

**REDI-ROCK®**

POSITIVE CONNECTION SYSTEM  
**DESIGN GUIDE**

# PC DESIGN MANUAL

# INTRODUCTION

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In the following pages you will find all the inputs you need to design with the Redi-Rock Positive Connection (PC) System, including:

- An overview of the system
- A description of the basic components of the system
- A review the connection between the facing blocks and the geogrid strip reinforcement
- Recommended design values for analysis
- Screen shots of the input screens for the computer software program MSEW 3.1
- An example design problem

Designing with the Redi-Rock Positive Connection (PC) System is not difficult, but it does require a familiarity with designing reinforced walls that have partial reinforcement coverage. Also, a good understanding of the FHWA publications, *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volumes 1 and 2*, is desired since the design of PC System walls closely follows the approach outlined in these documents.

# What is the PC System?

The Redi-Rock PC System is a powerful mechanically stabilized earth (MSE) retaining wall system that consists of precast concrete modular blocks and 12 inch (300mm) wide strips of PVC coated polyester geogrid.

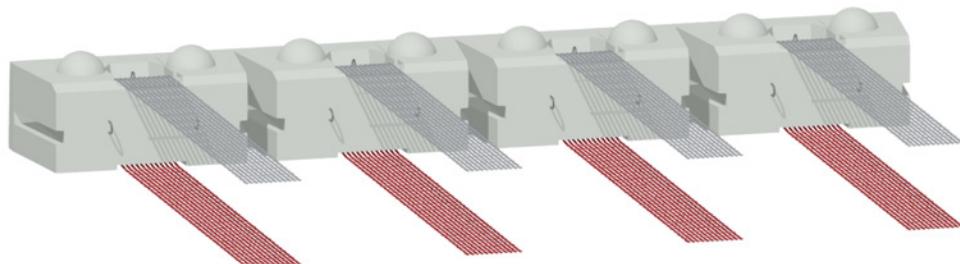
The heart and soul of the PC System is its superior connection strength. Unlike friction connections featured in other geosynthetic reinforced wall systems, there is virtually no chance of a pullout connection failure with the PC System because the grid wraps through the block (**Figure 1**). The length of each geogrid strip is determined based upon wall height, soil shear strength parameters, and loading conditions consistent with standard MSE retaining wall design principles. The result is a weight independent connection whose strength is directly proportional to the strength of the geogrid.

A significant benefit to the Redi-Rock PC System comes from the use of strips, rather than full sheets, of geogrid reinforcement. The strips of geogrid allow for design of the MSE structure with partial reinforcement coverage, which is discussed in Section 3.3.3 of FHWA-NHI-10-024 (2009) and is permitted by Section 11.10.6.4.1-2 of AASHTO (2012). Similar to MSE systems that use strips of steel reinforcement which have been used for decades, partial coverage available with the Redi-Rock PC System allows for design and installation efficiencies by providing reinforcement only where it is needed in the wall.

Geogrid reinforcement strips are typically installed through each and every facing block 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, the top and bottom layers of geogrid reinforcement in the wall consist of a 12 inch (300 mm) width of geogrid placed at 46 inches (1170 mm) on center developing roughly 25 percent coverage, as shown in **Figure 2**.

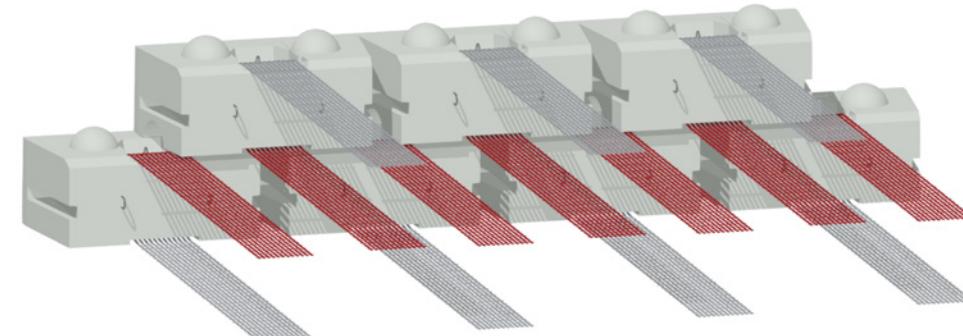


**Figure 1 – Redi-Rock PC System Facing Block with 12" Wide Strip of Mirafi XT Geogrid Soil Reinforcement**

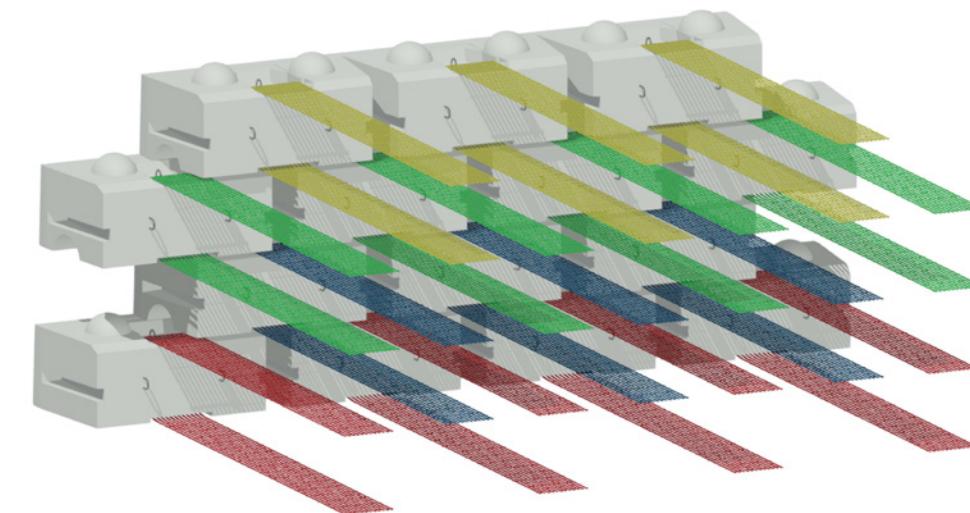


**Figure 2 – Rear View Schematic Showing 25% Coverage on the Bottom Layer of Geogrid**

When subsequent block courses are installed in a running bond configuration, reinforcement is provided on the top block of the first course and the bottom of the block on the next course, as shown in **Figure 3**. The result is all intermediate layers of geogrid reinforcement in the wall consist of a 12 inch (300 mm) width of geogrid placed at 23 inches (584 mm) on center for roughly 50 percent coverage. A section of wall with multiple courses is shown in **Figure 4**.



**Figure 3 – Rear View Schematic Showing 50% Coverage on an Intermediate Layer of Geogrid**



**Figure 4 – Rear View Schematic of a Redi-Rock PC System MSE Wall with Multiple Courses of Blocks and Geogrid Reinforcement**

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, providing an opportunity to optimize the design or account for obstructions in the reinforced soil zone.

# Where has the PC System Been Used?



## The Parklands Chooses Redi-Rock for Multiple Phases

### The Challenge:

Due to the topography of the area, retaining walls have played a key role in linking four major parks in The Parklands system.

### The Solution:

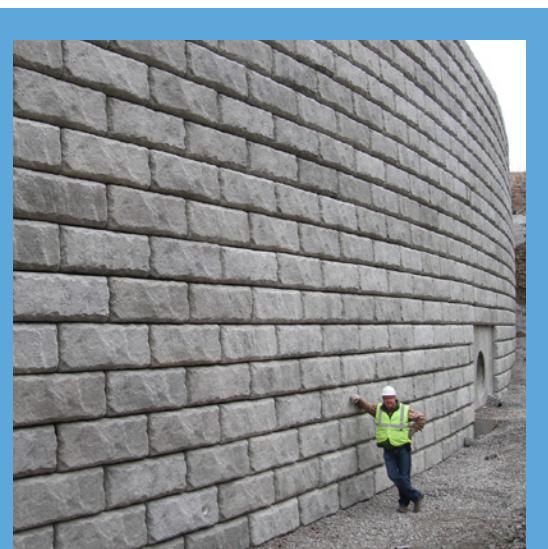
For a solution for the first phase of the project, which included both gravity and reinforced Positive Connection (PC) System walls, the Parklands turned to Redi-Rock of Kentuckiana.

"It was chosen for a couple reasons," explained Joe Daley, Architect and Project Manager for 21st Century Parks. "One, was the aesthetics; this is a park project, not a highway project. It had to fit in with the stone and other materials being used in the park. Also the cost and the time frame were big considerations."

The next phase of the project included creating an overpass for Interstate 64. To keep the stone in place the project required a 1200 sq. ft. (111 sq. m) gravity headwall. "We went with Redi-Rock because of the footprint that was needed to put the walls in," explained Burleigh Law, senior project engineer with HNTB Corporation.

An additional phase of the Parklands project required 3 separate walls, totaling 21,000 sq. ft. (1,950 sq. m) of Redi-Rock to handle the significant grade changes on site. This phase included a 41 ft. (12.5 m) tall PC System wall that is the tallest Redi-Rock PC wall in the world to date.

"The high efficiency of the PC System really made it possible to design tiered walls with those loads at that height," said design engineer Clint Hines, PE. "It would be hard to make it work with anything else."



**Project:** The Parklands

**Customer:** 21st Century Parks

**Specifying Architects:** Wallace, Roberts & Todd, and Bravura Architects

**Specifying Engineers:** HNTB and QK4

**Retaining Wall Engineers:** Civil Design Professionals, HNTB, and JC Hines & Associates

**Manufacturer:** Redi-Rock of Kentuckiana

**Installer:** MAC Construction, Redi-Rock of Kentuckiana

**Location:** Louisville, KY

**Years Built:** 2010-2013

## Back-to-Back Walls Support Freight Line

### The Challenge:

In 2011, the Canadian National (CN) Railway and the Montreal Metro began construction to eliminate an at-grade crossing where the CN Rail line crossed over the Société de Transport de Montréal (STM) light commuter Metro line.

