Elevation [ft]	Coverage Ratio	Factored: Stat./Seis. Tmax [lb/ft]	Tmd [lb/ft]	Le [ft]	La [ft]	Avail.Static Pullout, Pr [lb/ft]	Specified Static CDR	Actual Static CDR	Avail.Seism. Pullout, Pr [lb/ft]	Specified seismic CDR	Actual seismic CDR
1	0.00	0.250	1347.7	N/A	25.00	0.00	27390.8	N/A	20.324	N/A	N/A	N/A
2	1.50	0.500	2608.4	N/A	24.33	0.67	52505.6	N/A	20.129	N/A	N/A	N/A
3	3.00	0.500	2492.5	N/A	23.67	1.33	49891.8	N/A	20.017	N/A	N/A	N/A
4	4.50	0.500	2376.6	N/A	23.00	2.00	46922.7	N/A	19.744	N/A	N/A	N/A
5	6.00	0.500	2260.6	N/A	22.33	2.67	43725.8	N/A	19.342	N/A	N/A	N/A
6	7.50	0.500	2144.7	N/A	21.67	3.33	40621.9	N/A	18.940	N/A	N/A	N/A
7	9.00	0.500	2028.8	N/A	21.00	4.00	37628.6	N/A	18.547	N/A	N/A	N/A
8	10.50	0.500	1912.9	N/A	20.34	4.66	34745.9	N/A	18.164	N/A	N/A	N/A
9	12.00	0.500	1796.9	N/A	19.67	5.33	31973.9	N/A	17.794	N/A	N/A	N/A
10	13.50	0.500	1681.0	N/A	19.00	6.00	29295.2	N/A	17.427	N/A	N/A	N/A
11	15.00	0.500	1565.1	N/A	18.34	6.66	26745.3	N/A	17.089	N/A	N/A	N/A
12	16.50	0.500	1449.1	N/A	17.67	7.33	24306.1	N/A	16.773	N/A	N/A	N/A
13	18.00	0.500	1333.2	N/A	17.00	8.00	21977.5	N/A	16.485	N/A	N/A	N/A
14	19.50	0.500	1217.3	N/A	16.34	8.66	19759.6	N/A	16.233	N/A	N/A	N/A
15	21.00	0.500	1101.3	N/A	15.67	9.33	17652.3	N/A	16.028	N/A	N/A	N/A
16	22.50	0.500	985.4	N/A	15.01	9.99	15655.6	N/A	15.887	N/A	N/A	N/A
17	24.00	0.500	869.5	N/A	14.34	10.66	13769.6	N/A	15.837	N/A	N/A	N/A
18	25.50	0.500	753.5	N/A	13.67	11.33	11994.2	N/A	15.917	N/A	N/A	N/A
19	27.00	0.500	637.6	N/A	13.01	11.99	10329.5	N/A	16.200	N/A	N/A	N/A
20	28.50	0.500	442.8	N/A	12.34	12.66	8775.4	N/A	19.818	N/A	N/A	N/A
21	29.50	0.250	296.3	N/A	11.90	13.10	3897.7	N/A	13.156	N/A	N/A	N/A

RESULTS for CONNECTION (static conditions)

Live Load included in calculating Tmax

#	Geogrid Elevation [ft]	Connection force, To [lb/ft]	Reduction factor for connection (short-term strength) CRult	Reduction factor for connection (long-term strength) CRcr	Available connection strength [lb/ft]	Available Geogrid strength, Tavailable [lb/ft]	CDR connection strength Specified	CDR connection strength Actual	CDR Geogrid strength Specified	CDR Geogrid strength Actual	Product name
1	0.00	1348	0.82	0.57	6108	7524	N/A	1.13	N/A		Miragrid 2..
2	1.50	2608	0.82	0.57	6108	7524	N/A	1.17	N/A		Miragrid 2..
3	3.00	2493	0.82	0.57	6108	7524	N/A	1.23	N/A		Miragrid 2..
4	4.50	2377	0.82	0.57	6108	7524	N/A	1.29	N/A		Miragrid 2..
5	6.00	2261	0.82	0.57	6108	7524	N/A	1.35	N/A		Miragrid 2..
6	7.50	2145	0.82	0.57	6108	7524	N/A	1.42	N/A		Miragrid 2..
7	9.00	2029	0.82	0.57	6108	7524	N/A	1.51	N/A		Miragrid 2..
8	10.50	1913	0.82	0.57	6108	7524	N/A	1.60	N/A		Miragrid 2..
9	12.00	1797	0.82	0.57	6108	7524	N/A	1.70	N/A		Miragrid 2..
10	13.50	1681	0.82	0.57	6108	7524	N/A	1.82	N/A		Miragrid 2..
11	15.00	1565	0.82	0.57	6108	7524	N/A	1.95	N/A		Miragrid 2..
12	16.50	1449	0.82	0.57	4214	5215	N/A	1.45	N/A		Miragrid 1..
13	18.00	1333	0.82	0.57	4214	5215	N/A	1.58	N/A		Miragrid 1..
14	19.50	1217	0.82	0.57	4214	5215	N/A	1.73	N/A		Miragrid 1..
15	21.00	1101	0.82	0.57	4214	5215	N/A	1.91	N/A		Miragrid 1..
16	22.50	985	0.82	0.57	4214	5215	N/A	2.14	N/A		Miragrid 1..
17	24.00	869	0.82	0.57	4214	5215	N/A	2.42	N/A		Miragrid 1..
18	25.50	754	0.82	0.57	4214	5215	N/A	2.80	N/A		Miragrid 1..
19	27.00	638	0.82	0.57	4214	5215	N/A	3.30	N/A		Miragrid 1..
20	28.50	443	0.82	0.57	4214	5215	N/A	4.76	N/A		Miragrid 1..
21	29.50	296	0.82	0.57	4214	5215	N/A	3.56	N/A		Miragrid 1..

APPENDIX: 3.1.2 INSTALLATION GUIDE

1. PURPOSE

This manual is intended to serve as a guide for the proper installation and construction of a Redi-Rock® retaining wall. The recommendations and guidelines presented here are intended to supplement detailed construction documents, plans, and specifications for the project.

2. RESPONSIBILITIES

Redi-Rock supports a Total Quality Management approach to Quality Assurance and Quality Control (QA/QC) in the planning, design, manufacture, installation, and final acceptance of a Redi-Rock wall. This approach requires the responsible party at each stage of the project ensure that proper procedures are followed for their portion of the work. The responsible parties during the construction phase of a Redi-Rock wall include the Contractor, Engineer or Owner's Representative, and Redi-Rock licensed manufacturer. Their specific responsibilities for compliance are as follows:

CONTRACTOR

The Contractor is responsible for providing construction according to the contract documents, plans, and specifications for the project. The Contractor shall ensure that employees engaged in construction of the Redi-Rock wall understand and follow the project plans and specifications, are familiar with construction methods required, and have adequate safety training.

ENGINEER OR OWNER'S REPRESENTATIVE

The Engineer or Owner's Representative is responsible for construction review to assure that the project is being constructed according to the contract documents (plans and specifications). The representative shall fully understand the project plans and specifications and shall perform adequate field verification checks to ensure construction is in conformance with the project requirements. The presence of the Engineer or Owner's representative does not relieve the Contractor of their responsibilities for compliance with the project plans and specifications.

REDI-ROCK LICENSED MANUFACTURER

Redi-Rock blocks are produced by independently-owned licensed manufacturers. The manufacturer is responsible for the production and delivery of Redi-Rock units to the job site in accordance with published material quality, size tolerances, construction documents, plans, and specifications. The licensed manufacturer is responsible for adherence to any project specific QA/QC requirements for the production of precast concrete retaining wall units. Often, additional services—such as installation training classes—are available through the Redi-Rock manufacturer.

3. PRE-CONSTRUCTION CHECKLIST

Before you start construction of a Redi-Rock wall, take the time to complete necessary planning and preparation. This process will help ensure a safe, efficient, and quality installation. It will also help avoid costly mistakes.

☐ SAFETY

Safety is of primary concern to Redi-Rock International. Redi-Rock walls must be installed in a safe manner. All local, state, and federal safety regulations must be followed. In addition, Redi-Rock International greatly encourages installers to set up company programs to help their people stay safe at work. These programs should address items such as: personal protective equipment, maintaining safe slopes and excavations, fall protection, rigging and lifting, and other safety precautions. Safety-training materials specific to your company can be found at **www.osha.gov**, by calling 1-800-321-OSHA (6742), or from your local government safety office.

☐ ENGINEERING AND PERMITS

Obtain necessary engineering and permits for your project. Your local building department is an excellent resource to help determine the requirements for your project.

> **This installation guide is intended to supplement a detailed, site-specific wall design prepared for your project by a Professional Engineer. The construction documents for your project supersede any recommendations presented here.**

☐ REVIEW THE PROJECT PLANS

Take the time to review and understand the project plans and specifications. Make sure that the plans take into account current site, soil, and water conditions. Pay close attention to silty or clayey soils and ground water or surface water on the site as these can significantly increase the forces on the wall. A pre-construction meeting with the wall design engineer, construction inspector, wall contractor, and owner or representative is recommended.

☐ CONSTRUCTION PLANNING

Develop a plan to coordinate construction activities on your site. Make sure your plan specifically addresses how to control surface water during construction.

☐ UTILITY LOCATION

Make sure to have underground utilities located and marked on the ground before starting any construction. Call 8-1-1, go online to **www.call811.com**, or contact your local utility company to schedule utility marking for your project site.

☐ MATERIAL STAGING

Store Redi-Rock blocks in a location close to the proposed wall. Blocks should be kept clean and mud free. Blocks should also be stored in a location which will minimize the amount of handling on the project site.

Store geogrid in a clean, dry location close to the proposed wall. Keep the geogrid covered and avoid exposure to direct sunlight.

Be careful where you stockpile excavation and backfill material. Do not stockpile material over buried utility pipes, cables, or near basement walls which could be damaged by the extra weight.

☐ MATERIAL VERIFICATION

Material planned for use as drainage aggregate between and behind Redi-Rock blocks and structural backfill material proposed for use in the reinforced soil zone of mechanically stabilized earth walls must be inspected and verified to comply with requirements of the construction documents, plans, and specifications.

