Shear Strength Evaluation of the EP Henry Cast Stone Wall System and Tencate Mirafi 2XT Geosynthetic Soil Reinforcement

for

EP Henry Corporation
PO Box 615
Woodbury, NJ 08096

DRAFT

Project No. 14-539-3
Date: February 26, 2015

Conducted by:

NATIONAL CONCRETE MASONRY ASSOCIATION
RESEARCH & DEVELOPMENT LABORATORY

IAS ACCREDITED

RESEARCH AND DEVELOPMENT LABORATORY

The NCMA Research and Development Laboratory is devoted to the scientific research and testing of concrete masonry products and systems. The Laboratory is staffed by professional engineers and technicians with many years of experience in the concrete masonry industry. The Laboratory is equipped to perform nearly any physical research or testing of concrete masonry units and assemblages. The Laboratory performs research and development work for both the Association and individual companies.

NATIONAL CONCRETE MASONRY ASSOCIATION

The National Concrete Masonry Association (NCMA) is a non-profit organization whose mission is to support and advance the common interests of its members in the manufacture, marketing, research, and application of concrete masonry products. The Association is an industry leader in providing technical assistance and education, marketing, research and development, and product and system innovation to its members and to the industry.

Research and Development Laboratory Staff
Dominick O. Dowds, P.E., *Manager, Research and Development Laboratory*
Douglas H. Ross, *Laboratory Supervisor*
Cory McGrath, *Laboratory Technician*
Henry Tarring, *Laboratory Technician*

NCMA Technical Staff
Jason J. Thompson, *Vice President of Engineering*
Dennis W. Graber, P.E., *Director of Technical Publications*
Nicholas R. Lang, P.E., *Director of Research and Development*
Gabriela Mariscal, *Geotechnical Engineer*

National Concrete Masonry Association
Research and Development Laboratory
13750 Sunrise Valley Drive
Herndon, Virginia 20171
(703) 713-1900
www.ncma.org

THIS PUBLICATION IS INTENDED FOR USE BY PROFESSIONAL PERSONNEL COMPETENT TO EVALUATE THE SIGNIFICANCE AND LIMITATIONS OF THE INFORMATION PROVIDED HEREIN, AND WILLING TO ACCEPT TOTAL RESPONSIBILITY FOR THE APPLICATION OF THIS INFORMATION IN SPECIFIC INSTANCES. RESULTS FROM TESTS MAY VARY AND THE NATIONAL CONCRETE MASONRY ASSOCIATION (NCMA) DOES NOT WARRANT THE RESULTS CONTAINED HEREIN FOR SPECIFIC USES OR PURPOSES AND THE FINDINGS ARE NOT A SUBSTITUTE FOR SOUND ENGINEERING EVALUATIONS, JUDGMENT AND OPINIONS FOR SPECIFIC PROJECTS OR USES. THE NCMA IS NOT RESPONSIBLE FOR THE USE OR APPLICATION OF THE INFORMATION CONTAINED IN THIS PUBLICATION AND DISCLAIMS ALL RESPONSIBILITY THEREFORE.

The measured and calculated values provided in this report are the official values resulting from this body of work. Values in parenthesis are mathematical conversions provided for reference only and may differ slightly from the official values due to conversion rounding.

This report was prepared for EP Henry Corporation by the National Concrete Masonry Association Research and Development Laboratory based upon testing, analyses, or observations performed by the National Concrete Masonry Association Research and Development Laboratory. Reference herein to any specific commercial product, process, or service by trade name, trademark, or manufacturer does not necessarily constitute or imply its endorsement or recommendation by the National Concrete Masonry Association or its staff. The contents of this report have been reviewed by the following individuals, who believe to the best of their ability that the observations, results, and conclusions presented in this report are an accurate and true representation of the services provided.

The NCMA Research and Development Laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2005. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (refer to the joint ISO-ILAC-IAF Communiqué dated 18 June 2005). All test results presented here are within the scope of accreditation for the NCMA Research and Development Laboratory.

Results for ultimate strength of geosynthetic reinforcement in accordance with ASTM D6637 were provided by the manufacturer. These results have not been evaluated by the NCMA Research and Development Laboratory nor are they covered in the Laboratory's scope of accreditation.

Dominick O. Dowds, Manager, Research and Development Laboratory Date

Nicholas R. Lang, Director of Director of Research and Development Date

This report shall not be reproduced, except in full, without the written authorization of the National Concrete Masonry Association Research and Development Laboratory.