These two lines ran through a narrow corridor with several sections of track overlapping. To completely separate the tracks, plans were made to elevate the CN Rail line on a bridge structure and excavate to relocate the Metro underground. To elevate the CN rail line, designers needed to build a gradual, walled slope leading up to a massive concrete bridge structure and then down the other side.

### The Solution:

When CN Rail geotechnical engineers saw the Redi-Rock Positive Connection (PC) System at the Transportation Research Board (TRB) meeting in early 2011, they began incorporating Redi-Rock PC walls from local manufacturer Graymont Materials into the design.

Explained David Chartier, junior engineer with V. Fournier & Associés: "The PC System is the only block with this type of connection which allowed it to handle the loads. When you have massive loads so near the block facing, it's hard to make a wall that will work. The walls are very high and the load is very close, but the civil engineering of this block made it a good fit."

To install the geogrid for a PC System wall, a 12" wide strip of geogrid was wrapped through each retaining wall block, tying the Redi-Rock facing blocks to the reinforced soil mass with a weight-independent positive connection.

In total, the project required 7,800 Redi-Rock blocks—equaling 44,850 sq. ft. (4,167 sq. m) Trains made their first run on the line in late 2013, and the project has been performing exactly as engineered.



**Project:** CN Rail Project

**Wall Engineer:** V. Fournier & Associés

**Project Engineer:** AECOM

**Owner:** City of Montreal

**General Contractor:** CN Rail

**Installer:** CRT Construction

**Manufacturer:** Graymont Materials

**Completed:** 2013

**Location:** Montreal, Quebec



## Precast Sea Wall Weathers Massive Storm

### The Challenge:

In late 2013, a new harbor sea wall made of Redi-Rock precast modular blocks was put to the test in Rhyl, North Wales. For days, a storm battered the United Kingdom and caused a 60 year high tidal surge. January wave heights were close to 100 year level.

The harbor wall was built as part of the Foryd Harbor Enhancement Project, with the goal of deepening the river channel, enlarging the marina, and improving the park area along the river. While this massive storm caused damage to many other structures in the area, designers were happy to see that the harbor wall performed exactly as engineered.

### The Solution:

How was the Redi-Rock wall able to stand up to such a harsh storm?

Designers for the project chose the Redi-Rock Positive Connection (PC) System to create the harbor wall that stands 23.4 ft. (7.4 m) high and stretches 617 ft. (188 lineal meters). Produced locally by Redi-Rock manufacturer CPM Group, the Redi-Rock PC walls were able to meet the structural requirements of the site as well as provide an aesthetic Limestone finish with the Redi-Rock PC System at a lesser cost than other options.

"The Redi-Rock product is very simple but massively effective," explained Jamie Turner, Site Agent for general contractor Dawnus Construction. "It is easy to install and the end product looks fantastic. I would definitely use this product again."

The City is now replacing 0.6 mi. (1 km) of walls using Redi-Rock because they were impressed with how the Redi-Rock wall performed during the storm.



**Project:** Foryd Harbour Enhancement

**Freestanding Wall Design:** CPM Group

**Reinforced Wall Design:** Groundslove Ltd

*Geotechnical Consultants in conjunction with CPM Group*

**Project Management:** Denbighshire County Council

**Manufacturer:** CPM Group

**General Contractor:** Dawnus Construction

**Construction:** May 2012 - Oct. 2013

**Location:** Rhyl, North Wales, United Kingdom

# PC DESIGN MANUAL

# COMPONENTS

## Dimensions, Weights, and Setbacks

Redi-Rock PC System facing blocks are machine placed, wet cast concrete, precast modular block units. Dimensions of the standard block facing blocks are 46 1/8 inches (1170 mm) long by 18 inches (457 mm) high by either 28 inches (710 mm) or 40 1/2 inches (1030 mm) wide. The face area of a PC block facing unit is approximately 5.77 square feet. The average weight of a 28 inch (710 mm) wide and a 40 1/2 inch (1030 mm) wide block is 1,520 pounds (690 kg) and 2,170 pounds (985 kg), respectively, and will vary slightly depending on the face texture chosen. Redi-Rock PC System middle blocks are shown in **Figure 5**.

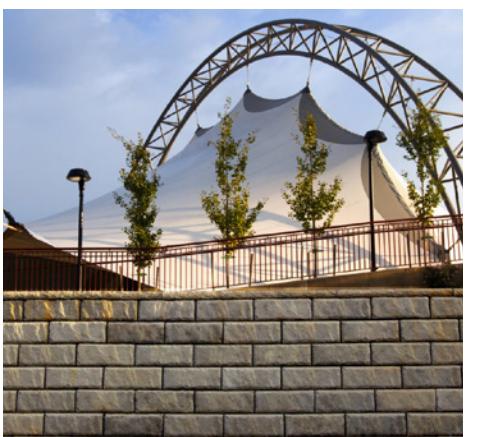
The block facing units interlock with each other through shear knobs on the top of the block that index into a continuous shear channel groove in the bottom of the block course above. Successive block courses are installed with a running bond configuration in which the upper block course is placed such that each block is centered above the vertical joint between adjacent blocks on the course immediately beneath.

## Material

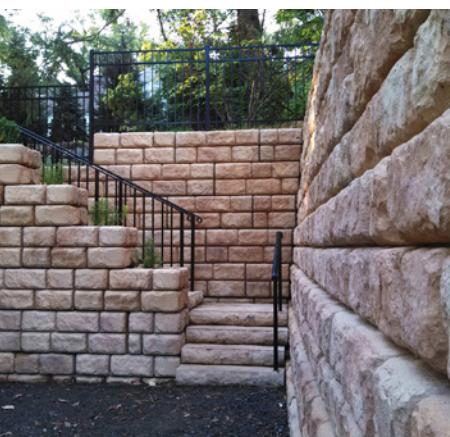
Redi-Rock PC System blocks are manufactured from first purpose, non-reconstituted structural grade concrete mixes in accordance with ASTM C94 or ASTM C685. The blocks have excellent resistance to freeze-thaw cycling, deicing chemical exposure, and submerged conditions in both fresh water and salt water applications. Concrete mix properties are in general accordance with ACI 318 for durability and ACI 201 for Alkali-aggregate reactivity mitigation. The minimum 28 day compressive strength of Redi Rock PC System blocks is 4,000 psi (27.6 MPa).

## Face Textures and Colors

Redi-Rock PC System blocks can be manufactured with different face textures and colors. Currently, there are three face textures available, Limestone, Cobblestone, and Ledgestone, as shown in **Figures 6, 7, and 8**. In addition to the face textures, Redi-Rock PC System blocks are available in several stock and custom color combinations. Each local Redi-Rock manufacturer will have sample colors available, which are specifically chosen to match the surrounding geographic region. **Refer to [www.redi-rock.com](http://www.redi-rock.com) to locate the manufacturer nearest to your project site.**



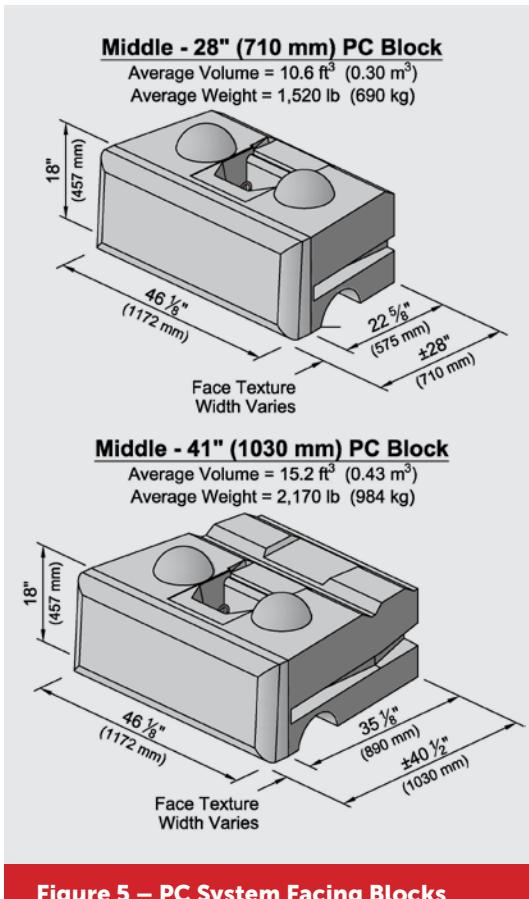
**Figure 6 – Limestone Face Texture**



**Figure 7 – Cobblestone Face Texture**



**Figure 8 – Ledgestone Face Texture**

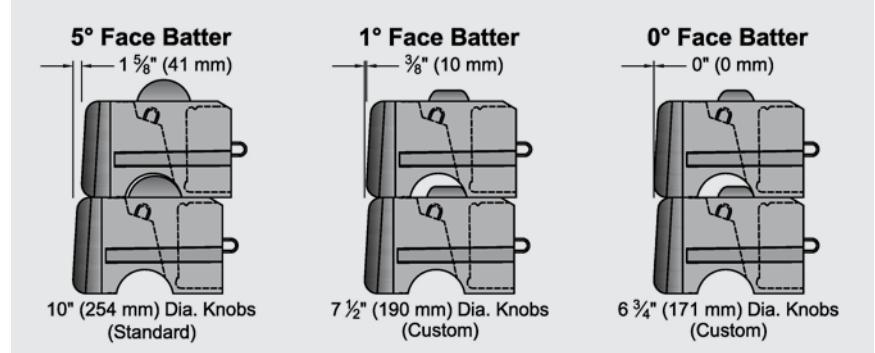


**Figure 5 – PC System Facing Blocks**

## Setback Options

Redi-Rock PC System blocks can be manufactured with three different size shear knobs. The different size shear knobs produce different setbacks on subsequent courses of blocks, resulting in wall face batters of 5 degrees, 1 degree, and 0 degrees with respect to vertical, as shown in **Figure 9**.