☐ EQUIPMENT

Make sure you have the proper equipment to handle Redi-Rock blocks and install the wall. Redi-Rock blocks are quite large and heavy. Make sure excavators and other construction equipment are properly sized to handle the blocks safely. **(Figure 1)**

Hand-operated equipment should include, at a minimum: shovels, 2-foot (0.6-meter) level, 4-foot (1.2-meter) level, broom, hammer, tape measure, string, spray paint, laser level, pry or Burke bar, walk-behind vibratory plate compactor (capable of delivering a minimum of 2000 lb (8.9 kN) centrifugal force), and a 16-inch (406-millimeter) concrete cut-off saw. **(Figure 2)**

Personal protective equipment should include, at a minimum: appropriate clothing, steel toe boots with metatarsal protection, eye protection, hard hat, gloves, hearing protection, fall protection rigging, and other items as necessary to ensure a safe working environment.

Figure 1

Figure 2

4. SUBGRADE SOILS

Proper base preparation is a critical element in the construction of your retaining wall. Not only is it important to provide a stable foundation for the wall, but a properly prepared base will greatly increase the speed and efficiency of your wall installation. Proper base preparation starts with the subgrade soils.

Existing soils must be removed to the bottom of the leveling pad elevation for the retaining wall.

The base and back of excavation should expose fresh, undisturbed soil or rock. Remove all organic, unsuitable, and disturbed soils that "fall-in" along the base of the wall or the back of the excavation. Always provide safe excavations in accordance with OSHA requirements.

The subgrade soil (below the leveling pad) should be evaluated by the Engineer or Owner's Representative to verify that it meets the design requirements and to determine its adequacy to support the retaining wall. Any unsuitable material shall be excavated and replaced as directed by the on-site representative and per the requirements of the contract drawings, plans, and specifications.

Subgrade soils must be compacted to a density as specified in the contract documents, plans, and specifications but not less than 90% maximum density at ± 2% optimum moisture content as determined by a modified proctor test (ASTM D1557). **(Figures 3 and 4)**

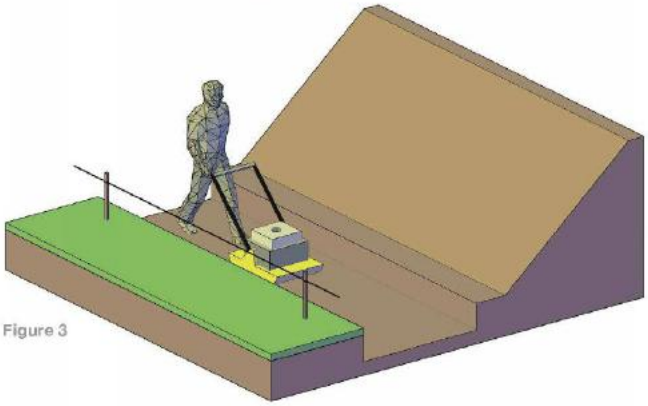


Figure 3

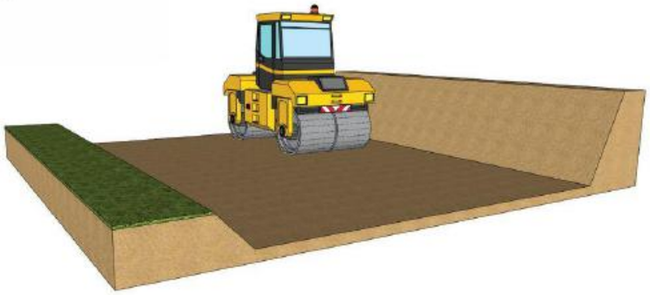


Figure 4

5. LEVELING PAD

Base preparation continues with proper leveling pad construction. Redi-Rock retaining walls can be designed with an open-graded crushed stone, dense-graded crushed stone (GAB), or concrete leveling pad which supports the bottom row of blocks. The choice of which type of leveling pad to use is made by the wall design engineer and depends on several factors including the bearing capacity of the native soil, location of the drain outlet, and conditions at the base of the wall.

Open-graded crushed stone is typically used in cases where the wall drain can outlet to daylight (by gravity) somewhere below the elevation of the bottom of the leveling pad. **(Figure 6A)** The material should be 1-inch (25-millimeter) diameter and smaller stone. A crushed stone meeting the gradation requirements of ASTM No. 57 with no material passing the No. 200 (74 μm) sieve is preferred. The leveling pad thickness shall be as designed by the wall design engineer. A minimum thickness of 6 inches (152 millimeters) or 12 inches (305 millimeters) is common. The leveling pad should extend at least 6 inches (152 millimeter) in front and 12 inches (305 millimeters) behind the bottom block. Make sure to check your construction documents for details.

Dense-graded crushed stone or graded aggregate base (GAB) material is typically used in cases where the wall drain can only outlet to daylight somewhere above the bottom of the leveling pad. **(Figure 6B)** The material should be dense-graded crushed stone with between 8 and 20% "fines" which will pass through a No. 200 (74 μm) sieve. The leveling pad thickness shall be as designed by the wall design engineer. Minimum dimensions are the same as those for an open-graded crushed stone leveling pad.

The leveling pad material should be placed and compacted to provide a uniform, level pad on which to construct the retaining wall. **(Figure 5)** Proper elevation can be established with a laser level or transit. You can also set two 20' (6 m) long grade (screed) pipes to the desired grade and screed the crushed stone material between the pipes.

Figure 5

Place the stone leveling pad in uniform loose lifts a maximum of 6 inches (152 millimeter) thick. Consolidate the stone with a minimum of three passes with a 24-inch (610-millimeter) wide walk-behind vibrating plate compactor capable of delivering at least 2000 pounds (8.9 kN) of centrifugal force. This should achieve 85% relative density of the stone determined in accordance with ASTM D-4253 and D-4254. In place density of the stone fill should be confirmed using ASTM D-6938. If you don't achieve a minimum of 85% relative density, place the stone in smaller lifts or apply more compaction effort until you do achieve desired density of the stone.

Unless specifically included in the design calculations, do NOT place a thin layer of sand between the leveling pad and bottom block. This layer will reduce the sliding resistance between the leveling pad and bottom block.

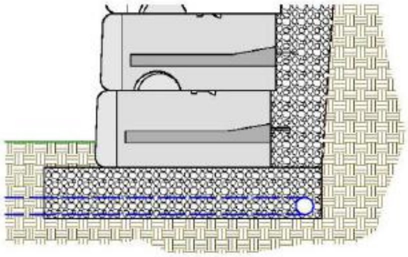
In some cases, the wall design requires the construction of a concrete leveling pad. **(Figures 6C and 6D)** Construct the leveling pad according to the detailed plans for your project.

Some designs require a shear key in the bottom of the footing and/or a lip in front of the Redi-Rock blocks. These items would be shown in the project plans.

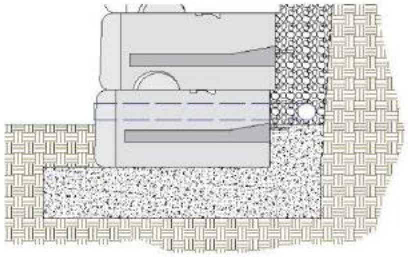
If steel rebar is to be placed in the footing, secure the bars together with wire ties in the pattern shown in the construction documents. Use rebar supports to hold the rebar structure in the proper position in the footing.

Place wood formwork at the front and back of the concrete leveling pad or footing. The top of the formwork should be placed at the elevation of the top of the concrete footing so you can screed the top smooth in preparation for block placement. It is important that the top surface be smooth and level for full contact of the retaining wall blocks. Place concrete as specified in the wall design. Once the concrete has been allowed to cure to the minimum specified strength, place the bottom blocks and continue construction of the retaining wall.

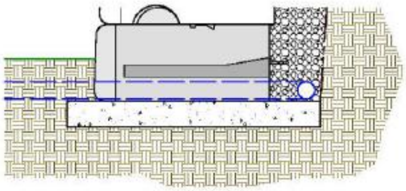
Figure 6



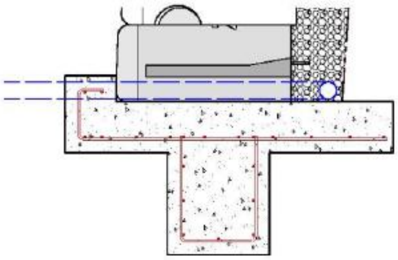
A. Open Graded Stone Leveling Pad



B. Dense Graded Stone Leveling Pad



C. Lean Concrete Leveling Pad



D. Reinforced Concrete Leveling Pad

6. SETTING THE BOTTOM ROW OF WALL BLOCKS

Redi-Rock blocks are typically delivered to the construction site using a flatbed trailer or boom truck. **(Figure 7)** Rubber tired backhoes, loaders, skid steers, or excavators are used to set the retaining wall blocks. **(Figure 8)** Make sure to use the proper sized equipment to handle the large blocks. All lifting chains, rigging, or slings must be OSHA compliant and safety rated for proper working loads.

Properly mark the location of the retaining wall. A string line or offset stakes are typically used to establish horizontal and vertical alignment. If offset stakes are used, the stakes should be placed at least 5 feet (1.5 meters) but no more than 10 feet (3 meters) in front of the face of the retaining wall. A stake should be provided at every elevation change and at a maximum of 50 feet (15 meters) apart.

Wall construction should start at a fixed point such as a building wall, 90° corner, or at the lowest elevation of the wall.

Place the blocks on the prepared leveling pad. Blocks shall be placed in full contact with the leveling pad and other immediately adjacent block units. **(Figure 9)** Block alignment should be established by lining up the "form line" where the face texture meets the steel form finished area at the top of the block, approximately 5 inches (127 millimeters) back from the front face. **(Figure 10)**

Check all blocks for level and alignment as they are placed. Small adjustments to the block location can be made with a large pry or Burke bar. Proper installation of the bottom block course is critical to maintaining the proper installation of all subsequent block courses within acceptable construction tolerance. It also makes installation of the upper rows of blocks much easier and more efficient.

Place and compact backfill in front of the bottom block course prior to placement of subsequent block courses or backfill. This will keep the blocks in place as drainage aggregate and backfill are placed and compacted.

Figure 7

Figure 8

Place an 18 inch x 12 inch (457 millimeter x 305 millimeter) piece of non-woven geotextile fabric in the vertical joint between the blocks to prevent the drainage aggregate and backfill material from migrating through the vertical joints between blocks. **(Figure 11)**

Place washed drainstone or open-graded crushed stone backfill between blocks and at least 12 inch (305 millimeter) behind the wall. A stone meeting the gradation requirements of ASTM No. 57 with no material passing the No. 200 (74 μm) sieve is preferred. Place the stone in uniform loose lifts a maximum of 6 inches (157 millimeter) thick. Consolidate the stone with a minimum of three passes with a 24-inch (610 millimeter) wide, walk-behind, vibrating plate compactor capable of delivering at least 2000 lb (8.9 kN) of centrifugal force. **(Figure 12)** This should achieve 85% relative density of the stone determined in accordance with ASTM D-4253 and D-4254. In place density of the stone fill should be confirmed using ASTM D-6938. If you don't achieve a minimum of 85% relative density, place the stone in smaller lifts or apply more compaction effort until you do achieve desired density of the stone.

