REPORT OF REVIEW THE KEYSTONE® KEYSYSTEM COMPAC III RETAINING WALL SYSTEM

June 2020

HIGHWAY INNOVATIONS, DEVELOPMENTS, ENHANCEMENTS AND ADVANCEMENTS (IDEA)[1]

The Keystone® KeySystem Compac III 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. Keystone's original HITEC evaluation published is 2012 consisted of Keystone's Compac II series unit for the evaluation. This update evaluation consists of review of Keystone Compac III series unit information; including connection strength. Updates to the unit consists of a slight change to the core of the unit, shortened the tail width and re-configured the unit sides. Additionally, update information on the soil reinforcement is included in this review.

Applicant Information

Keystone® Retaining Wall Systems LLC
Attn: Dan Tix, P.E.
4444 West 78th Street
Minneapolis, MN 55435
Ph: 952-879-1040
www.keystonewalls.com

Review Summary

Following its initial review of the Keystone® KeySystem Compac III Retaining Wall System submittal, the review team provided the applicant with several 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 Keystone® KeySystem Compac III Retaining Wall System IDEA submittal for projects where the KeySystem Compac III Retaining Wall System is proposed.**

Submittal Checklist

The checklist used from the IDEA protocol for this evaluation is D1 – Technical Re-evaluation Checklist for Concrete Modular Block Paired with Extensible Reinforcement. This is the first update of a previous HITEC evaluation for a system with concrete modular block paired with extensible reinforcement evaluated by IDEA.

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 Keystone® KeySystem Compac III Retaining Wall System no information has been designated by the applicant as confidential.

---

[1] See the Report of Review of Initial Technical Evaluation of the VISTAWALL STABILIZED EARTH WALL SYSTEM on the Geo-Institute website (under Special Projects tab) for information on the IDEA program.

System Description

Components
Keystone® KeySystem Compac III Retaining Wall System is comprised of dry cast concrete Compac III modular block facing units and Miragrid XT polyester geogrid soil reinforcements. Other components include gravel core fill, cap units, traffic barriers, and alignment pins. The standard facing unit is 18 inches wide, 8 inches high, and 12 inches deep. The connection of geosynthetic reinforcement to the Compac III unit is derived from frictional interface of the facing units as well as the mechanical interlock of the gravel core fill and the fiberglass alignment pins. The geosynthetic reinforcement is extended to within 4 inches of the front of the lower block face and is hooked over the alignment pins. Grades of Miragrid XT geogrids used with this system are 3XT, 5XT, 7XT, 8XT, and 10XT.

System History
See the KeySystem HITEC report 2012 (attached as part of the current evaluation submittal).

System Properties
The following properties are reported by the applicant for Keystone® KeySystem Compac III Retaining Wall System.

Soil reinforcement ultimate tensile strengths. The ultimate tensile strengths for the Miragrid XT polyester geogrid soil reinforcements are the minimum average roll values (MARV) as published by the geogrid manufacturer, Ten Cate Geosynthetics Americas. 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. This is an updated NTPEP evaluation of the Miragrid XT geogrids. The HITEC evaluation was based on a 2008 NTPEP report.

Soil reinforcement nominal tensile strengths. The nominal tensile strengths (T_{al}) for the Miragrid XT polyester geogrid soil reinforcements are 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 values (NTPEP, 2019) of 1.44 and 1.45 are used for a 75- and 100-year design life, respectively. 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 or value ranges are presented for two wall fills with maximum gradation sizes 3/8- and 3/4-inch. A maximum fill particle size of ¾-inch is recommended unless construction damage assessment tests are performed with the specific granular fill or have been performed with similarly graded large size granular fill; and similar lift heights and compaction techniques/equipment.

Soil reinforcement-facing unit connection capacity. The connection capacities of the Miragrid XT geogrids and the KeySystem Compac III units have been evaluated by short-term and long-term connection strength testing. The long-term creep connection testing has defined a connection creep reduction factor; that may be applied across the family of Miragrid grades used with this wall system.

System Innovations

The Keystone® KeySystem Compac III Retaining Wall System was submitted for this update evaluation with no claim of an innovation.

References

HITEC (2012). *Technical Evaluation Report, Evaluation of the KeySystem II Retaining Wall System, with TenCate Geosynthetic Geogrid Reinforcement,* Highway Innovation Technology Evaluation Center, American Society of Civil Engineers, Washington, D.C.

NTPEP (2019). Laboratory Evaluation of Geosynthetic Reinforcement, Final Product Qualification Report for Miragrid XT Geogrid Product Line, Submitting Manufacturer: TenCate 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., 143p.

Summary Table of MSEW Program Input Parameters for Keystone® KeySystem III Retaining Wall System						
Geogrid Soil Reinforcement						
Data / Geogrid		3XT	5XT	7XT	8XT	10XT
T_{ult} (lb/ft)		3500	4700	5900	7400	9500
Durability Reduction Factor, RF_D	5<pH<8	1.15[a]	1.15[a]	1.15[a]	1.15[a]	1.15[a]
	4.5≤pH≤5	1.3	1.3	1.3	1.3	1.3
	8≤pH≤9	1.3	1.3	1.3	1.3	1.3
Installation Damage Reduction Factor, RF_{ID}[b]	100% < 3/4-in.; D_{50} = 0.21-in.	1.05	1.10	1.1	1.1	1.15
	100% < 3/8-in.; D_{50} < #16	1.05	1.10	1.1	1.2	1.1
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		1.0	1.0	1.0	1.0	1.0
Friction Coefficient along geogrid-soil Interface, ρ	Fine to Medium Sands[c]	0.8	0.8	0.8	0.8	0.8
	Well-graded sands[d], sand & gravel[c]	0.9	0.9	0.9	0.9	0.9
Pullout Resistance factor, F*	Sands[c]	0.6	0.6	0.6	0.6	0.6
	Gravels[c]	0.67 tan φ	0.67 tan φ	0.67 tan φ	0.67 tan φ	0.67 tan φ
Scale-effect correction factor, α	Sands[c]	1.0	1.0	1.0	1.0	1.0
	Gravels[c]	0.8	0.8	0.8	0.8	0.8
Facia Geometry and Unit Weight:		Depth/height = 1.0 ft / 0.667 ft				
		Horizontal distance to center of gravity = 0.50 ft				
		Average unit weight of block = 120 lb/ft^3				
Connection Strengths:		$CRcr^{e}$ x (T_{LOT}/T_{MARV}),[f]				
	$\sigma^{d,e}$ (lb/ft^2)	3XT	5XT	7XT	8XT	10XT
	0	0.23	0.17	0.13	0.12	0.06
	1100	-	0.37	0.29	-	-
	1150	-	-	-	-	0.18
	1300	0.51	-	-	-	-
	1680	-	-	-	0.28	-
	2250	0.55	-	-	-	-
	2800	-	0.48	-	-	-
	3373	-	-	-	-	0.29

"Advancing the geo-professional community"

	3380	-	-	0.43	0.38	-
	5000	0.55	0.48	0.43	0.38	0.29
Connection strength reduction factor, Rf_d[a,d]		1.15	1.15	1.15	1.15	1.15
Creep Reduction Factor, Rf_c[d,f]		1.20	1.31	1.28	1.30	1.39

[a] Increase value to 1.3 for cases where the MBW facing is anticipated to be wet for an extended period of time; [b] Project-specific (or representative) installation damage testing and Rfid quantification should be performed for MSE fills with a maximum aggregate size greater than 3/4"; [c]Predominant material; [d] Normal pressure (lb/ft^2); [e]MSEW program term (Tcre/Tult); [f] Values are product CR_{cr} and ratio of T_{LOT} of material used in connection testing to T_{MARV} of the corresponding production run.

June 26, 2020

Jeffery Greenwald, P.E., CAE
IDEA Program Manager
ASCE Geo-Institute

Re: Keystone Retaining Wall Systems LLC – KeySystem III product update evaluation for IDEA

Mr. Greenwald Et al.,

Keystone is pleased to submit the Appendix D1 documentation for IDEA update Evaluation of our KeySystem II HITEC evaluation to KeySystem III IDEA evaluation. Enclosed with this cover letter is the requested documentation per the provided Appendix D1 checklist.

All correspondence may be directed to my attention at the following contact information:
dtix@keystonewalls.com
651-353-1632

or

Keystone Retaining Wall Systems LLC
4444 West 78th Street
Minneapolis, MN 55435

Regards,

Daniel Tix, P.E. (MN)
Director of Technical Services

Cc: Pat Stiemke, Keith Miller, John Schramm – Keystone, Ryan Berg, Jim Collin – Geo-Institute

Enclosures

Table of Contents

APPENDIX D

Highway Innovation Developments, Enhancements and Advancements (IDEA)
Update Evaluation Concrete Modular Block Unit Paired with Extensible Reinforcement

Appendix D1
Technical Re-evaluation Checklist for Concrete Modular Block Unit Paired with Extensible Reinforcement

Guidelines for the Applicant to use this checklist:

1. Provide your submittal in Adobe portable document format (i.e. PDF).

2. Organize the submittal based on the numbered outline shown in the checklist below. Use the numbered outline as for a table of contents (TOC). Provide the response for each item in your report. Create *links* between the items in the TOC and the items in the report and appendices.

3. If reports, drawings or calculations are requested for a section, provide them in the appendix tabbed for that section. For example, design calculations are required for Item 2.3.1. They should be included in Appendix 2.3.1.

4. Mark the checklist at each item to indicate "yes" you have included the relevant information. If you must check "no", please provide a brief explanation if appropriate.

Section 1: ERS Components

1.1	Tab 1.1		Facing Unit
	Yes	No	Item
1.1.1	☐	☒	Does the system contain what you consider to be an innovation that is related to the facing unit? If yes, please describe the innovation briefly. As items below apply to the innovation, please describe the innovation in further detail.
1.1.2	☒	☐	Has the facing unit changed since the original evaluation?
1.1.3	☒	☐	If the answer is yes to 1.1.2, provide a description of the changes along with drawings showing the dimensions of the original facing unit and the revised facing unit.
1.1.4	☐	☒	Has the connection changed, if yes provide a description of the changes.
1.1.5	☐	☒	Describe any other changes to the facing unit (i.e., 28 day compressive strength, freeze thaw durability, etc.)
1.1.6	☒	☐	Provide inter-unit shear test results and design shear capacity envelopes.

1.2	Tab 1.2		Extensible Reinforcement
	Yes	No	Item
1.2.1	☐	☒	Does the ERS contain what you consider to be an innovation that is related to the reinforcement? If yes, please describe the innovation briefly. As items below apply to the innovation, please describe the innovation in further detail.
1.2.2	☐	☒	Has the reinforcement changed or been modified since the original evaluation.
1.2.3	☒	☐	Provide the current NTPEP report.
1.2.4	☒	☐	Reinforcement Reduction Factors and Nominal Strengths
1.2.5	☒	☐	Describe the facing unit-reinforcement connection with text and drawings.
1.2.6	☒	☐	List short- and long-term facing unit-reinforcement connection strength tests performed on the current system components, provide test results and strength envelopes the Applicant recommends for design.
1.2.7	☒	☐	List reinforcement pullout (ASTM D6706) tests performed on the current system components and provide results. Provide test soil properties, corresponding

1.2	Tab 1.2	Extensible Reinforcement
		pullout friction factors (F*) and scale effect correction factors (α) Applicant recommends for design. Discuss how test results support these recommendations based on Appendix B at FHWA-NHI-10-025.
1.2.8	☒ ☐	List soil-geosynthetic interface shear (ASTM D5321) tests performed on the current system components and provide results. List interface friction angle (ρ) Applicant recommends for design. Discuss how test results support these recommendations.
1.2.9	☒ ☐	Summary table of input parameters used with (e.g., MSEW) computer design program.

1.3	Tab 1.3	Additional Information
	Yes No	Item
1.3.1	☒ ☐	Does the system have a HITEC Evaluation? If so, provide a copy.
1.3.2	☒ ☐	Does the system have an independent evaluation performed by a subject matter expert? If so, provide a copy.
1.3.3	☒ ☐	Drainage - Describe with text any internal and external drainage measures that are inherent in the system. That is, they are not optional measures such as blanket and chimney drains or drainage swales, but are built-into ERS components.

IDEA Update Evaluation Concrete Modular Block Unit Paired with Extensible Reinforcement - Appendix D Commentary

For
Keystone Retaining Wall Systems
KeySystem II update to KeySystem III

Section 1 – Tab 1.1 Facing Unit:

Item 1.1.1 – N/A
Item 1.1.2 – N/A
Item 1.1.3 - Keystone's original HITEC evaluation published is 2012 consisted of Keystone's Compac II series unit for the evaluation. This update evaluation consists of Keystone Compac III series unit information. Updates to the unit consists of a slight change to the core of the unit, shortened the tail width and re-configured the unit sides. With the changes to the core configuration and sides, the series III unit allows for vertically aligned core when installed in running bond. Additionally, with these revisions the nominal weight for the series III is 75 lbs, versus the nominal weight of the II series of 85 lbs. The Bathurst interface block shear reports and short term connection reports have incorrectly reported the unit weight of the Compac III at 90 lbs. Click Here for Unit Detail Comparison.
Item 1.1.4 – N/A
Item 1.1.5 – N/A
Item 1.1.6 – Click Here for Inter-Unit Shear test results and design shear envelopes.

Section 1 – Tab 1.2 Extensible Reinforcement:

Item 1.2.1 – N/A
Item 1.2.2 – N/A, Click Here for a letter from Tencate Mirafi dated 11/22/19, indicating the manufacturing process has not changed since 2002.
Item 1.2.3 – Click Here for Tencate Mirafi NTPEP Report
Item 1.2.4 – Reduction factors utilized in this table are consistent with the values noted in the Mirafi NTPEP evaluation and AASHTO/FHWA criteria. The creep reduction factor could be considered as low as 1.44 per the NTPEP. Summary table noted below:

Geogrid Soil Reinforcement						
Data / Geogrid		3XT	5XT	7XT	8XT	10XT
T_{ult} (lb/ft)		3500	4700	5900	7400	9500
Durability Reduction Factor, RF_D	5<pH<8	1.15[a]	1.15[a]	1.15[a]	1.15[a]	1.15[a]
	4.5≤pH≤5	1.3	1.3	1.3	1.3	1.3
	8≤pH≤9	1.3	1.3	1.3	1.3	1.3
Installation Damage Reduction Factor, RF_{ID}[c]	100%<3/8"; D_{50}=0.21-in.	1.10	1.10	1.10 - 1.20[b]	1.15 - 1.20[b]	1.15 - 1.20[b]
	100%<3/4"; D_{50}=0.21-in.	1.10	1.10	1.10 - 1.20[b]	1.20 - 1.30[b]	1.20 - 1.30[b]
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

[a] Increase value to 1.3 for cases where the MBW facing is anticipated to be wet for an extended period of time;
[b] The upper end of the range value is recommended in absence of site specific (or representative) tests;
[c] Project-specific (or representative) installation damage testing and Rfid quantification should be performed for MSE fills with a maximum aggregate size greater than 3/4";

Item 1.2.5:
The connection detail for the KeySystem III requires placing the fiberglass alignment pins in the front pin hole, then filling block openings with unit fill gravel and placing the geogrid over the fiberglass pins. Next, place the next row of units on top the lower units and geogrid, and then pulling the geogrid taut and placement of wall fill. The connection capacity between the Keystone Compac III units and Miragrid geogrid is developed by: interface friction between the MBW units and geogrid; granular interlock of the unit fill and geogrid; and interlock with the fiberglass alignment pins.* The reinforcement placed over the pins provides a minimum of 8" embedment between the rows of MBW units and full overlap of the aggregate unit fill.**

Click Here for drawing details.

*,** - Evaluation of The KeySystem II Retaining Wall By Keystone Retaining Wall Systems, Inc. with TenCate Geosynthetics Geogrid Reinforcement, HITEC May 2012

Item 1.2.6 – List of reports noted below. Click Here for Short Term and Long Term Connection Strength Reports, strength envelopes.

Short-term Connection Tests

1. Compac III with Miragrid 3XT Connection Capacity Testing - Bathurst, Clarabut Geotechnical Testing, Inc., Date 10/27/09
2. Compac III with Miragrid 5XT Connection Capacity Testing - Bathurst, Clarabut Geotechnical Testing, Inc., Date 10/27/09
3. Compac III with Miragrid 7XT Connection Capacity Testing - Bathurst, Clarabut Geotechnical Testing, Inc., Date 10/27/09
4. Compac III with Miragrid 8XT Connection Capacity Testing - Bathurst, Clarabut Geotechnical Testing, Inc., Date 10/27/09
5. Compac III with Miragrid 10XT Connection Capacity Testing - Bathurst, Clarabut Geotechnical Testing, Inc., Date 10/27/09

Long-term Sustained Load Connection Test

1. Sustained Load Connection Testing Compac III and Miragrid 3XT – TRI Environmental, Inc., Date 10/22/14
2. Sustained Load Connection Testing Compac III and Miragrid 7XT – TRI Environmental, Inc., Date 7/18/13

Tables 1 and 2 are the summarized results from the long-term sustained load testing on Miragrid 3XT and 7XT. Tables 3-5 are the summarized data for a total of 5 reinforcement strengths. The information for strengths 5XT, 8XT and 10XT were interpreted from the short term testing performed and long term testing data from 3XT and 7XT. This interpretation was consistent with the previous HITEC manual. 2 stage connection curves were developed in conjunction with these tables, table 5. 2 stage curves were utilized to better represent the connection curves and the data presented. Click Here for connection curve information. Note that the Actual Peak Curve (lines) were used for the Capacity equations (in Table 5), and that T_{lot}/T_{ult} normalization is included in the $RF_{CONNTOT}$ (in Tables 4 & 5).

Sustained Load Summary Tables based on previous HITEC Manual

Normal Load N, (lb/ft)	Index Peak Capacity T_{CONN} (lb/ft)	75-year Creep-reduced Connection Strength T_{CONN75} (lb/ft)	Connection Creep Reduction Factor $RF_{connCR} = T_{conn} / T_{conn75}$
500	1255	1134	1.11
1000	1531	1447	1.06
2000	2084	1854	1.12

Table 1: Miragrid 3XT Sustained Load Connection Factors

Normal Load N, (lb/ft)	Index Peak Capacity T_{CONN} (lb/ft)	75-year Creep-reduced Connection Strength T_{CONN75} (lb/ft)	Connection Creep Reduction Factor $RF_{connCR} = T_{conn} / T_{conn75}$
1000	1962	1678	1.17
2000	2412	2163	1.12
3000	2862	2371	1.20

Table 2: Miragrid 7XT Sustained Load Connection Factors

Miragrid	$T_{ult\text{-}MARV}$ (plf)	T_{lot} (plf)	$T_{lot} / T_{ult\text{-}MARV}$ (plf)	Lot
3XT	3500	3484	1.00	032092006/06244-2-4
5XT	4700	5130	1.09	031106986/08234-1-4
7XT	5900	6317	1.07	031062656/06334-1-4
8XT	7400	7987	1.08	031109345/08288-1-1
10XT	9500	10973	1.16	031109615/08296-1-3

Table 3: $T_{lot} / T_{ult\text{-}MARV}$ Normalization

Miragrid		Reduction Factors to the Ultimate Connection Strength			Long Term (75 year) Connection Reduction Factor $RF_{ConnTot} = RF_{connCR} \times (T_{LOT}/T_{MARV})$
Type	T_{ULT} (lb/ft)	RF_{connCR}, Connection Creep Rupture	RF_d, Durability	$T_{lot} / T_{ult\text{-}MARV}$ (plf)	
3XT	3500	1.20	1.15	1.00	1.20
5XT	4700	1.20	1.15	1.09	1.31
7XT	5900	1.20	1.15	1.07	1.28
8XT	7400	1.20	1.15	1.08	1.30
10Xt	9500	1.20	1.15	1.16	1.39

Table 4: Long Term Connection Reduction Factors

Miragrid	T_{ult} (plf) - Miragrid Ultimate Strength	Normal Load (N) in equivalent wall height	Long Term Design Capacity, T_{Conn75} (lb/ft)	
3XT	3500	0 < H < 10.83	N < 1300	T_{Conn75} = (1/1.20)(975 + N tan 42.3°)
		10.83 < H < 18.75	1300 < N < 2250	T_{Conn75} = (1/1.20)(1973 + N tan 8.1°)
5XT	4700	0 < H < 9.17	N < 1100	T_{Conn75} = (1/1.31)(1022 + N tan 48°)
		9.17 < H < 23.33	1100 < N < 2800	T_{Conn75} = (1/1.31)(1804 + N tan 21.8°)
7XT	5900	0 < H < 9.17	N < 1100	T_{Conn75} = (1/1.28)(970 + N tan 47.6°)
		9.17 < H < 28.17	1100 < N < 3380	T_{Conn75} = (1/1.28)(1648 + N tan 25.6°)
8XT	7400	0 < H < 14	N < 1680	T_{Conn75} = (1/1.30)(1150 + N tan 42.5°)
		14 < H < 28.17	1680 < N < 3380	T_{Conn75} = (1/1.30)(1739 + N tan 29.5°)
10XT	9500	0 < H < 9.6	N < 1150	T_{Conn75} = (1/1.39)(850 + N tan 53°)
		9.6 < H < 28.1	1150 < N < 3373	T_{Conn75} = (1/1.39)(1621 + N tan 33.3°)

Table 5: Design Capacity

Item 1.2.7:
We believe no changes from the previous HITEC manual were needed regarding Friction coefficient along geogrid-soil interface, ρ, pullout resistance factor, F*, and scale-effect correction factor, α as the values are consistent with the default values of FHWA(2009). No additional commentary changes to the previous HITEC manual.

Item 1.2.8 – N/A
Item 1.2.9 – See MSEW Program Summary Table Below

Summary Table of MSEW Program Input Parameters for Keystone ® KeySystem III Retaining Wall System

Geogrid Soil Reinforcement - Data/Geogrid		**3XT**	**5XT**	**7XT**	**8XT**	**10XT**
$T_{ULT-MARV}$ (lb/ft)		3500	4700	5900	7400	9500
Durability Reduction Factor, RF_D	5<pH<8	1.15[a]	1.15[a]	1.15[a]	1.15[a]	1.15[a]
	4.5≤pH≤5	1.3	1.3	1.3	1.3	1.3
	8≤pH≤9	1.3	1.3	1.3	1.3	1.3
Installation Damage Reduction Factor, RF_{ID}[b]	100%<3/8"; D_{50}=0.21-in.	1.05	1.10	1.1	1.1	1.15
	100% < 3/8-in.; D50 < #16	1.05	1.10	1.1	1.2	1.1
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		1.0	1.0	1.0	1.0	1.0
Friction Coefficient along geogrid-soil Interface, ρ	Fine to Medium Sands[c]	0.8	0.8	0.8	0.8	0.8
	Well-graded sands, sand & gravel[c]	0.9	0.9	0.9	0.9	0.9
Pullout Resistance factor, F*	Sands[c]	0.6	0.6	0.6	0.6	0.6
	Gravels[c]	0.67 tanΦ	0.67 tanΦ	0.67 tanΦ	0.67 tanΦ	0.67 tanΦ
Scale-effect correction factor, α	Sands[c]	1.0	1.0	1.0	1.0	1.0
	Gravels[c]	0.8	0.8	0.8	0.8	0.8
Facia Geometry and Unit Weight:		Depth/height = 1.0 ft / 0.667 ft				
		Horizontal distance to center of gravity = 0.50 ft				
		Average unit weight of block = 120 lb/ft³				
Connection Strengths:		$CRcr^e \times (T_{LOT}/T_{ULT-MARV})^f$				
	$\Sigma^{d,e}$ (lb/ft²)	3XT	5XT	7XT	8XT	10XT
	0	0.23	0.17	0.13	0.12	0.06
	1100	-	0.37	0.29	-	-
	1150	-	-	-	-	0.18
	1300	0.51	-	-	-	-
	1680	-	-	-	0.28	-
	2250	0.55	-	-	-	-
	2800	-	0.48	-	-	-
	3373	-	-	-	-	0.29
	3380	-	-	0.43	0.38	-
	5000	0.55	0.48	0.43	0.38	0.29
Connection strength durability reduction factor, Rf_d[a,d]		1.15	1.15	1.15	1.15	1.15
Creep Reduction Factor, Rf_c[d]		1.20	1.31	1.28	1.30	1.39

Notes:

[a] Increase value to 1.3 for cases where the MBW facing is anticipated to be wet for an extended period of time;
[b] Project-specific (or representative) installation damage testing and RF_{ID} quantification should be performed for MSE fills with a maximum aggregate size greater than 3/4 in. (19 mm);
[c] Predominent material;
[d] Normal pressure (lb/ft²)
[e] MSEW program term (T_{CRE}/T_{ULT});
[f] Values are product of CR_{CR} and ratio of T_{LOT} of material used in connection testing to T_{MARV} of the corresponding production run.

Section 1 – Tab 1.2 Extensible Reinforcement:

Item 1.3.1 – Click Here for HITEC Evaluation

Item 1.3.2 – Click Here for the following report:

Keystone Compac II/Miragrid Retaining Wall System with Compac III / Miragrid Addition – Maryland Department of Transportation Proprietary Retaining Wall Approval Process, The Collin Group, Date 4/15/18

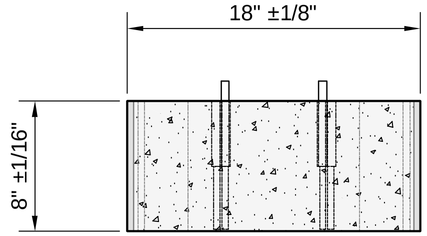
Item 1.3.3 – Drainage

We believe no changes to the previous section in the HITEC Manual are required for this section. For reference, HITEC Manual Section 3.6.3 Wall Drainage is paraphrased below for the face drain requirements.

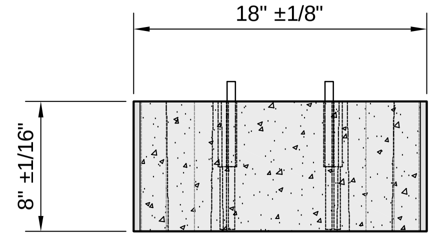
Drainage of water from the reinforced soil zone is primarily through joints between facing units. According to Keystone, the installation of weep holes is not required. To facilitate movement of water to the drainage aggregate identified by Keystone as "drain rock" is placed in facing unit voids, between units, and for a distance of 2 ft (600 mm) as measured from the wall face. This exceeds the minimum of 1 ft^3/ft^2 of wall face of drainage fill within and/or behind the face block, as recommended by FHWA (2009). The material specified by Keystone as unit fill/drainage aggregate conforms with the specification requirement in section 10.9 (FHWA, 2009, but is on the coarser side of the gradation range, as follows:

Sieve Size	Percent Passing	
	FHWA (2009)	Keystone III
1-1/2 in. (38 mm)	100	-
1 in. (25 mm)	75-100	100
3/4 in. (19 mm)	50-75	50-75
No. 4 (4.74 mm)	0-60	0-10
No. 40 (425 um)	0-50	-
No. 50 (300 um)	-	0-5
No. 200 (75 um)	0-5	-

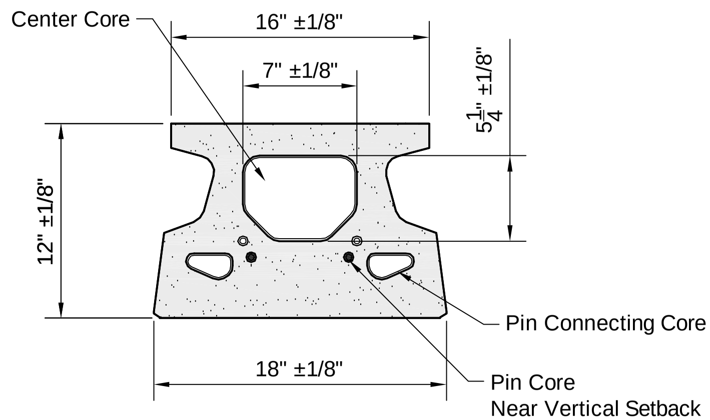
Keystone recommends that a design check should be made of grain size compatibility between the drain aggregate and reinforced fill using standard geotechnical filter criteria as provided in the submittal document, where there may be water flow through the reinforced wall fill to the face that could cause piping or loss of fines. Where filter criteria cannot be achieved with a graded filter, or where wave action on the wall would cause inward and outward flow, Keystone recommends that geotextile filter be installed between the drain rock and reinforced fill. The geotextile is required to conform to the requirements of AASHTO M288 (2006).



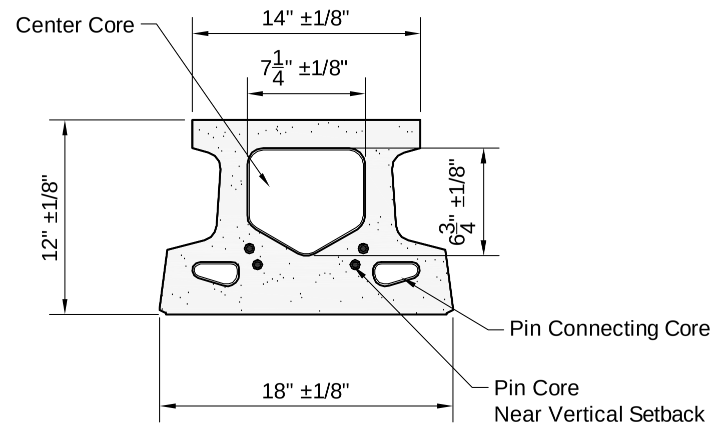
Straight Face Compac II Unit Elevation



Straight Face Compac III Unit Elevation



Straight Face Compac II Unit Plan



Straight Face Compac III Unit Plan

Compac II Unit

Compac III Unit

KEYSTONE® RETAINING WALL SYSTEMS
4444 West 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: DMT	Title:	Unit Drawing Item 1.1.3	Date: 10/2019
Checked By: PJS	Project:	IDEA Evaluation	Project No: IDEA
Scale: No Scale			Drawing No: 1 of 1

Series BCGT2544

REPORT

RESULTS

OF

COMPAC III BLOCK UNITS

INTERFACE SHEAR CAPACITY TESTING

submitted to

Keystone Retaining Wall Systems

CONFIDENTIAL

Distribution:

2 copies Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435
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 Compac III® (Light) modular concrete block units.

The test program was initiated in response to a verbal authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 27 July 2009.

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 Compac III concrete block units placed in a staggered joint (running bond) configuration 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 Compac III 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 Compac III blocks.