Blocks manufactured with 10 inch (254 mm) diameter knobs that produce a 5 degree face batter are standard. Walls requiring either a 1 degree or vertical face batter typically require custom blocks cast specifically for the project.



**Figure 9 – Setback Options**

## Block to Block Interface Shear

Full-scale interface shear testing in accordance with ASTM D6916 and NCMA SRWU-2 test methods have been conducted on the Redi-Rock PC System blocks with both the standard 10 inch (254 mm) diameter shear knobs and the 3 1/4 inch (171 mm) diameter shear knobs. Recommended interface shear parameters for the different shear knob sizes are summarized in **Table 1** below based upon a minimum 28-day concrete compressive strength of 4,000 psi. **Copies of the complete laboratory testing reports are available at [www.redi-rock.com/testing](http://www.redi-rock.com/testing).**

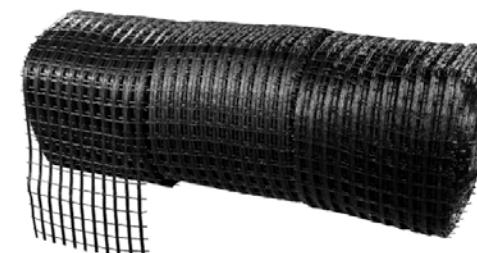
**Table 1 – Block-to-Block Interface Shear @ 4,000 psi**

Shear Knob Diameter	Peak Interface Shear	Service State Shear
10"	$S_p = 6,061 + (N \times \tan 44^\circ)$ $S_p(\max) = 11,276 \text{ lb/ft}$	$S_{ss} = 3,390 + (N \times \tan 51^\circ)$ $S_{ss(\max)} = 11,276 \text{ lb/ft}$
7 1/2" and 6 3/4"	$S_p = 1,178 + (N \times \tan 54^\circ)$ $S_p(\max) = 10,970 \text{ lb/ft}$	$S_{ss} = 616 + (N \times \tan 52^\circ)$ $S_{ss(\max)} = 10,970 \text{ lb/ft}$

## Geogrid Strips

Geogrid reinforcement used with the Redi-Rock PC System consist of 12 inch (300 mm) wide strips of Mirafi XT geogrid made of polyvinyl chloride (PVC) coated high tenacity polyethylene terephthalate (PET). The strips are manufactured in 200 foot (61 m) long rolls. Three rolls are placed on a single cardboard tube as shown in **Figure 10**. Depending on the weight and thickness of the geogrid, 9 to 20 tubes of geogrid are packaged on a pallet for shipment to the job site as shown in **Figure 11**. Strips of Mirafi Miragrid 5XT, 8XT, 10XT, 20XT, and 24XT are available.

**Only use Factory Cut and Certified Geogrid for your project. Field cutting standard geogrid rolls almost always results in damage to one or more of the main longitudinal load carrying strands in the geogrid, significantly reducing available strength of the reinforcement. Don't let your design be compromised! Contact your local Redi-Rock Manufacturer for certified rolls of geogrid.**



**Figure 10 – Geogrid Rolls**



**Figure 11 – Geogrid Shipping Pallet**

Mirafi geogrids have been extensively tested and documented by AASHTO's National Transportation Product Evaluation Program. **Table 2** summarizes the ultimate tensile strength and long-term reduction factors of the Miragrid XT products recommended for use with the Redi-Rock PC System.

**Table 2 - 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
<b>Creep Reduction Factor, <math>RF_{CR}</math></b>					
Reference Temperature 20°C (68°F)	75-year design	1.56	1.56	1.56	1.56
	100-year design	1.58	1.58	1.58	1.58
Reference Temperature 30°C (86°F)	75-year design	1.65	1.65	1.65	1.65
	100-year design	1.66	1.66	1.66	1.66
Reference Temperature 40°C (104°F)	75-year design	1.76	1.76	1.76	1.76
	100-year design	1.77	1.77	1.77	1.77
<b>Installation Damage Reduction Factor, <math>RF_{ID}</math></b>					
Soil Type 1: Coarse Aggregate (GP, $\phi=34^\circ$ 19 mm (3/4") < $D_{50} \leq$ 38 mm (1 1/2")		1.61	1.60	1.58	1.53
Soil Type 2: Sandy Gravel/Coarse Sand (GP or SP, $\phi=34^\circ$ $D_{50} \leq$ 19 mm (3/4")		1.25	1.20	1.20	1.15
<b>Durability Reduction Factor, <math>RF_D</math></b>					
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

## Additional Components

### Infill Stone

Durable crushed stone is placed in the vertical core slots and triangular spaces between adjacent block facing units. The stone provides a free-draining zone and fills void spaces in the vertical core slot and between the PC block facing units. Additionally, the crushed stone may be placed immediately behind the block facing units to a minimum depth of 12 in. The crushed stone behind the block facing units provides an extra free-draining zone behind the units. It also provides consistent, high shear strength, easily consolidated material immediately behind the PC block facing units. Recommended particle size distribution requirements for the infill stone is provided in **Table 3**. Material meeting the size requirements of No. 57, 6, 67, 68, or 7 per AASHTO M 43 will meet these recommendations.

The stone is intended to be consolidated, but the actual amount of compaction effort will vary depending on the location of the stone infill. In order to avoid damage to the geogrid reinforcement strips, hand tamping is used to consolidate the stone in the vertical core slot. Hand tamping is also used to consolidate the stone in the triangular shaped void area between adjacent blocks and in the ends of the shear groove on the bottom of the blocks. A walk-behind, vibrating plate compactor should be used to consolidate the stone behind the blocks.

**Table 3 - Recommended Infill Stone Gradation Requirements**

Sieve Size	Percent Passing
1 1/2 inch	100
1 inch	95 - 100
3/4 inch	90 - 100
1/2 inch	20 - 100
3/8 inch	0 - 70
No. 4	0 - 25
No. 8	0 - 10
No. 16	0 - 5

### Non-Woven Geotextile Fabric

Nonwoven geotextile can be used as both a filter and a separator at three possible locations behind the PC block facing unit, depending on the specific installation detail used. These locations include:

- The vertical joint between adjacent PC block facing units to prevent the loss of unit fill stone through the joint.
- Between the drain stone and the reinforced backfill when the two materials differ in their gradation.
- Between the reinforced backfill and the retained fill when two materials differ in their gradation such that natural filter criteria are not met and separation is required.

A nonwoven geotextile fabric meeting the physical properties for Class 3 Construction Survivability in accordance with AASHTO M 288 will ordinarily meet the minimum performance requirements for the above applications. The values in **Table 4** represent the minimum requirement for typical applications of geotextile used with the PC System.

**Table 4 – Nonwoven Geotextile Physical Properties**

Mechanical Property	Test Method	Unit	Minimum Average Roll Value (MARV)	
			MD	CD
Grab Tensile	ASTM D4632	lb	115	115
Puncture Resistance	ASTM D4833	lb	45	45
Trapezoid Tear Strength	ASTM D4533	lb	45	45
Apparent Opening Size	ASTM D4751	U.S. Sieve	70	
Flow Rate	ASTM D4491	gal / min / ft <sup>2</sup>	120	

Some commercially available geotextile products that meet the requirements in Table 4 are; Mirafi 140N, Propex Geotex 451, Skaps GT-142, Thrace-Linq 140EX, and Carthage Mills FX-40HS.

### Reinforced Fill Soil

One of the biggest challenges facing a wall design engineer is what type of soil to specify for the reinforced fill zone. Often, on-site soils are preferred because they are readily available; however, they may not be the best choice for long-term performance of the wall. A significant amount of research has been done over the last several decades on the impact of using different types of soil in the reinforced soil zone, and it can be shown that use of soils with a significant portion of fine grained particles (passing a No. 200 sieve) do not work well in this application.

Recommended soil gradation requirements for soil used in the reinforced fill zone are provided in several sources, including the National Concrete Masonry Association (NCMA) *Design Manual for Segmental Retaining Walls, 3rd Edition*, Federal Highway Administration (FHWA) publications FHWA-NHI-10-024 and 10-025 *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volumes 1 and 2*, and the AASHTO *LRFD Bridge Design Specifications, 6th Edition* (2012).

Redi-Rock International recommends that the designer follow the gradation limits from one of these documents when specifying soil requirements for a particular project. Specifically, extremely coarse particles should be limited to a maximum diameter between 1 in (25 mm) and 4 inches (100 mm) and the maximum percentage of fine grained particles (passing a No. 200 sieve) should be between 15% and 35%. In all cases, Redi-Rock International recommends that the wall designer pay careful attention to both internal and external drainage.

## Leveling Pad

The leveling pad can either be crushed stone or unreinforced concrete depending on the specifics of the design. A crushed stone leveling pad is the most common leveling pad used with Redi-Rock walls. Specific gradation requirements of the stone will depend on whether or not the wall drain can outlet below the elevation of the leveling pad. If there is adequate drainage, a coarse stone with a small percentage of fine materials (passing the number 200 sieve) is typically used to make sure that any water can easily drain away. If the drainage outlet is above the elevation of the leveling pad, a dense graded stone is typically used to prevent water from ponding in the leveling pad material.

For some projects, an unreinforced concrete leveling pad is used. Per FHWA guidelines, a concrete leveling pad typically has a 28-day compressive strength of 2,500 psi (17 MPa).

The leveling pad should extend at least 6 inches (150 mm) in front and 12 inches (300 mm) behind the PC block facing units. Of course, the leveling pad is to be smooth and level. If proper care is taken in the early stages to prepare the subgrade, place the leveling pad, and place the bottom course of blocks, then the speed and ease of installation of the entire wall will be greatly improved.