Place non-woven geotextile fabric between the drainstone and the remaining backfill material if specified.

Backfill behind the drainage aggregate with material as specified in the project construction documents. Place the lifts as specified, but not to exceed 9 inches (229 millimeter) maximum. Granular backfill shall be compacted to a minimum of 90% maximum density at ± 2% optimum moisture content as determined by a modified proctor test (ASTM D1557). Use proper equipment to insure complete compaction of the backfill material. It may be necessary to wet or dry the backfill material, place the material in smaller lifts, and/or apply more compaction effort to reach 90% maximum density. Do not use any organic, topsoil, frozen, soft, wet, or loose soils when backfilling the wall.

Re-check all units for level and alignment and sweep the top of each course of blocks clean before starting construction of the next course.

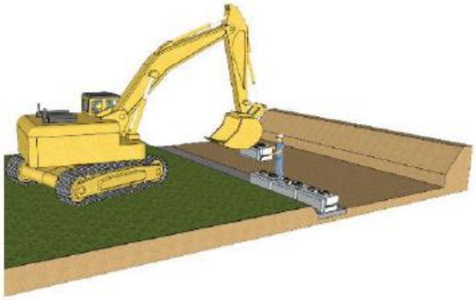


Figure 9

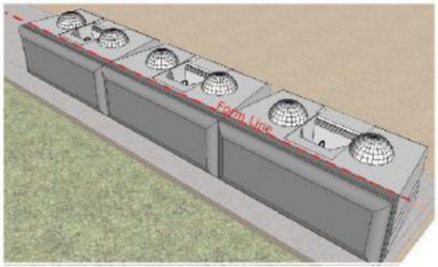


Figure 10

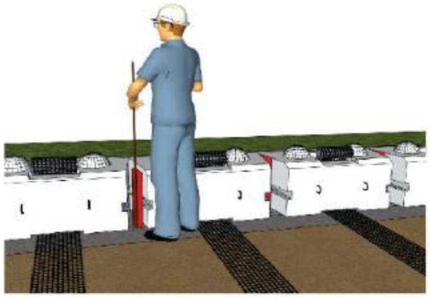


Figure 11

Figure 12

7. INSTALLING THE WALL DRAIN

A drain is placed behind the Redi-Rock wall blocks at the lowest elevation where the pipe can safely outlet to daylight. Drainage aggregate should be placed to the bottom of the drain as shown in the construction documents. A 4-inch (102 millimeter) perforated sock drain is commonly used for the drain pipe. Often the drain is encapsulated with drainage aggregate and wrapped with a non-woven geotextile fabric. The drain should run the entire length of the wall and needs to have proper outlets on the ends and at regularly spaced points along the wall. Solid pipe should be used for weep hole outlets through the face or under the retaining wall. **(Figure 13)**

Care needs to be taken during installation to avoid crushing or damaging the drain pipe or outlets.

8. SETTING UPPER ROWS OF WALL BLOCKS

Once the backfill is fully placed and compacted for the block course below, place the next row of blocks in a running bond configuration with the vertical joint of the lower block units centered under the mid-point of the block units above. If needed, a half block can be used at the end of every other row to maintain a running bond. **(Figure 14)**

Push the Redi-Rock blocks forward until the groove on the bottom of the block comes in full contact with the knobs on the blocks below. Adjacent blocks shall be placed with their front edges tightly abutted together.

Place non-woven geotextile fabric in the vertical joint between the blocks, and place and compact the drainage aggregate and backfill material the same way you did for the bottom row.

Never install more than one course of blocks without placing and compacting drainage aggregate and backfill to the full height of the block units. Placing multiple courses of blocks without backfill will prevent the proper placement and consolidation of the drainage aggregate between the blocks.

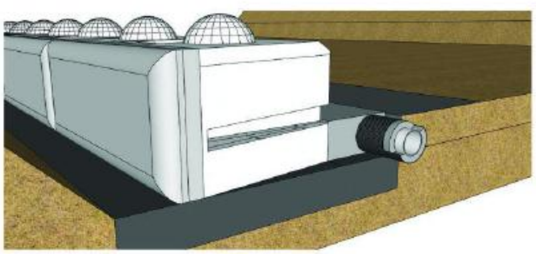


Figure 13

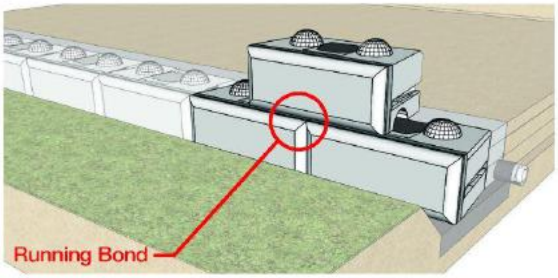


Figure 14

9. INSTALLING GEOGRID FOR MECHANICALLY STABILIZED EARTH WALLS

Redi-Rock blocks are designed to allow you to build relatively tall non-reinforced (or gravity) walls which use the weight of the blocks to provide stability. However, for some projects you may need to build even taller walls. In these cases, mechanically stabilized earth (MSE) retaining walls can be built with the Redi-Rock Positive Connection (PC) System.

The geogrid used in Redi-Rock PC System walls are 12-inch (305-millimeter) wide strips of PVC coated polyester geogrid that wrap through a vertical core slot cast into the block and extend full length into the reinforced soil zone on both the top and bottom of the block.

It is critical that you only use factory cut strips of Mirafi geogrid that are certified by TenCate Mirafi for width and strength. Field cutting strips of geogrid from larger rolls can significantly degrade the capacity of the wall system and is not allowed. Geogrid strips are only available through a Redi-Rock Manufacturer. (Figure 15)

Verify that you have the correct geogrid material and then cut the individual strips to the required length. The distance a geogrid strip must extend into the reinforced soil zone (design length) is measured from the back of the block to the end of the geogrid. Since the geogrid wraps through the block, the actual cut length of a given geogrid strip is two (2) times the design length plus enough additional geogrid to wrap though the block. For the Redi-Rock 28-inch (710-millimeter) PC blocks, the cut length is two (2) times the design length plus 3 feet (0.9 meters).

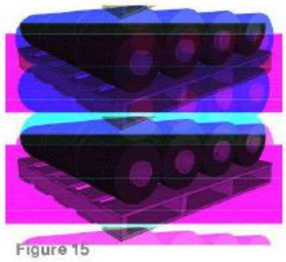


Figure 15

Inspect the Redi-Rock PC blocks for any concrete flashing or sharp edges in the slot and groove through the block. Remove any flashing and grind smooth any sharp edges which could damage the geogrid reinforcement.

Place the geogrid strip in the vertical core slot from the bottom of the block and pull approximately half of the length of the strip up through the core slot. Measure from the back of the block unit to the required design length and pin the bottom leg of the geogrid strip with staples, stakes, or other appropriate methods. Pull the geogrid strip tight to remove any slack, wrinkles, or folds. Secure the geogrid firmly in place by putting a pin through the geogrid and the steel lifting insert which is located in the recessed area on the top of the PC block (Figure 16) or placing drainage aggregate in the vertical core slot.

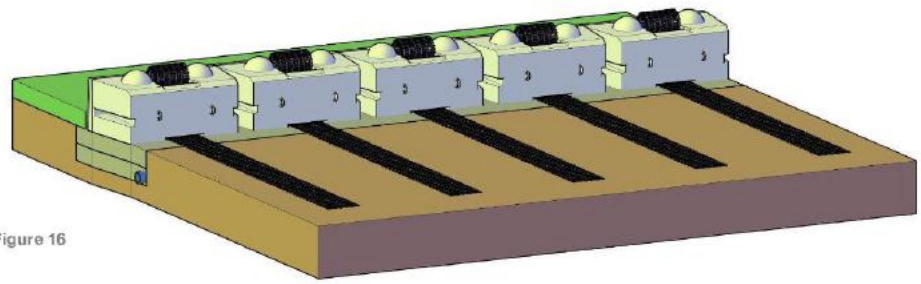


Figure 16

Place drainage aggregate between and behind the blocks. **(Figure 17)** Place the stone in uniform loose lifts as required in the project plans and specifications. Consolidate the stone between the blocks by hand tamping. Make sure to tamp stone into the ends of the groove on the bottom of the Redi-Rock PC blocks. Consolidate the stone behind the blocks with a minimum of three passes with a 24-inch (610-millimeter) wide walk-behind vibrating plate compactor capable of delivering at least 2000 lb (8.9 kN) of centrifugal force. Provide further compaction if needed to meet the density specified in the contract documents, but not less than 85% relative density of the stone determined in accordance with ASTM D-4253 and D-4254.

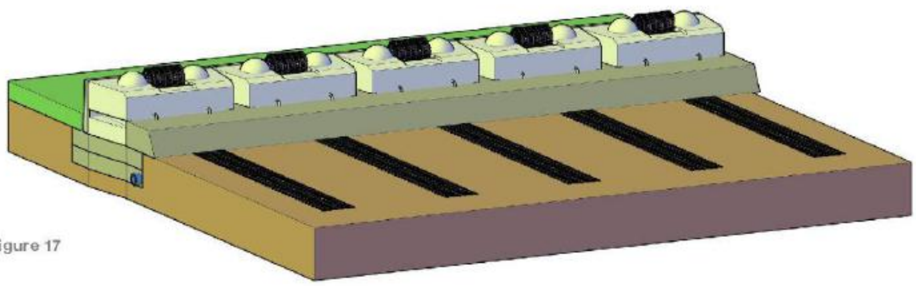


Figure 17

Place a strip of non-woven geotextile fabric between the drainage aggregate and the reinforced soil zone if specified.

Place the reinforced soil zone material in uniform loose lifts as required in the project plans and specifications. Reinforced soil zone material must be compacted to a density as specified in the contract documents, plans, and specifications but not less than 90% maximum density as determined by a modified proctor test (ASTM D1557).

Begin compaction at the back of the wall blocks and proceed to the embedded end of the geogrid strip using care to maintain the reinforcement strip in a level, taut condition oriented perpendicular to the back of the block unit to which it is attached.

Use hand operated compaction equipment within 3 feet (1 meter) of the back of the PC blocks. Heavier equipment can be used beyond 3 feet (1 meter) away from the PC blocks. Tracked construction equipment must not be operated directly on the geogrid strip reinforcement. A minimum fill thickness of 6 inches (150 millimeter) is required for the operation of tracked vehicles over the geogrid strips. Turning of tracked vehicles should be kept to a minimum to prevent displacement of the fill and the geogrid strips. Rubber-tired vehicles may pass over the geogrid strips at a slow speed of less than 5 mph (8 km/hr). Sudden breaking and sharp turning should be avoided.