Materials

Keystone Compac III blocks are hollow concrete blocks weighing approximately 90 pounds per unit (weight/unit measured in our laboratory) which are normally filled with a select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. The installation arrangement is illustrated in **Figure 1**. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 13 April 2007 and designated as BIC 07-017.

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 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 in excess of 35,000 pounds 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 two underlying units to simulate the staggered construction procedure typically used in the field. The spaces between the blocks were infilled with a 3/4 inch crushed limestone and lightly compacted. **Figure 2** illustrates the particle size distribution of the infill used in this test series. Wall heights were simulated by placing a single block over the interface and applying additional normal load using the air bag 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 micro-computer/data acquisition system. Each test was continued until large shear displacements were achieved. Following each test, the blocks were removed and the units examined to confirm failure modes (if applicable). In order to minimize the number of blocks used in this investigation, blocks used for the lower courses were re-used as the top layer block in subsequent tests. However, the interface along which shear was developed was initially undamaged in each test. Virgin fiberglass shear pins were used in each test.

The only 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). The normal loads used in the test program are given in **Table 1**.

Test results

Results of interface shear tests are summarized in **Table 1**. Peak interface shear capacities and shear capacity at the displacement criterion (0.16 inch) are plotted against normal load in **Figure 3**. The displacement criterion was calculated to be 0.16 inch based on 2% of the block height. The minimum *peak* shear capacity recorded from the test series was 1635 lb/ft.

The test results reveal some scatter in shear capacity for tests carried out at nominal similar normal loads. The three tests carried out at the same equivalent normal load of 1375 lb/ft (**Tests 1**, **4** and **7**) gave peak shear capacity values that ranged from 2190 to 2400 lb/ft with a mean value of 2320 lb/ft. Peak shear capacity values varied by 5.6% of the mean value and hence are within acceptance limits for test repeatability as recommended by the NCMA. The trends in data for shear capacity based on the displacement criterion and peak shear have been plotted using linear curves. However, there are small differences in the magnitude of the measured shear capacity from the linear curves used to approximate the data over the range of tests. These differences are likely the result of small variations in laying out of the block units, placement and compaction of the granular fill, and possibly minor variability in the dimensions of the block units.

Implications to interface shear capacity design and construction with Compac III block units

The interface shear strength in the field may be less than the values determined in this test series for the same method and quality of construction. The NCMA Segmental Retaining Wall Design Manual 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 0.16 inch displacement criterion. The *design* interface shear capacity envelope shown in **Figure 4** is controlled by the peak shear capacity values.

The design shear capacity envelope illustrated in **Figure 4** 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 and passive resistance of the fiberglass shear pins.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional performance of the shear capacity between Compac III segmental concrete units. The following conclusions can be drawn:

1. The minimum *peak* shear capacity recorded from this test series was 1635 lb/ft (height above interface equal to 7.8 block units). Variability in shear capacity between nominal identical tests was probably due to small differences in setting up of the blocks, placement and compaction of the granular fill, and possibly small variations in block dimensions and shear pin strength.
2. Care must be taken during the installation of Compac III 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 Compac III facing unit system.
3. The design envelope in **Figure 4** is based on interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual. The choice of design interface shear capacity may vary with quality of construction in the field and hence lower design values than those taken from **Figure 4** may be appropriate.

Concluding remarks

The test results presented here are applicable to gravity and geosynthetic reinforced-soil segmental retaining wall designs that employ Compac III units. 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.

R. J. Bathurst, Ph.D., P. Eng.

P. Clarabut

Table 1
Test Program:
Shear capacity results for Compac III modular block units

Test number	normal load (lb/ft)	approximate wall height (ft)	approximate number of blocks	shear load at 0.16 inch displacement (lb/ft)	shear load at PEAK (lb/ft)
1	1380	15.0	22.5	1766	2400
2	480	5.2	7.8	1583	1635
3	930	10.1	15.2	1881	2130
4	1380	15.0	22.5	1334	2190
5	1845	20.1	30.1	2312	2580
6	2310	25.1	37.7	2451	3285
7	1365	14.8	22.3	1457	2370
8	2745	29.8	44.8	2646	3060

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., Althoff, S.., and Linnenbaum, P., 2008. *Inluence of test method on direct shear behavior of segmental retaining wall unit,* ASTM Geotechnical Testing Journal, Vol. 31 No. 2, pp. 157-165.

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	loading frame	2	horizontal actuator
3	horizontal load cell	4	reaction beam
5	vertical load cell	6	air bag
7	platform	8	spacers
9	Compac III	10	displacement transducer

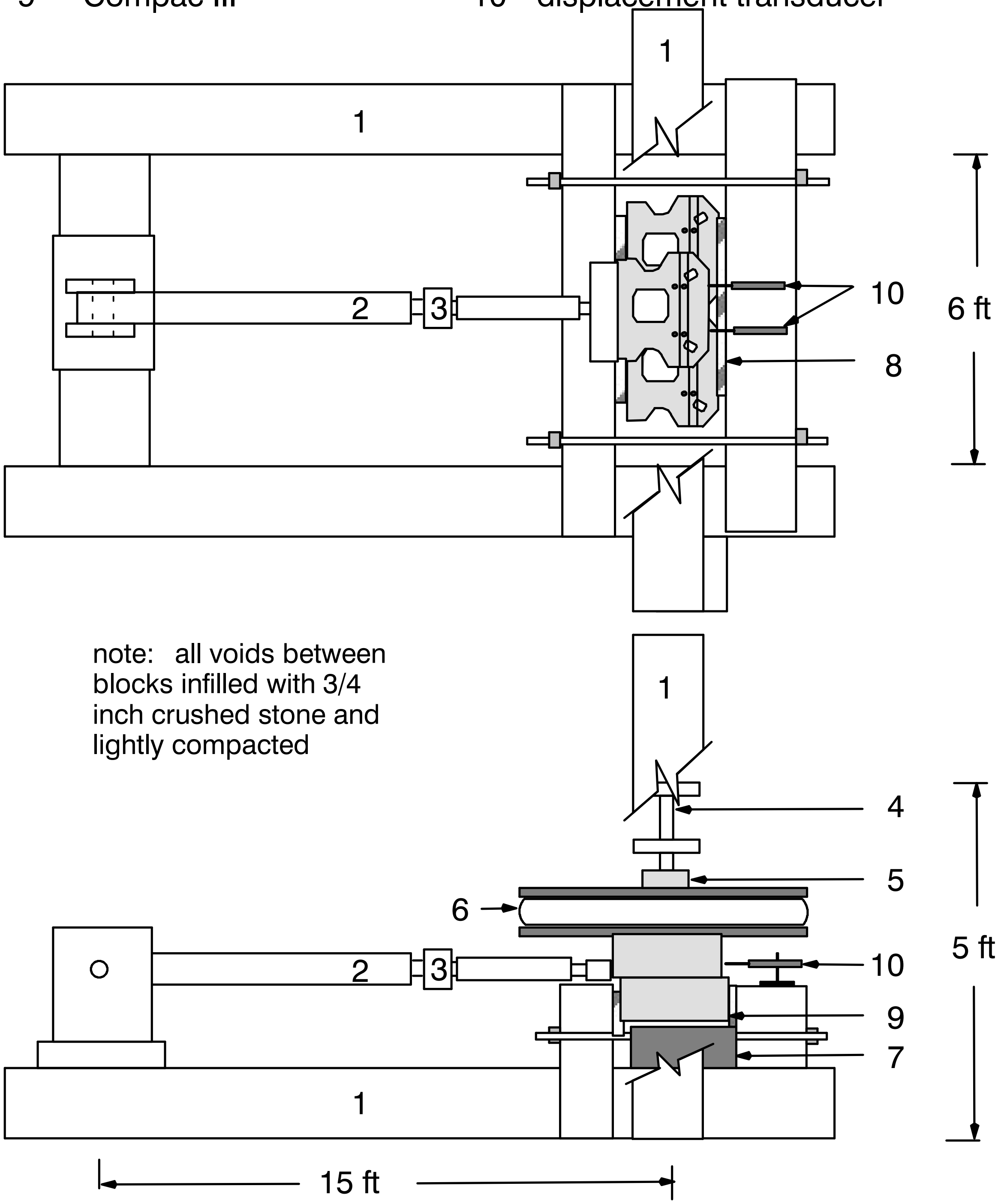


Figure 1: Schematic of shear capacity test apparatus showing Compac III modular concrete block units

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

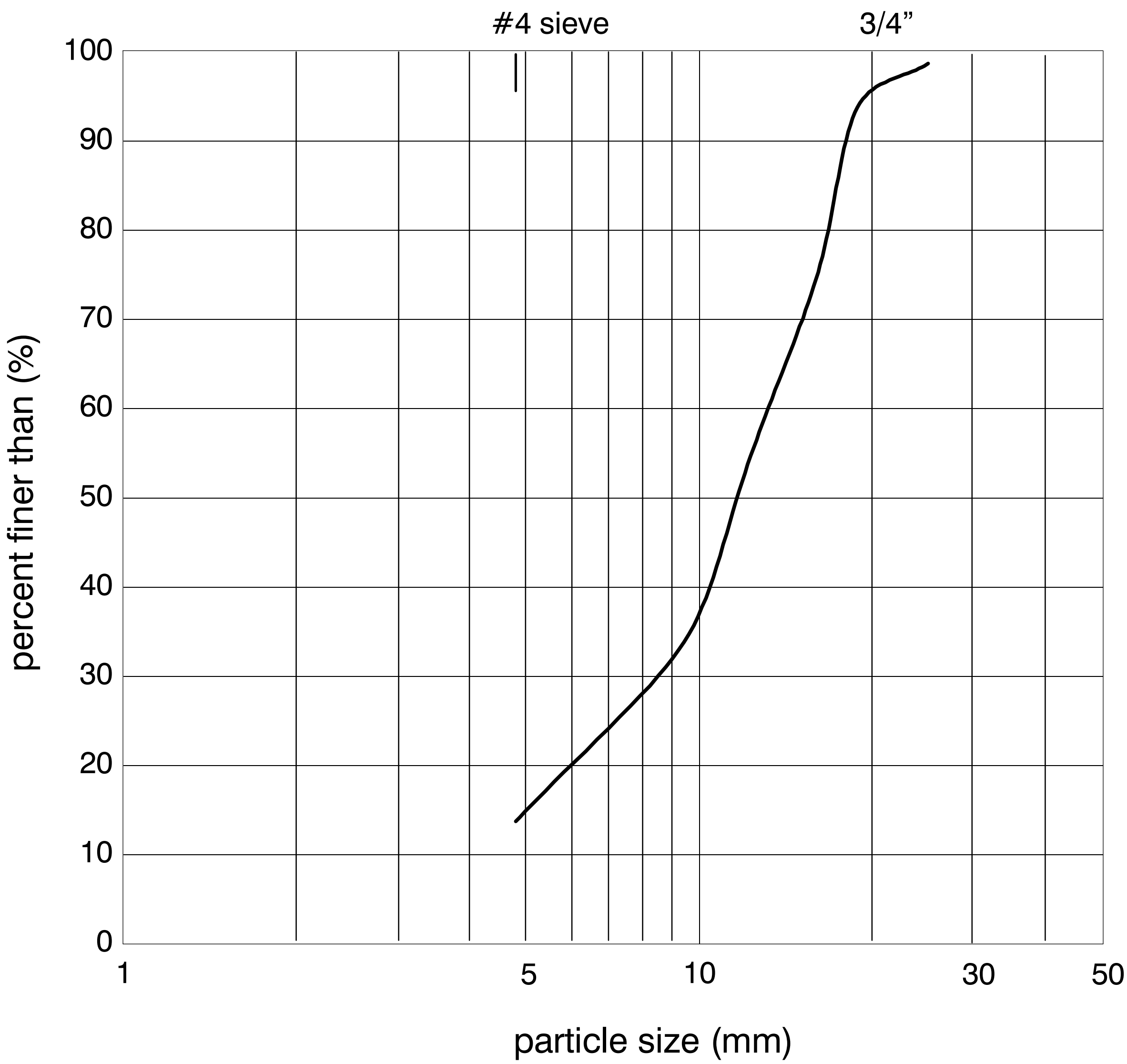


Figure 2: Particle size distribution for 100% crushed granular stone used in Compac III block shear capacity tests

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

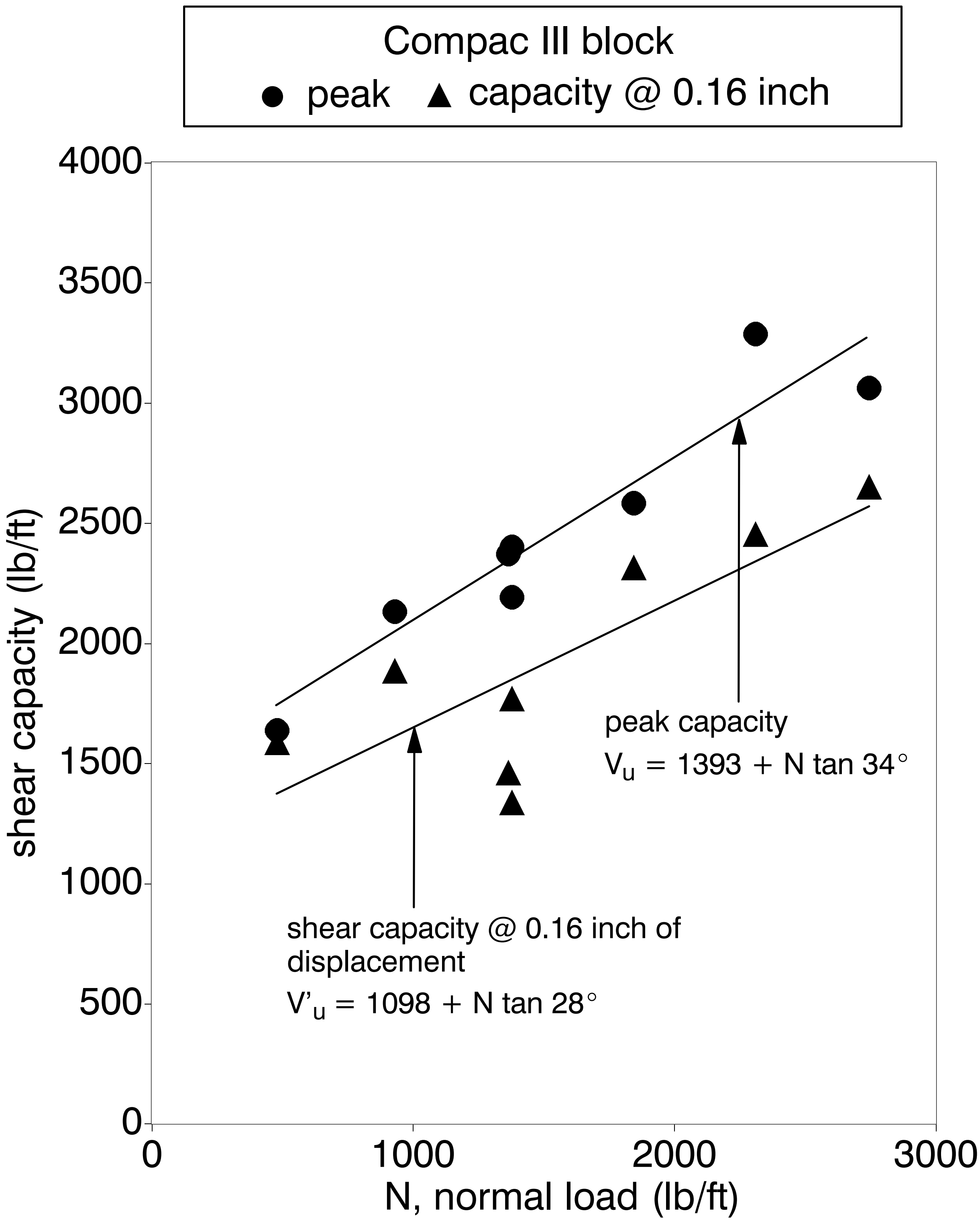


Figure 3: Summary of interface shear capacities for Compac III block

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

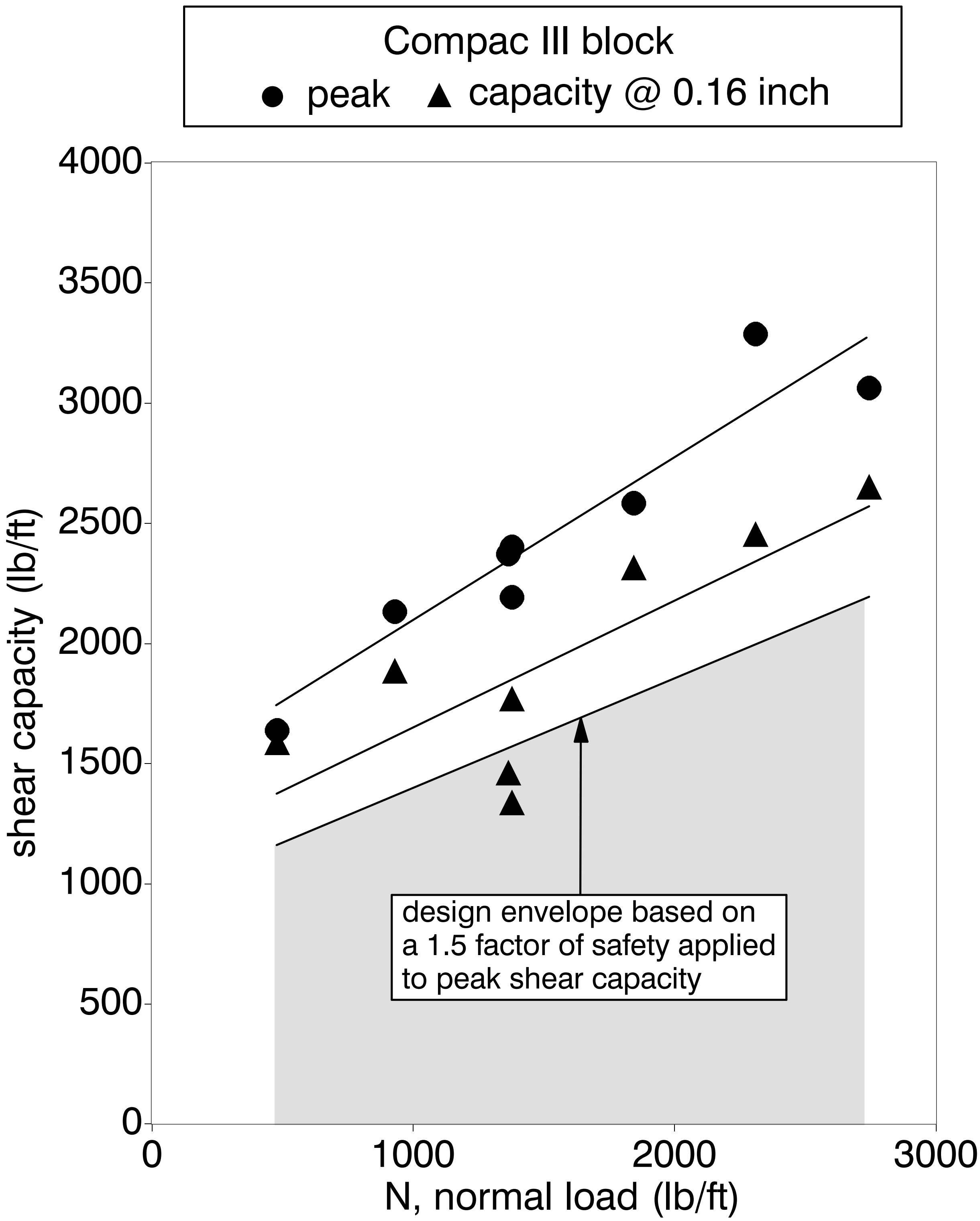


Figure 4: Shear capacity design envelope for Compac III block

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

REPORT

RESULTS

OF

COMPAC III BLOCK UNITS WITH A SINGLE LAYER INCLUSION OF MIRAGRID 7XT INTERFACE SHEAR CAPACITY TESTING

submitted to

Keystone Retaining Wall Systems

CONFIDENTIAL

Distribution:

2 copies Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435
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 Compac III® (Light) modular concrete block units with a single layer inclusion of Miragrid 7XT.

The test program was initiated in response to a verbal authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 27 July 2009.

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 Compac III concrete block units with a single layer inclusion of Miragrid 7XT placed in a staggered joint (running bond) configuration 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 Compac III block units with a single layer inclusion of Miragrid 7XT. 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 Compac III blocks and Miragrid 7XT.

Materials

Keystone Compac III blocks are hollow concrete blocks weighing approximately 90 pounds per unit (weight/unit measured in our laboratory) which are normally filled with a select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. The installation arrangement is illustrated in **Figure 1**. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 13 April 2007 and designated as BIC 07-017.

Miragrid 7XT is a bi-directional geogrid composed of 100% polyester multifilament yarn with a tensile strength of 5900 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009). The geogrid specimens used in this series of testing were cut from roll/lot # 031062656 / 06334-1-4 received at our laboratory on 8 December 2006.

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 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 in excess of 35,000 pounds 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 a geogrid specimen and one centrally located running bond (joint) formed by two underlying units to simulate the staggered construction procedure typically used in the field. The spaces between the blocks were infilled with a 3/4 inch crushed limestone and lightly compacted. **Figure 2** illustrates the particle size distribution of the infill used in this test series. Wall heights were simulated by placing a single block over the interface and applying additional normal load using the air bag 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 large shear displacements were achieved. Following each test, the blocks were removed and the units examined to confirm failure modes (if applicable). In order to minimize the number of blocks used in this investigation, blocks used for the lower courses were re-used as the top layer block in subsequent tests. However, the interface along which shear was developed was initially undamaged in each test. Virgin geogrid specimens and fiberglass shear pins were used in each test.

The only 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). The normal loads used in the test program are given in **Table 1**.

Test results

Results of interface shear tests are summarized in **Table 1**. Peak interface shear capacities and shear capacity at the displacement criterion (0.16 inch) are plotted against normal load in **Figure 3**. The displacement criterion was calculated to be 0.16 inch based on 2% of the block height. The minimum *peak* shear capacity recorded from the test series was 1170 lb/ft.

The test results reveal some scatter in shear capacity for tests carried out at nominal similar normal loads. The three tests carried out at the same equivalent normal load of 1385 lb/ft (**Tests 1**, **4** and **7**) gave peak shear capacity values that ranged from 2025 to 2340 lb/ft with a mean value of 2200 lb/ft. Peak shear capacity values varied by 8.0% of the mean value and hence are within acceptance limits for test repeatability as recommended by the NCMA. The trends in data for shear capacity based on the displacement criterion and peak shear have been plotted using bi-linear curves. However, there are small differences in the magnitude of the measured shear capacity from the bi-linear curves used to approximate the data over the range of tests. These differences are likely the result of small variations in laying out of the block units, placement of the geogrid specimen, placement and compaction of the granular fill, and possibly minor variability in the dimensions of the block units.

Implications to interface shear capacity design and construction with Compac III block units with a single layer inclusion of Miragrid 7XT

The interface shear strength in the field may be less than the values determined in this test series for the same method and quality of construction. The NCMA Segmental Retaining Wall Design Manual 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 0.16 inch displacement criterion. The *design* interface shear capacity envelope shown in **Figure 4** is controlled largely by the peak shear capacity values.

The design shear capacity envelope illustrated in **Figure 4** 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 and passive resistance of the fiberglass shear pins.

Summary of conclusions

A laboratory testing program was carried out to evaluate the mechanical/frictional performance of the shear capacity between Compac III segmental concrete units. The following conclusions can be drawn:

1. The minimum *peak* shear capacity recorded from this test series was 1170 lb/ft (height above interface equal to 7.8 block units). Variability in shear capacity between nominal identical tests was probably due to small differences in setting up of the blocks, placement and compaction of the granular fill, placement of the geogrid specimen and possibly small variations in block dimensions and shear pin strength.
2. Care must be taken during the installation of Compac III 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 Compac III facing unit system.
3. The design envelope in **Figure 4** is based on interpretation of test data as recommended in the NCMA Segmental Retaining Wall Design Manual. The choice of design interface shear capacity may vary with quality of construction in the field and hence lower design values than those taken from **Figure 4** may be appropriate.

Concluding remarks

The test results presented here are applicable to geosynthetic reinforced-soil segmental retaining wall designs that employ Compac III units and Miragrid 7XT. The inclusion of a layer of geosynthetic reinforcement other than Miragrid 7XT between courses may reduce the interface shear capacity to values less than those reported in this investigation.

R. J. Bathurst, Ph.D., P. Eng.

P. Clarabut

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., Althoff, S.., and Linnenbaum, P., 2008. *Inluence of test method on direct shear behavior of segmental retaining wall unit,* ASTM Geotechnical Testing Journal, Vol. 31 No. 2, pp. 157-165.

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:

Shear capacity results for Compac III modular block units with a single layer inclusion of Miragrid 7XT

Test number	normal load (lb/ft)	approximate wall height (ft)	approximate number of blocks	shear load at 0.16 inch displacement (lb/ft)	shear load at PEAK (lb/ft)
1	1395	15.2	22.7	1307	2025
2	2760	30.0	45.0	2022	2685
3	2295	24.9	37.4	2169	2805
4	1380	15.0	22.5	1943	2235
5	1860	20.2	30.3	2057	2655
6	915	9.9	14.9	816	2010
7	1380	15.0	22.5	1280	2340
8	480	5.2	7.8	1080	1170

1	loading frame	2	horizontal actuator
3	horizontal load cell	4	reaction beam
5	vertical load cell	6	air bag
7	platform	8	spacers
9	Compac III	10	displacement transducer
11	Miragrid 7XT		

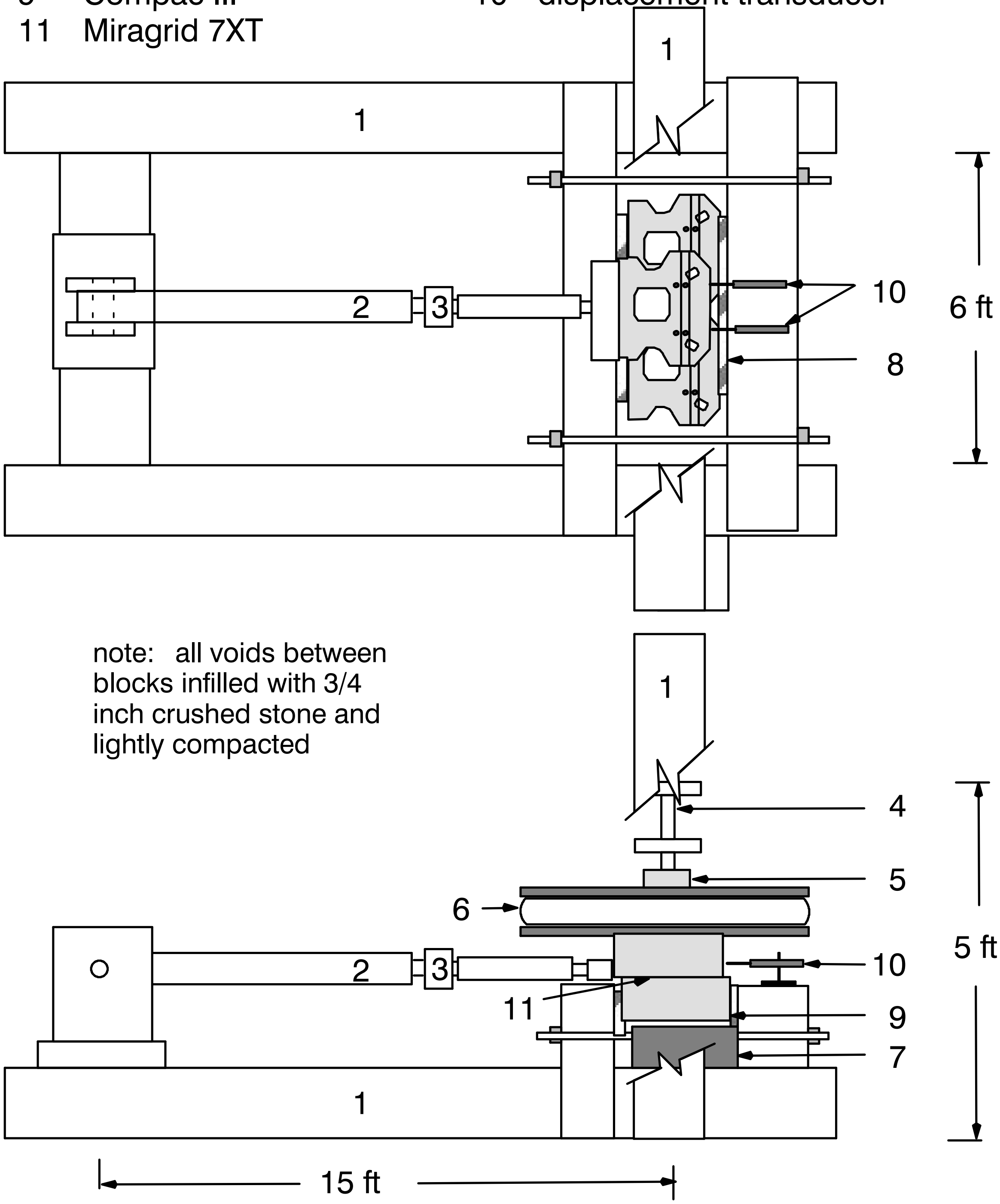


Figure 1: Schematic of shear capacity test apparatus showing Compac III modular concrete block units