## Drain

Drainage collection pipe is typically a 4 inch diameter, perforated, HDPE pipe with a minimum pipe stiffness of at least 22 psi (ASTM D2412). ADS 3000 Triple Wall pipe as manufactured by Advanced Drainage Systems is one example. In some cases the pipe may be surrounded by infill stone and wrapped with a non-woven geotextile.

## Coping

Redi-Rock PC walls can be finished with either a Redi-Rock top block or a Redi-Rock freestanding block on the top row of blocks. The top 5 inches (127 mm) of the top block facing unit is recessed just behind the face of the block 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. Remember to include a layer of non-woven geotextile fabric between the topsoil and the infill stone to keep the topsoil from migrating into the clean stone.

Freestanding blocks are finished on two or three sides, and can be used when part or all of the back and end of the top row of blocks is exposed. If desired, an additional cap may be placed on the top of the freestanding unit. The coping option with freestanding and cap blocks is often used when pedestrian traffic must be accommodated at the top of the retaining wall. If needed, the freestanding blocks can be physically attached to the PC blocks with a galvanized steel j-bolt as shown in **Figure 12**.

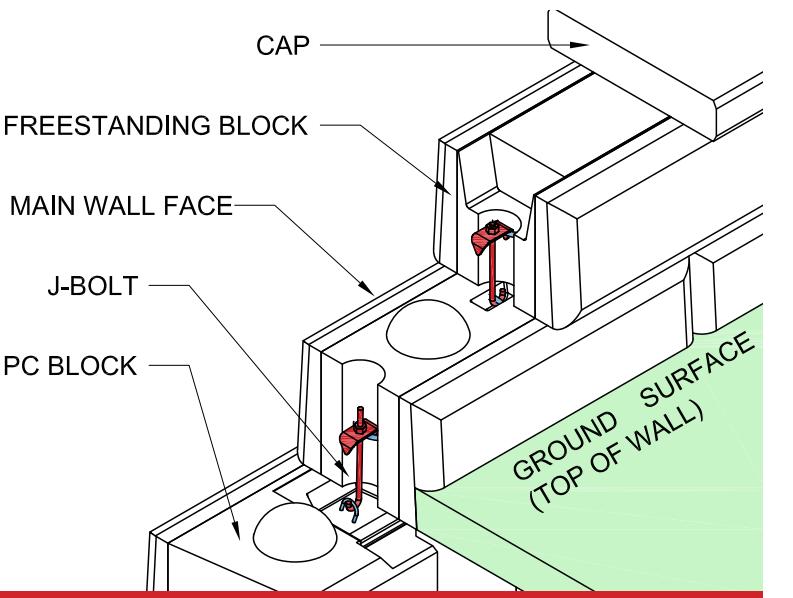
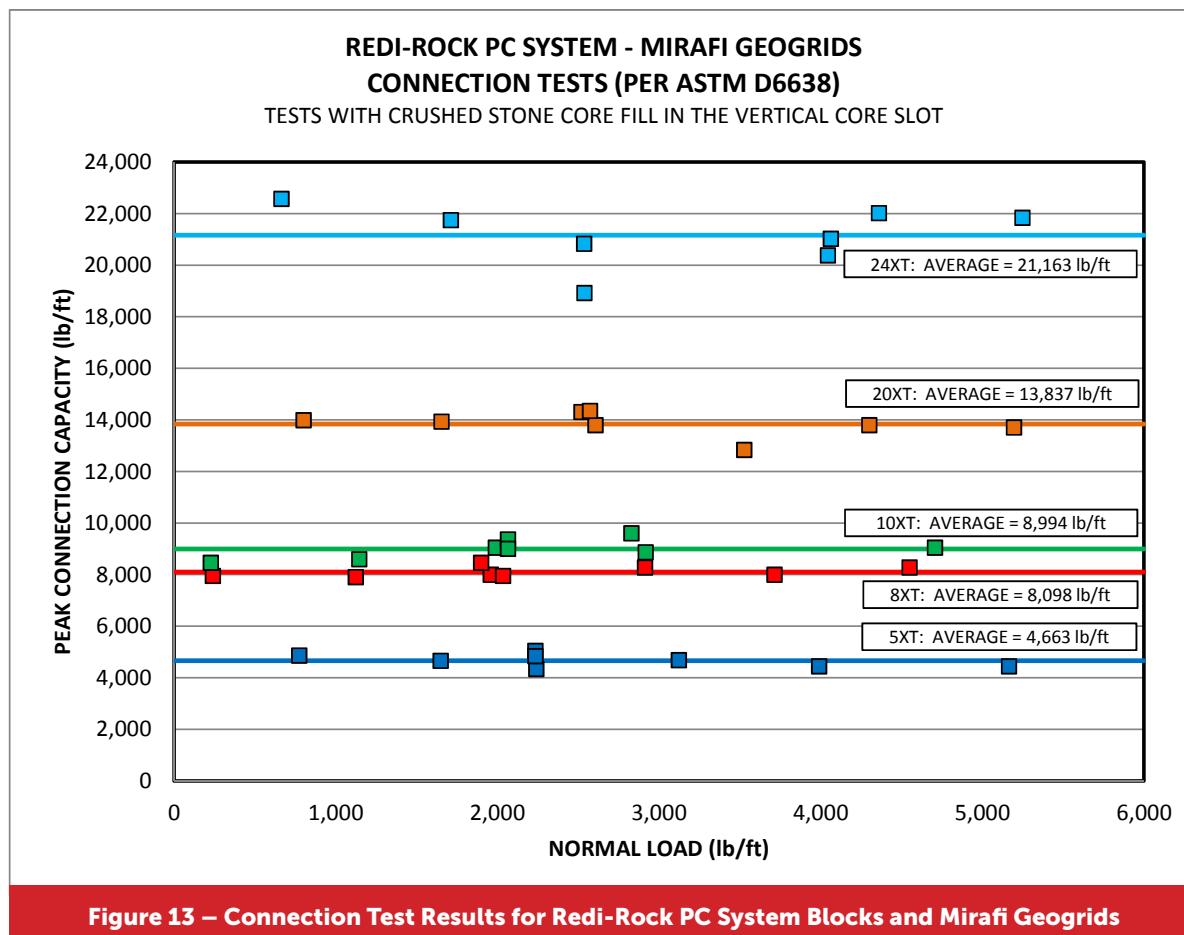


Figure 12 – J-Bolt Connection for a Freestanding Block Coping

# PC DESIGN MANUAL

# CONNECTION

The Redi-Rock PC System has a weight independent, positive connection between the facing blocks and geogrid reinforcement. Connection tests show that connection strength is not dependent on the normal load on the connection, as shown in **Figure 13**.



**Figure 13 – Connection Test Results for Redi-Rock PC System Blocks and Mirafi Geogrids**

The implication for design is significant. Simply put, the connection between the facing blocks and the soil reinforcement does not lose any capacity with decreasing normal loads. The Redi-Rock PC System makes it much easier for engineers to design MSE walls with high live loads, tiered wall sections, seismic loads, water applications, and other design situations where high connection strengths are required near the top of the walls. The connection strength is the same from the top to the bottom of the wall.

Redi-Rock has performed extensive, full scale connection testing between Redi-Rock PC System blocks and Mirafi geogrids. **Copies of the complete laboratory testing reports are available at [www.redi-rock.com/testing](http://www.redi-rock.com/testing).**

**Table 5** summarizes the connection information necessary for design of the Redi-Rock PC System.

**Table 5 – Redi-Rock PC System - 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, $CR_u$	0.84	0.84	0.82	0.80	0.69
Creep Reduction Factor (20°C)					
75-Year Design, $RF_{CR(75)}$	1.56	1.56	1.56	1.56	1.56
100-Year Design, $RF_{CR(100)}$	1.58	1.58	1.58	1.58	1.58
Durability Reduction Factor, $RF_D^{(1)}$	1.15	1.15	1.15	1.15	1.15
Long-term Connection Strength Reduction Factor ( $CR_u / RF_{CR}$ )					
75-Year Design, $CR_{cr}$	0.54	0.54	0.53	0.51	0.44
100-Year Design, $CR_{cr}$	0.53	0.53	0.52	0.51	0.44
Nominal Long-term Geosynthetic Connection Strength $[(MARV * CR_u) / (RF_{CR} * RF_D)]$					
75-Year Design, $T_{ac(75)}$ (lb / ft)	2,201	3,465	4,342	6,111	10,544
100-Year Design, $T_{ac(100)}$ (lb / ft)	2,173	3,421	4,287	6,034	10,411

(1) Recommended value for  $5 < pH < 8$ .  $RF_D$  value of 1.3 recommended for  $4.5 \leq pH \leq 5$  and  $8 \leq pH \leq 9$ . 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 B.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 should be followed to ensure proper performance of the PC System.
- Substitution of a weaker geogrid style than that required (i.e.: 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.

# Analysis with Computer Software

The Redi-Rock PC System is easily analyzed using a program such as MSEW by ADAMA Engineering that allows for MSE walls with partial reinforcement coverage.