DRAFT

TABLE OF CONTENTS

DRAFT

Shear Strength Evaluation of the EP Henry Cast Stone Wall System and Tencate Mirafi 2XT Geosynthetic Soil Reinforcement

1.0 INTRODUCTION

The shear strength of a segmental retaining wall (SRW) unit system is a design component of these systems. This shear strength is determined through testing in accordance with ASTM D6916-06c (2011), *Standard Test Method for Determining the Shear Strength Between Segmental Concrete Units (Modular Concrete Blocks)* (Ref. 1). In this project, the shear strength of the EP Henry Cast Stone Wall System with Tencate Mirafi 2XT geosynthetic within the shear interface was evaluated, the results of which are reported herein.

2.0 MATERIALS

All SRW units, alignment connectors, and geosynthetic reinforcement were sampled and provided by the client. The SRW units are dry-cast concrete blocks and part of the wall system with the trade name 'EP Henry Cast Stone Wall System'. Figure 1 shows the configuration of these units. Table 1 provides the representative dimensions of the units determined by the Laboratory as applicable to this testing program. At the direction of the client, testing for other unit physical properties, such as compressive strength and absorption, were not determined as part of this project.

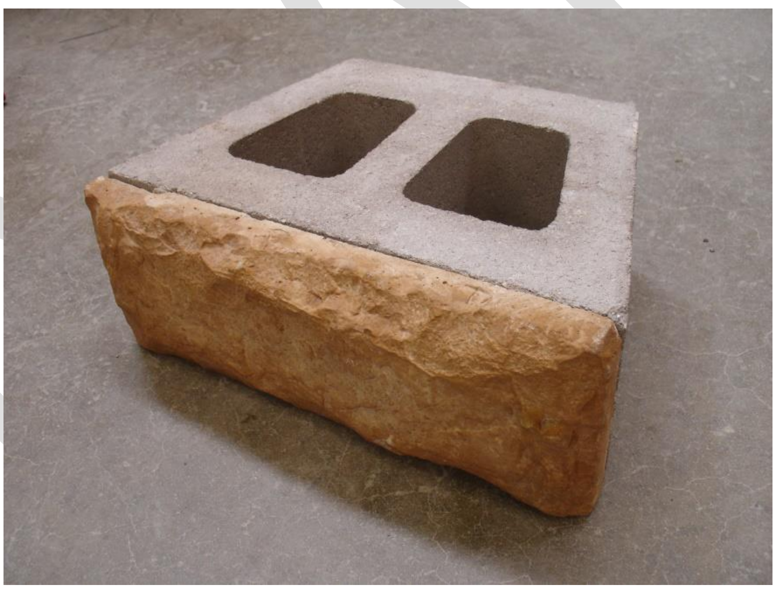
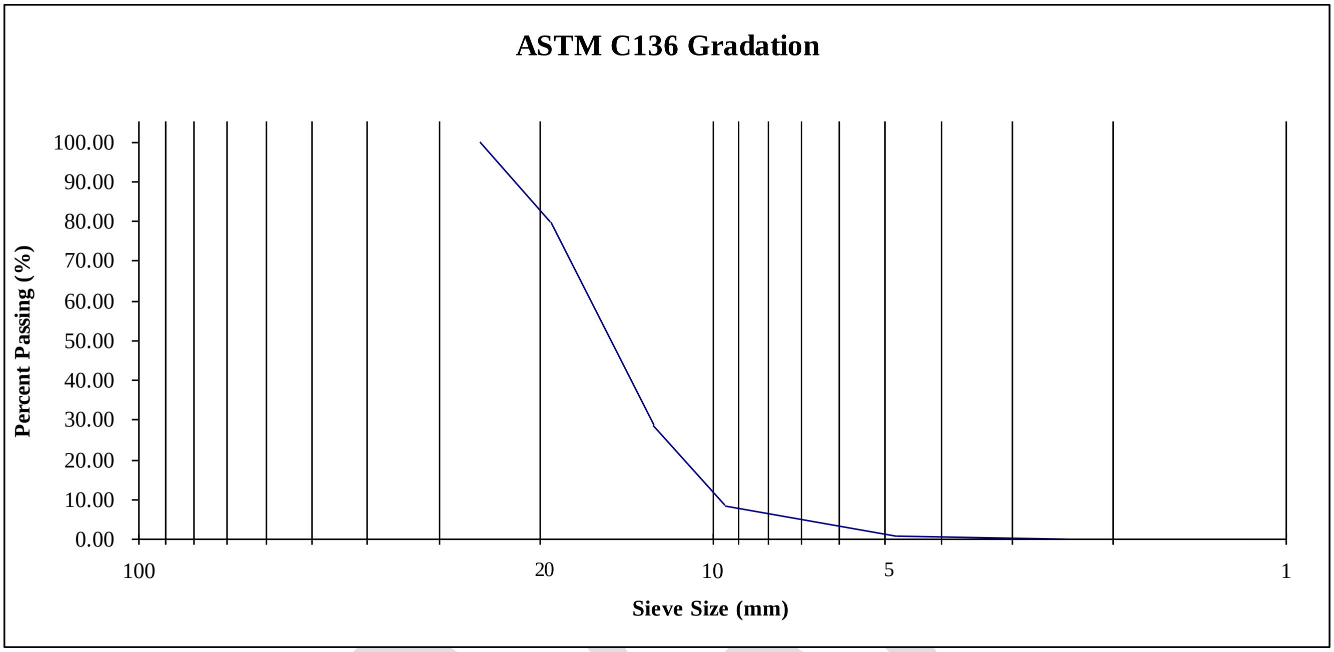