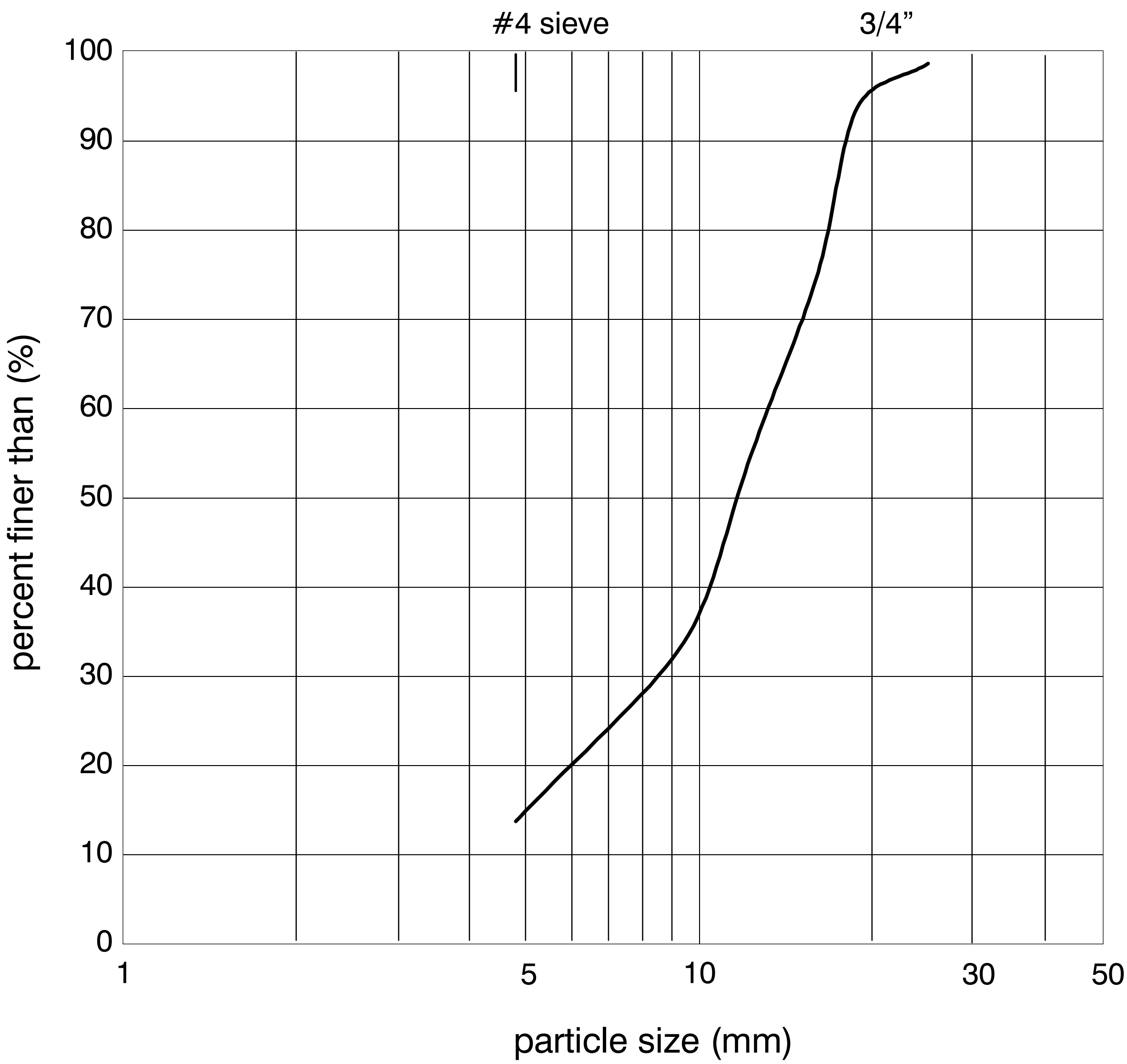


Figure 2: Particle size distribution for 100% crushed granular stone used in Compac III block shear capacity tests

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

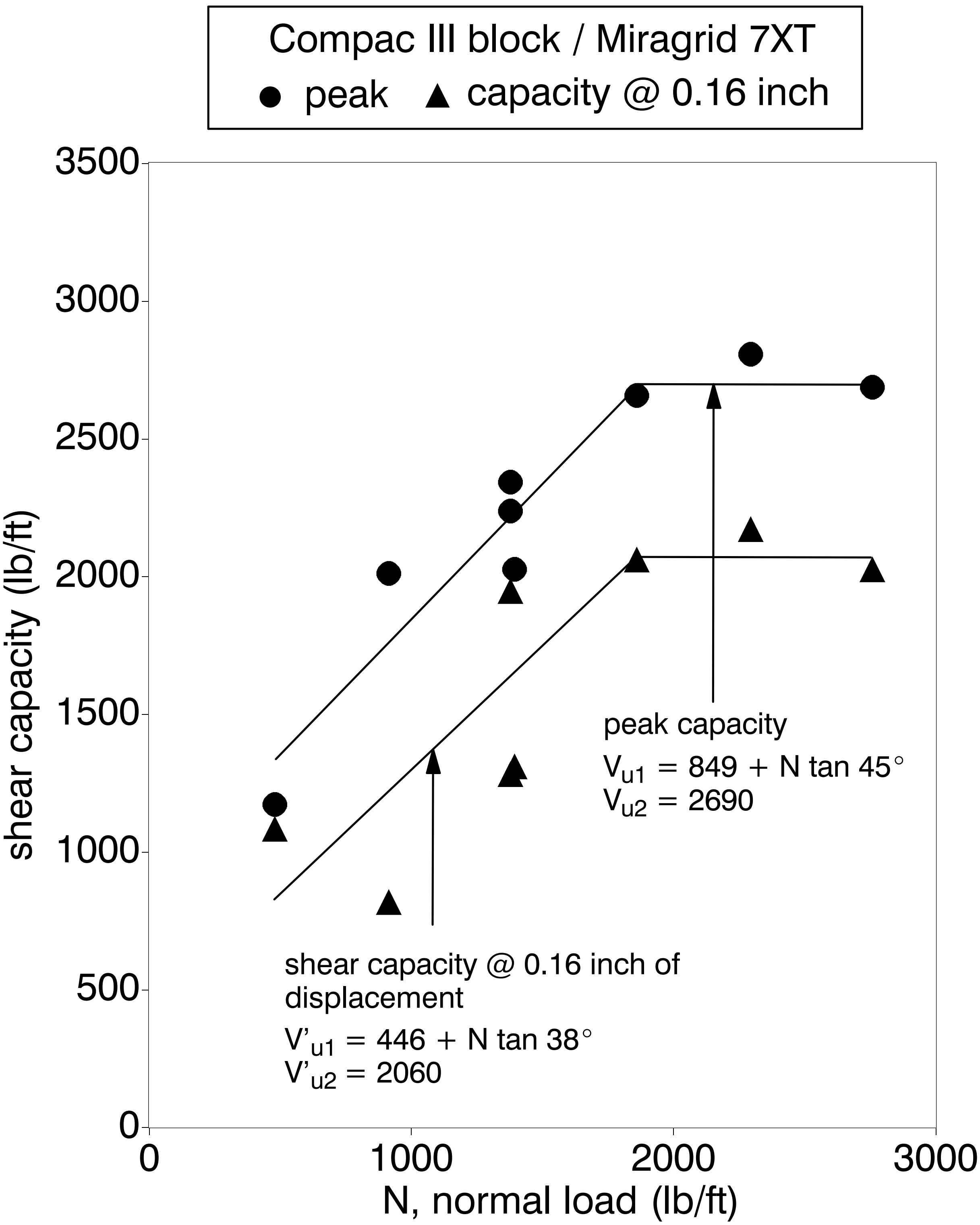


Figure 3: Summary of interface shear capacities for Compac III block / Miragrid 7XT combination

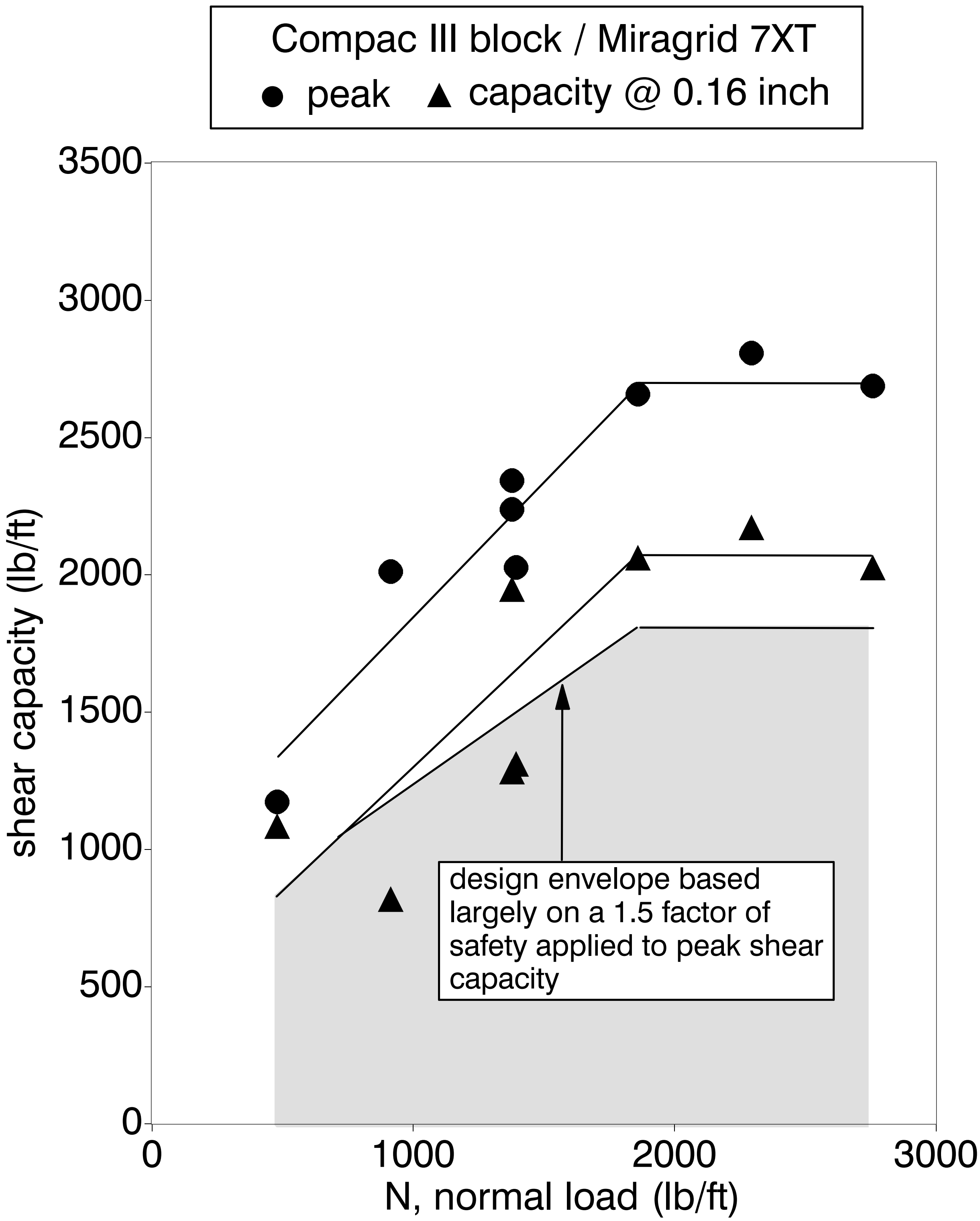


Figure 4: Shear capacity design envelope for Compac III unit with a single layer inclusion of Miragrid 7XT

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

TENCATE GEOSYNTHETICS
North America

November 21, 2019

Mr. Dan Tix
Keystone Retaining Wall Systems
4444 West 78th Street
Bloomington, MN

RE: Keystone Compac III/Miragrid® XT Geogrid IDEA Evaluation, Miragrid Manufacturing Process

Miragrid® XT geogrids have been manufactured with the same methods/machines/processes since 2002.

Please let me know if you have any questions or need any additional information.

Sincerely,

Joe Friederichs
Commercial Director – Engineered Structures
j.friederichs@tencategeo.com
952-250-6908

2019 NTPEP Report Series

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

LABORATORY EVALUATION OF GEOSYNTHETIC REINFORCEMENT

FINAL PRODUCT QUALIFICATION REPORT FOR MIRAGRID XT GEOGRID PRODUCT LINE

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

American Association of State Highway and Transportation Officials (AASHTO)

Executive Office: 444 North Capitol Street, NW, Suite 249 • Washington, DC • 20001
(t) 202.624.5800 • (f) 202.624.5469 • www.NTPEP.ORG

DOWNLOAD DATA FILES FOR THIS NTPEP REPORT @ NTPEP.org

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

Table of Contents

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. Samples of these products were taken by an independent sampler on behalf of NTPEP on March 10, 2017, at the Miragrid manufacturing plant 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. Samples of these products were taken by an independent sampler on behalf of NTPEP on March 10, 2017, at the Miragrid manufacturing plant located in Pendergrass, GA.

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

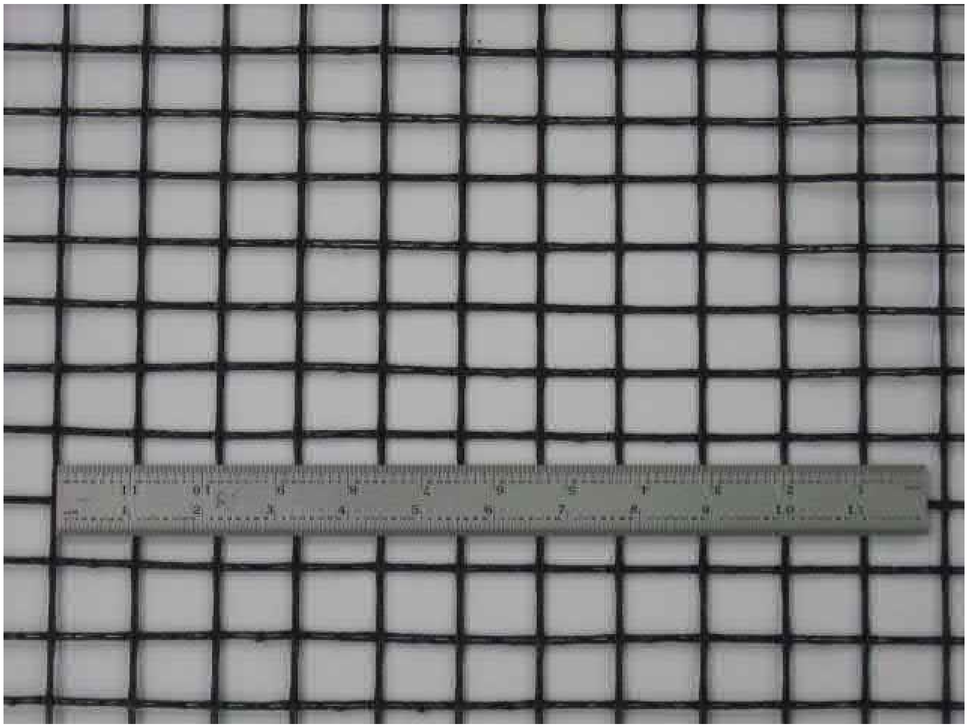


Figure 1-1. Photo of Miragrid 2XT (machine direction is perpendicular to ruler shown).

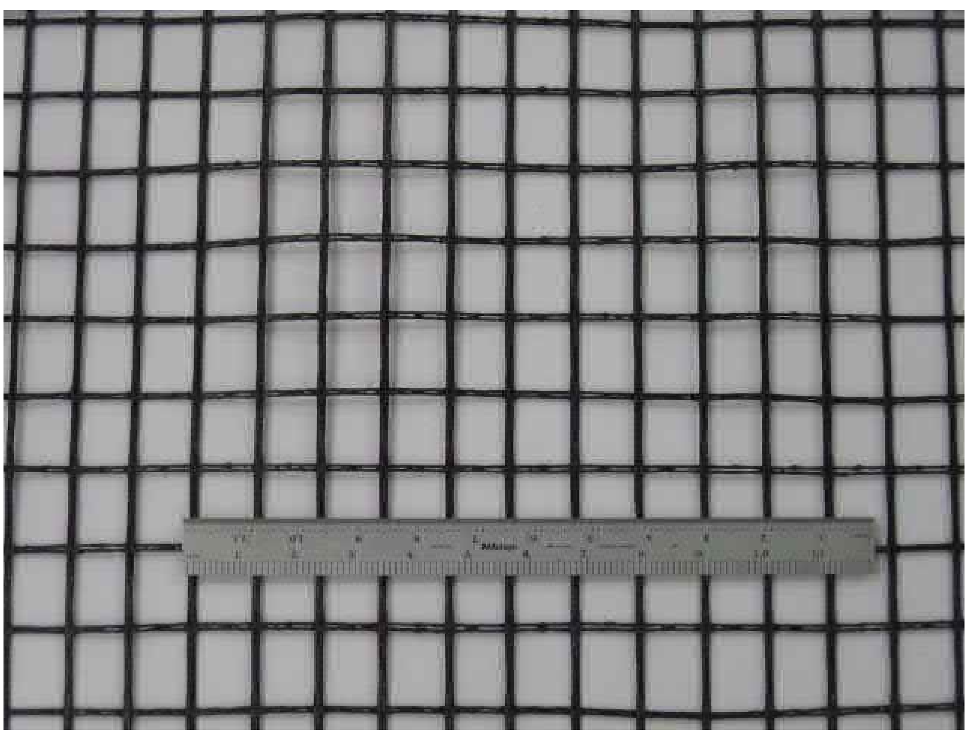


Figure 1-2. Photo of Miragrid 3XT (machine direction is perpendicular to ruler shown).

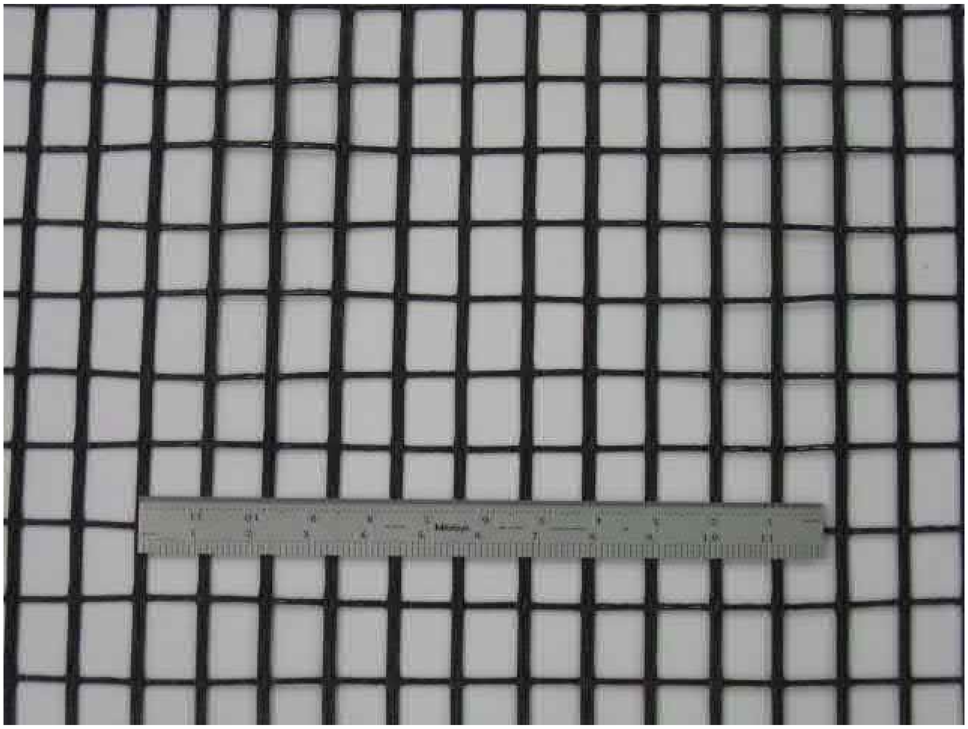


Figure 1-3. Photo of Miragrid 5XT (machine direction is perpendicular to ruler shown).

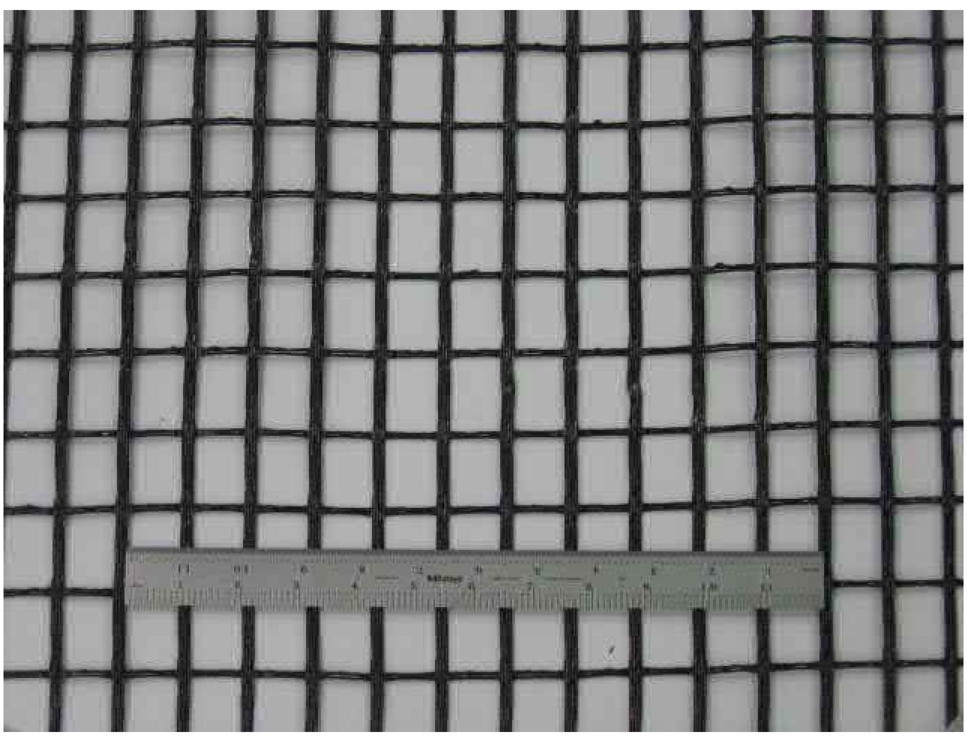


Figure 1-4. Photo of Miragrid 7XT (machine direction is perpendicular to ruler shown).

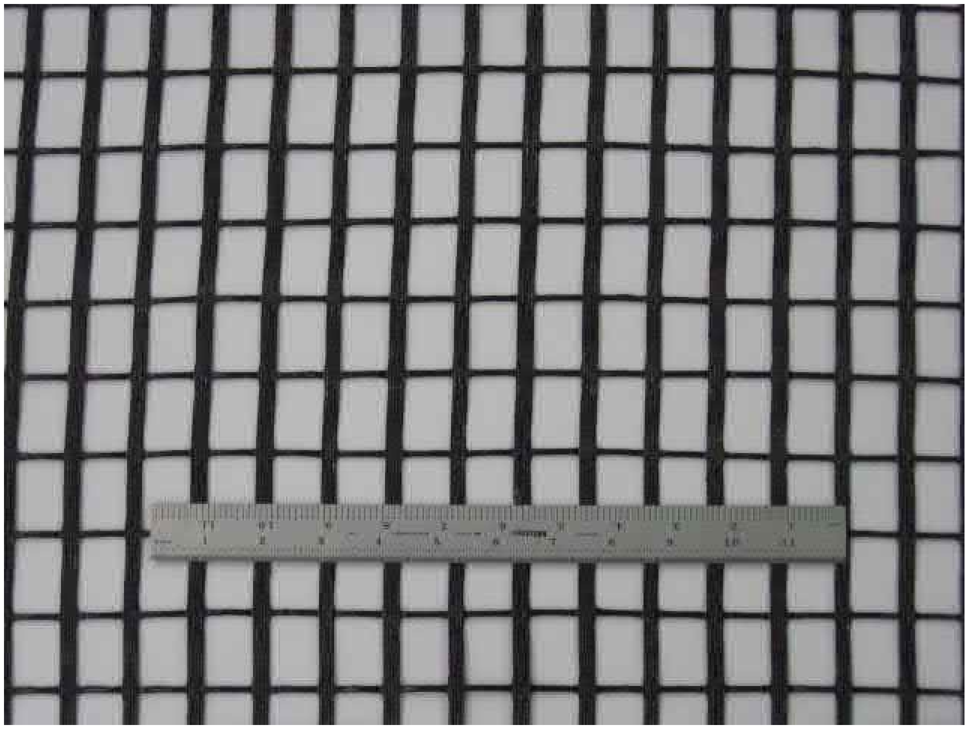


Figure 1-5. Photo of Miragrid 8XT (machine direction is perpendicular to ruler shown).

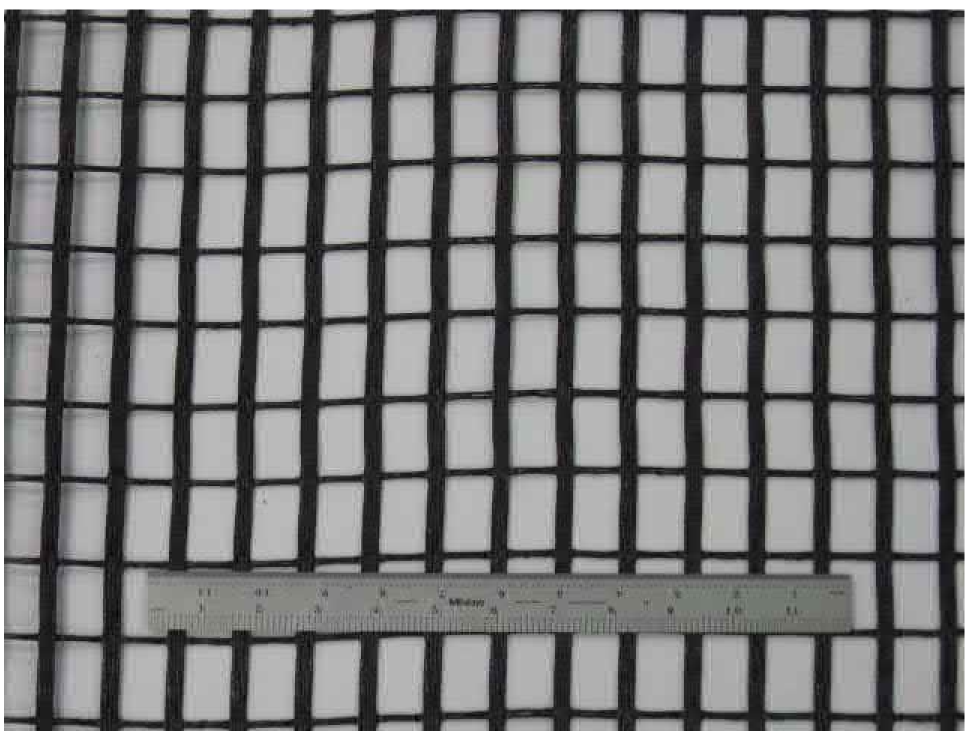


Figure 1-6. Photo of Miragrid 10XT (machine direction is perpendicular to ruler shown).

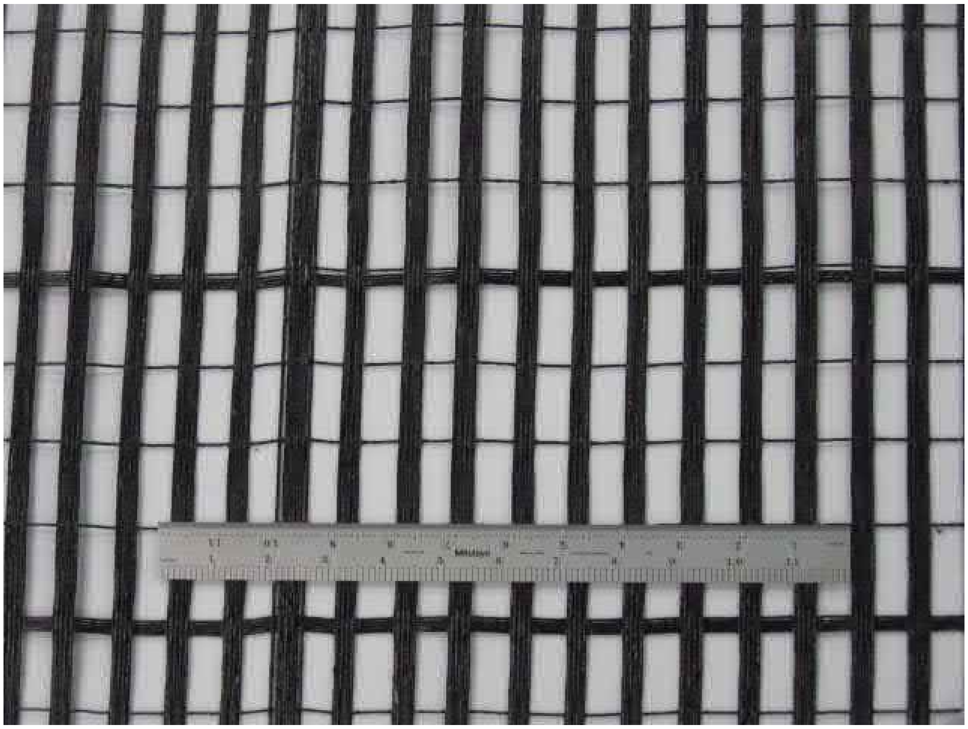


Figure 1-7. Photo of Miragrid 20XT (machine direction is perpendicular to ruler shown).

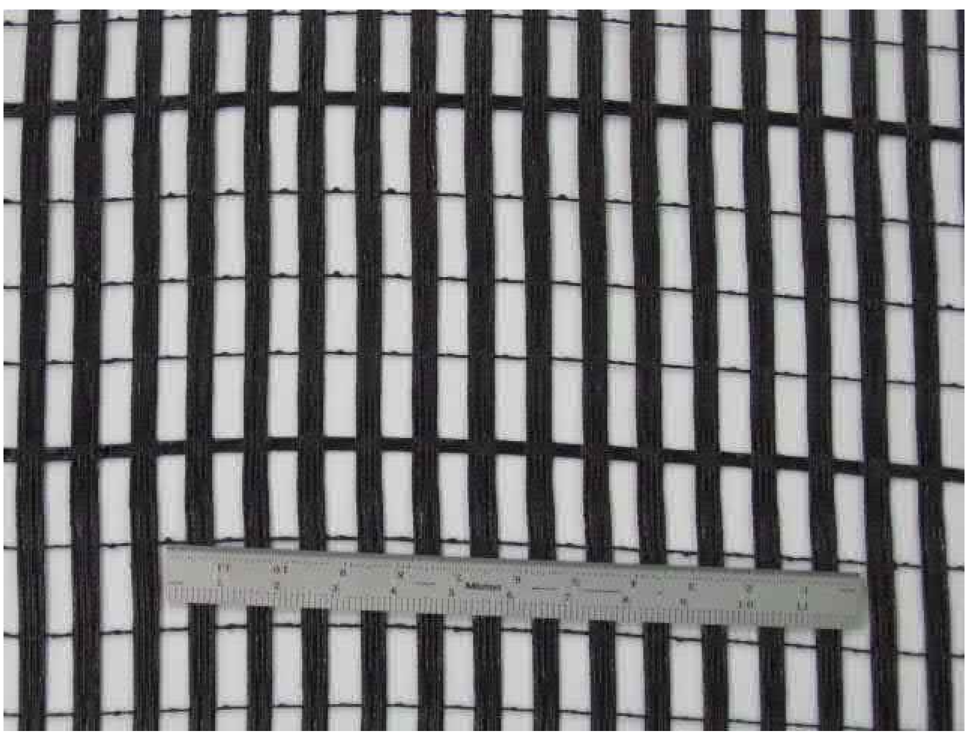


Figure 1-8. Photo of Miragrid 22XT (machine direction is perpendicular to ruler shown).