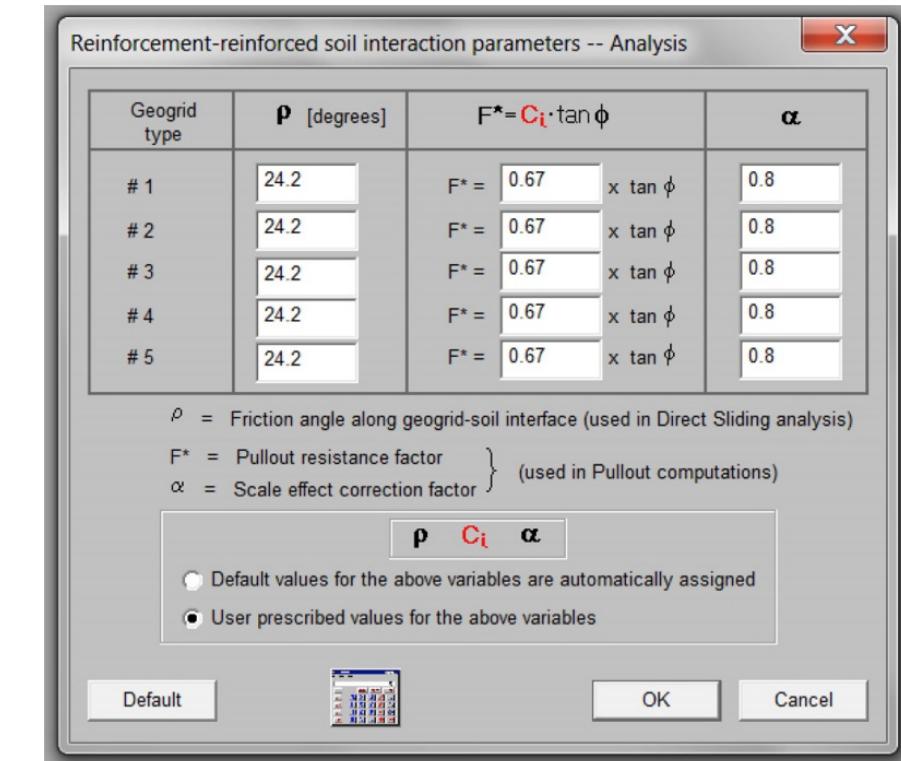
Input parameters for MSEW version 3 are provided in **Table 6**.

**Table 6 - Miragrid XT Input Parameters for MSEW Design Software**

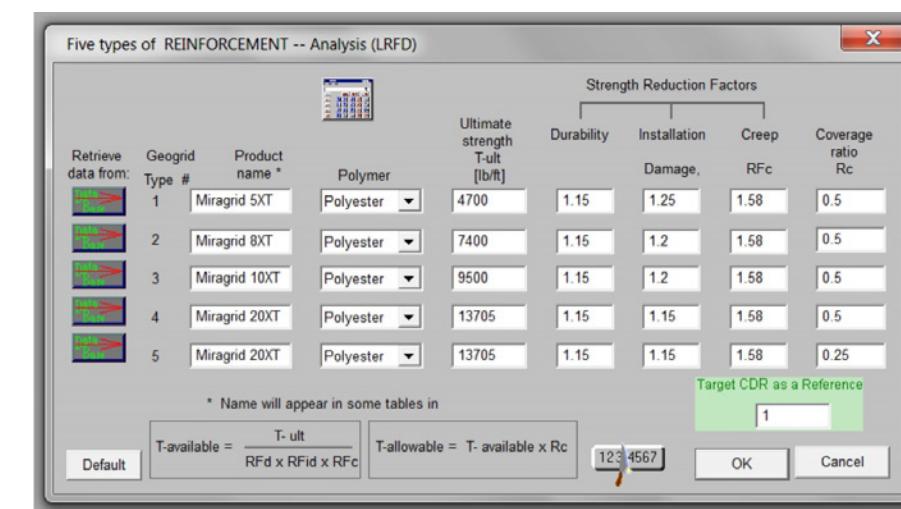
Input Parameter	Miragrid 5XT	Miragrid 8XT	Miragrid 10XT	Miragrid 20XT	Miragrid 24XT
Polymer	Polyester	Polyester	Polyester	Polyester	Polyester
Ultimate Strength (lbs./ft.), $T_{ult}$	4,700	7,400	9,500	13,705	27,415
Coverage Ratio, $R_c$	0.25/0.50	0.25/0.50	0.25/0.50	0.25/0.50	0.25/0.50
Strength Reduction Factors					
Durability, $R_D$	1.15	1.15	1.15	1.15	1.15
Installation Damage, $RF_{ID}$					
Soil Type 1: Coarse Aggregate (GP, $\phi=34^\circ$ ) $3/4'' < D_{50} \leq 1-1/2''$	1.61	1.60	1.58	1.53	1.35
Soil Type 2: Sandy Gravel/Coarse Sand (GP or SP, $\phi=34^\circ$ ) $D_{50} \leq 3/4''$	1.25	1.20	1.20	1.15	1.10
Creep (20°C), $RF_{CR}$					
75-year design, $RF_{CR(75)}$	1.56	1.56	1.56	1.56	1.56
100-year design, $RF_{CR(100)}$	1.58	1.58	1.58	1.58	1.58
Reinforcement - Reinforced Soil Interaction Parameters					
Interface Friction Angle, represented as $\tan \rho$	2/3 $\tan \phi$				
Interaction Factor, $C_i$	0.67	0.67	0.67	0.67	0.67
Scale Effect Correction Factor, $\alpha$	0.8	0.8	0.8	0.8	0.8
Connection Strength					
Connection Strength Reduction for Environmental Aging, $RF_D^{(1)}$	1.15	1.15	1.15	1.15	1.15
Ultimate Connection Strength Reduction Factor (Pull-out), $CR_{ult}$	1.00	1.00	1.00	1.00	1.00
Long-term Connection Strength Reduction Factor					
75-year design, $CR_{cr(75)}$	0.54	0.54	0.53	0.51	0.44
100-year design, $CR_{cr(100)}$	0.53	0.53	0.52	0.51	0.44
Long-Term Strength Reduction to Resist Seismic Loads					
Seismic Analysis, $R_s$	100	100	100	100	100
Facing Data					
Depth of the facing unit, $W_u$ (ft)		2.33			
Height of the facing unit, $H_u$ (ft)		1.5			
Avg. unit weight of facing unit, $\gamma_f$ (pcf)		129			
Horiz. distance to the center of gravity, (ft)		1.175			

(1) Recommended value for  $5 < pH < 8$ . RFD value of 1.3 recommended for  $4.5 \leq pH \leq 5$  and  $8 \leq pH \leq 9$ . Use outside of  $3 < pH < 9$  range is not recommended per FHWA-NHI-10-024 (2009).

The following screen shots shown in **Figure 14** to **Figure 18** highlight the input screens within MSEW where data unique to the PC System must be added. Each of the following input screens assumes Type 2 (sandy gravel or coarse sand) reinforced backfill, 20°C creep reference temperature and a 100-year design life.



**Figure 14 - MSEW Reinforced Soil Interaction Parameters Screen**



**Figure 15 - MSEW Soil Reinforcement Data Screen**

**Facing Data**

**NOTE: Facing data cannot be retrieved from database.  
Only one facing is used by MSEW.**

Depth of facing unit,  $W_u$  [ft] 2.33 

Height of facing unit,  $H_u$  [ft] 1.5

Average unit weight of facing unit,  $\gamma_f$  [lb/ft<sup>3</sup>] 129

Horizontal distance to the center of gravity of facing unit, including aggregate fill, measured from the front of the unit, [ft] 1.175

To explore the effects of maximum possible hinge height, set  $G_u$  to zero.

Ignore hinge height calculations for exploration beyond AASHTO and NCMA. If checked, connection capacity is calculated using batter = zero.

The shear strength of the facing system is conservatively neglected in calculations. Click for note on effects of facing in external stability calculations.

NOTE: MSEW produces the facing resistance,  $R_f$ , needed to render sufficient direct sliding resistance. When in results click on "Direct sliding" for  $R_f$  at each elevation

Specify: To / Tmax

Default  **NEXT** Cancel

**Figure 16 - MSEW Facing Data Screen**

**Reduction factors at connection**

Long term connection strength is known based on testing (Appendix A.3 -- AASHTO 2002)

Geogrid type Number	Connection Strength is reduced for long term environmental aging by RFd
1. Miragrid 5XT	1.15
2. Miragrid 8XT	1.15
3. Miragrid 10XT	1.15
4. Miragrid 20XT	1.15
5. Miragrid 20XT	1.15

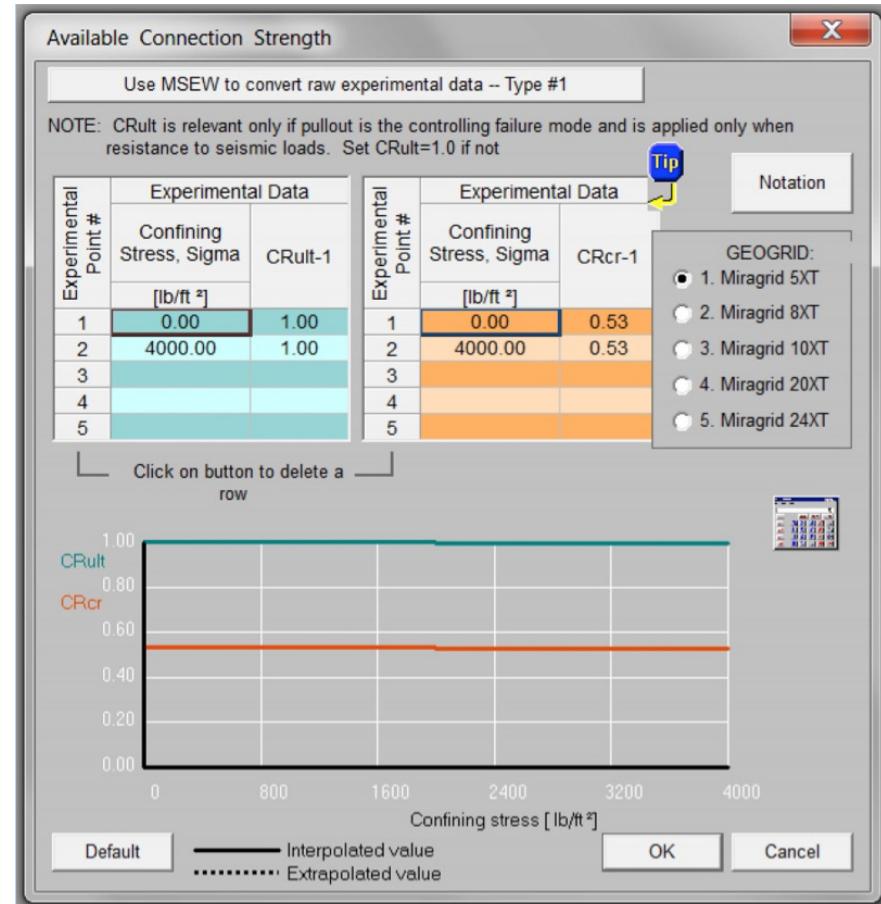
In a seismic analysis (if applicable), reduce the long term strength to resist seismic loads to :  
 $Rs = 100$  percent of its static value