Figure 1 – Representative SRW Unit

Table 1 – Representative SRW Unit Physical Properties	
Length front of unit, in. (mm)	16.0 (406)
Length back of unit, in. (mm)	10.5 (267)
Height front of unit, in. (mm)	11.5 (292)
Width, in. (mm)	6.0 (152)
Received weight, lb (kg)	48.18 (21.85)

DRAFT

For shear strength testing the cores and spaces between the SRW units were filled with aggregate. The gradation of the aggregate was determined in accordance with ASTM C136-06, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates* (Ref. 3). Figure 2 shows the gradation of the aggregate used. The aggregate was compacted into the voids between the units.



Note – to convert sieve size to inch, divide by 25.4.

Figure 2 – Aggregate Gradation

The shear strength was determined using geosynthetic reinforcement with the trade name “Mirafi 2XT”, manufactured by Tencate Geosynthetics. This geosynthetic is constructed out of high molecular weight and high tenacity polyester yarns utilizing a complex knitting process and a polymeric coating. The manufacturer’s website (www.geogrid.com) contains published information for the ultimate tensile strength of the geosynthetic materials used in this project. As provided by the manufacturer the ultimate tensile strength reportedly obtained when tested in accordance with ASTM D6637 (2010), *Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi Rib Tensile Method* (Ref. 3), is 2,000 lb/ft (29.2 kN/m) for this geosynthetic.

3.0 SHEAR STRENGTH PROCEDURES

The shear strength tests were performed in accordance with ASTM D6916-06c (2011). All tests were performed with the same configuration. The testing configuration is described below and accompanying photographs are provided below.

- A bottom course was constructed using two SRW units and aggregate was added to the cores of the units and spaces between the units as needed (Figure 3).
- A 15.7 in. (398 mm) piece of geosynthetic was placed on top of the lower units, covering the shear interface (Figure 4).
- A third SRW unit was placed on top of the lower course of units and the geosynthetic reinforcement. The top unit was placed so there was no setback between the bottom and the top courses. The cores of the unit were filled with aggregate (Figure 5).
- A neoprene pad and steel plate was placed on the top unit. Rollers were placed on top of this plate to facilitate even loading during testing (Figure 6).
- A steel plate was placed on top of the rollers and additional spacers were added to allow for contact with the vertical hydraulic ram and load cell. Two linear displacement potentiometers were attached to the front corners of the top unit to measure the amount of shear displacement during testing (Figure 7).
- The resulting shear interface using this testing configuration was 1.3 ft (0.40 m).

DRAFT

Figure 3 – Lower Units

Figure 4 – Placement of Geosynthetic

Figure 5 – Top Unit

Figure 6 – Plate and Rollers

Figure 7 – Overall Test Setup

Once the test specimen was constructed it was tested using the procedures defined by ASTM D6916-06c (2011):

- Normal load was applied to the test specimen through a hydraulic loading system applied to the steel spacers, plates, and neoprene pad. The magnitude of the normal load was maintained at a constant level and monitored using an electronic load cell and a data acquisition system.
- With the normal load applied, the upper SRW unit was subjected to a horizontal load by displacing the loading arm that contacts the top SRW unit at a rate equal to 0.20 in./min (5 mm/min). The test was continued until either the shear strength significantly decreased or the displacement exceeded the capacity of the testing equipment.
- Horizontal displacement of the upper SRW unit was recorded during testing.