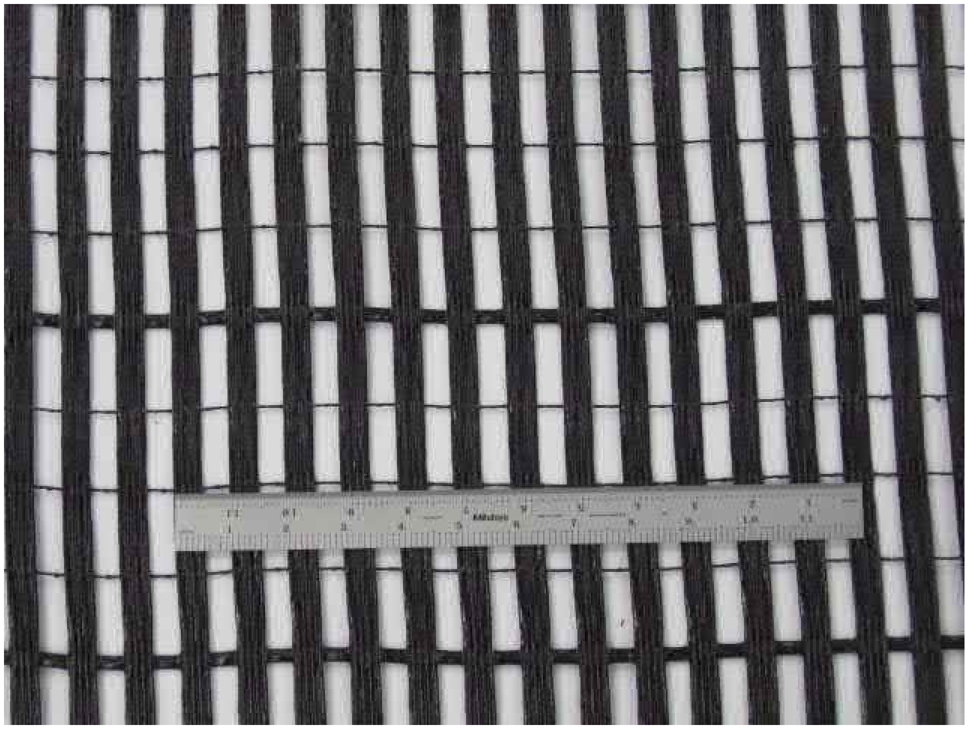


Figure 1-9. Photo of Miragrid 24XT (machine direction is perpendicular to ruler shown).

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.

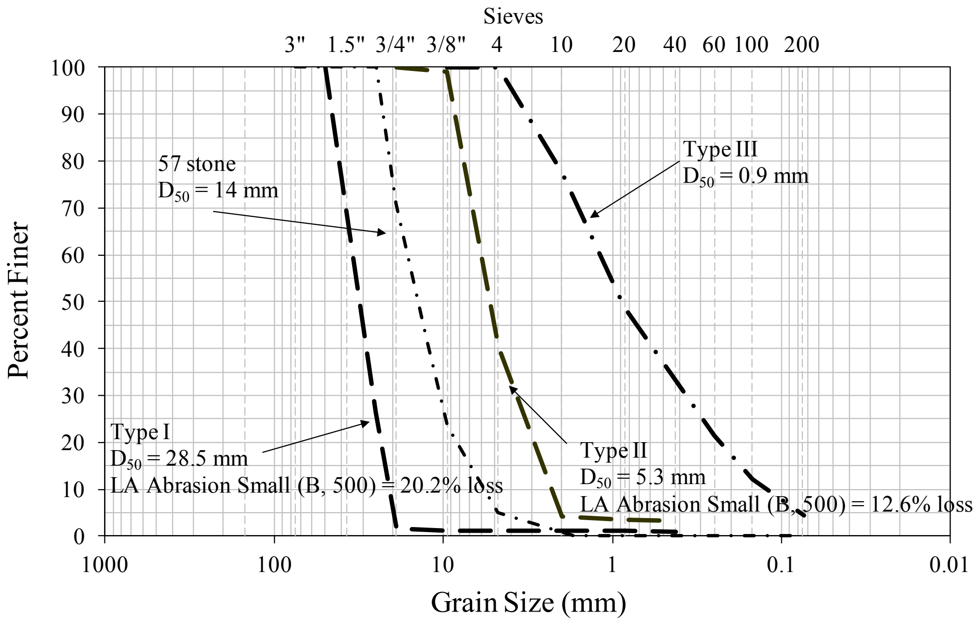


Figure 4-1. Test soil grain size distribution.

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

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

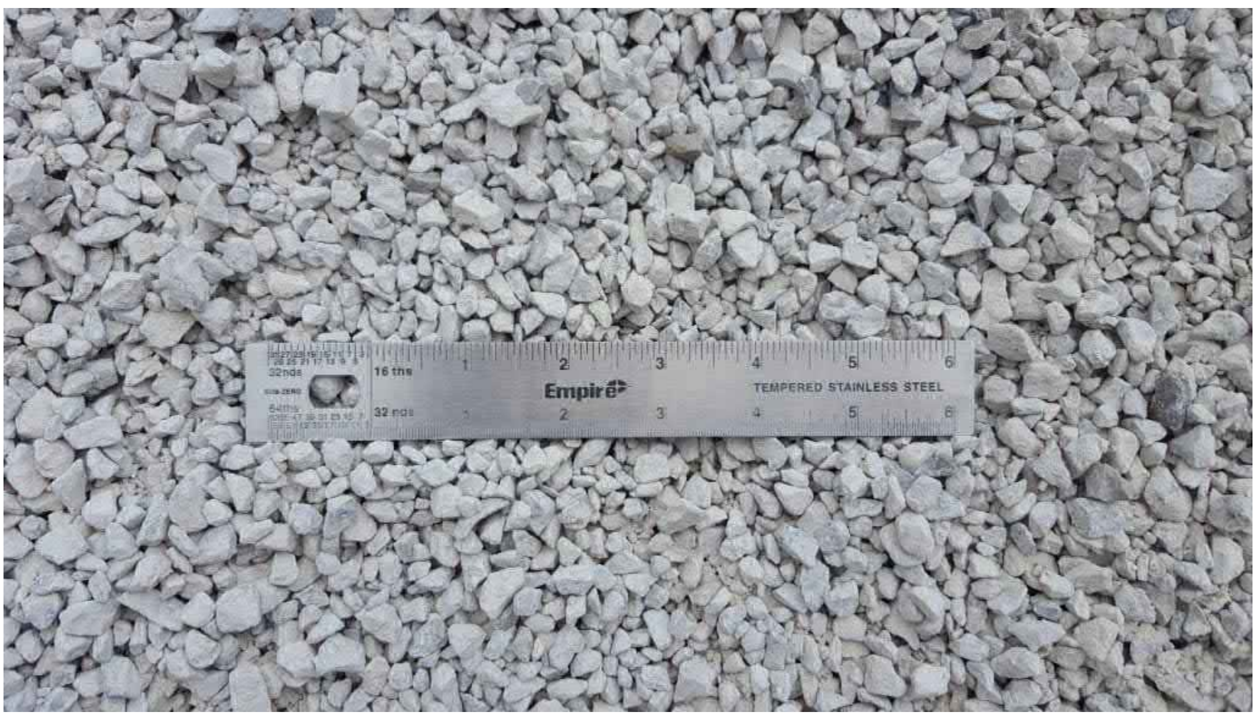


Figure 4-4. Installation damage Type 2 test aggregate.

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)

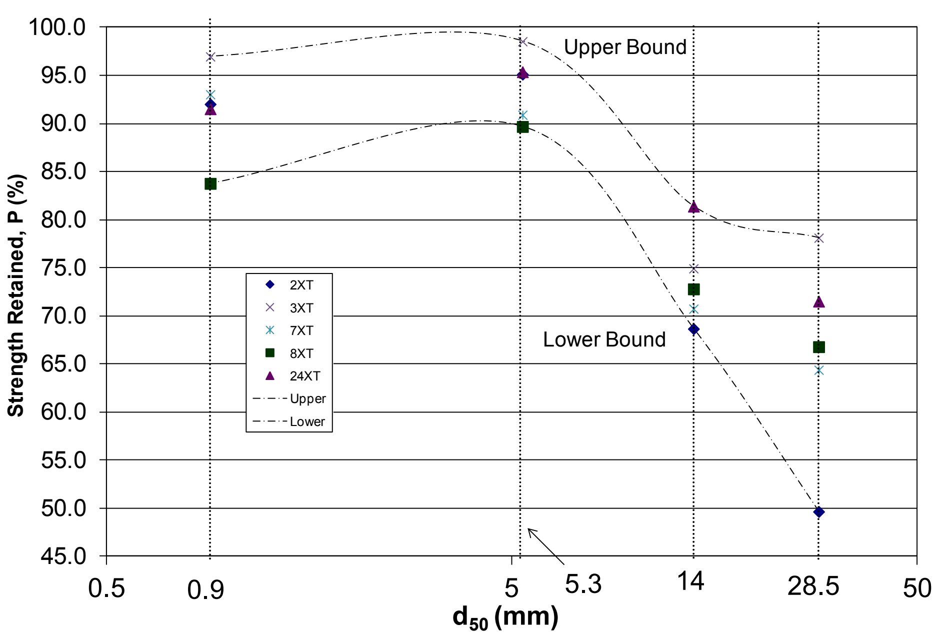
Table 4-3. Measured RF_{ID}.

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.

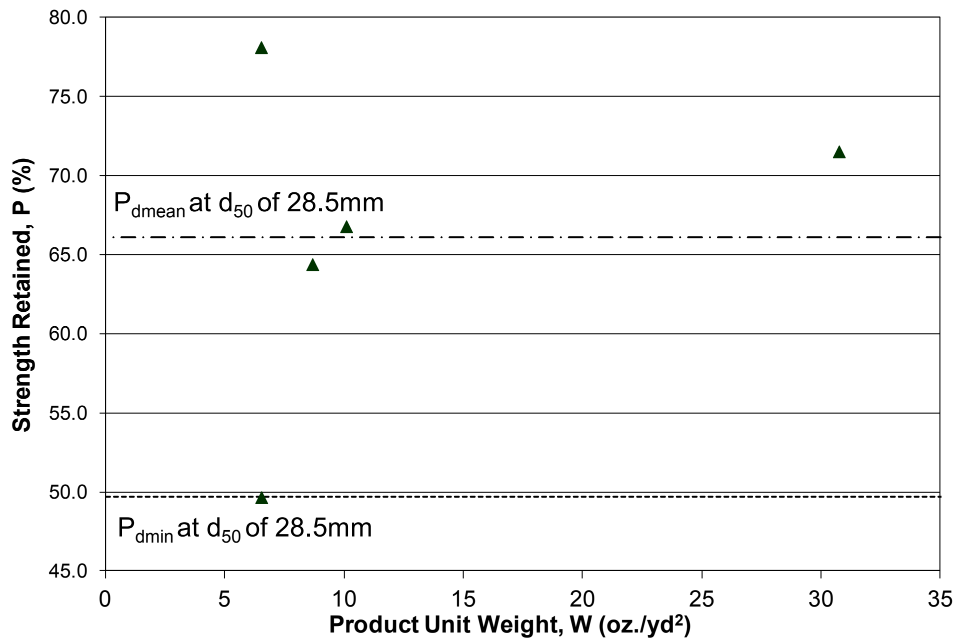


Figure 4-6. Miragrid XT product line installation damage as a function of product unit weight for type 1 soil (coarse gravel - GP).

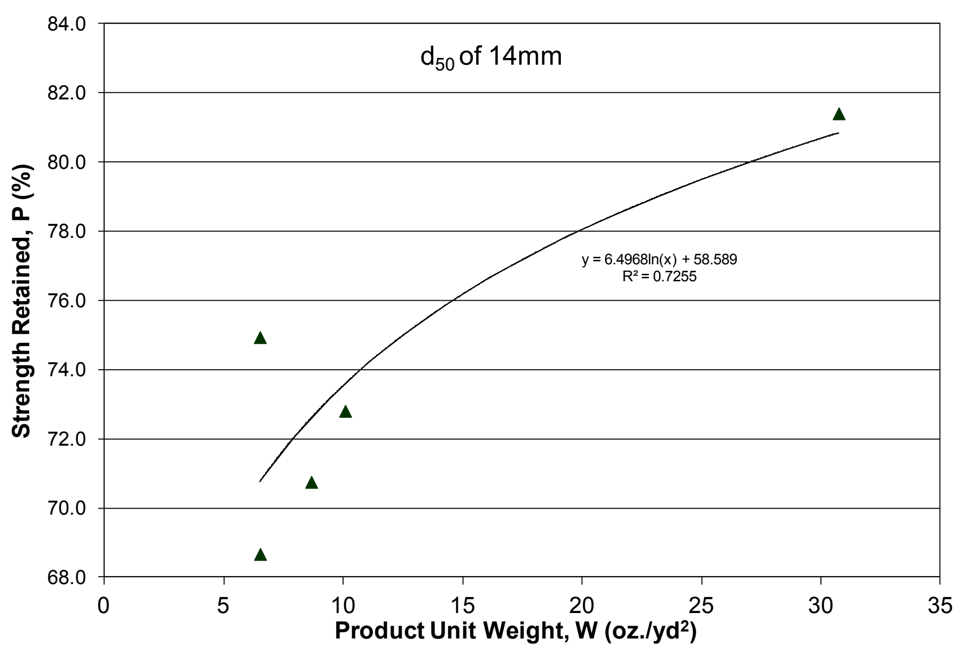


Figure 4-7. Miragrid XT product line installation damage as a function of product unit weight for 57 stone (GP).

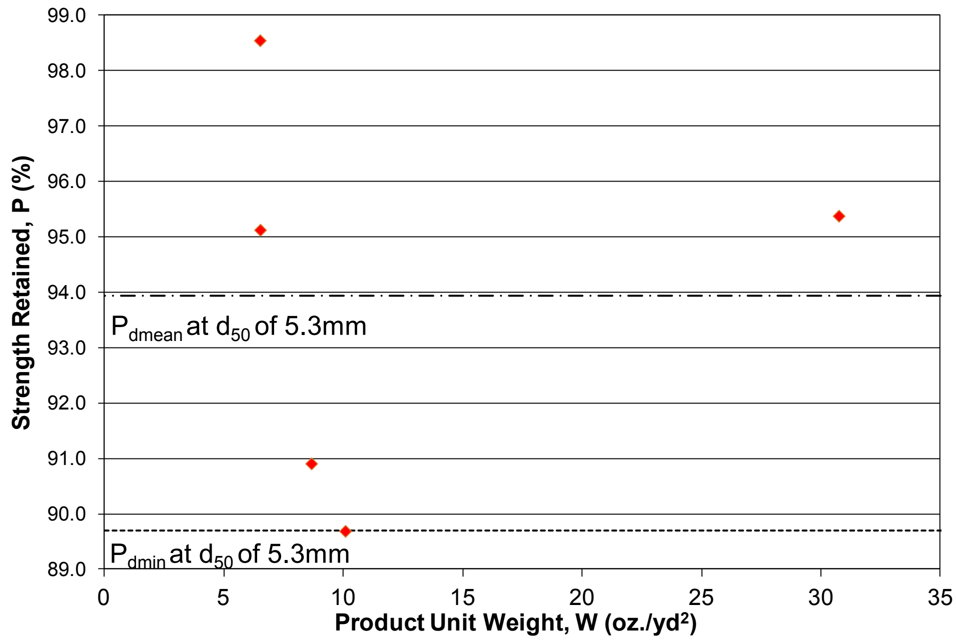


Figure 4-8. Miragrid XT product line installation damage as a function of product unit weight for type 2 soil (sandy gravel - GP).

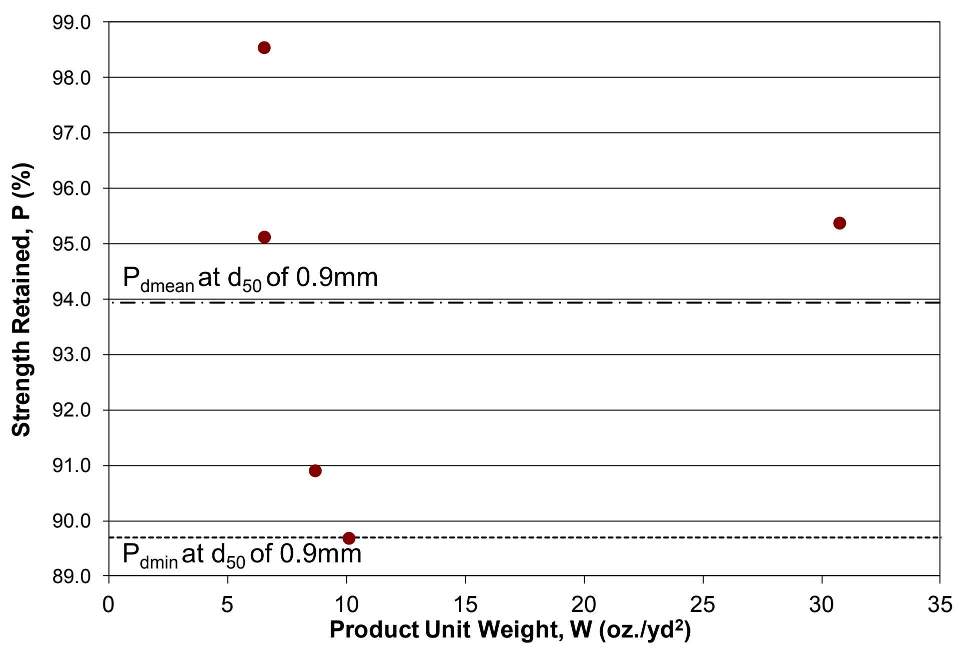


Figure 4-9. Miragrid XT product line installation damage as a function of product unit weight for type 3 soil (silty sand – SM).

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^o F (20^o 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^o F (20^o 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

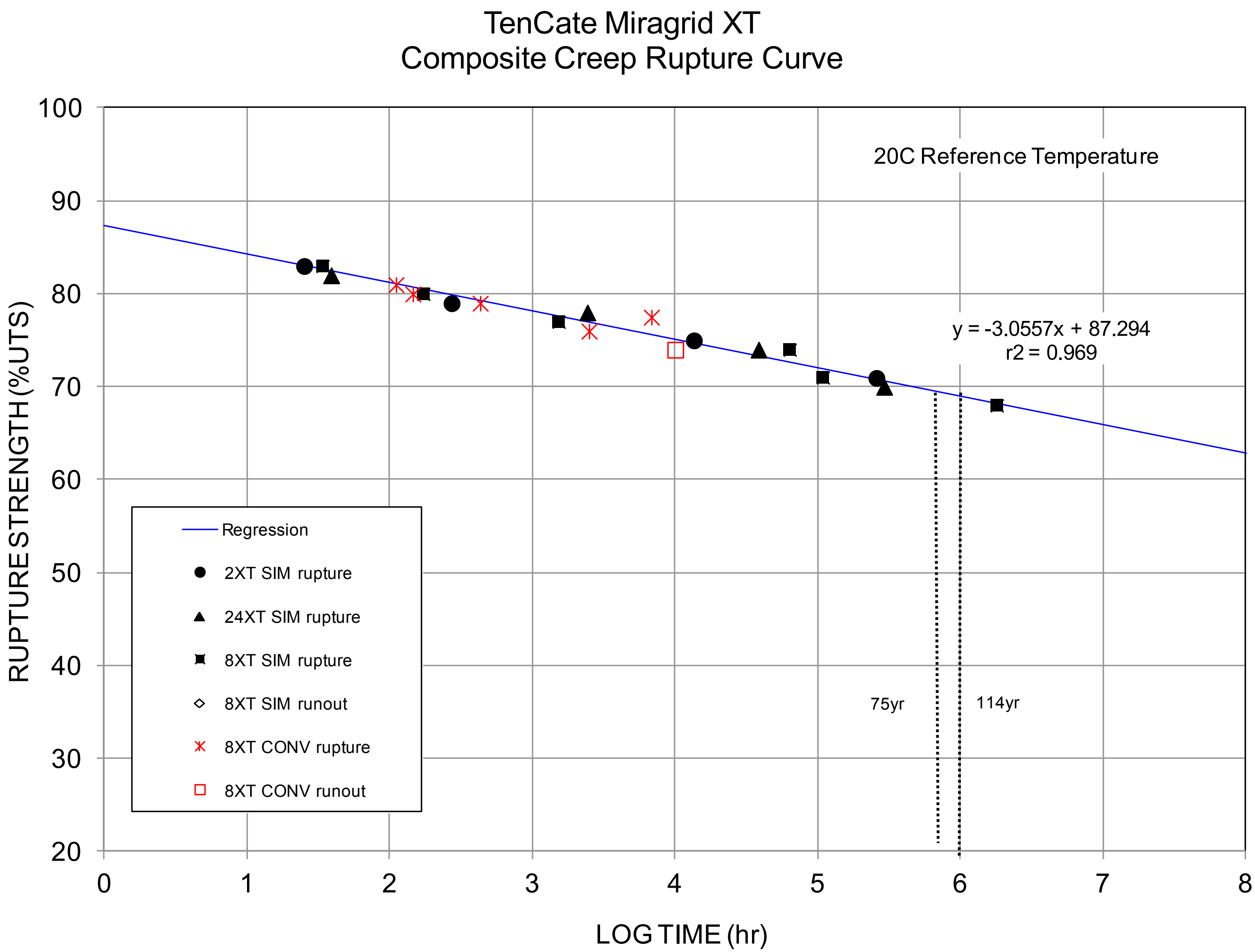


Figure 5-1. Composite creep rupture data/envelope for the Miragrid XT geogrid product line.

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^{o}F (30^{o}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.

[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^{o} F (20^{o} 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)

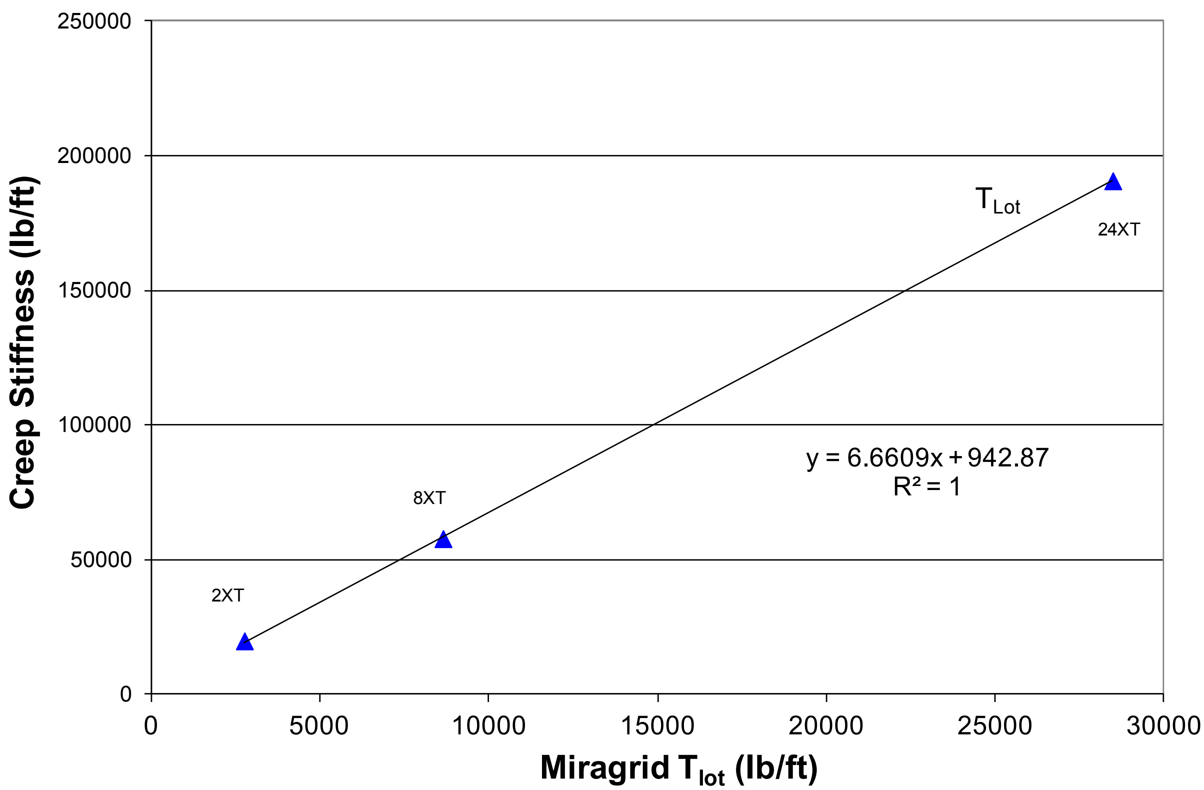


Figure 7-1. Miragrid XT creep stiffness for 2 % strain @ 1000 hours.

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
Lee, Derek	derek.lee@state.ma.us	Massachusetts Department of Transportation	Member	Voting
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
Lindemann, Mark	mark.lindemann@nebraska.gov	Nebraska Department of Transportation	Member	Voting
Burnett, Thomas W	Tom.Burnett@dot.ny.gov	New York State Department of Transportation	Member	Voting
Merklin, Christopher	chris.merklin@dot.ohio.gov	Ohio Department of Transportation	Member	Voting
Brown, Sophie	sophie.brown@odot.state.or.us	Oregon Department of Transportation	Member	Voting
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
Collin, James G	jim@thecollingroup.com	The Collin Group, Ltd	Member	Non-Voting
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					MEAN	STD. DEV.
		1	2	3	4	5		
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					MEAN	STD. DEV.
	1	2	3	4	5		
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					MEAN	STD. DEV.
	1	2	3	4	5		
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					MEAN	STD. DEV.
		1	2	3	4	5		
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					MEAN	STD. DEV.
	1	2	3	4	5		
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					MEAN	STD. DEV.
		1	2	3	4	5		
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 (yd^2)	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					MEAN	STD. DEV.	MARV
	1	**2**	**3**	**4**	**5**			
Single Rib Tensile Properties (ASTM D 6637, Method A)								
MD - Number of Ribs per foot:	10.91							
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.

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

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:	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					MEAN	STD. DEV.	MARV
	1	**2**	**3**	**4**	**5**			
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					MEAN	STD. DEV.	MARV
	1	2	3	4	5			
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.