After placing and properly compacting backfill to the elevation of the geogrid strip at the top of the block, extend the top leg of the geogrid strip to the design length required. Pull the geogrid strip tight to remove any slack, wrinkles, or folds. **(Figure 18)** Pin the top leg of the geogrid strip with staples, stakes, or other appropriate methods to hold it in place and keep the geogrid strip taut.

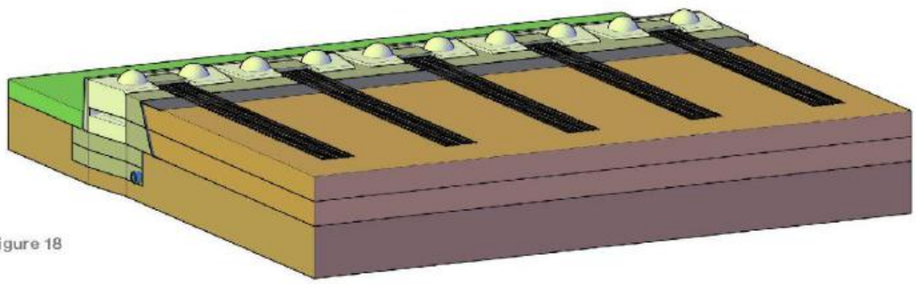


Figure 18

Fill the center slot in the PC blocks with drainage aggregate. Be careful to keep the grid flat against the back of the slot in the PC block and prevent any stone from lodging between the geogrid and the concrete block. Fill the vertical core slot completely with drainage aggregate. Consolidate the drainage aggregate by hand tamping. Use a broom to sweep clean the top of the blocks. Do not operate a walk behind vibratory plate compactor on top of the Redi-Rock PC blocks.

Place retained soil immediately between the end of the reinforced soil zone (identified as the embedded end of the geogrid reinforcement strips) and the back of the excavation. Compact retained soil to a density as specified in the contract documents, plans, and specifications but not less than 90% maximum density at ± 2% optimum moisture content as determined by a modified proctor test (ASTM D1557). Maximum differential elevation between the reinforced fill and the retained soil fill should never exceed 18 inches (457 millimeters).

Continue construction in a similar fashion to the top of the wall. **(Figure 19)**

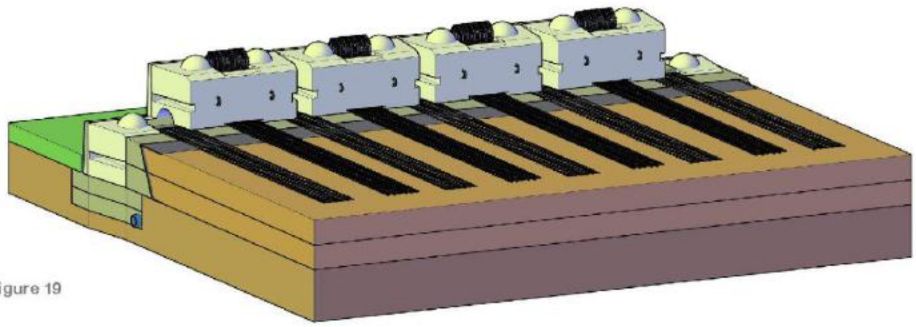


Figure 19

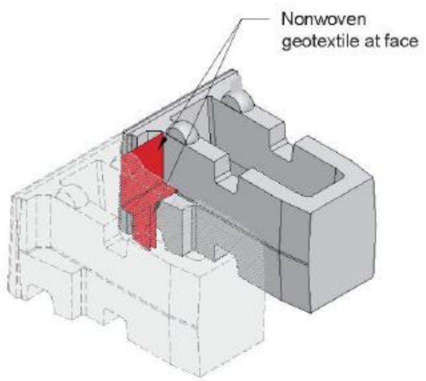
10. XL HOLLOW-CORE RETAINING BLOCKS

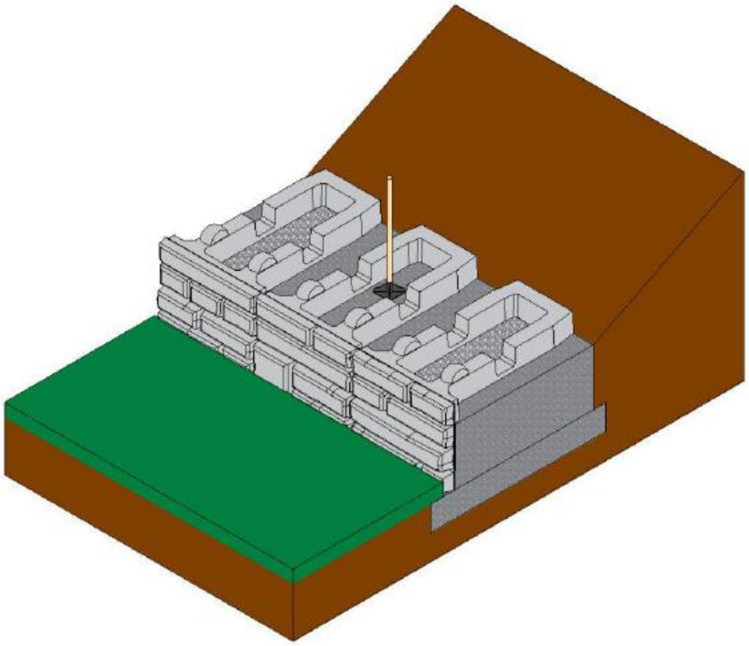
The greater width of XL blocks allows gravity walls to be built to greater height, while the greater individual block heights means that each block creates more area of wall face. XL block retaining wall installation generally follows the procedures of other Redi-Rock products, with a few differences.

Following the general procedures of sections 1 to 9, prepare the subgrade soils and place the leveling pad. The required leveling pad thickness will depend on the design by the wall design engineer, but will generally be a minimum of 12 inches (305 mm) thick.

Use appropriately-rated rigging fastened to the three lift hooks (one in the middle and two in the back of the blocks) and suitable heavy equipment to lift blocks into place. Place the first row of blocks to the correct line and grade. Just as with other Redi-Rock products, extra attention to ensure the first row of blocks is level and installed to the correct line and grade will save effort later as the installation proceeds.

Place two 18-inch (457 mm) by 18-inch (457 mm) pieces of non-woven geotextile fabric in each vertical joint between blocks – one on the upper half of the joint and one in the lower, wedge-shaped portion of the joint - to prevent the drainage aggregate and backfill material from migrating through the vertical joints at the blocks' face. Place washed drainstone or open-graded crushed stone backfill into the hollow cores of the blocks and between blocks in lifts of no more than 9 inches (230 mm) deep. Compact each lift by tamping until no further consolidation occurs with a soil tamper or other similar method. Strike off the top and sweep the upper surface of the blocks so the next row will sit cleanly on the lower row.





Due to the high percentage of open-graded stone within and between blocks, a drainage course behind the blocks is not required, but may be desirable to ease compaction of backfill and improve drainage. Place a layer of nonwoven geotextile fabric between the back of blocks (or drainstone layer, if used) and retained backfill.

Place and compact backfill as described above and repeat as necessary to reach the required height. Finish the top of wall with one or more rows of 18-inch (457 mm) high retaining blocks or freestanding blocks.

11. SPECIAL FEATURES

Some walls require special features such as curves, corners, top of wall details, details for elevated groundwater applications, and other details. Refer to the construction documents, plans, and specifications for details to construct these features. Additional general reference construction details are available on the Redi-Rock website, **redi-rock.com**.

Figure 21

Figure 22

Figure 23

12. IMPORTANT NOTES

Best practice dictates that wall construction should continue without interruption or delays. This will help expedite construction and minimize the time the excavation is open.

The construction site should be graded and maintained to direct surface water runoff away from the retaining wall throughout the entire construction process.

Do not exceed the allowable construction tolerances specified in the contract documents, plans, and specifications. At no time should tolerances at the wall face exceed 1° vertically and 1" in 10' (1:120) horizontally.

Immediately report the following site conditions, if encountered, to the Engineer or Owner's representative to determine the corrective action needed:

- Any observed groundwater seepage.
- Surface water run-off directed toward the retaining wall during construction.
- Erosion or scour of material near the wall.
- Ponded water near the wall.
- Wet, soft, or easily compressible soils in the foundation zone.
- Existing rock that differs in location from that shown on the project plans or rock located above the elevation of the bottom of the leveling pad.
- Existing or proposed toe or crest slopes that differ from typical cross-sections shown in the project plans.
- Any other items not specifically mentioned which raise questions or cause concerns during wall construction.

Immediately implement any corrective action before resuming wall construction.

13. FREESTANDING WALLS

Redi-Rock freestanding wall blocks have facing texture on two or three sides. They are used in applications where two or three sides of the wall are visible. Freestanding blocks can be installed as "stand alone" walls, such as perimeter walls or fences. They can also be designed and installed as the finishing top courses on a Redi-Rock retaining wall.

Freestanding wall installation is similar to that for Redi-Rock retaining walls. The main exception is that there is typically no backfill material behind the freestanding walls. Even though there is no backfill acting on the walls, freestanding walls need to be properly engineered. They require adequate stability at the base of the wall and they need to resist any applied forces such as wind loads or forces from railings or fences.

If you are building a "stand alone" freestanding wall, prepare the subgrade soils and leveling pad as described previously. Place bottom blocks on the leveling pad. A 6 inch (152 millimeter) minimum bury on the bottom block is typical. Extra bury may be required for some projects. Middle and top blocks are placed directly on top of the bottom blocks with no batter.

If you are building a freestanding wall on the top of a Redi-Rock retaining wall, end the last row of retaining wall blocks with a middle block. The size of the knob on top of the last row of retaining wall blocks will establish the setback for the first row of freestanding blocks. Retaining blocks with a 10-inch (254-millimeter) diameter knob will produce a 2 7/8 inch (73 millimeter) setback between the retaining block and the first freestanding block. If the retaining blocks have a 7 ½ inch (190 millimeter) diameter knob, the setback between the retaining block and the first freestanding block will be 1 5/8 inches (41 millimeters). Be sure to contact your local Redi-Rock manufacturer to determine availability of blocks with different knob sizes.

Begin and end freestanding walls with full or half Corner blocks.

Freestanding walls are installed plumb with no batter.