Testing was performed at five unique normal load levels. One normal load was repeated twice, for a total of seven unique shear strength tests.

4.0 RESULTS

Shear strength is defined as the shear load divided by the width of the shear interface, which for this project is taken equal to the largest width of the top segmental retaining wall unit. The peak shear strength is defined as the highest recorded value of shear strength. ASTM D6916-06c (2011) requires reporting of serviceability shear strength, but the displacement that defines the serviceability strength is not specified. In this project, the service state connection strength is determined based on the criteria outlined in ICC-ES AC276, *Acceptance Criteria for Segmental Retaining Walls* (Ref. 4), which requires the deformation criterion to either be ¾ inch (19 mm) or a value equal to 2 percent of the block height, whichever is less. The height of these units is 6.0 inch (152 mm) and thus would be limited by the 2% criteria, which is 0.12 inch (3.0 mm).

DRAFT

Results for the shear strength testing are provided in the appendix and the results are summarized in Table 2. In addition to the data presented, a plot of shear strength vs. displacement as well as shear strength vs. normal load is also provided in the appendix.

As required by the test method, one axial load level was tested three times to determine repeatability. The axial load repeated was 600 lb/ft (8.8 kN/m), and the results of those tests were within the general range of repeatability of the test method (± 10% from the mean of the three tests for the peak shear strength).

Table 2 – Summary of Shear Strength Tests

Test Number	Average Axial Load lb/ft (kN/m)	Approximate Wall Height based on Axial Load ft (m)	Service State Shear Strength lb/ft (kN/m)	Peak Shear Strength lb/ft (kN/m)
1	233 (3.4)	2.4 (0.74)	83 (1.2)	360 (5.3)
2	600 (8.8)	6.2 (1.90)	450 (6.6)	803 (11.7)
3	405 (5.9)	4.2 (1.28)	368 (5.4)	728 (10.6)
4	600 (8.8)	6.2 (1.90)	330 (4.8)	953 (13.9)
5	780 (11.4)	8.1 (2.47)	525 (7.7)	1,095 (16.0)
6	593 (8.7)	6.1 (1.87)	405 (5.9)	855 (12.5)
7	968 (14.1)	10.0 (3.06)	578 (8.4)	1,335 (19.5)

For each test run, the system failed by displacement of the upper unit. Figure 8 shows a typical failure seen in this project.

Figure 8 – Typical Failure Mode

5.0 DISCUSSION

The following discussion is not a required portion of the ASTM D6916-06c (2011) standard, but is provided for the reference and convenience of the reader.

DRAFT

A plot of normal load versus shear strength is also provided in the appendix. As can be seen from this figure, a relationship can be determined for both the serviceability shear strength (at 0.14 in. [3.6 mm] displacement) as well as the peak shear strength as a function of normal load. Using best-fit linear trend lines, relationships are determined in accordance with the NCMA *Design Manual for Segmental Retaining Walls* (Ref. 5). The third edition of this design manual does not include provisions for the serviceability shear strength. While ASTM D6916-06c (2011) requires that serviceability shear strength be determined, it does not define the specified displacement, leaving this displacement to be prescribed by the user. A value of 0.14 in. (3.6 mm) is reported here as this value is required by ICC-ES AC276. Relationships are provided for both the peak shear strength (V_u) as well as the service state shear strength (V'_u) within the range of normal load tested in this study.

These relationships apply to the combination of SRW units, geosynthetic reinforcement, and aggregate used in this study.

6.0 REFERENCES

1. ASTM Standard D6916, 2006c (Reapproved 2011), "Standard Test Method for Determining the Shear Strength Between Segmental Concrete Units (Modular Concrete Block)", ASTM International, West Conshohocken, PA, www.astm.org.
2. ASTM Standard C136, 2006, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates", ASTM International, West Conshohocken, PA, www.astm.org.
3. ASTM Standard D6637, 2010, "Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method", ASTM International, West Conshohocken, PA, www.astm.org.
4. ICC-ES AC276, *Acceptance Criteria for Segmental Retaining Walls*, 2004, ICC Evaluation Service, LLC, Whittier, CA, www.icc-es.org.
5. *NCMA Design Manual for Segmental Retaining Walls, Third Edition*, 2009, National Concrete Masonry Association, 13750 Sunrise Valley Drive, Herndon, VA 20171-4662.