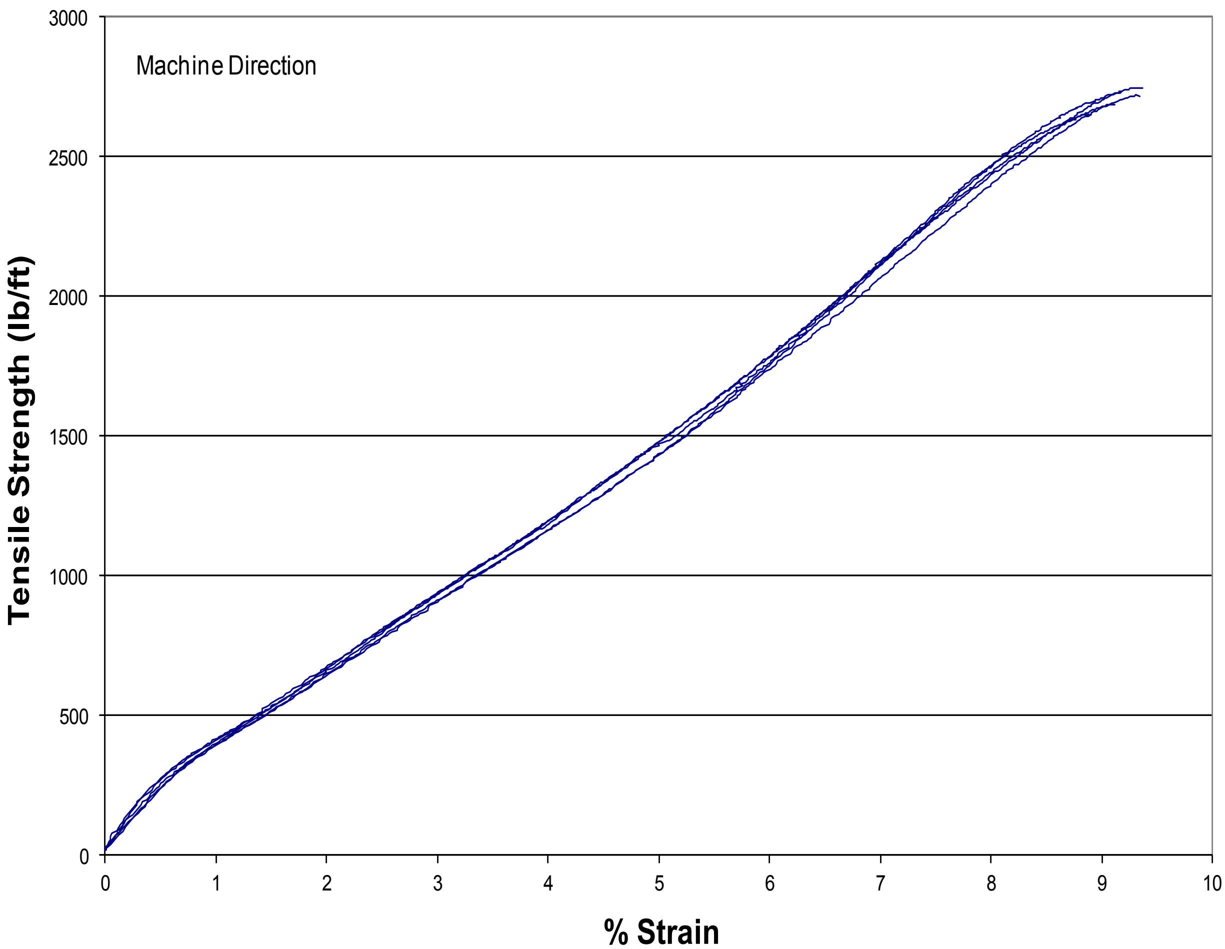


Figure C-1. Geogrid tensile test load-strain curve for 2XT

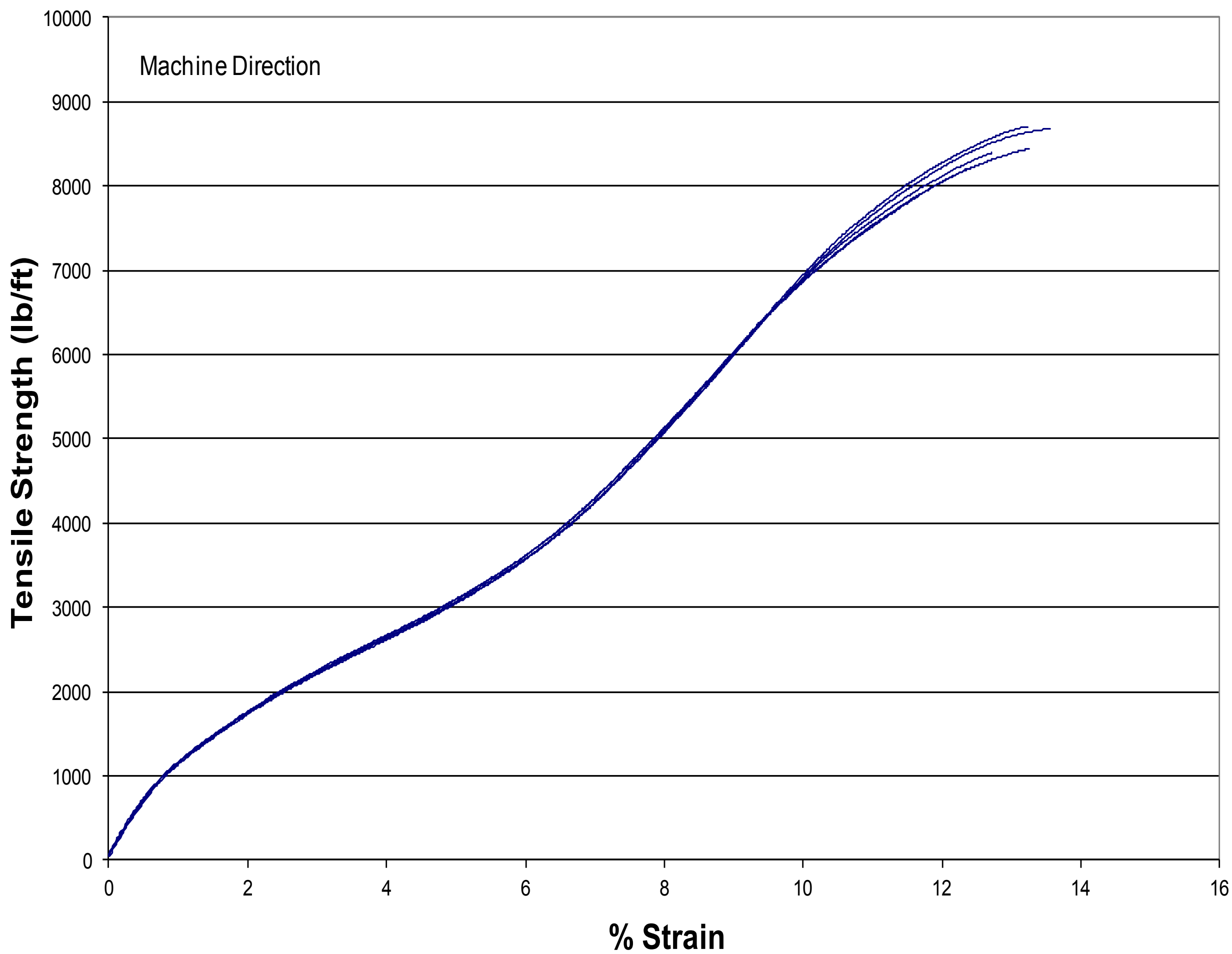


Figure C-2. Geogrid tensile test load-strain curve for 8XT

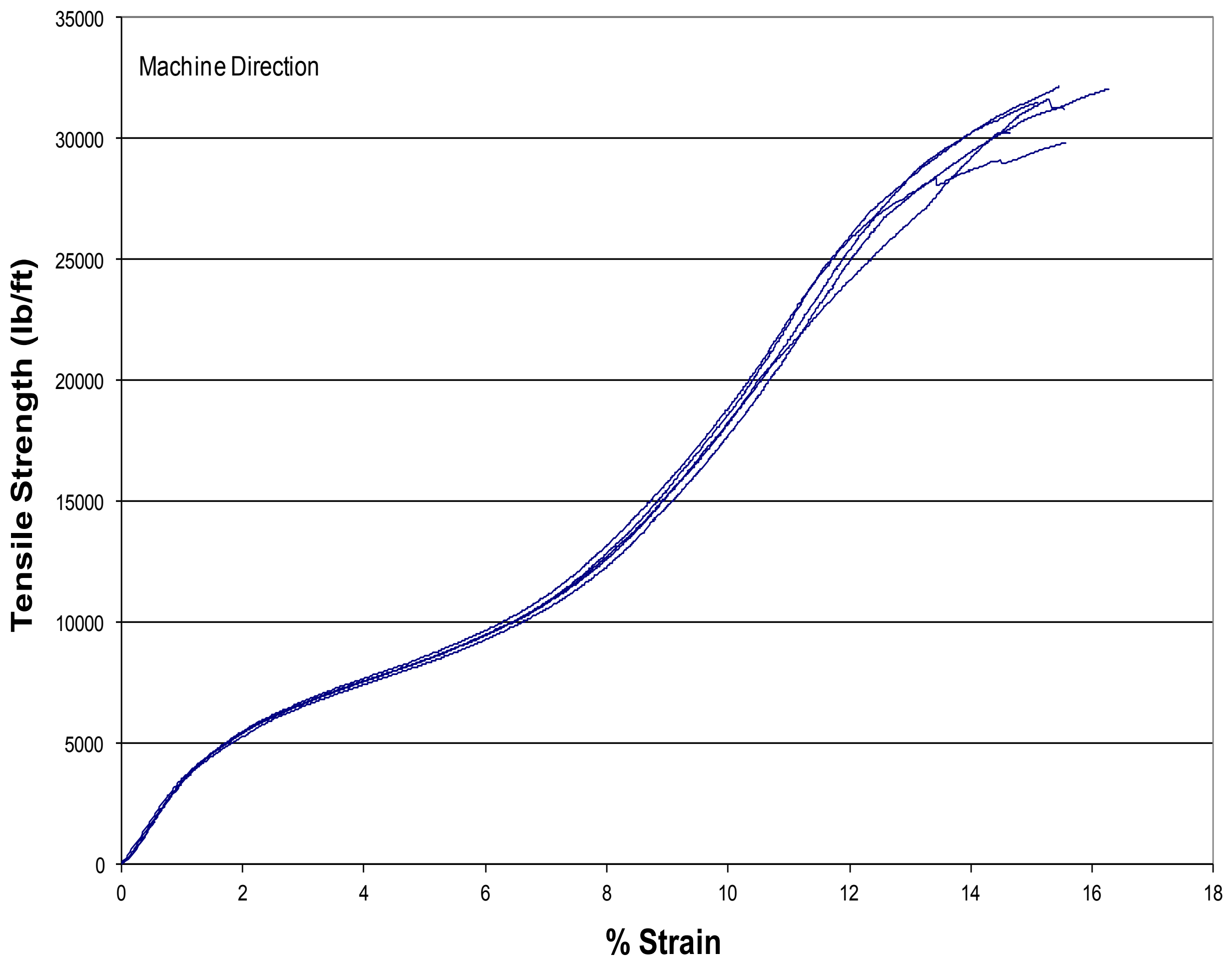


Figure C-3. Geogrid tensile test load-strain curve for 24XT

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)
	1	10.75	7	2457	3773	55.1	8.91	585	898	13.12	1185	1820	26.6			
3XT	2	10.75	7	2428	3729	54.4	8.91	582	894	13.05	1182	1815	26.5			
Baseline	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)
	1	10.75	7	1580	2426	35.4	7.60	538	826	12.06	1132	1738	25.4			
3XT	2	10.75	7	1592	2445	35.7	6.69	559	858	12.53	1177	1808	26.4			
installed in	3	10.75	7	2050	3148	46.0	8.29	540	829	12.11	1136	1745	25.5			
57 Stone	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)
	1	12.10	8	21182	32038	467.8	16.2	3519	5322	77.70	5500	8319	121.5	11763	17792	259.8
24XT	2	12.10	8	20833	31510	460.0	15.1	3596	5439	79.41	5596	8464	123.6	12043	18214	265.9
Baseline	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)
	1	12.10	8	17439	26376	385.1	11.8	3813	5767	84.20	5764	8718	127.3	13845	20941	305.7
24XT	2	12.10	8	17197	26010	379.8	11.4	3881	5870	85.70	5851	8850	129.2	13949	21098	308.0
installed in	3	12.10	8	17523	26504	387.0	11.4	3965	5997	87.56	5976	9039	132.0	14522	21965	320.7
57 Stone	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.

.

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					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:	10.80								
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					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:	10.75								
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					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:	10.91								
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					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:	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					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:	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					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:	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: 66.00

Ultimate Tensile Strength: 100.0 kN/m Rupture: YES

Dwell Seq	t'	t	$(t-t')_i$	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

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	$(t-t')_i$	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	-

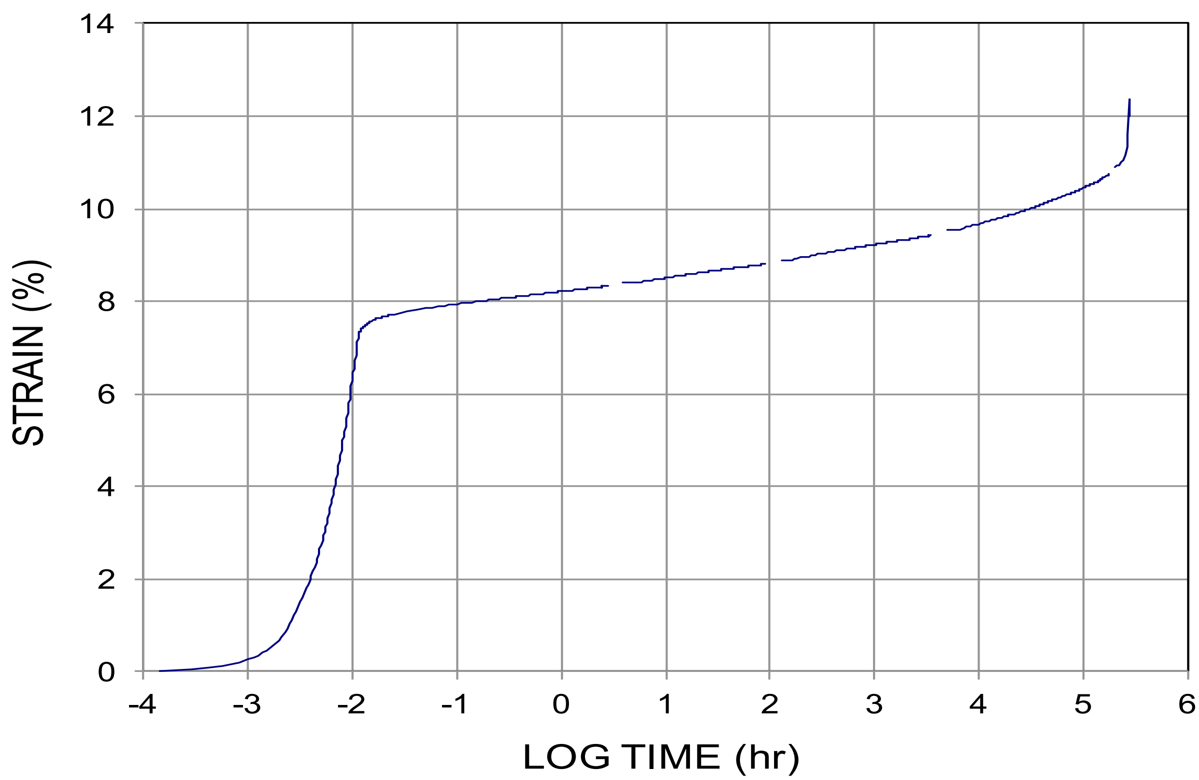


Figure F-1. SIM/Creep data/curve for 2XT at load level of 70.96% UTS.

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	$(t-t')_i$	Vshift(%)	$logA_T$	Temp	$logA_T/T$
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	-
$logA_T(t-t')$	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	-

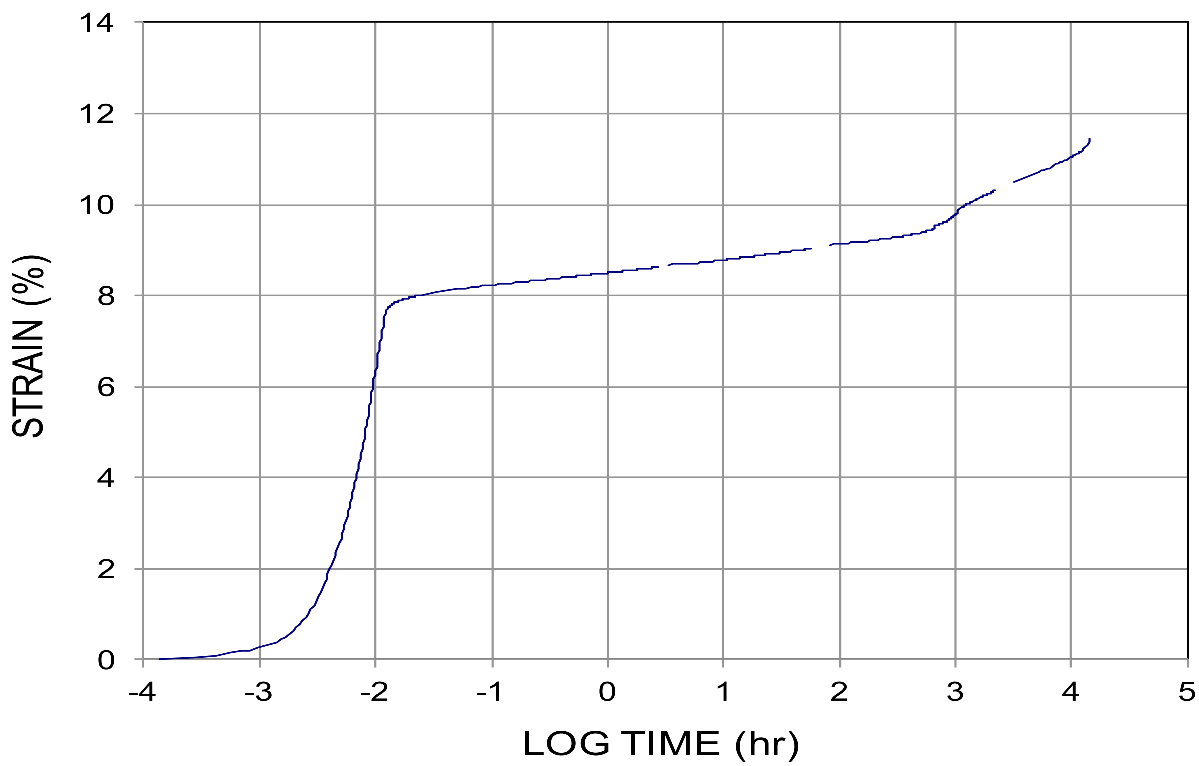


Figure F-2. SIM/Creep data/curve for 2XT at load level of 75.0% UTS.

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	$(t-t')_i$	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							

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	-

AVG 0.0914

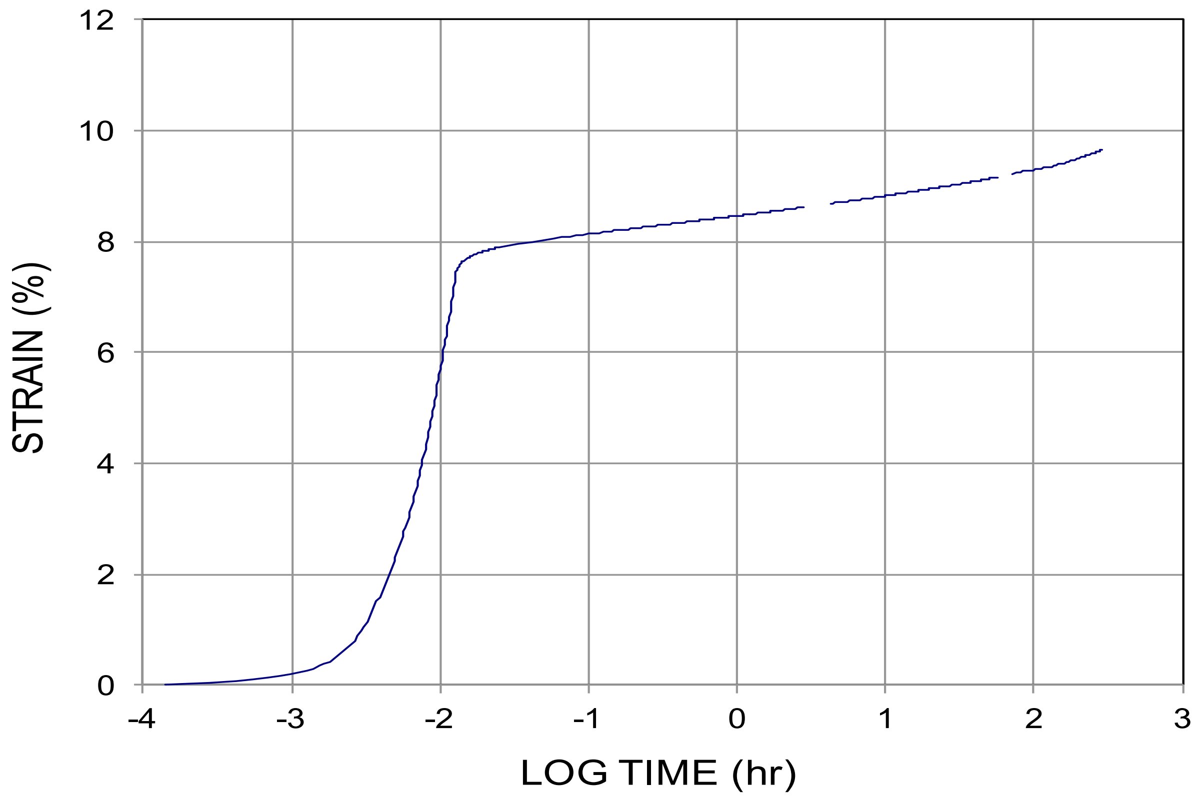


Figure F-3. SIM/Creep data/curve for 2XT at load level of 79.0% UTS.

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	$(t-t')_i$	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							
						AVG	0.1055

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	-

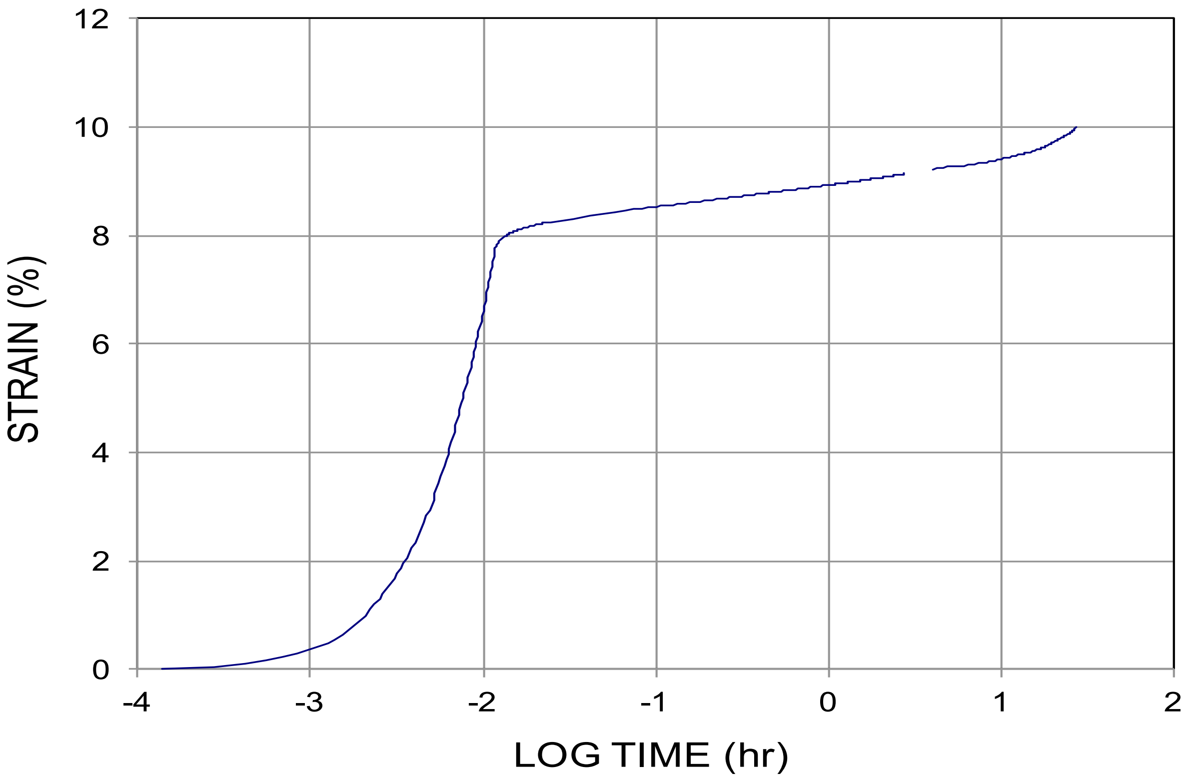


Figure F-4. SIM/Creep data/curve for 2XT at load level of 83.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim6ɩ 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	$(t-t')_i$	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
						AVG	0.0903

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	-

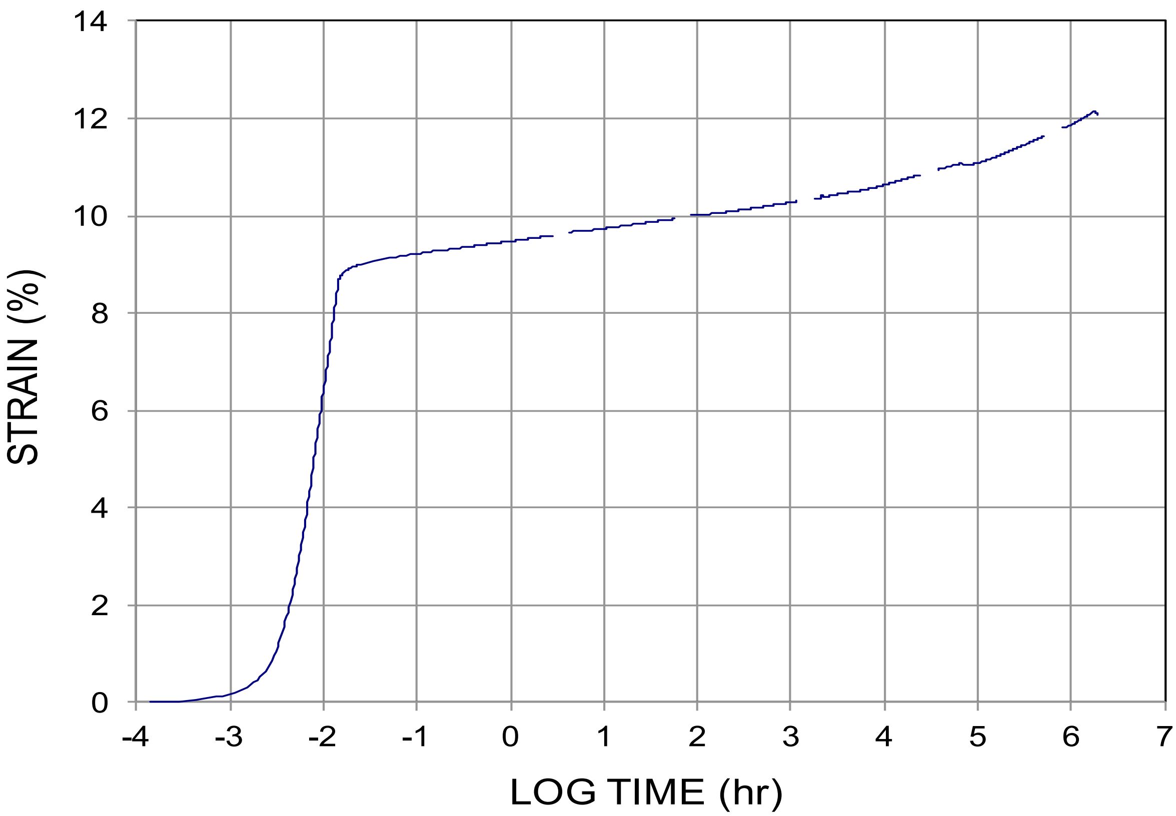


Figure F-5. SIM/Creep data/curve for 8XT at load level of 68.0% UTS.

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	$(t-t')_i$	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							
						AVG	0.0843

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	-

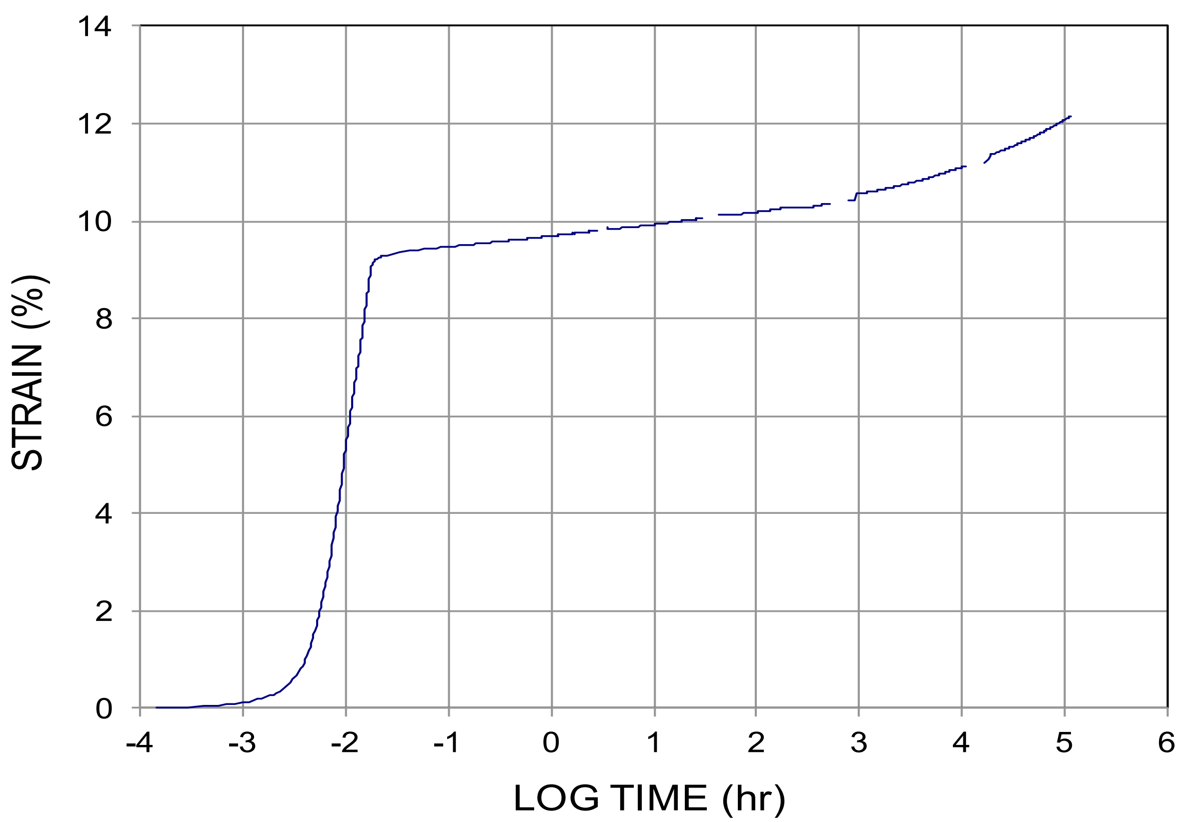


Figure F-6. SIM/Creep data/curve for 8XT at load level of 71.0% UTS.

Accelerated Creep Rupture via SIM - ASTM D 6992

SUMMARY CREEP PARAMETERS: NTPEP - TenCate
Miragrid 8XT

Specimen: 27463n2m-8XT-sim74 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	$(t-t')_i$	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							
						AVG	0.0852

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	-

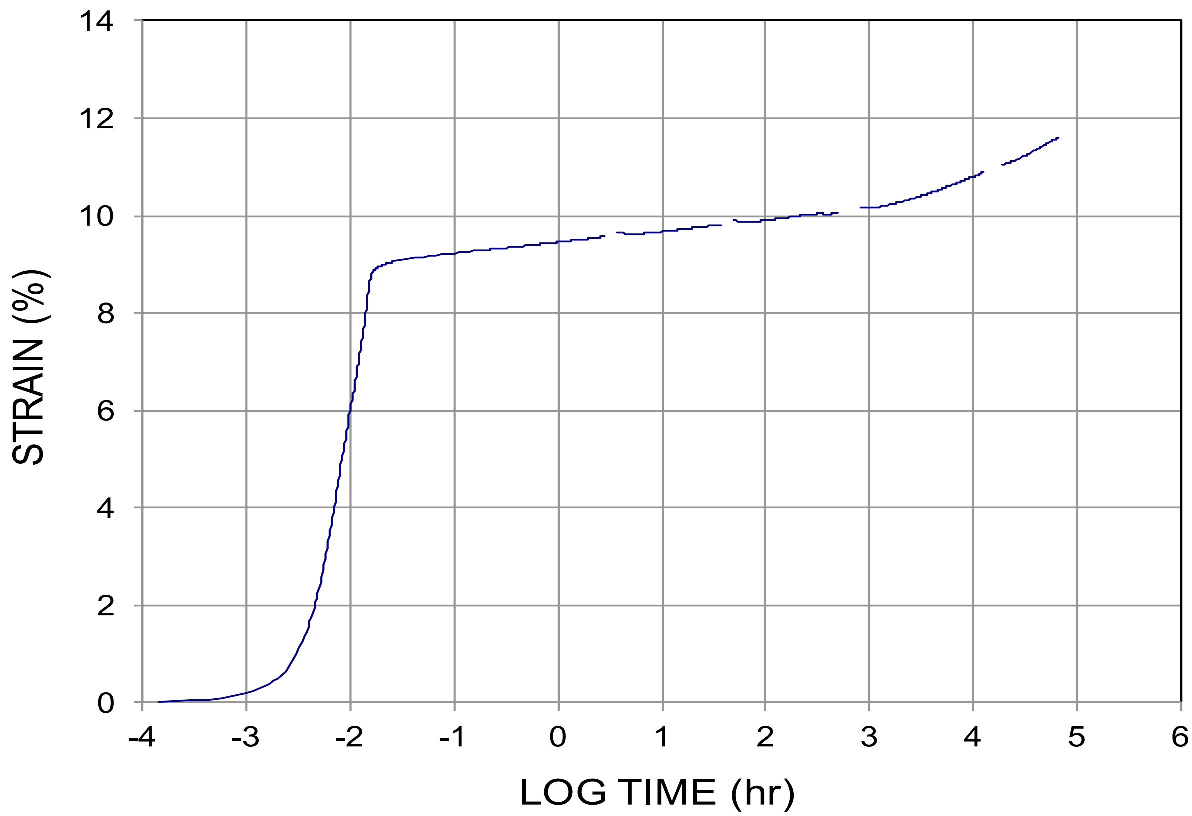


Figure F-7. SIM/Creep data/curve for 8XT at load level of 74.0% UTS.