Figure 24

Variable radius freestanding blocks with a 4 inch x 12 inch (102 millimeter x 305 millimeter) pocket in one or two ends of the block are used to make curved walls. Field cut the relatively thin face texture on the ends of the variable radius blocks as needed to make the desired radius for your wall. **(Figure 24)**

Colored foam "Backer Rod" can be used to fill any small gaps which may occur between the blocks when installing walls. Backer rods can be purchased from concrete supply centers. Call your local Redi-Rock manufacturer for help locating foam backer rods for your project.

14. MAGIC BLOCK HOLLOW-CORE FREESTANDING WALLS

Redi-Rock Magic Block freestanding hollow-core units are stacked, similar to other Redi-Rock freestanding blocks, but then filled with concrete. Freestanding Hollow-Core Blocks work well for freestanding barriers, and can also be utilized for cantilever retaining walls.

CANTILEVERED WALLS

For many applications, the Freestanding Hollow-Core Blocks will be supported by a reinforced concrete footing. Prior to placing the footing, layout the wall to determine the locations of the open cores in the staggered rows of hollow-core units. This will help determine where rebar should be placed in the footing. When determining vertical rebar placement, consider the equipment that will be used to set the block to help avoid conflicts. Number and size of rebar will depend upon the engineer's structural design.

Construct the footing on a competent subgrade per the design drawings. Once the footing has cured, use a stringline to mark the alignment of the blocks (usually the inside of the block). Begin setting blocks. A scissors-type clamp works well. **(Figure 25)** Alternatively, straps looped around the interior ribs can be used, as well.

Figure 25

Corners can be constructed in the wall using hollow-core corner blocks. These blocks have texture on three sides. For a tight fit between blocks, the texture on the corner block can be trimmed by 2 or 3 inches where it abuts the adjacent block. If the design requires continuous rebar, cut a section out of the side of the corner block aligned with the hollow core of the adjacent block. **(Figure 26)**

Place horizontal rebar in the blocks, supported in the grooves on the interior structural ribs. Place the vertical rebar, lapping and tying, as required.

Stack the next row of block, making sure to carefully align the blocks and staggering the joints to create a running bond. We recommend stacking no more than three courses of block without filling the core.

Prior to infilling the wall, we suggest grouting the joints between blocks with non-shrink standard grout. This helps prevent leakage during infilling, and provides an aesthetic element.

Infill the hollow core of the wall with ready-mix concrete meeting the requirements of the design. Place the concrete carefully to prevent misalignment of the rebar. While filling, use an internal concrete vibrator to ensure consolidation and eliminate voids.

Figure 26

COPING

Magic Block Freestanding Hollow-Core Blocks can be placed on Redi-Rock PC-series walls to create a free-standing coping. The connection uses a No. 3 rebar hook to tie the coping to the upper PC blocks.

Install a No. 3 rebar hook through the lifting hook in each PC block and let the hook lay on the shear knob.

Install PC geogrid strips, if required. Fill the PC core with stone to the recess area. Place plastic sheeting over the geogrid exposed in the PC core.

Set the Freestanding Hollow-Core Blocks in place on the PC blocks.

Install the horizontal and vertical reinforcing steel, as required by the design. Pull the rebar hooks up into the Freestanding Hollow-Core Blocks core and engage with the horizontal rebar. Fill the hollow cores with concrete. **(Figures 27 & 28)**

Figure 27

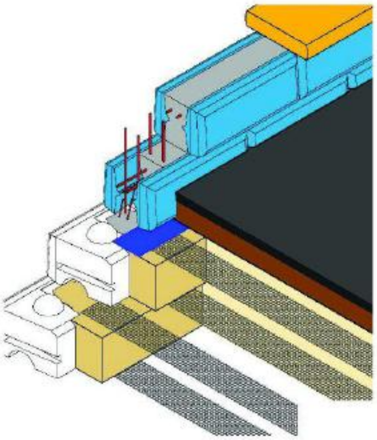


Figure 28

WATER CONTROL APPLICATIONS

A few additional details can be incorporated into Freestanding Hollow-Core walls to improve their water-tightness for flood control and other water-related applications. **(Figure 29)**

Prior to constructing the footing, perform any subgrade preparation, soil improvements, and/or drainage installation as required by the design.

Install an appropriate waterstop at the joint between the footing and the bottom of the wall, following the waterstop manufacturer's recommendations.

When using a ribbed center bulb strip, install it prior to pouring concrete for the footing such that it will be half embedded in the footing. Commonly, it will require attaching to the footing rebar with wire ties.

A bentonite/butyl rubber expandable waterstop can be installed on top of the footing prior to installing the first row of blocks. Be sure to protect the strip from damage and keep it clean.

A keyway can be cast into the footing if required by the design.

Avoid block-to-block joints where structural ribs from adjacent blocks will be in contact, as this will result in a joint with little, if any, cast-in-place concrete available to resist water flow. If necessary, remove one of the offending ribs with a concrete saw.

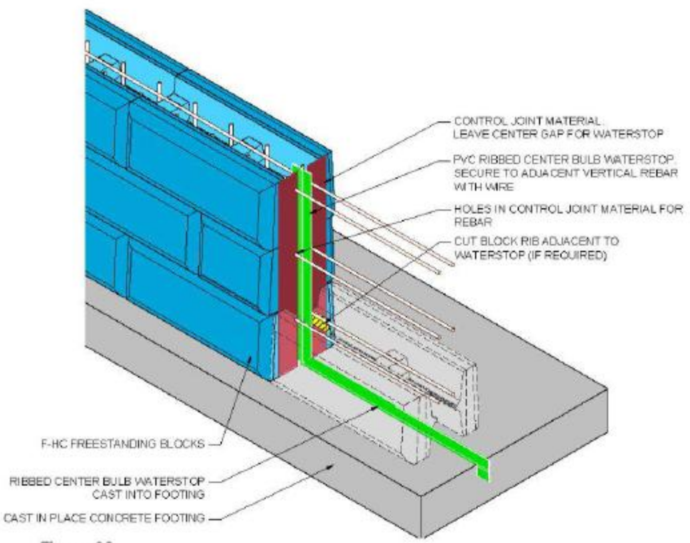


Figure 29

When placing concrete, extra care should be taken to fully consolidate the concrete to eliminate voids which could become conduits for water. Integral crystalline waterproofing admixtures are available that can reduce permeability and seal small cracks. Additional measures, such as sealing exposed joints with non-shrink grout and/or mastic and casting a slab against the wall can also be used to reduce water penetration. Foundation waterproofing experts should be consulted to select and assist with the installation of any performance improvement measures.

15. CAP INSTALLATION

Cap or step blocks are commonly used on top of freestanding walls to provide a finished look. **(Figure 30)**

Mark the center of the freestanding blocks to monitor the correct running bond spacing.

Secure the cap with construction adhesive, polyurethane sealant, or mortar. If construction adhesive is used, it should meet the requirements of ASTM D3498 and C557 and HUD/FHA Use of Materials Bulletin #60. Two examples are Titebond Heavy Duty Construction Adhesive by Franklin International or PL Premium Construction Adhesive. If polyurethane sealant is used, it should be one-component, highly-flexible, non-priming, gun-grade, high-performance elastomeric polyurethane sealant with movement of ± 25% per ASTM C719, tensile strength greater than 200 psi (1.4 MPa) per ASTM D412, and adhesion to peel on concrete greater than 20 PLI per ASTM C794.

Adhesive or sealants should be applied in 1.5 inch (38 millimeter) diameter round "Hershey Kiss" shaped dollops located in two rows at the top of the freestanding blocks at 8 inches (203 millimeter) on center.

Caps can be cut as needed for proper alignment. If desired, grout the joints between cap blocks after installation with a non-shrink grout.

Figure 30

16. FORCE PROTECTION WALLS

Install a threaded termination end on the end of the cable. Electroline M Series terminations manufactured by *Esmet, Inc.* work well.

Thread cable with a termination end through all the blocks. It is important that the cable is placed in each course of blocks prior to placing the next course.

Pull the cable through the block on the far end of the wall until approximately 2 inches (51 millimeters) of threads protrude beyond the end of the blocks. The exposed threads will provide room to place for a 5/8 inch x 6 inch x 9 inch (16 millimeter x 152 millimeter x 229 millimeter) steel plate over the exposed threads and start the nut.

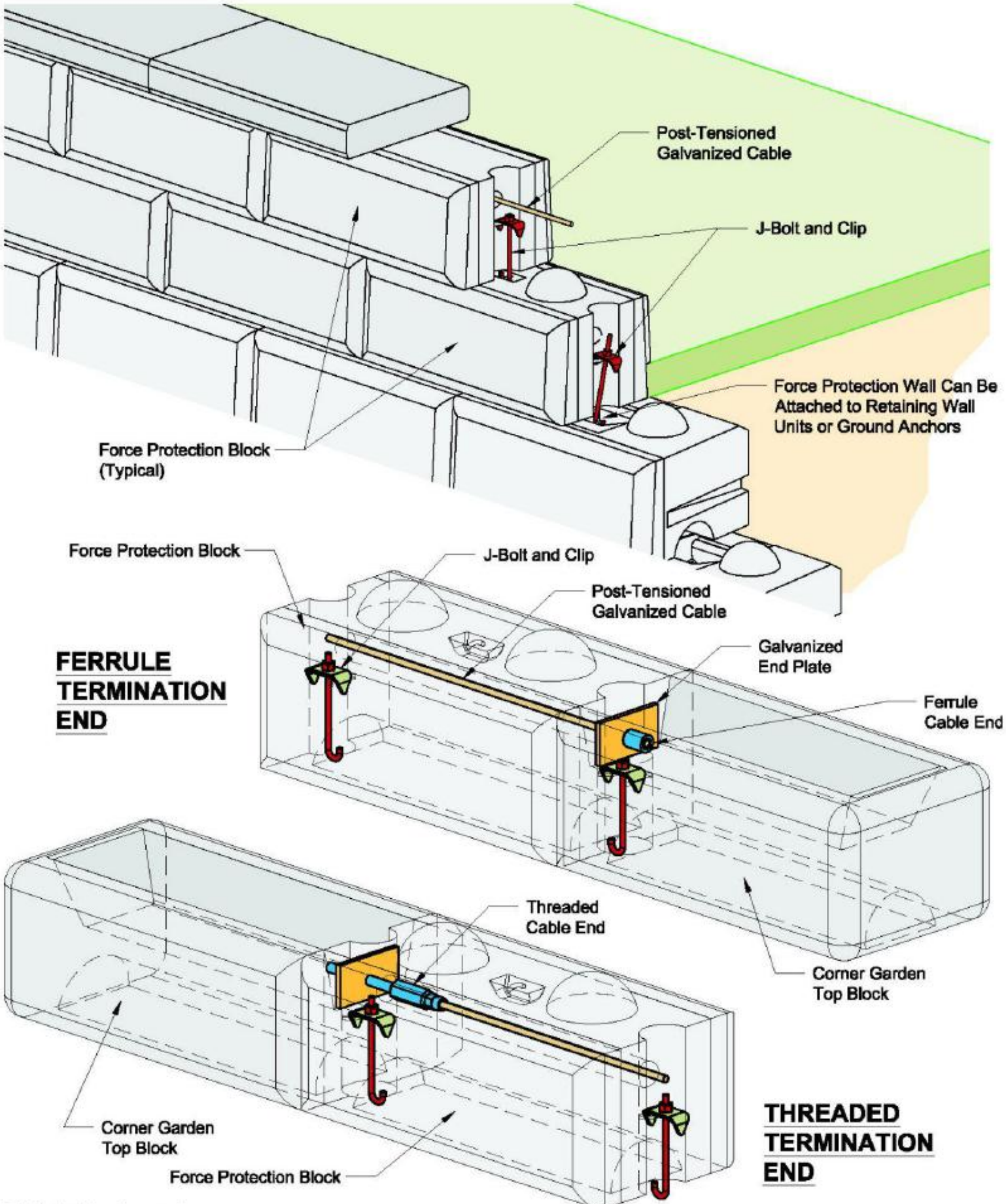
Mark and cut the cable at the starting end of the wall so that 4 inches (102 millimeter) of cable protrudes beyond the block, providing room a 5/8 inch x 6 inch x 9 inch (16 millimeter x 152 millimeter x 229 millimeter) steel plate and ferrule termination fitting.