DRAFT

APPENDIX A – EP HENRY CAST STONE WALL SYSTEM AND MIRAFI 2XT RESULTS

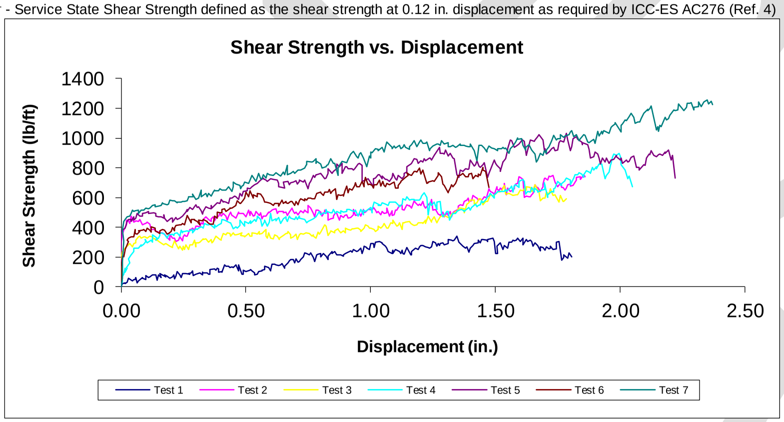
Shear Strength Test Set EP Henry Cast Stone Wall System / Miragrid 2XT Geosynthetic NCMA Job Number 14-539-3A

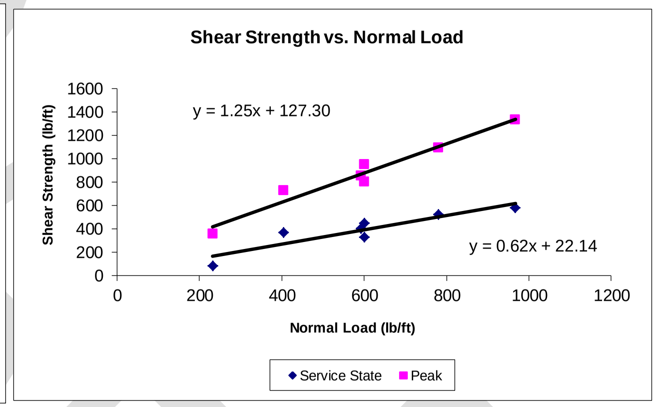
Segmental Retaining Wall Units - EP Henry Cast Stone Wall System

Geosynthetic - Miragrid 2XT (Ultimate Tensile Strength, Tindex (ASTM D6687)) = 2,000 lb/ft

Test Series Number	Shear Interface Width (ft)	Average Axial Load (lb)	Average Axial Load (lb/ft)	Approximate Wall Height Corresponding to Applied Axial Load (ft)	Shear Load at Service State Deformation[1] (lb)	Service State Shear Strength (lb/ft)	Service State Displacement (in.)	Peak Shear Load (lb)	Peak Shear Strength (lb/ft)	Peak Displacement (in.)
1	1.3	310	233	2.4	110	83	0.13	480	360	1.35
2	1.3	800	600	6.2	600	450	0.12	1070	803	1.85
3	1.3	540	405	4.2	490	368	0.12	970	728	1.66
4	1.3	800	600	6.2	440	330	0.12	1270	953	2.00
5	1.3	1040	780	8.1	700	525	0.13	1460	1095	1.79
6	1.3	790	593	6.1	540	405	0.12	1140	855	1.45
7	1.3	1290	968	10.0	770	578	0.13	1780	1335	2.35

[1] - Service State Shear Strength defined as the shear strength at 0.12 in. displacement as required by ICC-ES AC276 (Ref. 4)





The following relationships are not required by D6916-06c (2011), but are provided for reference. Using best fit linear trend lines, the following relationships have been determined using the methodology found in the NCMA Design Manual for Segmental Retaining Walls (Ref. 5):