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	$(t-t')_i$	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	-

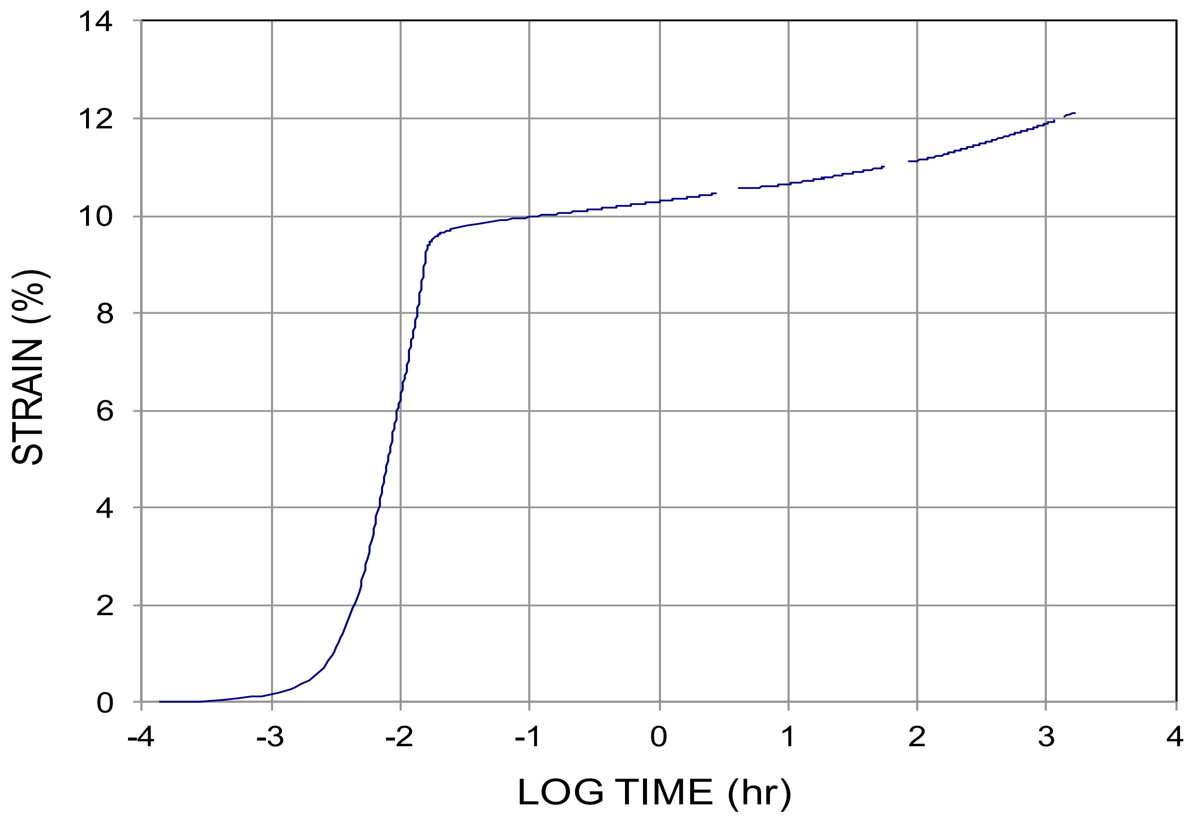


Figure F-8. SIM/Creep data/curve for 8XT at load level of 77.0% UTS.

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	$(t-t')_i$	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							
						AVG	0.0832

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	-

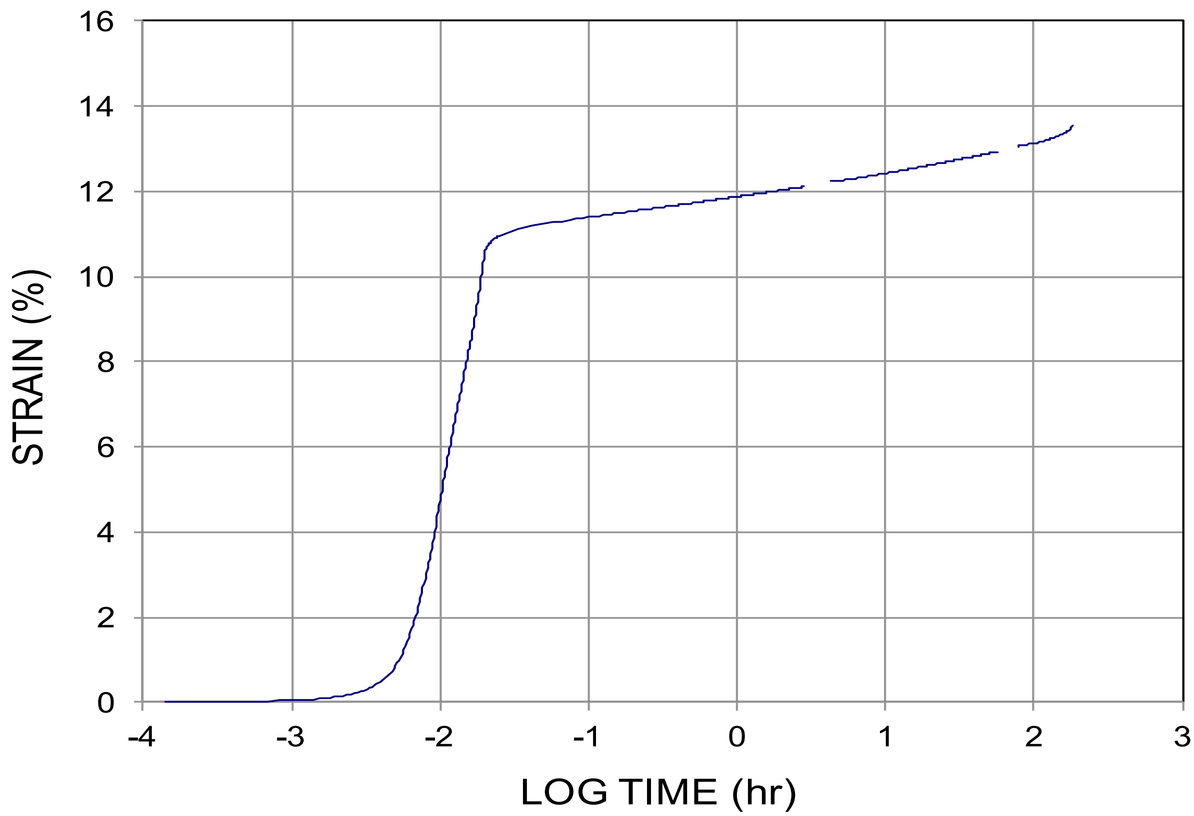


Figure F-9. SIM/Creep data/curve for 8XT at load level of 80.0% UTS.

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	$(t-t')_i$	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							

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	-

AVG 0.0831

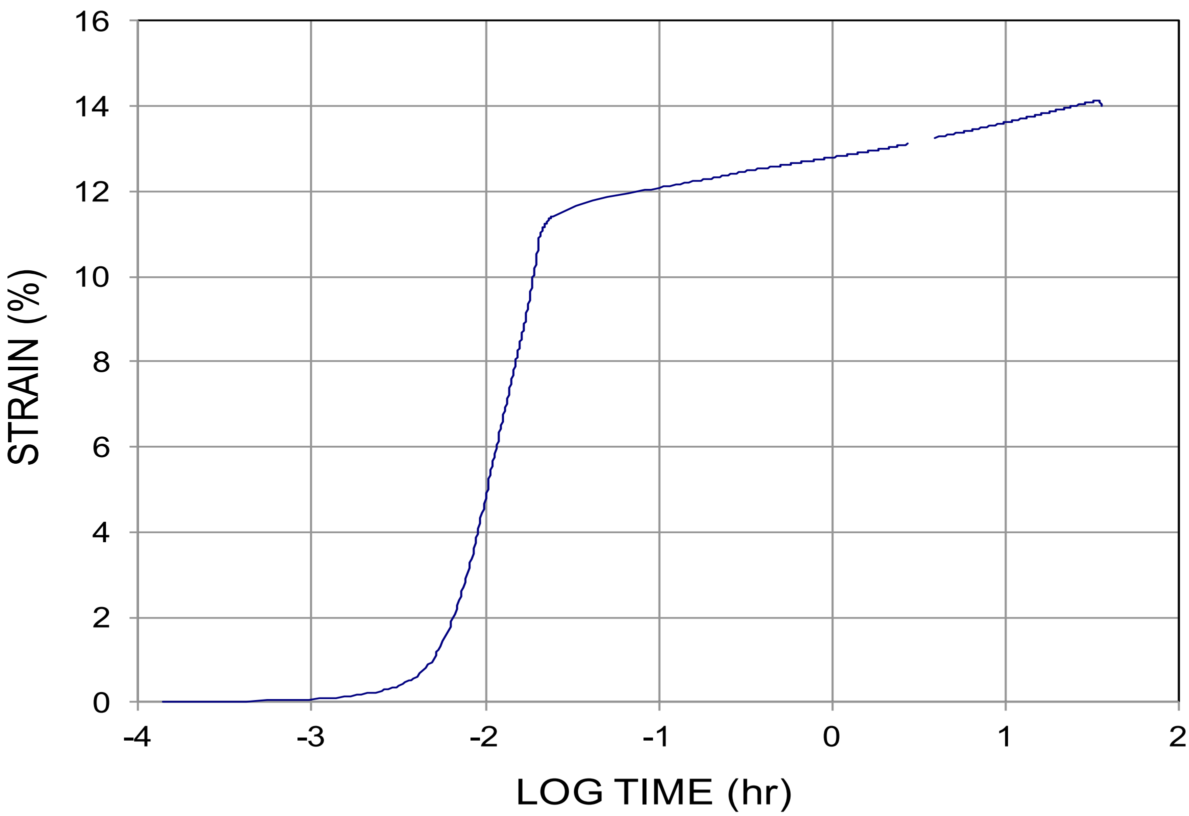


Figure F-10. SIM/Creep data/curve for 8XT at load level of 83.0% UTS.

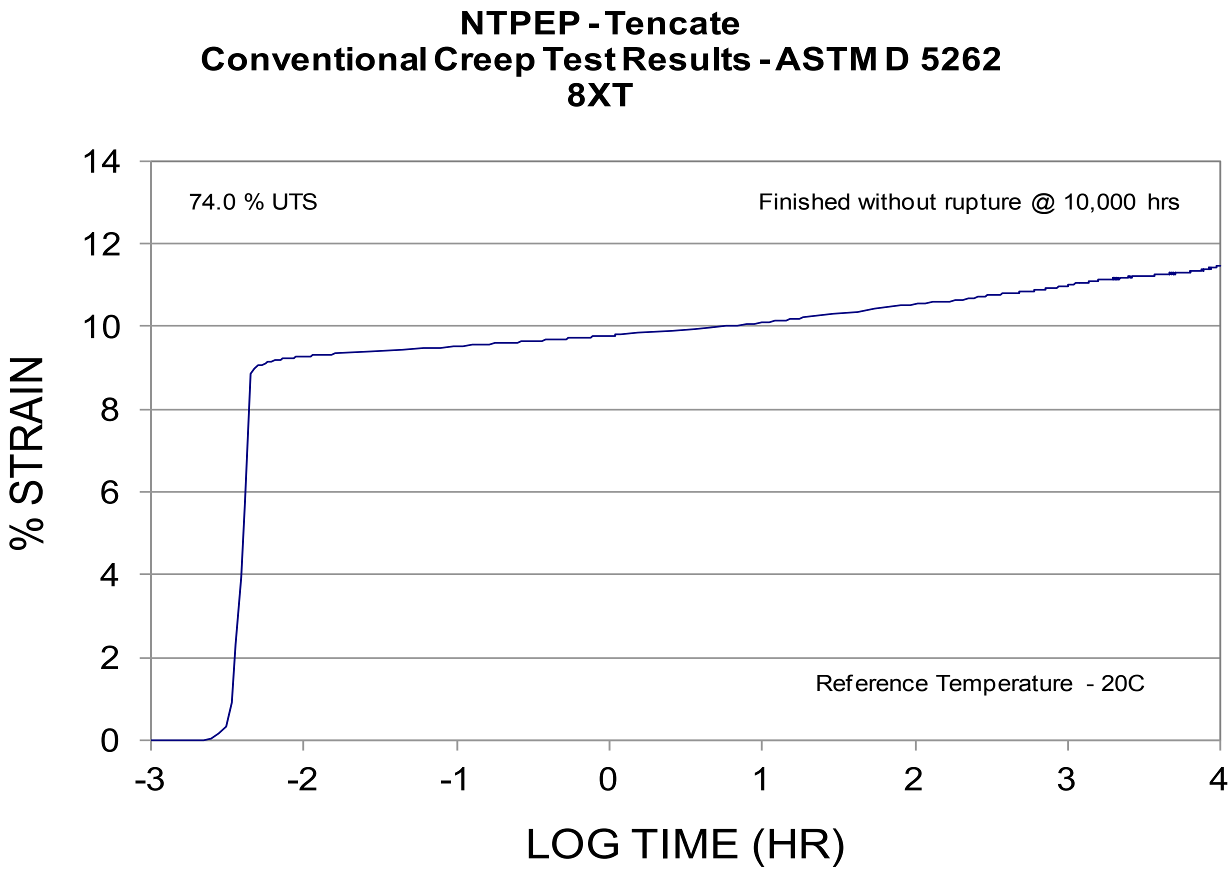


Figure F-11. Creep data/curve per ASTM D5262 for 8XT at a load level of 74.0% UTS and 68°F(20°C)

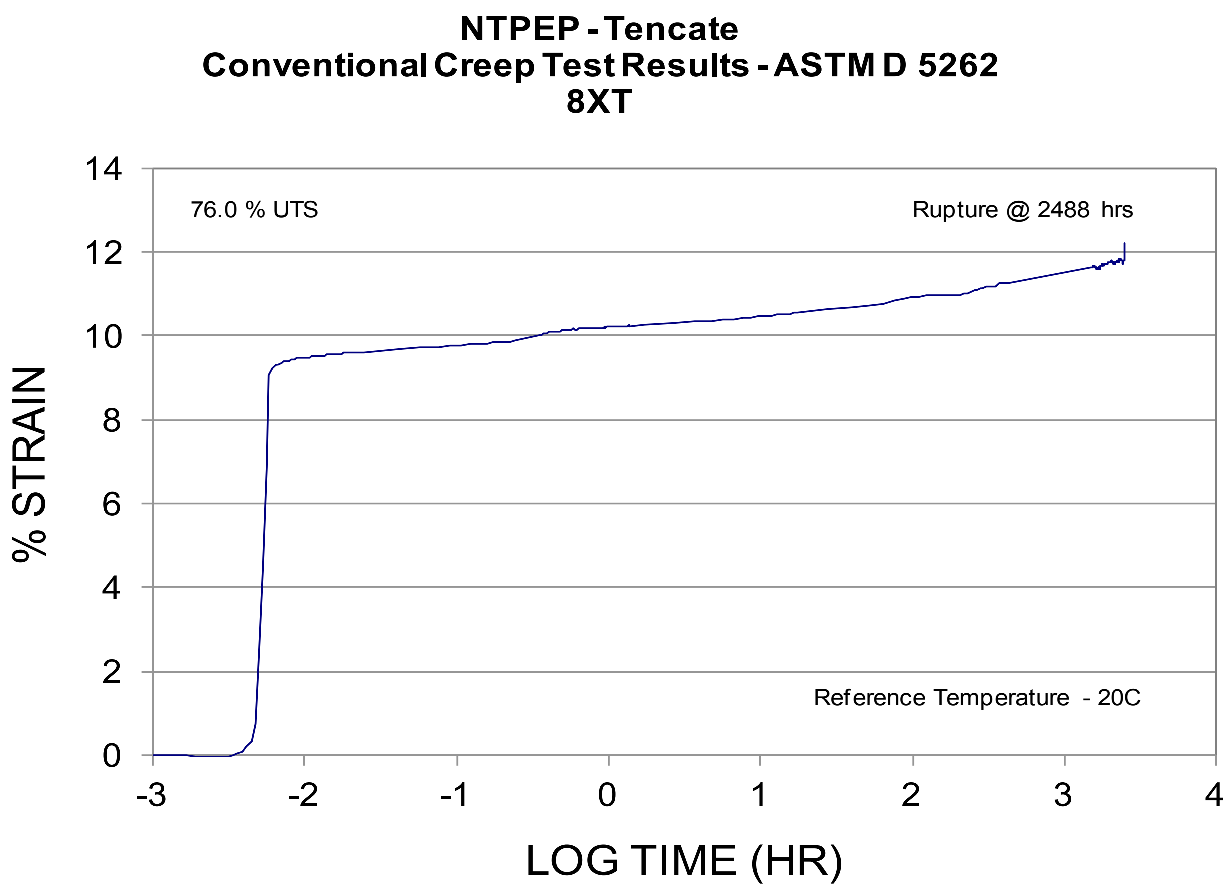


Figure F-12. Creep data/curve per ASTM D5262 for 8XT at a load level of 76.0% UTS and 68°F(20°C)

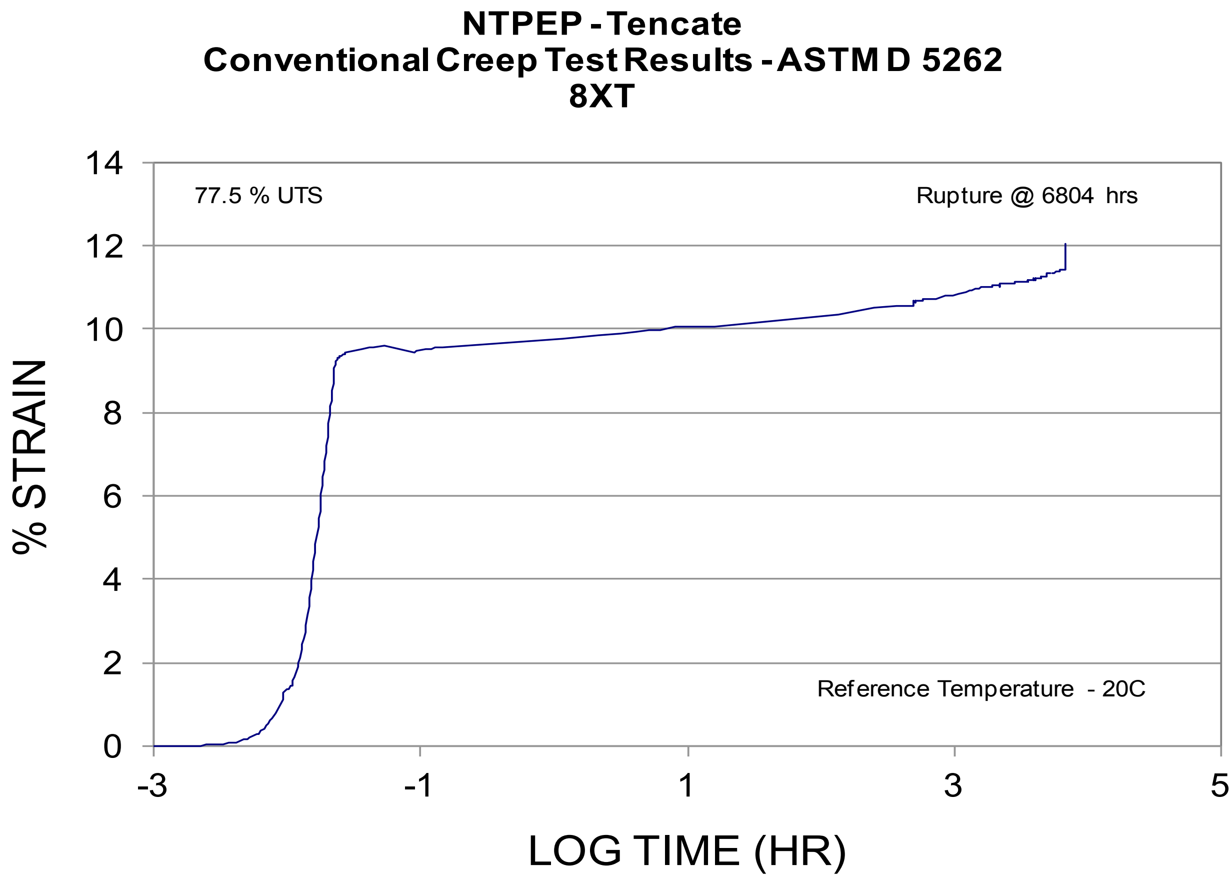


Figure F-13. Creep data/curve per ASTM D5262 for 8XT at a load level of 77.5% UTS and 68°F(20°C)

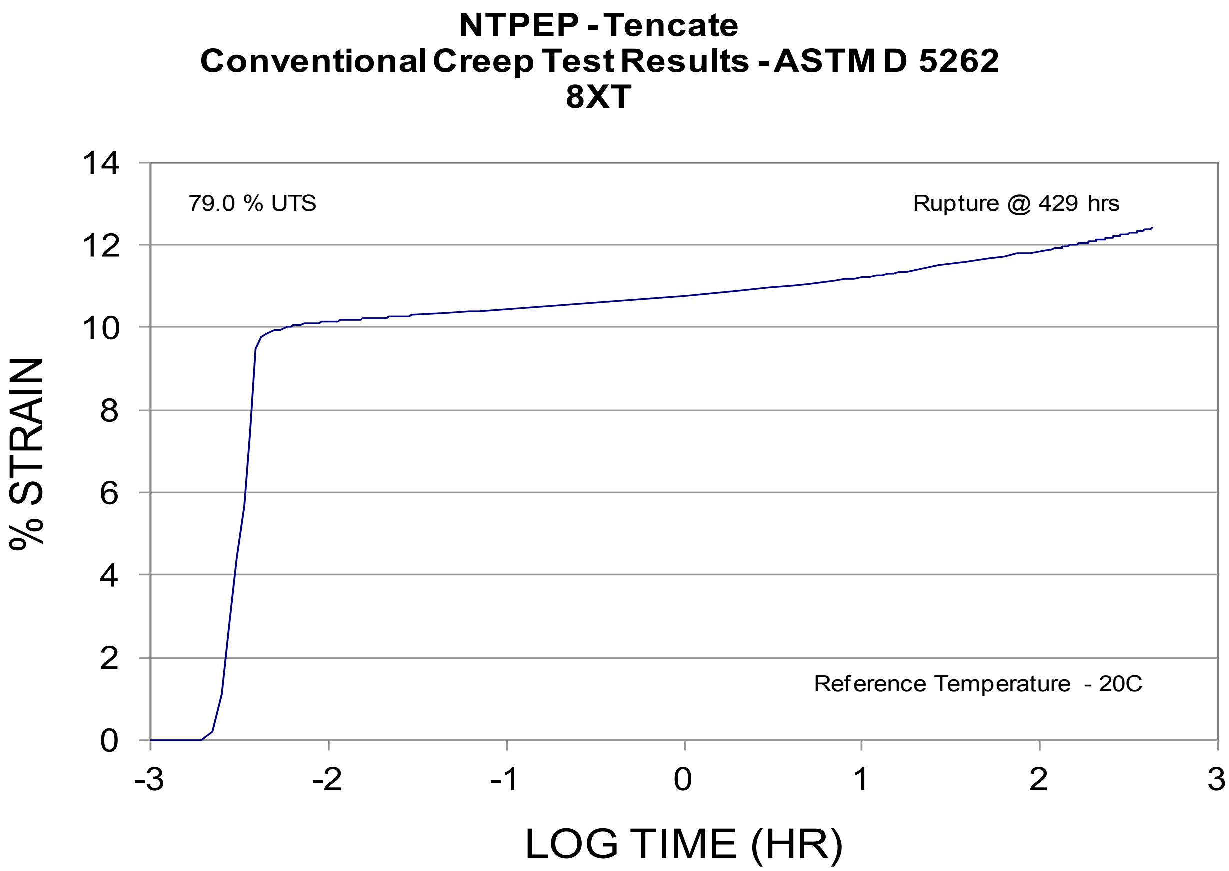


Figure F-14. Creep data/curve per ASTM D5262 for 8XT at a load level of 79.0% UTS and 68°F(20°C)

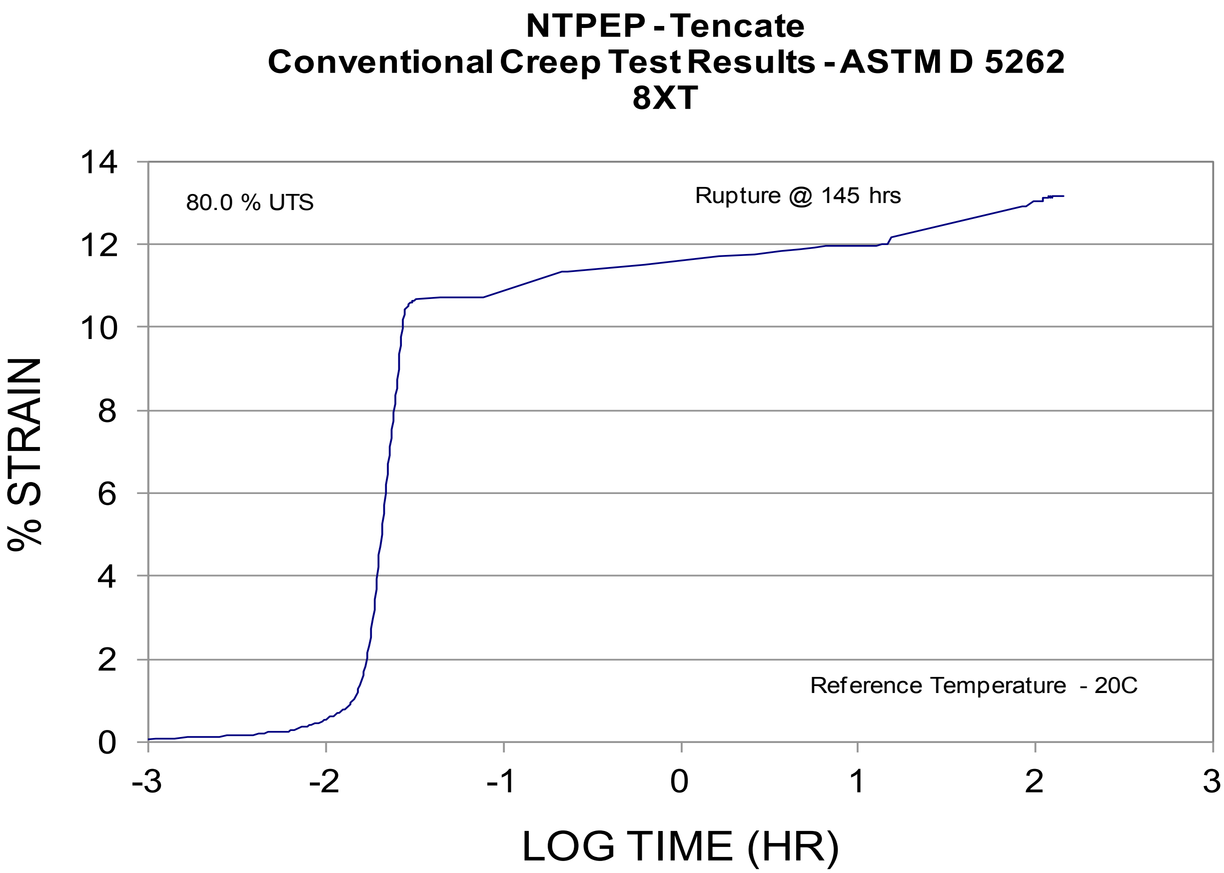


Figure F-15. Creep data/curve per ASTM D5262 for 8XT at a load level of 80.0% UTS and 68°F(20°C)