(" Where the long-term connection strength is partially or fully dependent on friction between the facing blocks and reinforcement, and connection pullout is the controlling failure mode, the long-term connection strength to resist seismic loads shall be reduced to  $Rs=80\%$  of its static value")

For Connection Strength : Target CDR as a Reference

Default **NEXT** Cancel

**Figure 17 - MSEW Reduction Factors at Connection Screen**



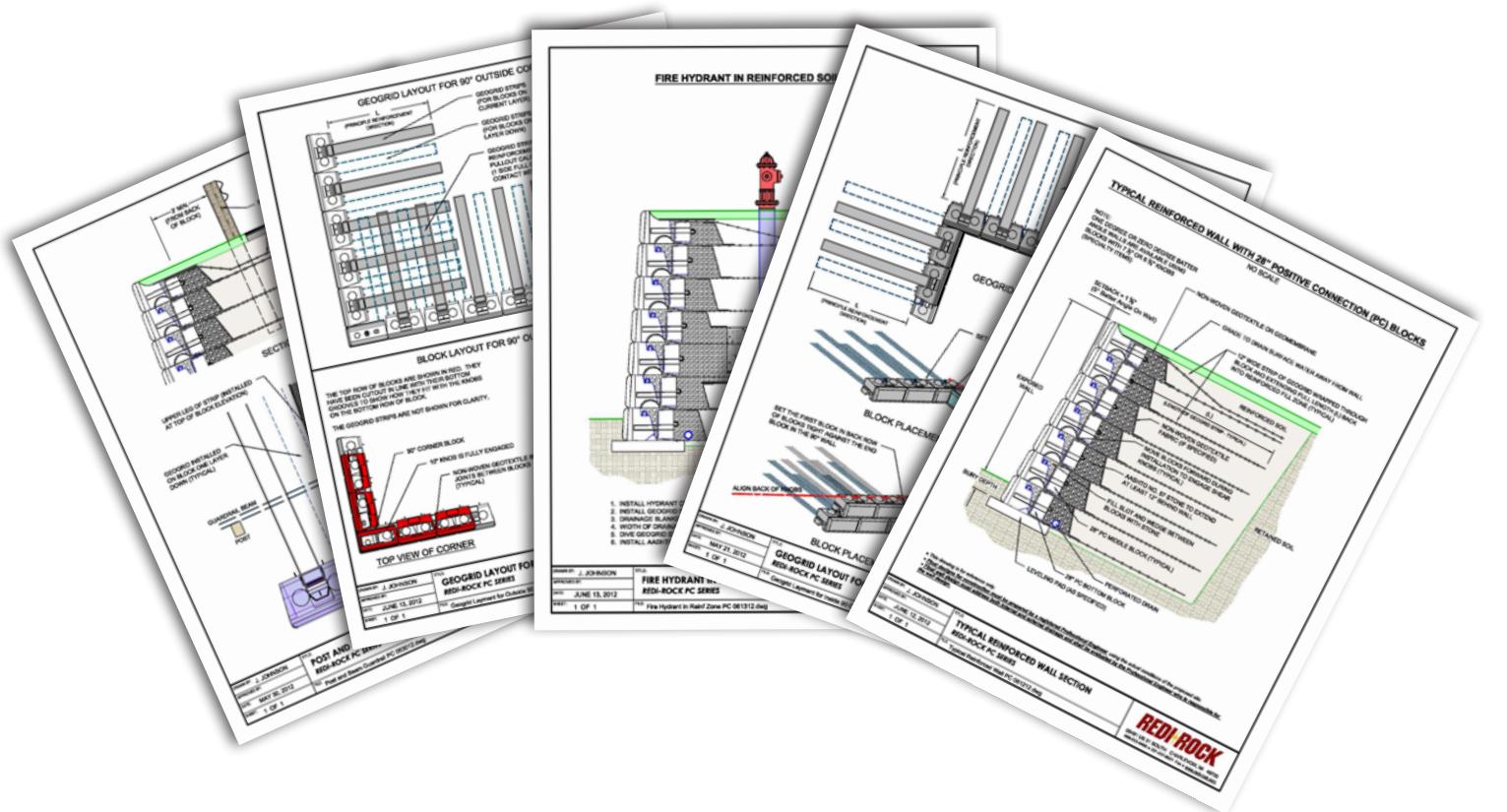
**Figure 18 - MSEW Connection Data Input Screen (Miragrid 5XT Shown)**

PC DESIGN MANUAL

TYPICAL DESIGN &  
CONSTRUCTION DETAILS

# PC DESIGN MANUAL

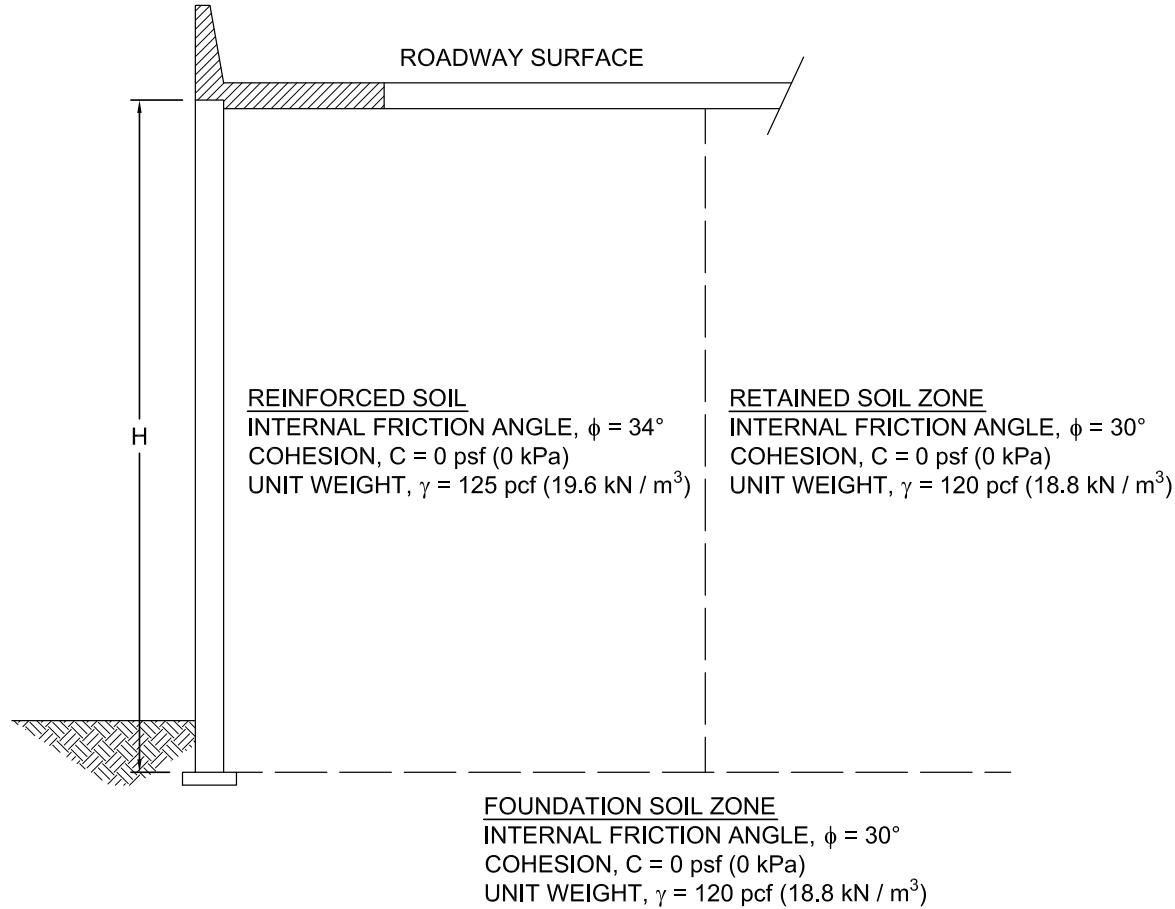
## EXAMPLE PROBLEM



Redi-Rock International has prepared typical drawings that detail how to build corners, curves, accommodate obstructions in the reinforced soil zone, incorporate slip joints, place vehicle barriers on the top of a PC System wall, and more. A full list of drawings in both AutoCad and pdf format is available at [www.redi-rock.com/pcdetails](http://www.redi-rock.com/pcdetails).

## The Problem

The following example demonstrates the design of the Redi-Rock PC System according to FHWA NHI 10 024/025. A generic cross-section of the desired MSE wall is shown in **Figure 19**.



**Figure 19 – Example Problem**

### Design Parameters:

- Design in accordance with FHWA-NHI-10-024/025 for a height, H, equal to 25ft (7.6 m) and for a 100 year service life. Also calculate the maximum wall height that can be attained.
- Load factors included:
  - EH horizontal earth load – yes
  - ES earth surcharge load – no
  - EV vertical pressure from dead load of earth fill – yes
  - DC components and attachments - no
  - CT vehicular collision force – yes
  - LL vehicular live load - yes
- Traffic barrier is designed in accordance with FHWA-NHI-10-024/025.
- Assume that allowable bearing pressure in foundation soil is adequate.
- Assume that overall stability does not govern reinforcement length.
- Assume that soils in the reinforced and retained zones are fully drained.