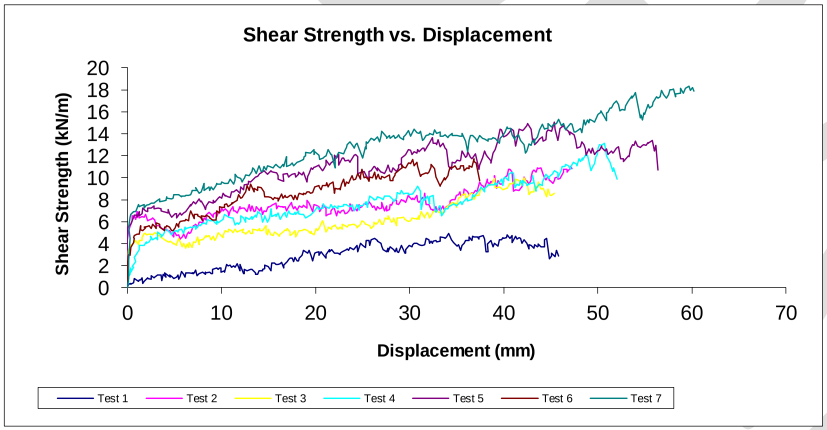
Peak Shear Strength, Vu, (lb/ft) = Normal Load * tan 38.3° + 318 lb/ft

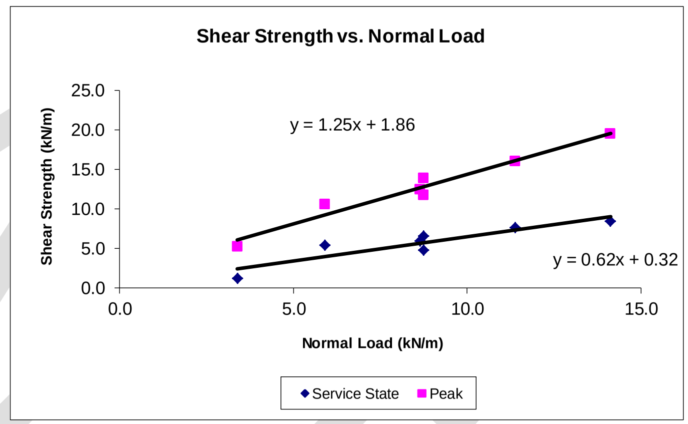
Service State Shear Strength, V'u (lb/ft) = Normal Load * tan 30.1° + 3 lb/ft

Shear Strength Test Set EP Henry Cast Stone Wall System / Miragrid 2XT Geosynthetic
Segmental Retaining Wall Units - EP Henry Cast Stone Wall System
Geosynthetic - Miragrid 2XT (Ultimate Tensile Strength, Tindex (ASTM D6687)) = 29.2 kN/m

Test Series Number	Shear Interface Width (m)	Average Axial Load (kN)	Average Axial Load (kN/m)	Approximate Wall Height Corresponding to Applied Axial Load (m)	Shear Load at Service State Deformation[1] (kN)	Service State Shear Strength (kN/m)	Service State Displacement (mm)	Peak Shear Load (kN)	Peak Shear Strength (kN/m)	Peak Displacement (mm)
1	0.41	1.4	3.4	0.74	0.5	1.2	3.2	2.1	5.3	34.2
2	0.41	3.6	8.8	1.90	2.7	6.6	2.9	4.8	11.7	47.0
3	0.41	2.4	5.9	1.28	2.2	5.4	2.9	4.3	10.6	42.2
4	0.41	3.6	8.8	1.90	2.0	4.8	3.0	5.7	13.9	50.7
5	0.41	4.6	11.4	2.47	3.1	7.7	3.3	6.5	16.0	45.3
6	0.41	3.5	8.7	1.87	2.4	5.9	2.9	5.1	12.5	36.8
7	0.41	5.7	14.1	3.06	3.4	8.4	3.2	7.9	19.5	59.7

[1] - Service State Shear Strength defined as the shear strength at 3.0 mm displacement as required by ICC-ES AC276 (Ref. 4)





The following relationships are not required by D6916-06c (2011), but are provided for reference. Using best fit linear trend lines, the following relationships have been determined using the methodology found in the NCMA Design Manual for Segmental Retaining Walls (Ref. 5):

Peak Shear Strength, Vu, (kN/m) = Normal Load * tan 38.3° + 4.64 kN/m

Service State Shear Strength, V'u (kN/m) = Normal Load * tan 30.1° + 0.05 kN/m