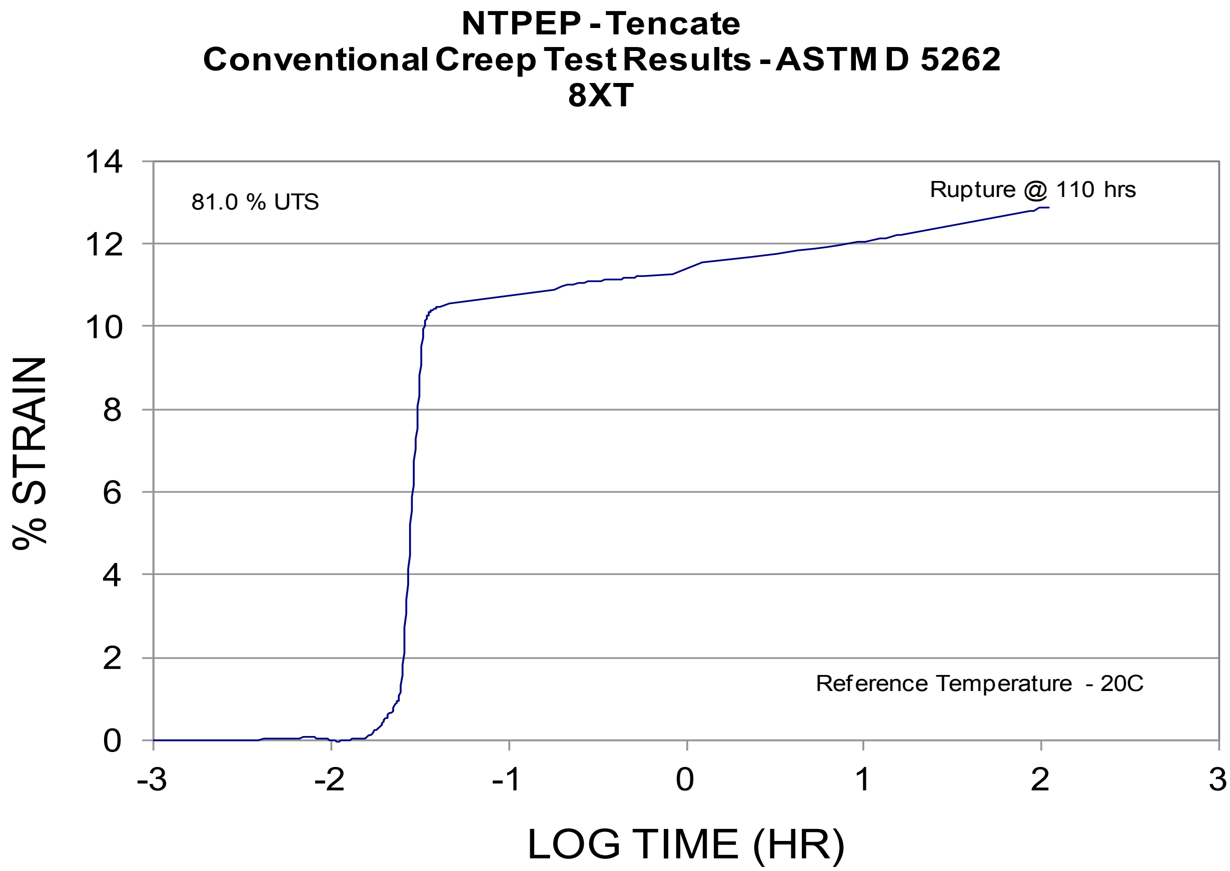


Figure F-16. Creep data/curve per ASTM D5262 for 8XT at a load level of 81.0% UTS and 68°F(20°C)

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	$(t-t')_i$	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	-

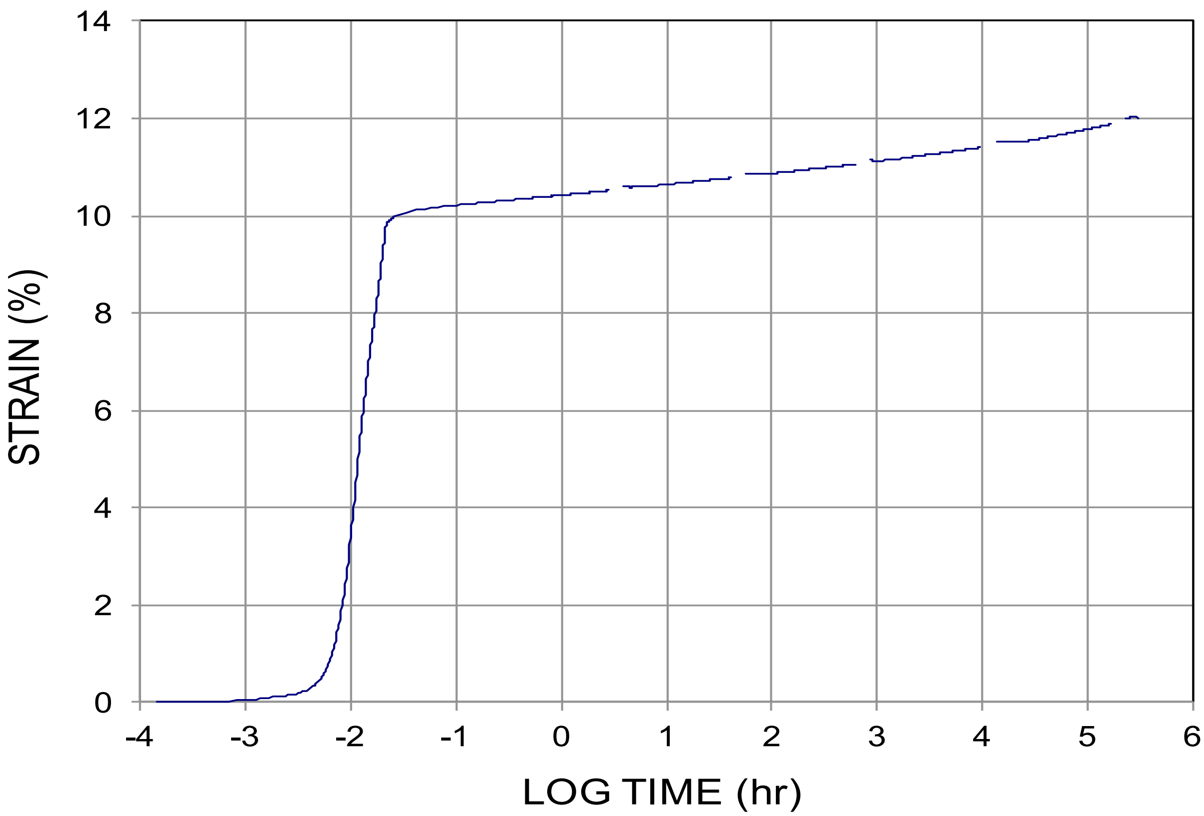


Figure F-17. SIM/Creep data/curve for 24XT at load level of 70.0% UTS.

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	$(t-t')_i$	Vshift(%)	$logA_T$	Temp	$logA_T/T$
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	-
$logA_T(t-t')$	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	-

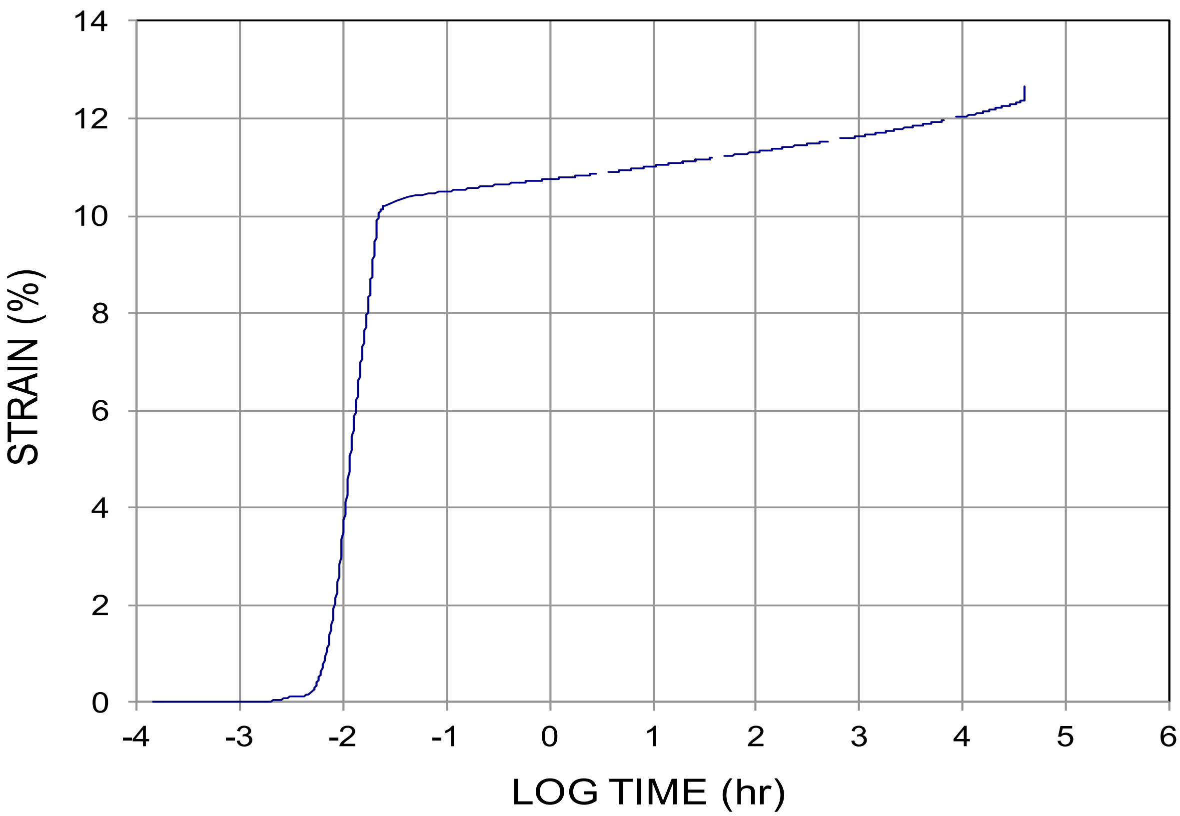


Figure F-18. SIM/Creep data/curve for 24XT at load level of 74.0% UTS.

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	$(t\text{-}t')_i$	Vshift(%)	$logA_T$	Temp	$logA_T/T$
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							

Summary	Initial	Final	Units	@20C refT
lab time	84.0	39960	sec	-
$logA_T(t\text{-}t')$	1.9242	6.9625	log hours	3.3838
$A_T(t\text{-}t')$	-	0.29	years	0.28
Strain	11.05	13.252	%	-
Modulus	202348.6	167584.4	lb/ft	-

AVG 0.0672

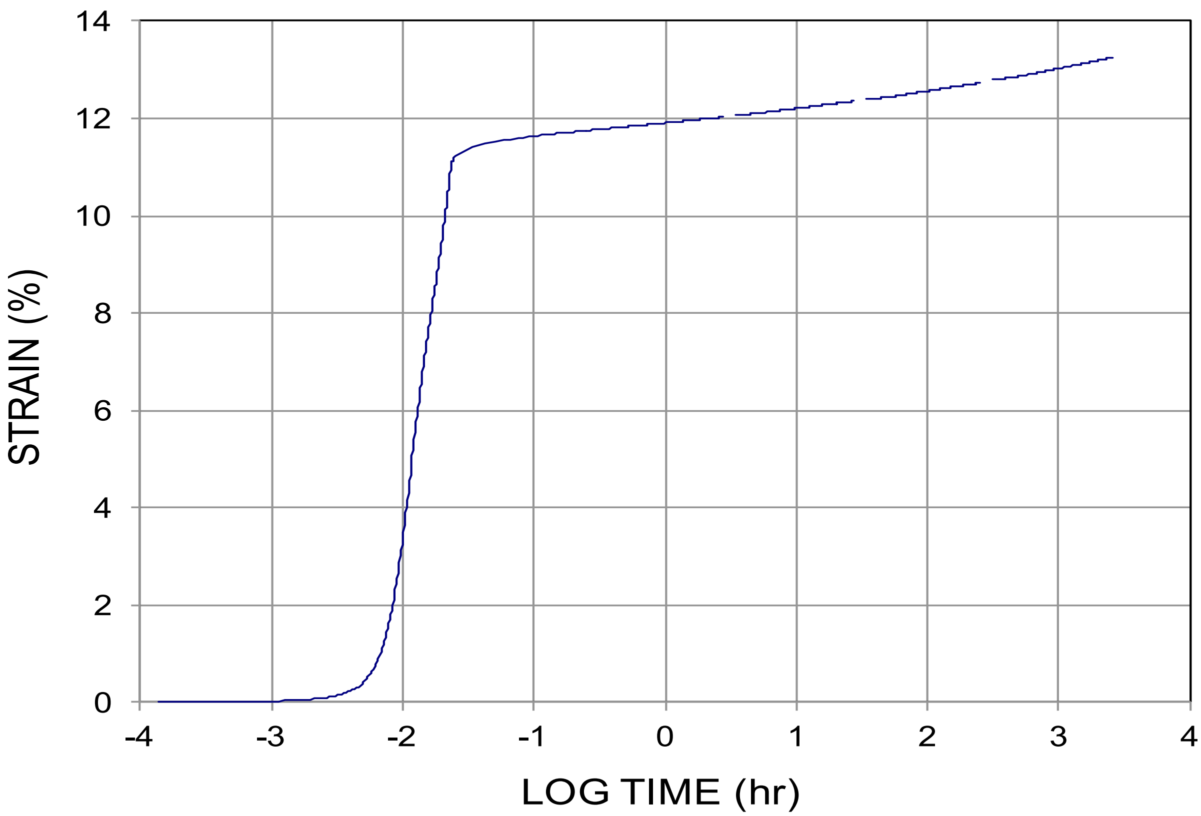


Figure F-19. SIM/Creep data/curve for 24XT at load level of 78.0% UTS.

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	$(t-t')_i$	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

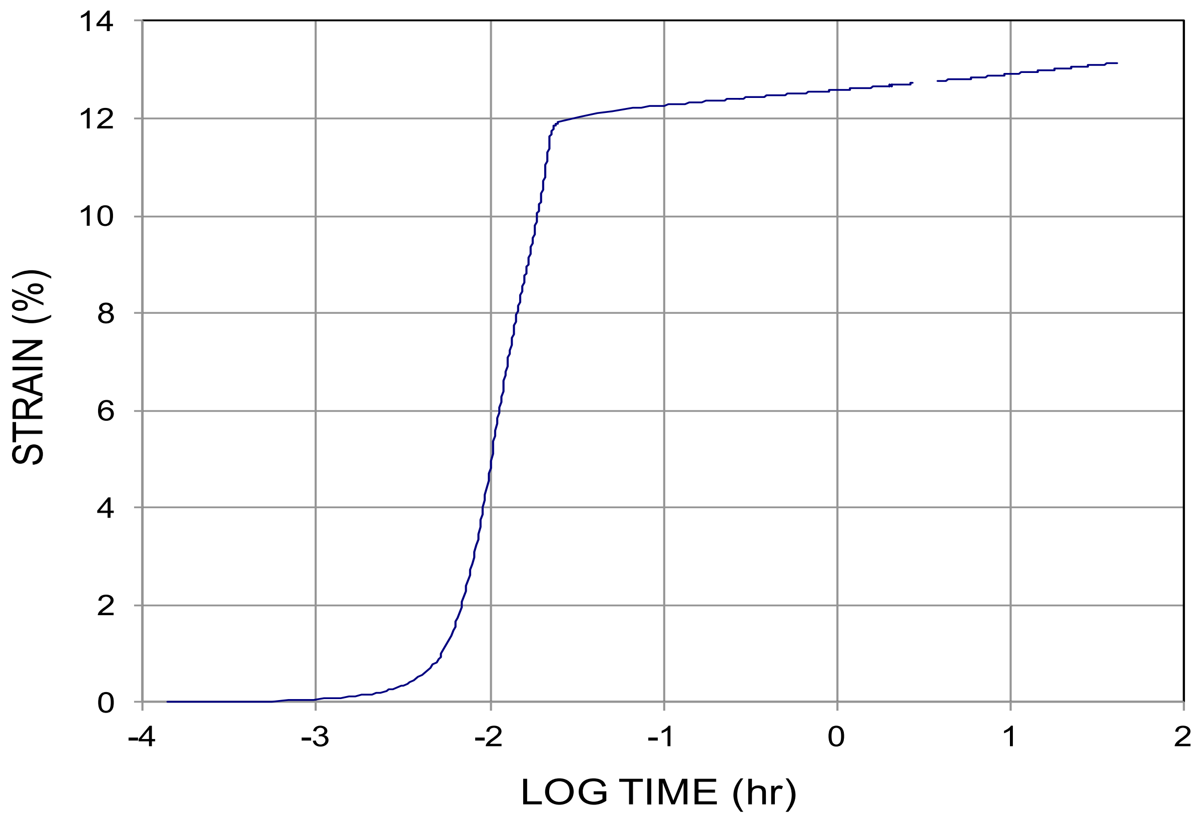


Figure F-20. SIM/Creep data/curve for 24XT at load level of 82.0% UTS.

TenCate Miragrid XT - Creep Rupture

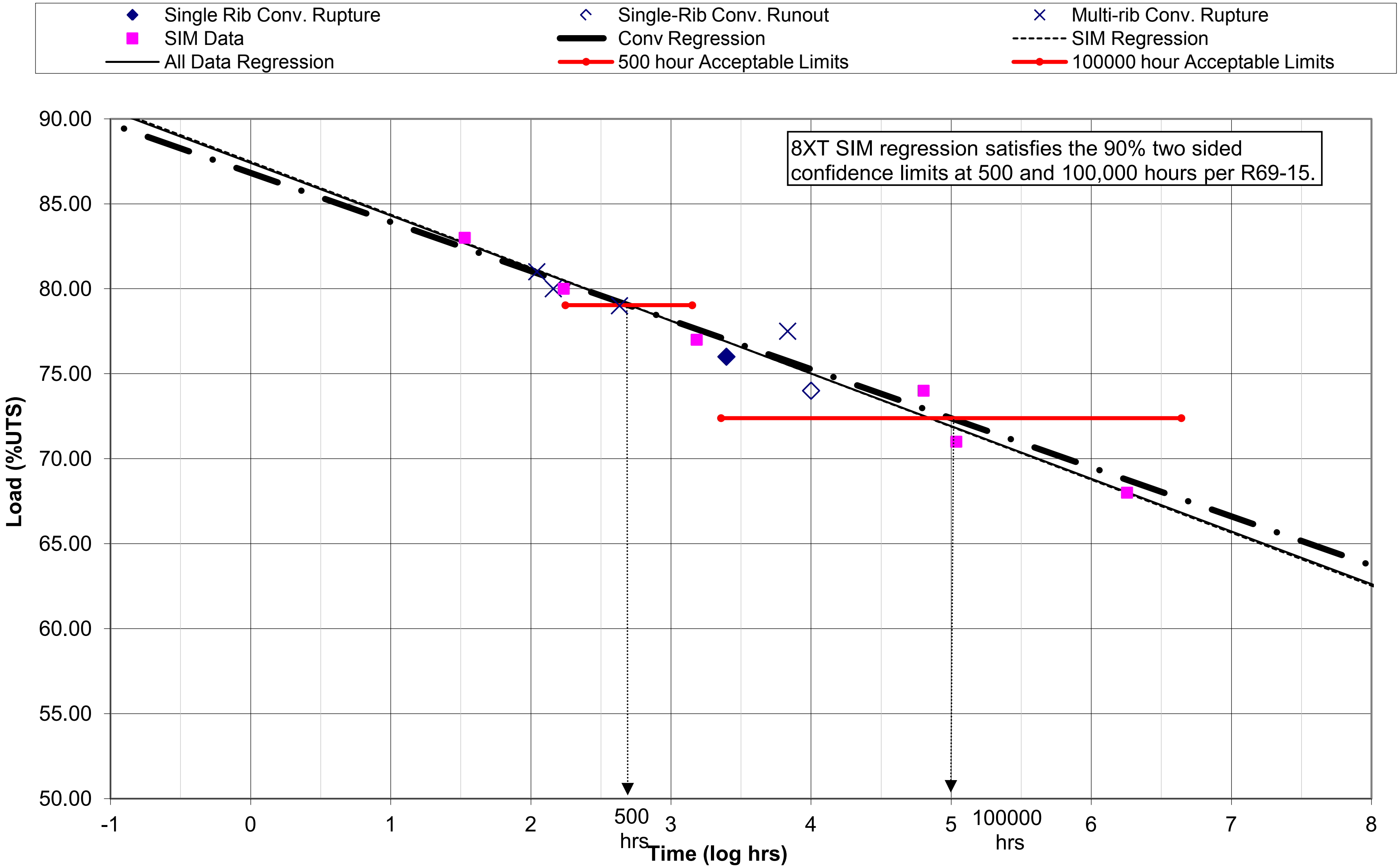


Figure F-21. Statistical evaluation results for determining validity of using SIM to extend TenCate Miragrid XT geogrid conventional creep rupture data, and to compare single-rib to multi-rib data.

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	6.2548	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	-1.77197
	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	1.0406	-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	3
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)			Conv - 100000 hrs (log 5.000)		
log tL - lower =	2.25	79.0283	log tL - lower =	3.36	72.3852
log tL - upper =	3.15	79.0283	log tL - upper =	6.64	72.3852
SIM - logtL @ Load =	**2.71 OK**		SIM - logtL @ Load =	**4.84 OK**	

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 - 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	0.978279	0.978279
	-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	

TenCate Miragrid 8XT - 2XT - 24XT - Creep Rupture

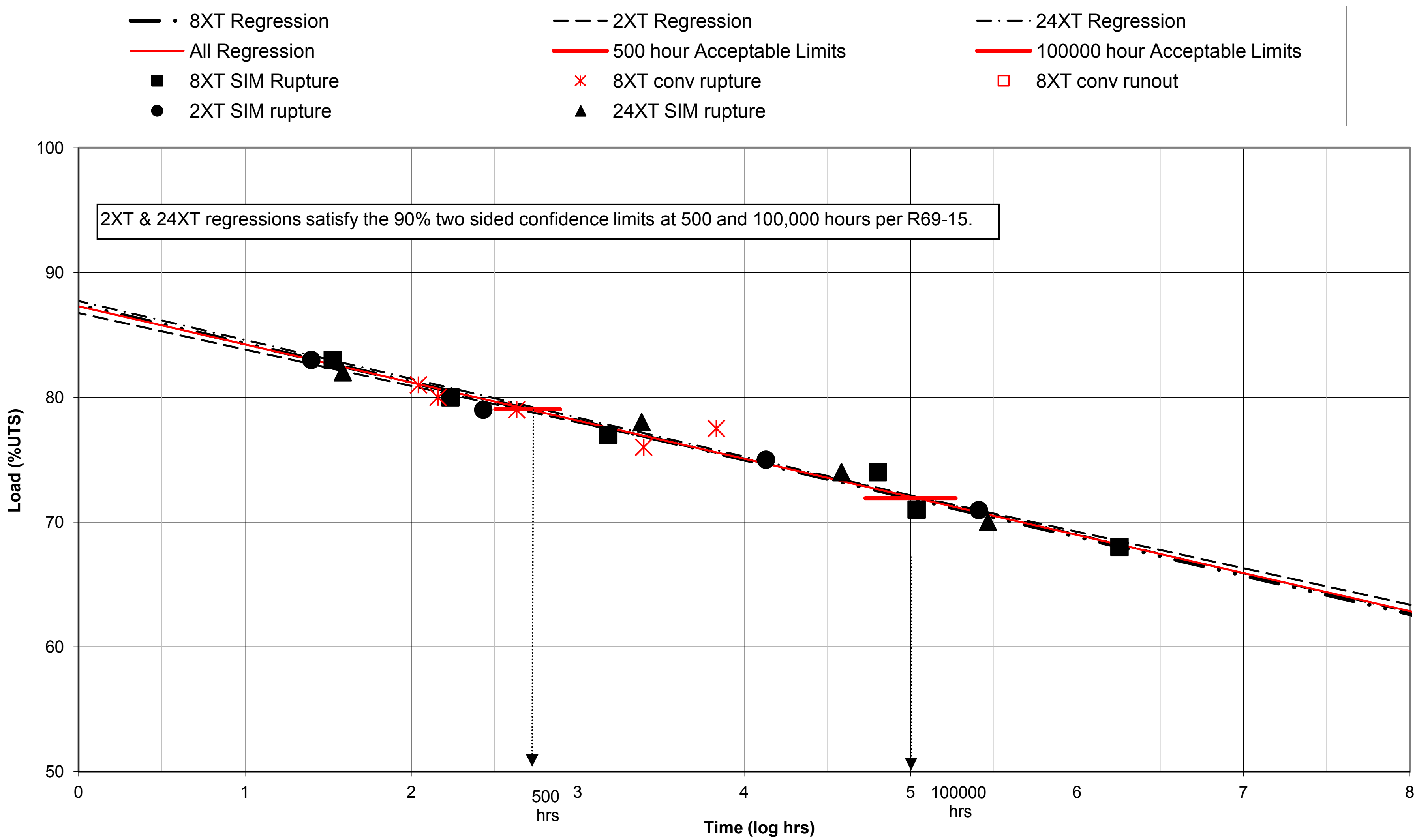


Figure F-22. Statistical evaluation results for determining validity of creating composite creep rupture envelope for the TenCate Miragrid XT geogrid product line.

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	70.96	70.96
	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 =	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	1.7706	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
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	29.69855	86.75427	
R squared	0.992249	0.992249	
	-2	92.5966	
	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	-0.32266	-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	

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	
5.8176	69.5786	= 75-yr intercept	
5.9425	69.19936	= 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	3.3838	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		

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	1.7706	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**

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

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	79.29224	= 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	-0.32266	-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

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	28.05057	87.58337
R squared	0.976551	0.976551
	-2	93.82805
	10	56.35998
5.8176	69.41885	= 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.

Stress, % of UTS

data for regression calculation

	product:	loghrs	all	2XT	24XT	8XT	sim rupture	rlt 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 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	93.454224
	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

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	29.69855	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

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

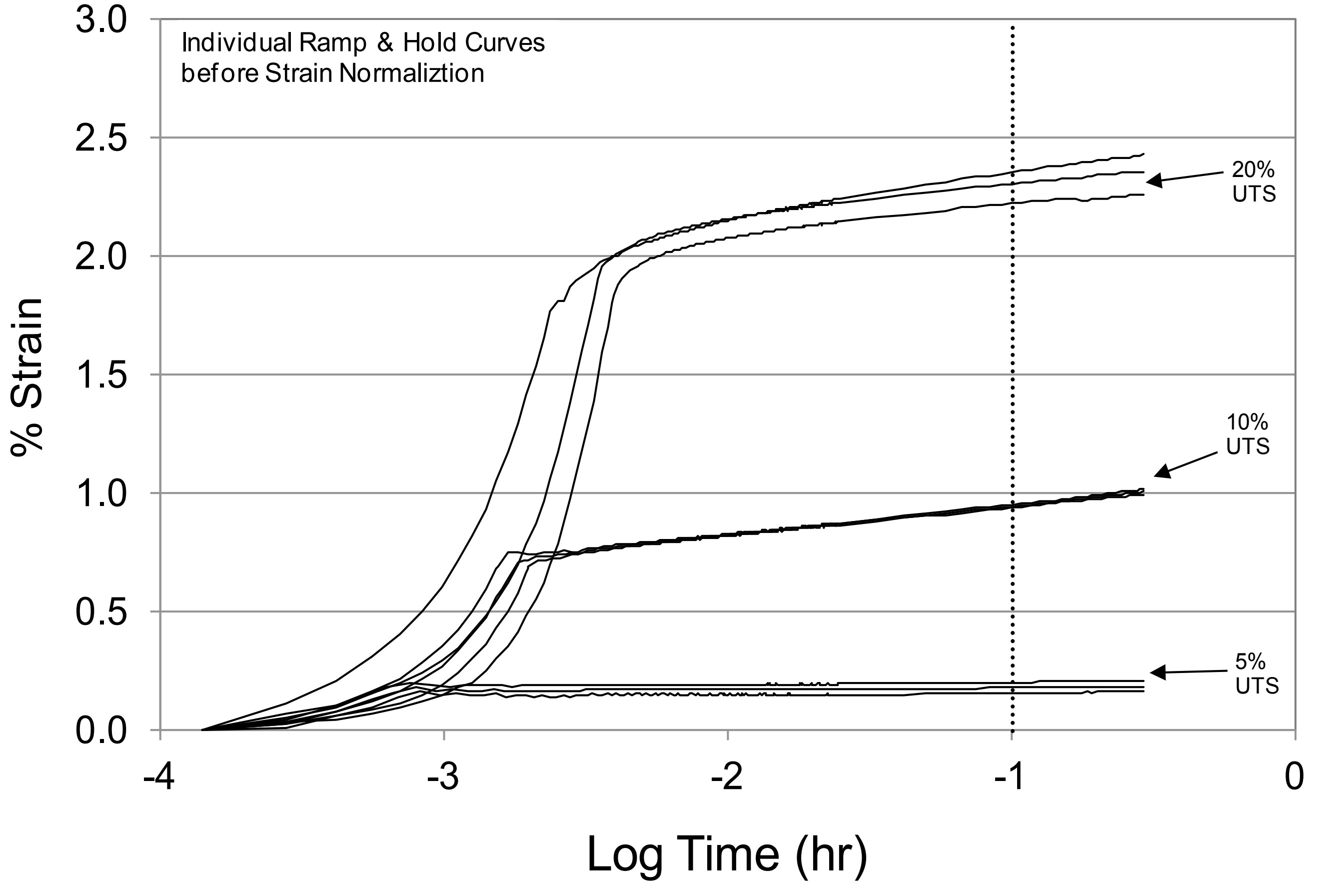


Figure H-1. Low strain ramp and hold tests for 2XT, before strain normalization.

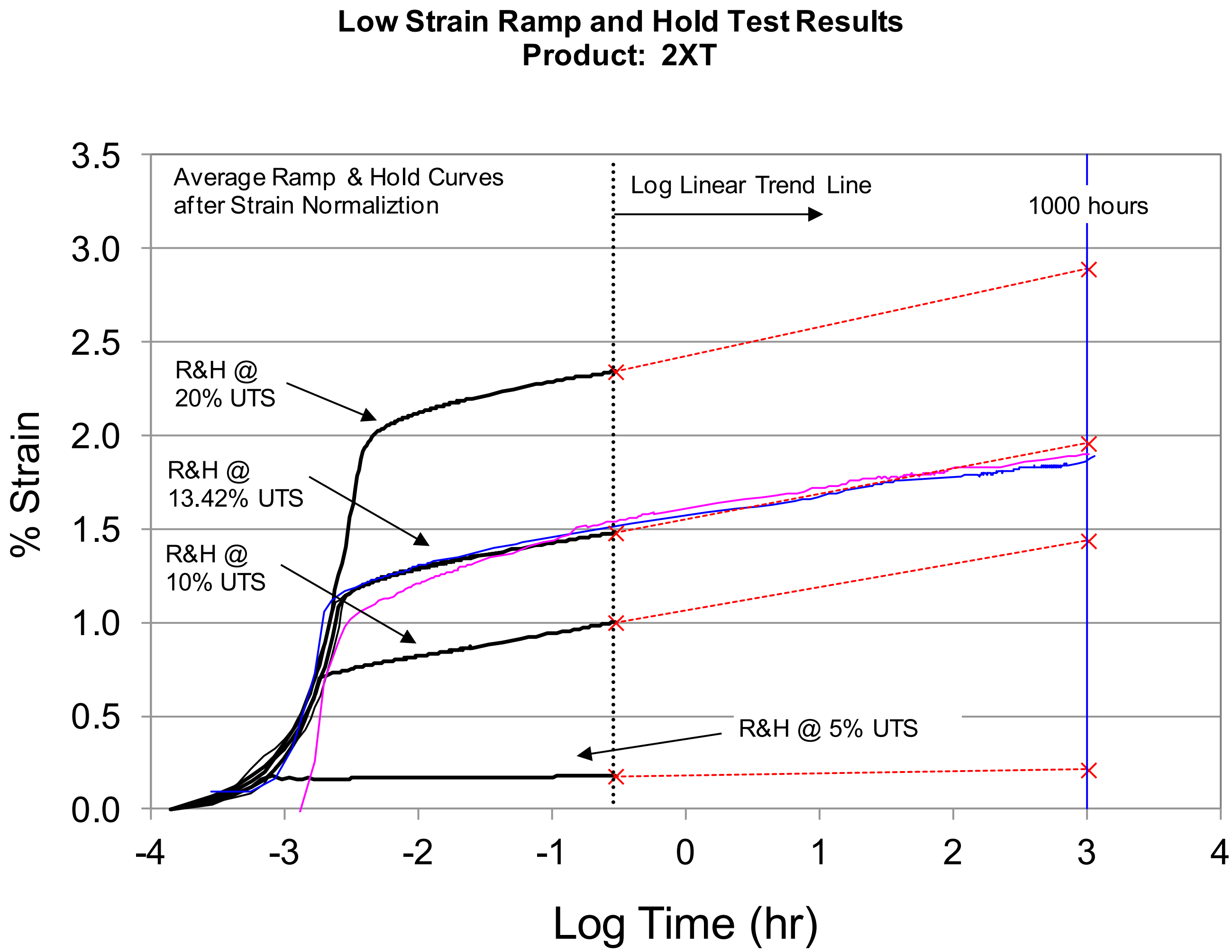


Figure H-2. Low strain ramp and hold tests for 2XT, after strain normalization, with 1000 hour low strain creep tests.