After the cable has been cut, slide the entire cable several feet (meters) towards the ferrule end so that you will have room to work. Install a steel plate and ferrule termination end on the cable.

Pull the cable snug so that the ferrule is against the steel plate. There will be 2 inches (51 millimeters) of thread exposed at the far end of the wall which has the termination end on the cable.

Place the steel plate over the threads and start the nut. The nut can be tightened to the desired tension.

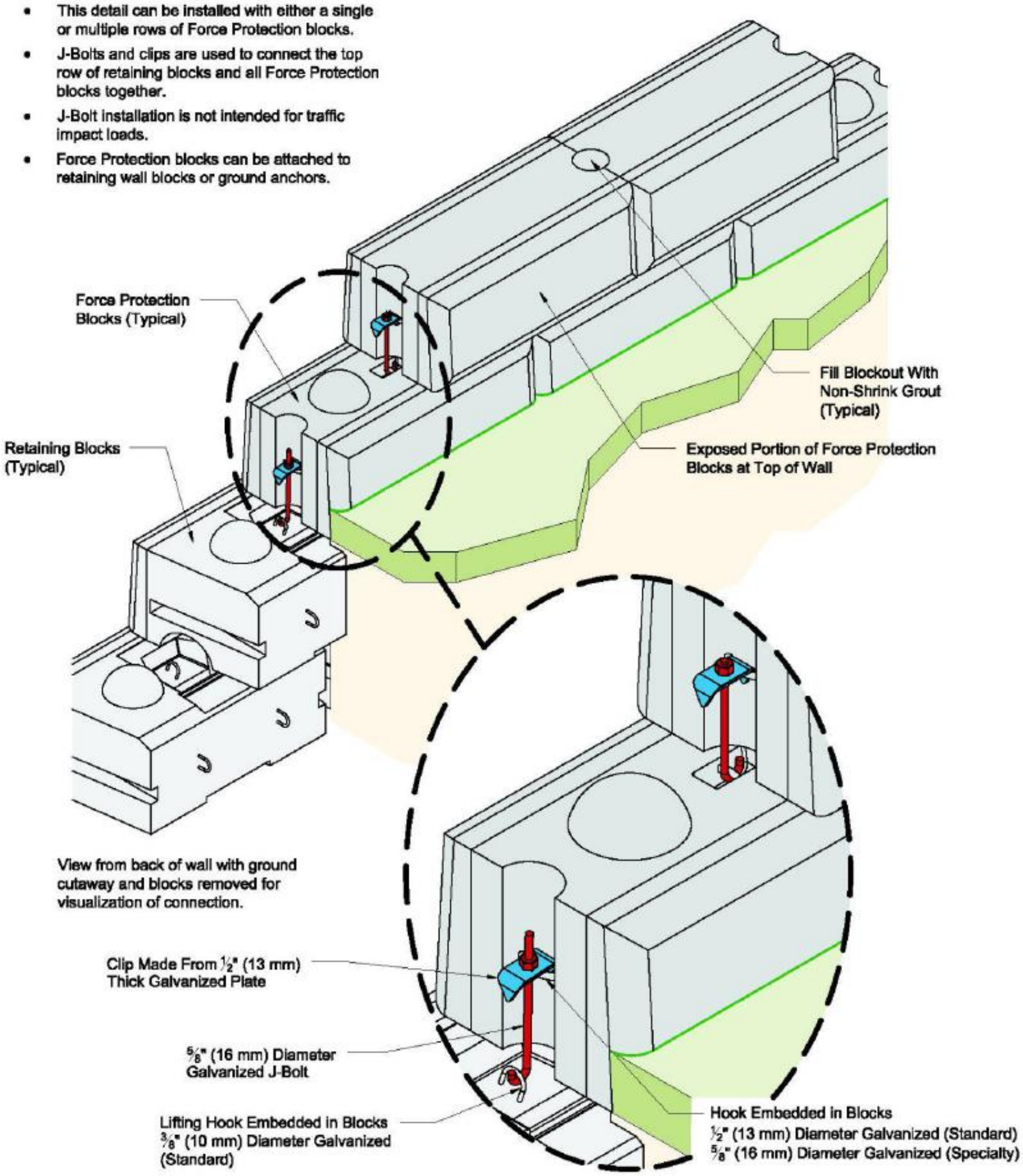
Force Protection Coping With J-Bolts and Post-Tensioned Cable



- *This drawing is for reference only.*
- ***Final designs for construction must be prepared by a registered Professional Engineer** using the actual conditions of the proposed site.*
- ***Final wall design must address both internal and external drainage and shall be evaluated by the Professional Engineer who is responsible for the wall design.***

Force Protection Coping With J-Bolts

- This detail can be installed with either a single or multiple rows of Force Protection blocks.
- J-Bolts and clips are used to connect the top row of retaining blocks and all Force Protection blocks together.
- J-Bolt installation is not intended for traffic impact loads.
- Force Protection blocks can be attached to retaining wall blocks or ground anchors.



- *This drawing is for reference only.*
- ***Final designs for construction must be prepared by a registered Professional Engineer** using the actual conditions of the proposed site.*
- ***Final wall design must address both internal and external drainage and shall be evaluated by the Professional Engineer who is responsible for the wall design.***

J-BOLT INSTALLATION

J-Bolts can be used to secure force protection walls to the top row of retaining wall blocks (when used on the top of a Redi-Rock wall) or to concrete anchors set in the ground (for a stand alone wall).

Set force protection blocks with the ends centered on ground anchors or the center of Redi-Rock middle retaining wall blocks immediately below.

Place a clip between blocks in hooks provided in the middle of the block on each end.

Place a J-bolt through center of the clip, thread a nut on the J-bolt, and tighten.

Repeat for all remaining courses of force protection blocks.

17. REDI-ROCK COLUMNS

Redi-Rock column blocks are available to complement Redi-Rock walls. Columns can be installed by themselves or with fences or gates.

Column blocks can be placed on properly prepared aggregate or concrete leveling pads or directly on Redi-Rock retaining wall blocks, depending on the specific design for your project.

Column blocks can be manufactured with pockets for concrete or split wood fence rails.

Concrete adhesive or polyurethane sealant can be used between stacked column blocks.

Install a cap on the top of a column. Adjust the cap position until all sides are equidistant and square to the column. Secure the column cap with construction adhesive or polyurethane sealant.

Special inserts are available for mounting gates or similar features to Redi-Rock columns.

Column blocks are available with 4 inch (102 millimeter) or tapered 8 inch (203 millimeter) diameter cores which can be filled with stone or concrete and steel rebar reinforcement.

A conduit can be left through the core if needed for lighting or other features.

APPENDIX: 4.1.1 UNIT MANUFACTURING QUALITY CONTROL

A "Road Map For Quality" For Redi-Rock Retaining Walls

TOTAL QUALITY MANAGEMENT FOR PRODUCTION AND INSTALLATION OF REDI-ROCK RETAINING WALLS

Redi-Rock has recognized that quality control requires a coordinated team effort to achieve the best results moving forward in the industry. These efforts are best described by the following six steps for everybody involved in building a Redi-Rock wall:

Step 1. Production of the steel forms by Redi-Rock International.

Step 2. Final assembly/adjustments of forms and shipment of forms and molds by Redi-Rock International.

Step 3. Production of Redi-Rock concrete units by individual Redi-Rock dealers. **Step 3 is the focus of this manual.**

Step 4. Preparation of the site specific drawings and specifications by a Professional Engineer.

Step 5. Installation of the wall by contractor.

Step 6. Acceptance of wall by purchaser.

The strategy of a Total Quality Management Program should be for each of the parties listed above to have a quality program which demonstrates that their product (stage of production) conforms to requirements and they are taking responsibility for demonstrating such.

This is accomplished by the various production steps performing an incoming quality check (IQ) and an out-going quality check (OQ). These steps are defined by each producer in order to meet their specific requirements and those of their customer (the receiver of their production step). For example,

Form manufacturers will have documentation demonstrating that they purchased specified materials to produce the forms (IQ) and they will have an (OQ) check demonstrating that the steel forms meet the requirements specified on form shop drawings and specifications.

Redi-Rock International will have an (IQ) check verifying the steel forms conform to shop drawings and specifications for manufacture of the forms. Redi-Rock's (OQ) will verify that the forms and molds meet specifications and will produce blocks which conform to the block specifications.

Dealers (block manufacturers) upon receipt of forms will verify (IQ) that the forms produce blocks conforming to block drawing specifications. The dealers (OQ) will verify that blocks produced/shipped conform to the block drawings and specifications.

Engineers should have their own (IQ) program which would deal with supply of site specific data for design of the final retaining wall. Their (OQ) would deal with checking the final design package.

The contractors (IQ) program would document purchasing/acquiring of the appropriate materials as specified in the final construction package. The contractors (OQ) will demonstrate the installation of the wall in accordance with the final construction drawings and specifications.

The purchaser, (IQ) when satisfied that he got what he paid for, will accept the wall by making final payment.

The above scenario basically says each producer is responsible for the quality of their product or work. It also is based on the assumption that everyone is honorable. When trust is compromised, systems change and others are hired to oversee the work of subsequent stages, but the verification still happens!