## The Solution

Load combinations are provided in FHWA-NHI-10-025 Appendix A. The two load combinations which apply to this example are Strength I and Extreme Event II. Both of these load combinations contain load factors which can either be maximum or minimum.

### Strength I Load Combination Limit State

Applicable loads included in Strength I are:

EH, Horizontal Earth Pressure  
EV, Vertical Earth Pressure  
LL, Vehicular Live Load

The possible Strength I load factor combinations are presented in **Table 7**. Corresponding resistance factors for the Strength I combinations are presented in **Table 8**.

**Table 7 - Possible Strength I Load Factor Combinations**

	Strength I (a)	Strength I (b)	Strength I (c)	Strength I (d)
EH	$\gamma_{P-EH} \text{ MAX} = 1.50$	$\gamma_{P-EH} \text{ MIN} = 0.90$	$\gamma_{P-EH} \text{ MAX} = 1.50$	$\gamma_{P-EH} \text{ MIN} = 0.90$
EV	$\gamma_{P-EV} \text{ MAX} = 1.35$	$\gamma_{P-EV} \text{ MIN} = 1.00$	$\gamma_{P-EV} \text{ MIN} = 1.00$	$\gamma_{P-EV} \text{ MAX} = 1.35$
LL	$\gamma_{LL} = 1.75$	$\gamma_{LL} = 1.75$	$\gamma_{LL} = 1.75$	$\gamma_{LL} = 1.75$

**Table 8 - Resistance Factors,  $\phi$ , for Strength I Load Factor Combinations**

Internal Stability	
Geogrid Tensile Rupture	$\phi = 0.90^{(1)}$
Geogrid / Block Connection	$\phi = 0.90^{(1)}$
Geogrid Pullout Resistance	$\phi = 0.90^{(1)}$
External Stability	
Bearing Resistance	$\phi = 0.65^{(2)}$
Sliding	$\phi = 1.00^{(3)}$
Overall (global) Stability <sup>(4)</sup>	

(1) AASHTO (2012) Table 11.5.7-1 and FHWA-NHI-10-024 Table 4-7,  $\phi = 0.90$ .

(2) AASHTO (2012) Table 11.5.7-1 and FHWA-NHI-10-024 Table 4-5,  $\phi = 0.65$ .

(3) AASHTO (2012) Table 11.5.7-1 and FHWA-NHI-10-024 Table 4-5,  $\phi = 1.00$ .

(4) Overall (global) Stability is assumed adequate and not considered as part of this example. If it were to be evaluated, Service I Load Combination would be used and the Resistance Factor would be taken as 0.65, which corresponds to a Factor of Safety of 1.5, per AASHTO (2012) Section 11.6.2.3 and FHWA-NHI-10-024 Section 4.4.9.

It takes a total of 4 separate MSEW wall analyses to investigate the possible Strength I combinations which are designated as Strength I(a) through Strength I(d).

### Extreme Event II Load Combination Limit State

Applicable loads included in Extreme Event II are:

EH, Horizontal Earth Pressure  
EV, Vertical Earth Pressure  
LL, Vehicular Live Load  
CT, Vehicular Collision Force

The possible Extreme Event II load factor combinations are presented in **Table 9**. Corresponding resistance factors for the Extreme Event combinations are presented in **Table 10**.

**Table 9 – Possible Extreme Event II Load Factor Combinations**

	Extreme Event II (a)	Extreme Event II (b)	Extreme Event II (c)	Extreme Event II (d)
EH	$\gamma_{P-EH} \text{ MAX} = 1.50$	$\gamma_{P-EH} \text{ MIN} = 0.90$	$\gamma_{P-EH} \text{ MAX} = 1.50$	$\gamma_{P-EH} \text{ MIN} = 0.90$
EV	$\gamma_{P-EV} \text{ MAX} = 1.35$	$\gamma_{P-EV} \text{ MIN} = 1.00$	$\gamma_{P-EV} \text{ MIN} = 1.00$	$\gamma_{P-EV} \text{ MAX} = 1.35$
LL	$\gamma_{LL} = 0.50$	$\gamma_{LL} = 0.50$	$\gamma_{LL} = 0.50$	$\gamma_{LL} = 0.50$
CT	$\gamma_{CT} = 1.00$	$\gamma_{CT} = 1.00$	$\gamma_{CT} = 1.00$	$\gamma_{CT} = 1.00$

**Table 10 - Resistance Factors,  $\phi$ , for Extreme Event II Load Factor Combinations**

Internal Stability	
Geogrid Tensile Rupture	$\phi = 1.20$ <sup>(A)</sup>
Geogrid / Block Connection	$\phi = 1.20$ <sup>(A)</sup>
Geogrid Pullout Resistance	$\phi = 1.00$ <sup>(B)</sup>
External Stability	
Bearing Resistance	$\phi = 0.90$ <sup>(C)</sup>
Sliding	$\phi = 1.00$ <sup>(D)</sup>
Overall (global) Stability <sup>(E)</sup>	

<sup>(A)</sup> AASHTO (2012) Section 11.5.8,  $\phi = 1.20$  and FHWA-NHI-10-024 Table 4-7,  $\phi = 1.20$ .

<sup>(B)</sup> AASHTO (2012) Section 11.5.8,  $\phi = 1.20$  and FHWA-NHI-10-024 Table 4-7,  $\phi = 1.00$ . The more conservative  $\phi = 1.00$  is used for this example calculation.

<sup>(C)</sup> AASHTO (2012) Commentary C11.5.8,  $\phi = 0.90$ .

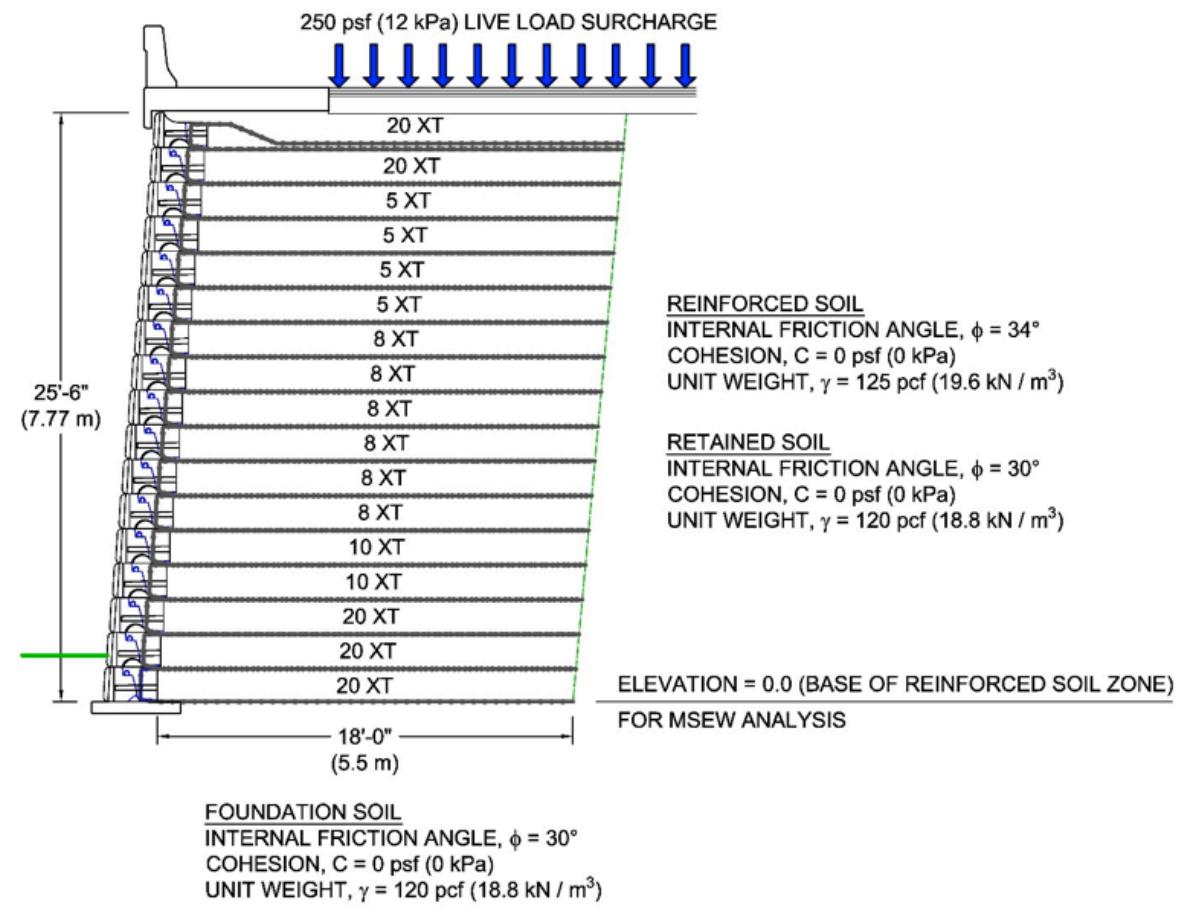
<sup>(D)</sup> AASHTO (2012) Commentary C11.5.8,  $\phi = 1.00$ .

<sup>(E)</sup> Overall (global) Stability is assumed adequate and not considered as part of this example. If it were to be evaluated, Extreme Event II Load Combination would be used and the Resistance Factor would be taken as 1.00 per AASHTO (2012) Section 11.5.8.

In addition to the load combinations and resistance factors outlined above, FHWA-NHI-10-024 Section 7.2.1 requires load factor  $\gamma_{P-EV} = 1.35$  be used for the traffic surcharge. This load factor along with the additional impact loads for the top two layers of geogrid are input into MSEW under the traffic impact screen in the geometry and surcharge input section, rather than the Load and Resistance Factor input screens.