THANK YOU FOR YOUR PARTICIPATION.

A QUALITY CONTROL PROCESS FOR THE PRODUCTION OF REDI-ROCK BLOCKS AT ______________________

(REDI-ROCK LICENSEE'S COMPANY NAME)

DAILY QUALITY CONTROL PROCEDURES

1. Batch tickets should be signed and proper mix design verified by the shop foreman (or designee) and copies filed with the quality control data collected.
2. A concrete cylinder sample will be taken for each mix design (at least once monthly or once every 150 cyds poured) and the result filed with other data collected to verify proper compressive strength and entrained-air content is achieved per Redi-Rock specifications. Standard Specifications for Ready-Mix concrete should follow ASTM C94.
3. A raised-texture number should be installed in each RRI cell so any block manufactured can be traced back to that cell, should a repeating flaw of any kind develop on the block.
4. The date of manufacture should be scribed or tagged in the back of each block so blocks could be tracked back to the batch ticket if needed.
5. Prior to placing the completed blocks into inventory, the shop foreman (or designee) will visually inspect each block for dimensions, aesthetics appearance, and proper lift device installation.
6. A designation shall be labeled on the back of any block not meeting proper specifications. These blocks shall be placed in a designated "seconds" pile away from good inventory.

CONCRETE MIX PROPERTIES [2]

FREEZE THAW EXPOSURE CLASS [4]	MINIMUM 28 DAY COMPRESSIVE STRENGTH [5]	MAXIMUM WATER CEMENT RATIO	NOMINAL MAXIMUM AGGREGATE SIZE	AGGREGATE CLASS DESIGNATION [6]	AIR CONTENT [7]
MODERATE	4,000 psi (27.6 MPa)	0.45	1 inch (25 mm)	3M	4.5% ± 1.5%
SEVERE	4,000 psi (27.6 MPa)	0.45	1 inch (25 mm)	3S	6.0% ± 1.5%
VERY SEVERE	4,500 psi (30.0 MPa)	0.40	1 inch (25 mm)	4S	6.0% ± 1.5%
MAXIMUM WATER-SOLUBLE CHLORIDE ION (Cl^-) CONTENT IN CONCRETE, PERCENT BY WEIGHT OF CEMENT [8]					0.015
MAXIMUM CHLORIDE AS Cl^- CONCENTRATION IN MIXING WATER, PARTS PER MILLION					1000
MAXIMUM PERCENTAGE OF TOTAL CEMENTITIOUS MATERIALS BY WEIGHT [9] (VERY SEVERE EXPOSURE CLASS ONLY)					
FLY ASH OR OTHER POZZOLANS CONFORMING TO ASTM C618					25
SLAG CONFORMING TO ASTM C989					50
SILICA FUME CONFORMING TO ASTM C1240					10
TOTAL OF FLY ASH OR OTHER POZZOLANS, SLAG, AND SILICA FUME [10]					50
TOTAL OF FLY ASH OR OTHER POZZOLANS AND SILICA FUME [10]					35

(3) Concrete mix properties are in general accordance with ACI 318 durability requirements. Research has shown that concrete manufactured to these standards demonstrates good durability and performance. When these requirements are followed, specific freeze-thaw testing of the concrete is typically NOT required.
(4) Exposure class is as described in ACI 318. "MODERATE" describes concrete that is exposed to freezing and thawing cycles and occasional exposure to moisture. "SEVERE" describes concrete that is exposed to freezing and thawing cycles and in continuous contact with moisture. "VERY SEVERE" describes concrete that is exposed to freezing and thawing cycles and in continuous contact with moisture and exposed to deicing chemicals. Exposure class should be specified by owner/purchaser prior to order placement. Longer lead times may be required for block units manufactured for "severe" and "very severe" exposure classes.
(5) Test method ASTM C39.
(6) Defined in ASTM C33 Table 3 *Limits for Deleterious Substances and Physical Property Requirements of Coarse Aggregate for Concrete.*
(7) Test method ASTM C231.
(8) Test method ASTM C1218 at age between 28 and 42 days.
(9) The total cementitious material also includes ASTM C150, C595, C845, and C1157 cement. The maximum percentages shall include:
   (a) Fly ash or other pozzolans in type IP, blended cement, ASTM C595, or ASTM C1157.
   (b) Slag used in the manufacture of an IS blended cement, ASTM C595, or ASTM C1157.
   (c) Silica fume, ASTM C1240, present in a blended cement.
(10) Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of the total weight of the cementitious materials.

MONTHLY QUALITY CONTROL PROCEDURES

1. Periodically (minimum of once monthly) during Redi-Rock production, a designated quality control person should fill out the following RRI Dimensional Data Sheet for one block from every retaining cell and free standing cell manufacturing Redi-Rock block. The shop foreman should review measurements for any deviations from the specifications and address any problems identified. Refer to the "Product Data Sheets" in the Design Resource Manual for dimensional properties of the blocks.
2. A designation shall be labeled on the back of any block not meeting proper specifications. These blocks shall be placed in a designated "seconds" pile away from good inventory.
3. The monthly quality assurance index should be calculated and monitored with a goal of zero percent (0%) failing. This sheet should be monitored monthly and filed with other quality control information.

ALKALI SILICA REACTION

As manufacturers of precast concrete products, Redi-Rock manufacturers need to be aware of production issues that can impact the quality of our concrete products. One of these issues is alkali-silica reaction, or ASR. ASR is a reaction which occurs over time in concrete between alkaline cement paste and reactive non-crystalline silica which found in many common aggregates. High cement content mix designs and concrete subject to warm, humid, or wet environments can be quite susceptible to ASR. External sources of alkalies such as deicing salts, seawater, groundwater, and water from industrial processes, or repeated cycles of wetting and drying can also lead to ASR in concrete. Since many Redi-Rock manufacturers use mix designs that allow multiple castings per day, we need to be aware of ASR. Even if you don't turn multiple blocks per day in the same form, Redi-Rock products can be used in applications where external alkalies are present. Quite simply, ASR is a topic that is important to all concrete manufacturers.

With ASR, the reaction between alkalis in the cement (calcium hydroxide) and silicas in the aggregates produces an expansive gel in the concrete. This gel creates internal stresses that eventually cause the concrete to split. Typical indicators of ASR are longitudinal cracks, map (random pattern) cracking, and in advanced cases, closed joints, spalled concrete surfaces, or relative displacements of different portions of a structure. Map cracking and spalled concrete surfaces are the most likely indicators in Redi-Rock products. ASR takes time to develop and, in many cases, ASR may not show up for 5 to 15 years. However, when it does appear, ASR can be quite extensive and costly to fix. Replacement rather than repair is often the only feasible option to correct the problem.

Here are a few options to reduce or completely eliminate ASR in concrete:

1. You can use non-susceptible aggregates. ASTM C1260 can be used to test your fine and coarse aggregates and determine whether or not your aggregates are reactive.
2. You can add pozzolans such as fly ash, slag, or silica fume to the concrete mix. ASTM C1567 can be used to test concrete mixes and determine whether or not the added pozzlans are enough to mitigate ASR in the concrete.
3. You can use low alkali cement. Check with you cement manufacturer to see if they can provide a cement with an alkali content below the threshold level commonly required to produce ASR in the concrete. Typically, the total alkali content is limited to a maximum 0.60%.
4. You can add lithium salts to the concrete mix. Products like Sika Control ASR (lithium nitrate admixture) can be used to control ASR in concrete. The Federal Highway Administration (FHWA) has published recommendations for the use of lithium to mitigate or prevent ASR.

An excellent source of information on ASR is available in the document *Diagnosis and Control of Alkali-Aggregate Reactions in Concrete* by Farny and Kerkhoff, published by the Portland Cement Association. A pdf copy is available on the Redi-Rock dealer secure website.

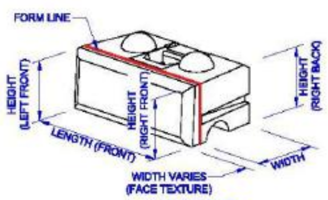
REDI-ROCK TARGET BLOCK QUALITY MEASUREMENT SHEET

MANUFACTURER: ____________________
INSPECTOR: ____________________
DATE CHECKED: ____________________
FORM NUMBER: ____________________

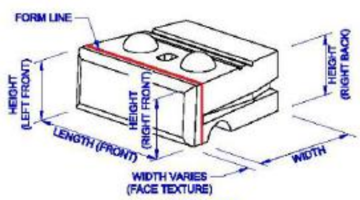
TARGET QUALITY PROPERTIES

TARGET DIMENSIONS (1)(2)	RETAINING BLOCKS			FREE STANDING BLOCKS		
	TARGET	TOLLERANCE	MEASUREMENT	TARGET	TOLLERANCE	MEASUREMENT
HEIGHT (LEFT FRONT OF BLOCK)	18 (457)	± 3/16 (± 5)		18 (457)	± 3/16 (± 5)	
HEIGHT (LEFT BACK OF BLOCK)	18 (457)	± 3/16 (± 5)		18 (457)	± 3/16 (± 5)	
HEIGHT (RIGHT FRONT OF BLOCK)	18 (457)	± 3/16 (± 5)		18 (457)	± 3/16 (± 5)	
HEIGHT (RIGHT BACK OF BLOCK)	18 (457)	± 3/16 (± 5)		18 (457)	± 3/16 (± 5)	
LENGTH (FRONT OF BLOCK)	46 1/8 (1172)	± 1/2 (± 13)		46 1/8 (1172)	± 1/2 (± 13)	
28" WIDTH (FORM LINE TO BACK)	22 5/8 (575)	± 1/2 (± 13)		24" NOMINAL FREESTANDING BLOCK WIDTH:		
41" WIDTH (FORM LINE TO BACK)	35 1/8 (892)	± 1/2 (± 13)		13 3/16 (335)	± 1/2 (± 13)	
TARGET OBSERVATIONS	CRITERIA			MEASUREMENT (CIRCLE ONE)		
CONCRETE BUG HOLES	LESS THAN 3/4 (20)			PASS / FAIL		
CONCRETE COLOR	AESTHETIC			PASS / FAIL		
A36 STEEL LIFTING INSERTS	PROPER NUMBER, TYPE, & LOCATION			PASS / FAIL		
CONCRETE OVERPOUR CHECK(3)	NONE PERMITTED			PASS / FAIL		
CONCRETE FLASHING PC INSERT	NONE PERMITTED ON ROUNDED SURFACES(5)			PASS / FAIL		
CONCRETE CHIPPING PC INSERT	NONE PERMITTED AT EDGES OF PC INSERT(5)			PASS / FAIL		

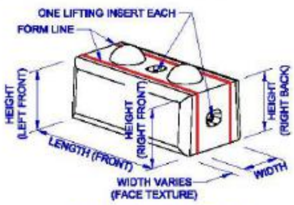
(1) All dimensions are *inches (mm)*.
(2) A square may assist in measuring blocks and helping to assure that surfaces are straight and true.
(3) Overpouring the block above the geogrid insert will result in a sharp edge that could damage the geogrid and not permit the blocks to lay level, thus creating a weaker wall and one that grows progressively out of level with each additional row of blocks. This edge needs to be removed before blocks are shipped to the jobsite. Refer to the sketch below.
(4) Quality Control problems need to be traced to the out of tolerance form, and out of spec blocks removed from inventory, and correct deficiencies within production operation. Re-check daily until block specifications are met, then as required periodically thereafter.
(5) Refer to the sketch below. Adjust PC insert as directed in User Manual to eliminate flashing or chipping / spalling around edge of PC pocket on top of block.