It takes a total of 4 separate MSEW wall analyses to investigate the possible Extreme Event II combinations which are designated as Extreme Event II(a) through Extreme Event II(d).

The final section for this example is shown in **Figure 20**.



**Figure 20 – Example Wall Section**

The geogrid reinforcement coverage ratio for the wall section shown is as follows:

Elevation 0.0,  $R_c = 0.25$

This coverage ratio corresponds to one 12 inch (300 mm) wide geogrid strip every 46 1/8 inches (1170 mm). It comes from the bottom leg of geogrid on the bottom course of facing units.

Elevation 1.5 to 24.0,  $R_c = 0.50$

This coverage ratio corresponds to one 12 inch (300 mm) wide geogrid strip every 23 inches (584 mm). It comes from the top leg of geogrid on the lower facing unit and bottom leg of geogrid on the upper facing unit installed in a running bond configuration.

Elevation 25.1, No Geogrid in Analysis

The geogrid at this elevation is detailed to provide an anchored tail. It is not considered in the wall design other than to secure the bottom leg of the geogrid for the layer below.

A summary of the controlling failure modes for the different Strength I load combinations is provided in **Table 11**. A summary of the controlling failure modes for the different Extreme Event II load combinations is provided in **Table 12**.

**Table 11 – Controlling Strength I Load Combination Failure Modes**

Failure Mode	Strength I(a) EH = Max. EV = Max. LL = 1.75 Min. CDR/Elev.	Strength I(b) EH = Min. EV = Min. LL = 1.75 Min. CDR/Elev.	Strength I(c) EH = Max. EV = Min. LL = 1.75 Min. CDR/Elev.	Strength I(d) EH = Min. EV = Max. LL = 1.75 Min. CDR/Elev.
Bearing Capacity	2.11 / 0.0	2.99 / 0.0	2.15 / 0.0	2.65 / 0.0
Direct Sliding Along Foundation	1.80 / 0.0	2.01 / 0.0	1.34 / 0.0	2.71 / 0.0
Eccentricity, e/L	0.132*	0.121*	0.189*	0.081*
Overturning	3.25 / 0.0	3.50 / 0.0	2.41 / 0.0	4.72 / 0.0
Block/Geogrid Connection Strength	1.04 / 7.5	1.35 / 7.5	1.35 / 7.5	1.04 / 7.5
Geogrid Strength	1.04 / 7.5	1.34 / 7.5	1.34 / 7.5	1.04 / 7.5
Geogrid Pullout Resistance	1.13 / 24.0	1.23 / 24.0	1.23 / 24.0	1.13 / 24.0
Direct Sliding Along Geogrid	1.85 / 1.5	2.06 / 1.5	1.37 / 1.5	2.78 / 1.5

\* e/L Ratio (Not Minimum CDR)

**Table 12 – Controlling Extreme Event II Load Combination Failure Modes**

Failure Mode	Extreme Event II(a) EH = Max. EV = Max. LL = 0.50 CT = 1.00 Min. CDR/Elev.	Extreme Event II(b) EH = Min. EV = Min. LL = 0.50 CT = 1.00 Min. CDR/Elev.	Extreme Event II(c) EH = Max. EV = Min. LL = 0.50 CT = 1.00 Min. CDR/Elev.	Extreme Event II(d) EH = Min. EV = Max. LL = 0.50 CT = 1.00 Min. CDR/Elev.
Bearing Capacity	2.41 / 0.0	3.58 / 0.0	2.54 / 0.0	3.05 / 0.0
Direct Sliding Along Foundation	2.04 / 0.0	2.43 / 0.0	1.51 / 0.0	3.28 / 0.0
Eccentricity, e/L	0.106*	0.086*	0.154*	0.055*
Overturning	3.87 / 0.0	4.54 / 0.0	2.86 / 0.0	6.13 / 0.0
Block/Geogrid Connection Strength	1.14 / 7.5	1.52 / 7.5	1.52 / 7.5	1.14 / 7.5
Geogrid Strength	1.14 / 7.5	1.52 / 7.5	1.52 / 7.5	1.14 / 7.5
Geogrid Pullout Resistance	2.26 / 24.0	2.67 / 24.0	2.67 / 24.0	2.26 / 24.0
Direct Sliding Along Geogrid	2.11 / 1.5	2.51 / 1.5	1.56 / 1.5	3.39 / 1.5
Traffic Barrier Impact				
Geogrid Strength				
Top Layer	1.49 / 24.0	1.51 / 24.0	1.51 / 24.0	1.49 / 24.0
Layer Below	1.30 / 22.5	1.38 / 22.5	1.38 / 22.5	1.30 / 22.5
Block/Geogrid Connection Strength				
Top Layer	1.38 / 24.0	1.40 / 24.0	1.40 / 24.0	1.38 / 24.0
Layer Below	1.30 / 22.5	1.38 / 22.5	1.38 / 22.5	1.30 / 22.5
Geogrid Pullout Resistance				
Top Layer	1.73 / 24.0	1.76 / 24.0	1.76 / 24.0	1.73 / 24.0
Layer Below	4.21 / 22.5	4.47 / 22.5	4.47 / 22.5	4.21 / 22.5

\* e/L Ratio (Not Minimum CDR)

**Notes:**

- Bearing capacity, connection strength, geogrid strength, and pullout resistance are controlled by the Strength I load combination with EH = Max, EV = Max, and LL = 1.50.
- Direct sliding along the foundation, eccentricity, overturning, and direct sliding on geogrid layers are controlled by Strength I load combination with EH = Max, EV = Min, and LL = 1.50.
- Geogrid strength, connection strength, and pullout resistance of the top two layers of geogrid due to the vehicle impact are controlled by the Extreme Event II load combination with EH = Max, EV = Max, LL = EV, and CT = 1.00.
- Maximum wall height that can be attained in these conditions is 63 feet (19.2 m).

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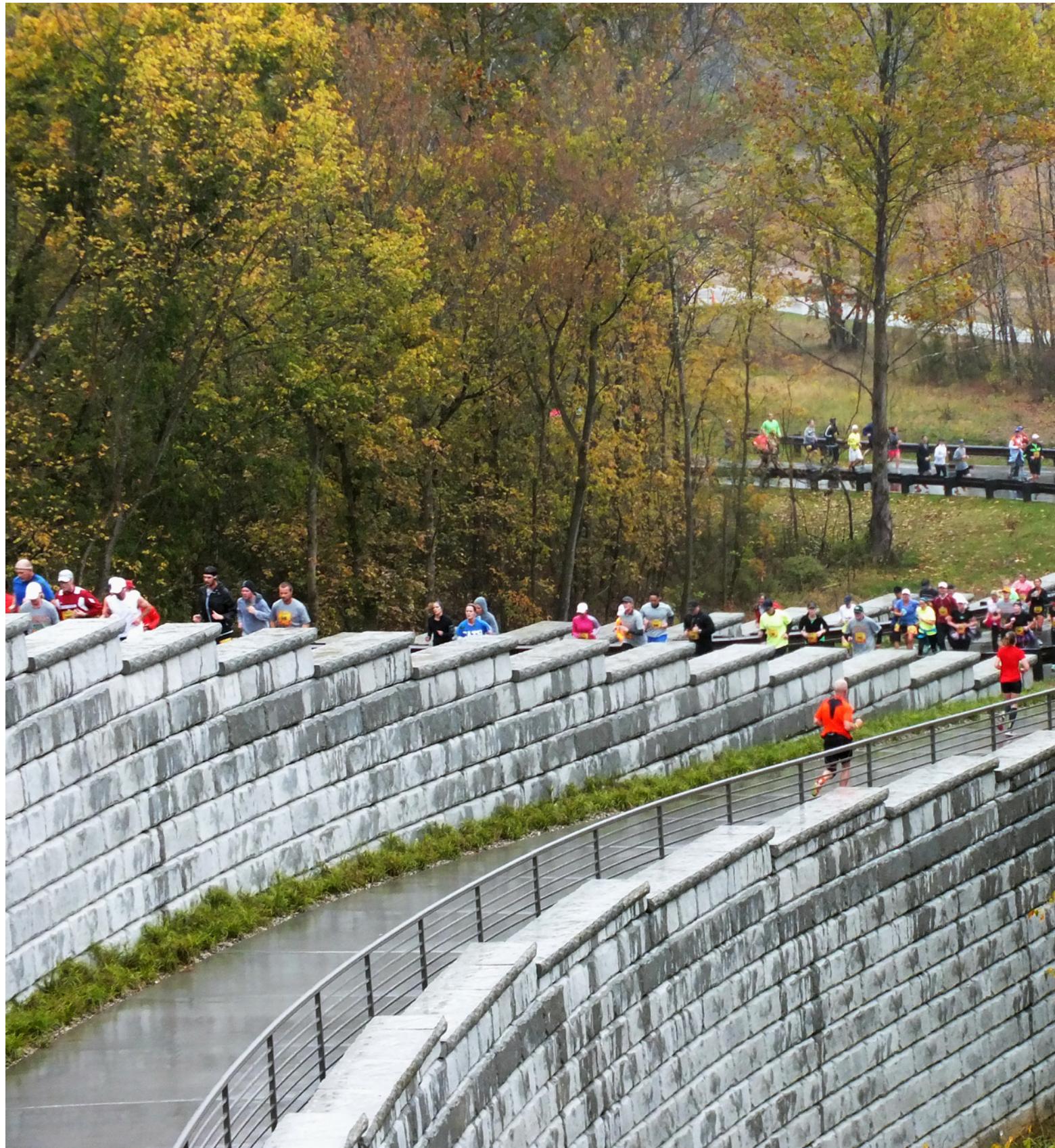
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