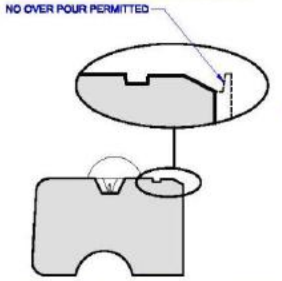
28" (710) PC RETAINING SERIES



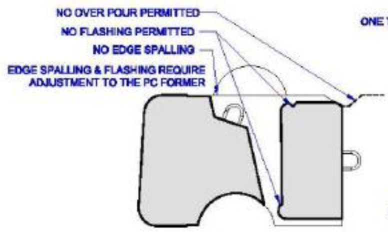
41" (1030) RETAINING SERIES



FREESTANDING SERIES



TYPE 1 & 1AT GEOGRID CONNECTOR



PC GEOGRID CONNECTOR

A36 STEEL LIFTING INSERTS

Quality Control Worksheet

(For Block Manufacturer's Internal Use)

Date	Problem Discovered	Date	Action Taken to Resolve Problem

PERIODIC REPORTING SUBMITTALS

1. Dimensional Data Sheets

(July 15th Submittal Each Year)

2. Product Verification Sheets

(July 15th Submittal Each Year)

____________________ Company   ____________________ Name

RRI Dimensional Data Sheet

Measurements should be done periodically on one block from each cell producing Redi-Rock

Date	Retaining/ Free Standing Cell #	Geo-Insert Type 1 or 2	Actual Block Dimension							Pass	Reason Failed
			Length	Width	Height Left		Height Right		Straight & True		
					Front	Back	Front	Back			

Month of ________ Calculation	Total Blocks Failing ÷	Total Blocks Inspected =	Monthly Quality Assurance Index

Redi-Rock Product Verification Sheet

In an effort to assure conformance of RRI products to Redi-Rock block specifications found in the Design Resource Manual, RRI is requesting that all dealers marketing their blocks under the name Redi-Rock certify the conformance of your blocks by completing, signing and returning this Product Verification Sheet. Please circle **Yes or No** below that apply to your operation.

We build 4,000 psi minimum blocks. **Yes or No**

We include air content between 1 ½% - 7½% air (Per latest RRI Specifications) **Yes or No**

We produce the following Redi-Rock products:

Retaining Series

- 41" series block **Yes or No**
- 60" Blocks **Yes or No**
- 28" series block **Yes or No**
- 9" Setback Blocks **Yes or No**

Free Standing Series **Yes or No**

Columns **Yes or No**

Steps **Yes or No**

Pavers **Yes or No**

Texture(s)

- Limestone face **Yes or No**
- Cobblestone face **Yes or No**
- Ledgestone face **Yes or No**

We have the following inserts installed in our retaining forms:

Geo 1 insert (For type 1 and type 1 AT connections) **Yes or No**

Positive Connection System insert **Yes or No**

We are Manufacturing Redi-Rock prodcuts to the Redi-Rock International specifications indicated in the latest RRI Design Resource Manual edition. **Yes or No**

Signature: ______________________ Title: ______________________

Company Name: ____

Date: ______________________

Before July 15th of Each Year, please sign, date and fax or email this form along with the RRI Dimensional Data Sheet with the dimensions of one block from every cell.

Fax 231-237-9521 or Email info@redi-rock.com

Revised KP 7/2/15

APPENDIX: 4.1.2 REINFORCEMENT QUALITY CONTROL

TENCATE

Quality Control Plan
Miragrid® and BXG

The Quality System

The Quality System is for the purpose of continuous improvement of our products and service. The Quality System is assessed annually through audits and Management Reviews. The Quality Manager is responsible for establishing, implementing, and maintaining the Quality System.

It is the responsibility of each employee to perform tasks under the quality system assigned to them and to take appropriate actions to ensure that the quality system is followed and that all products of TenCate Geosynthetics Americas conform to specification.

Personnel

The Quality Control Lab consists of sufficient staff and testing equipment to properly conduct quality testing on TenCate Geosynthetics Americas products. The Quality Manager determines “sufficient staff” based on testing needs. Resource requirements are reviewed regularly during Management Review.

Training

A job description is maintained for each job classification. A training form, detailing training activities, is maintained for each employee in the QC Lab. The Quality Manager and/or Human Resources maintain Job descriptions and training forms.

Individuals are qualified based on their abilities, education, on-the-job training, and other special skills.

Outside Services and Supplies

TenCate Geosynthetics Americas solicits qualified vendors for products and services in order to maintain Quality Control and to ensure that the inspection practices and techniques assure delivery of only high standard quality materials and services.
Vendors are approved prior to procurement, for their ability to meet requirements, performance records, and quality history.

Manufacturing Quality Control

All testing is accomplished in accordance with documented and controlled test methods. Where methods of inspection are not specified, methods shall be selected that have been published in international or national standards by reputable technical organizations or in relevant scientific texts or journals. Use of selected methods are verified and approved by the Quality Manager.

Testing is carried out under controlled conditions including the following:

Overall management of process control is governed by documented procedures.

Documented test methods and work instructions govern the comprehensive inspection and testing of each lot.

Testing equipment is selected based upon needs and the ability to satisfy specified requirements and the equipment is suitably maintained.

Training of personnel is adequate and documented.

Appropriate Quality Records are maintained.

Material is visually inspected during production and during sampling for adequate coating on geogrid.

Each sample to be tested in the lab is accompanied with a label for that particular roll number. Test results are recorded on Quality Control Test Reports by number and then entered into the computer database by roll number.

All samples are delivered to the Quality Control lab and tested as delivered to minimum specification values. The standard operating procedure for each test is documented and copies of ASTM procedures are kept in the laboratory.

Preparation for each sample is conducted in accordance with Standard Operating Procedures and ASTM requirements.

Testing Frequency

<table>
<tr><td>Physical Property</td><td>2XT-10XT</td><td>20XT-24XT</td><td>BXG11
BXG12</td></tr>
<tr><td>Mass per Unit Area (ASTM D5261)</td><td>15,000 yd²</td><td>8,000 yd²</td><td>14,400 yd²</td></tr>
<tr><td>Tensile Properties (ASTM D6637 Method)</td><td>15,000 yd²</td><td>8,000 yd²</td><td>4,800 yd²</td></tr>
<tr><td>Junction Strength (ASTM D7737 replaced GRI GG-2)</td><td>15,000 yd²</td><td>8,000 yd²</td><td>14,400 yd²</td></tr>
<tr><td>Aperture Size</td><td>Start of Production Run</td><td>Start of Production Run</td><td>Start of Production Run</td></tr>
<tr><td>CEG</td><td colspan="3" rowspan="2">Once per year</td></tr>
<tr><td>Molecular Weight</td></tr>
</table>

Identification

All material is identified with a style number, which corresponds to a specification. Individual production runs are assigned a lot number for the purpose of controlling production, recording production and maintaining records for that lot. Individual rolls within a lot are assigned a roll number in sequential order.

Handling/Storage

Handling methods and practices are intended to prevent damage and deterioration to material during the manufacturing process. All geotextile rolls are furnished with suitable wrapping for protection against moisture and extended ultraviolet exposure prior to placement. Each roll is labeled or tagged to provide product identification sufficient for inventory and quality control purposes. Rolls are stored in a manner, which protects them from the elements.

Archived samples are identified by a label and adequately stored to prevent deterioration.

Supporting Documentation

ASTM D4354 Practice for Sampling of Geosynthetics for Testing
ASTM D4873 Guide for Identification, Storage, and Handling of Geotextiles

Control of Nonconforming Product

TenCate Geosynthetics Americas procedures require the documentation of all nonconformances. Nonconforming material is tagged and/or segregated. The status of nonconforming product is reviewed to determine whether the material is scrapped, reworked, downgraded or continued through processing. Reworked material is re inspected and must meet requirements.

Corrective and Preventative Action

TenCate Geosynthetics Americas recognizes that the effectiveness of the corrective and preventative action policy is crucial to the success of the Quality System.

Corrective Action procedures include:

- Analyzing customer complaints.
- Investigation into the root cause of nonconforming products and system nonconformances.
- Determination of corrective action to eliminate the cause of the nonconformance.

The quality system provides for preventative action by reviewing data including customer complaints, audit results, and past non-conformances to detect and eliminate potential causes of non-conformances

Statement Of Authority

The Quality Manager has been assigned ultimate responsibility for implementing the Quality System and the authority for assuring its maintenance.

In the absence of the Quality Manager, the delegation of responsibility is assigned to persons to act in those instances to ensure continuation of operations. Responsibility for activities described under each element may be assigned to appropriate supervisors. Delegation of responsibility and authority includes responsibility to ensure all activities described in a procedure are implemented as written.

Certifications

All product certifications originate from the Quality Manager and are supported by test data.

Each shipment of material is certified to meet product specifications and is supported with actual test results. The results of each test, or series of tests, is recorded in a test report or test certificate and contains all the necessary information as follows:

Report identifiers
Identification of the test method
Property values
Date of issue

The Quality Manager is responsible for signing reports or designating personnel to sign reports accepting responsibility that the content of the report is accurate.

In the event a report or certification is sent to a customer and is determined to have an erroneous result, the Quality Manager amends the report, and the report reflects a revision.

Where appropriate, statements concerning confidentiality and reproducibility are included on the report.

Accreditations:

TenCate Geosynthetics Americas laboratory facilities:

• GAI-LAP

TenCate Geosynthetic Manufacturing Facility

• ISO 9001:2008

REDI-ROCK INTERNATIONAL, LLC
A subsidiary of ASTER BRANDS
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Petoskey, Michigan 49770
866-222-8400