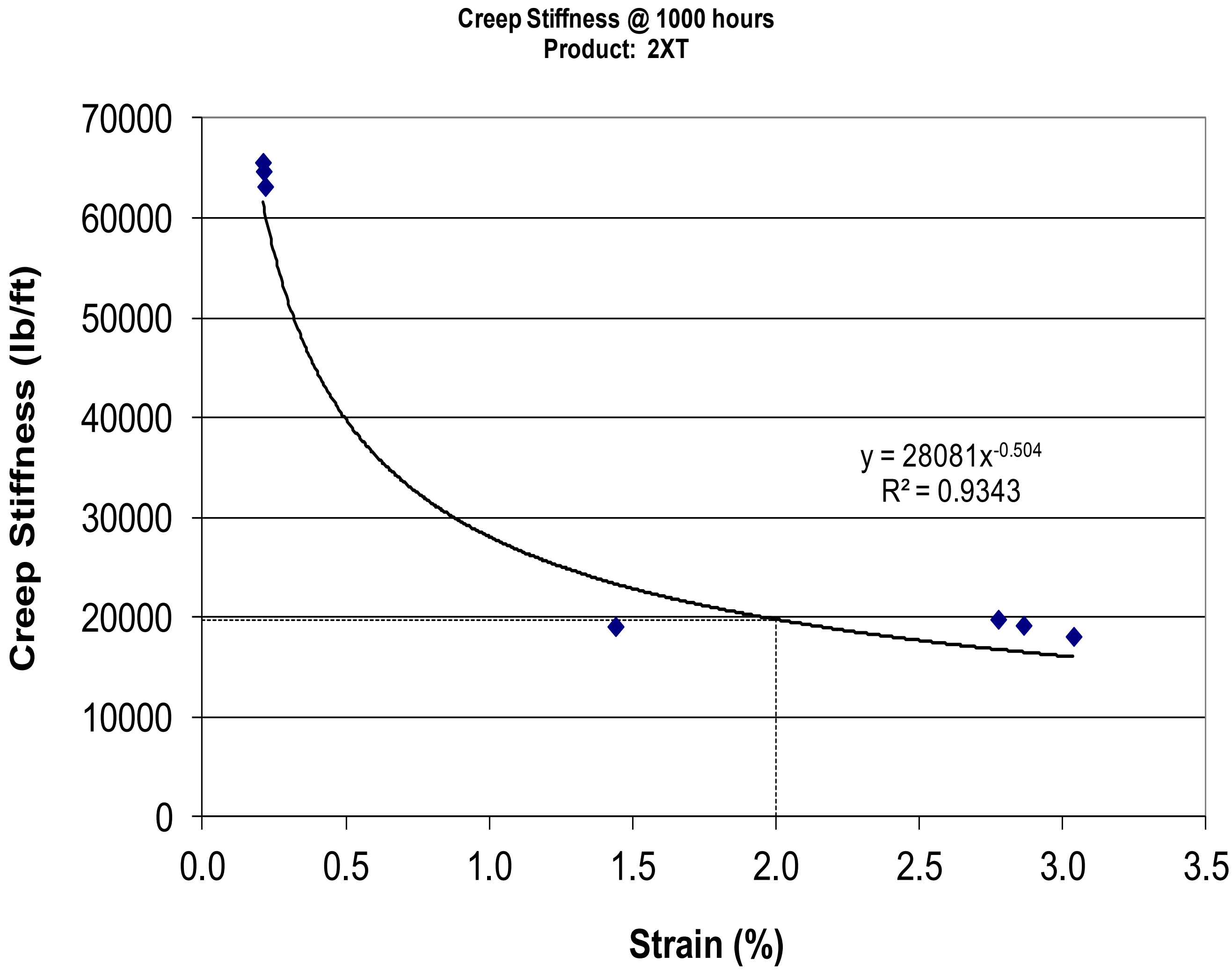


Figure H-3. Creep stiffness versus strain at 1,000 hours for 2XT.

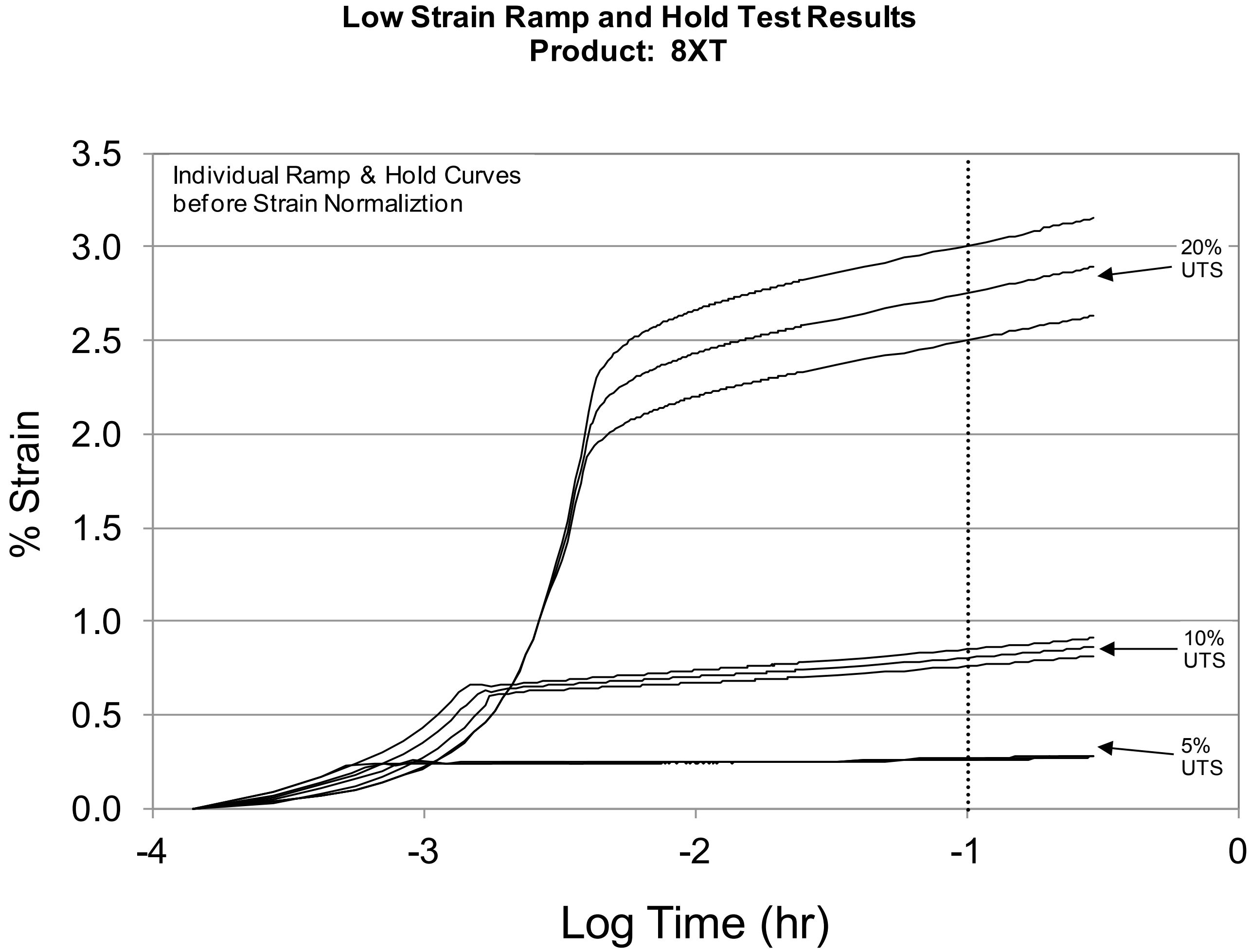


Figure H-4. Low strain ramp and hold tests for 8XT, before strain normalization.

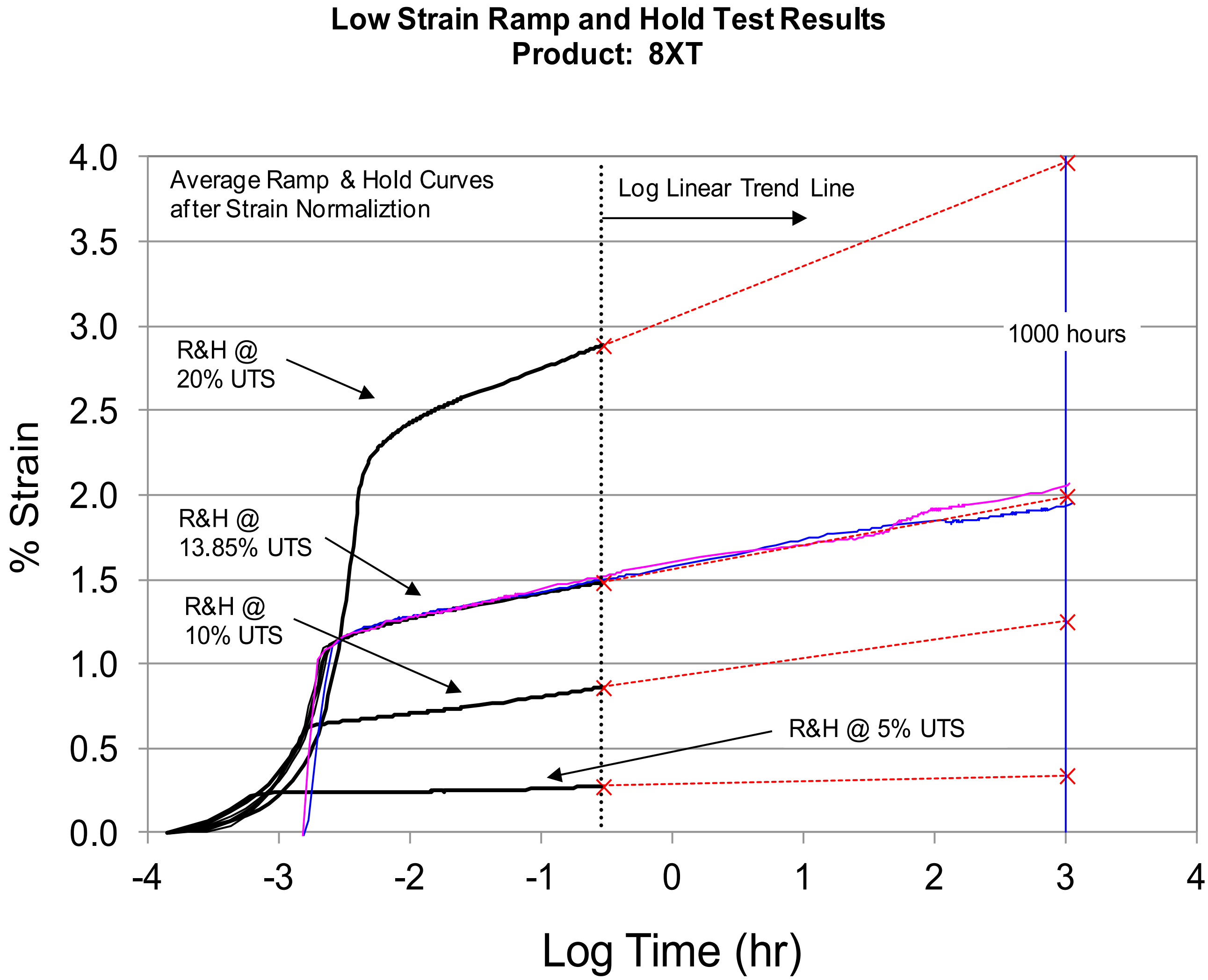


Figure H-5. Low strain ramp and hold tests for 8XT, after strain normalization, with 1000 hour low strain creep tests.

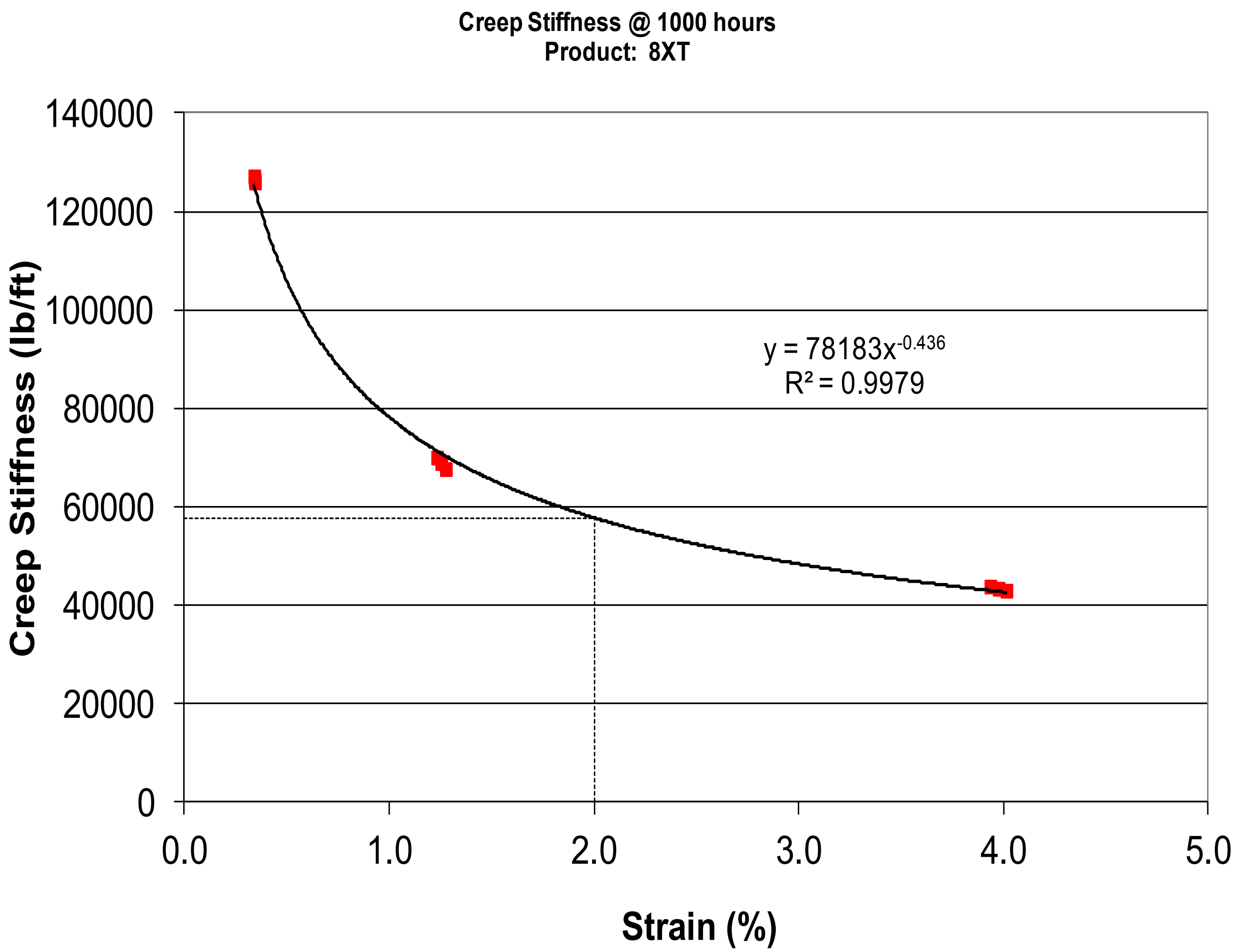


Figure H-6. Creep stiffness versus strain at 1,000 hours for 8XT.

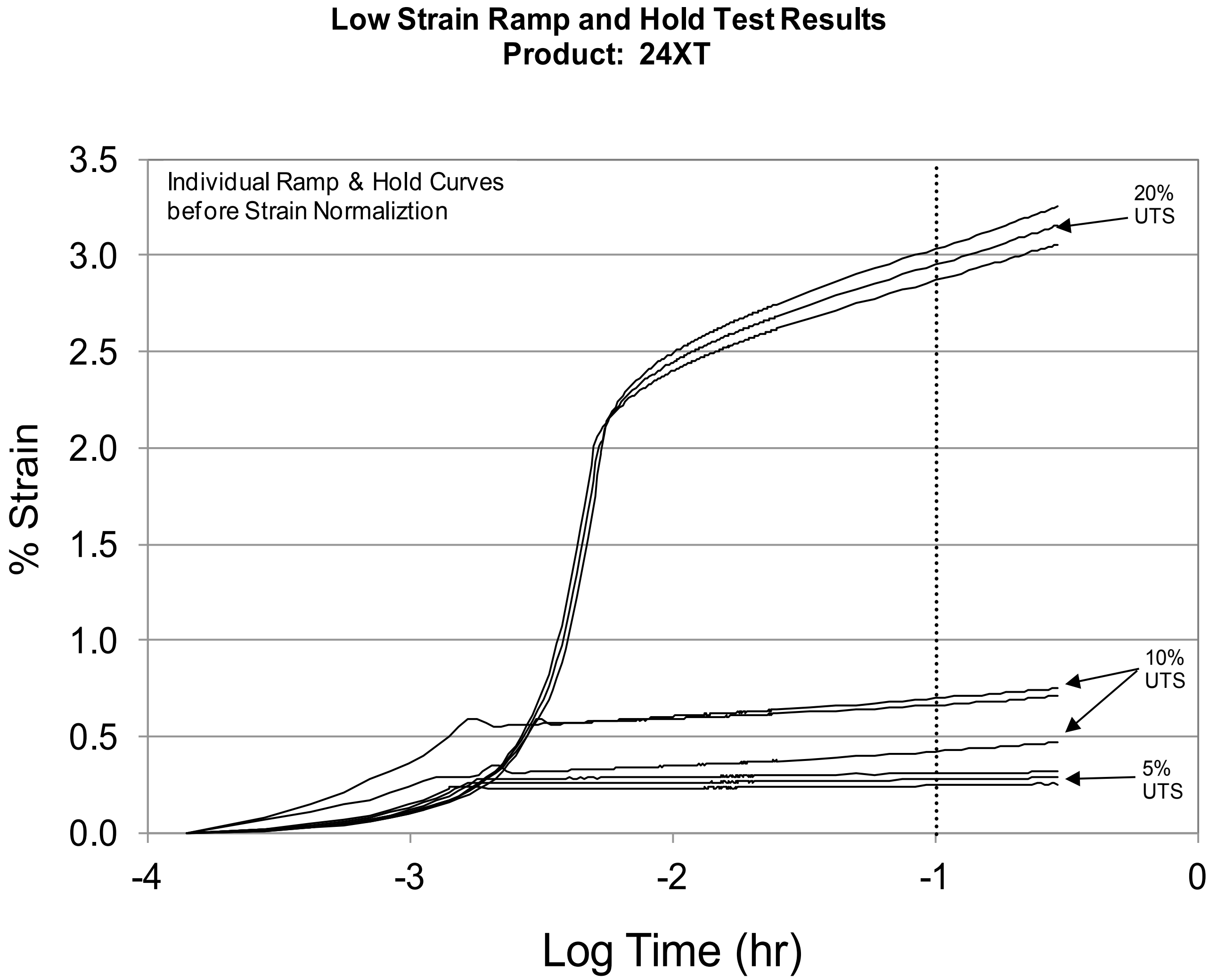


Figure H-7. Low strain ramp and hold tests for 24XT, before strain normalization.

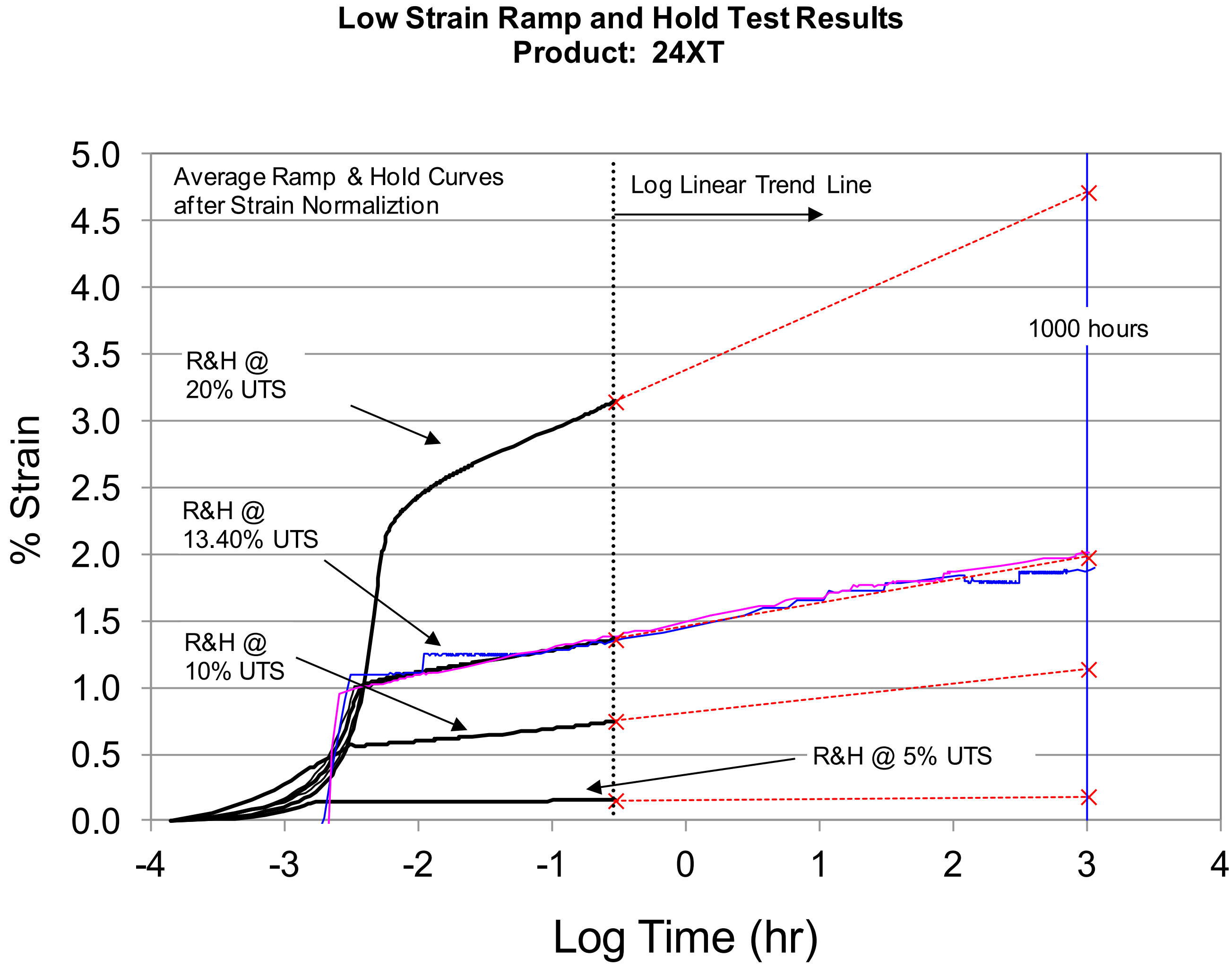


Figure H-8. Low strain ramp and hold tests for 24XT, after strain normalization, with 1000 hour low strain creep tests.

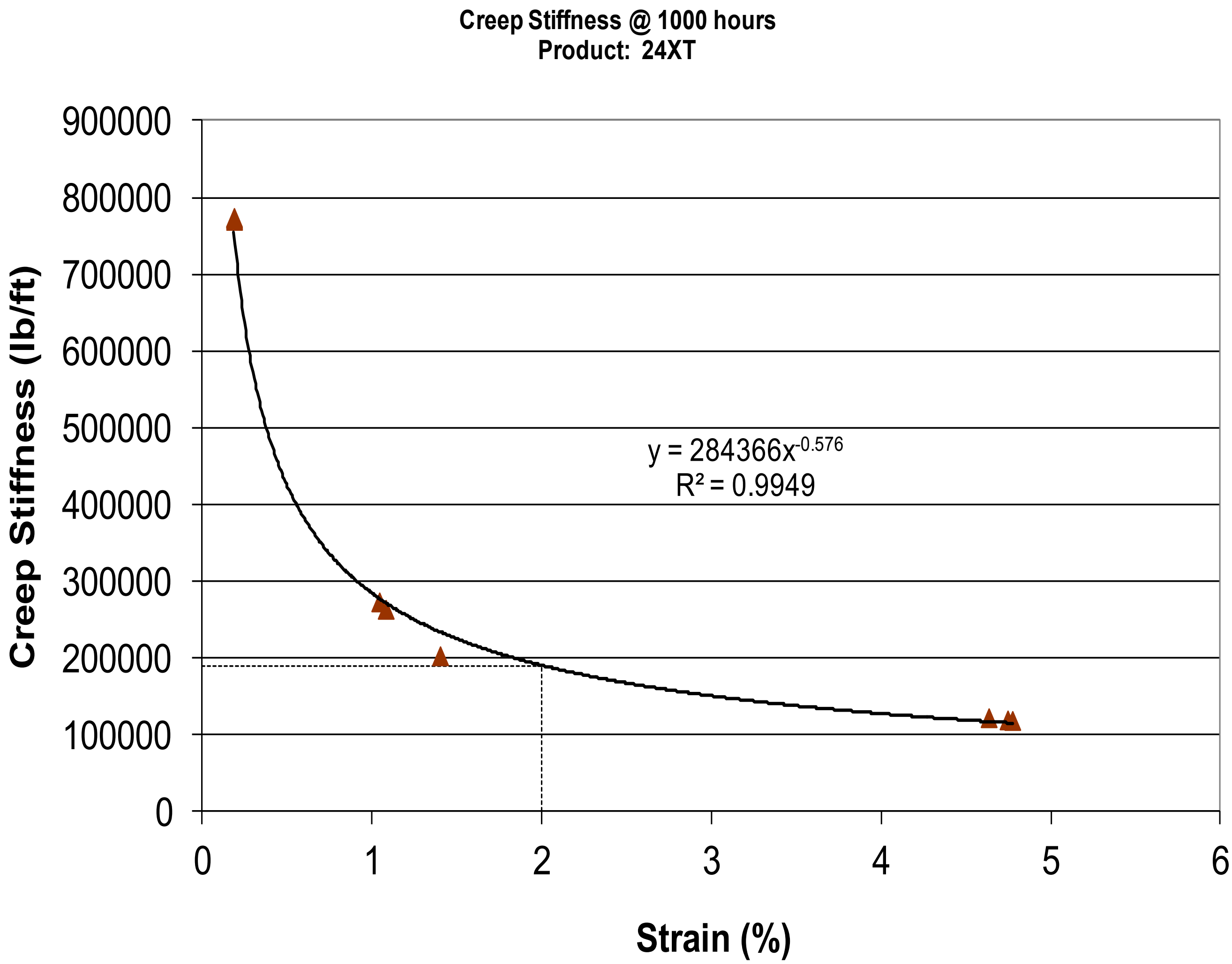


Figure H-9. Creep stiffness versus strain at 1,000 hours for 24XT.

"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**

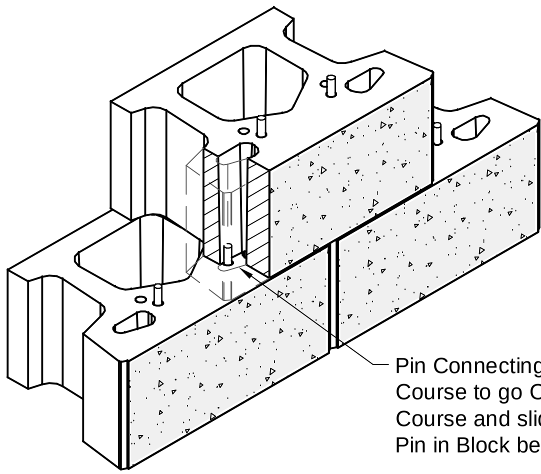
-- Rick Smutzer (IN), former NTPEP Chairman

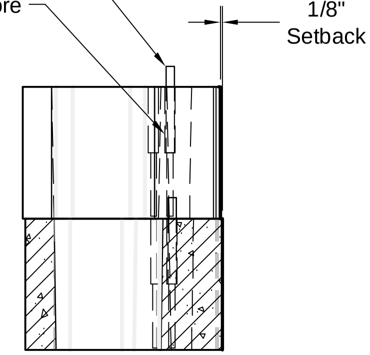
call 1.202.624.5800
fax 1.800.525.5469
online www.NTPEP.ORG

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

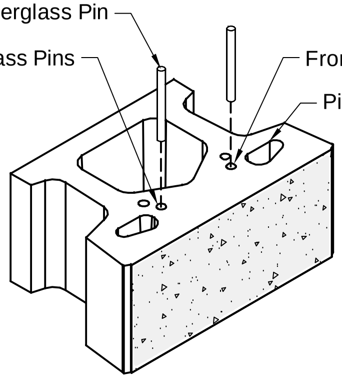
AASHTO
THE VOICE OF TRANSPORTATION

Note:
Place two Keystone fiberglass pins in each unit.

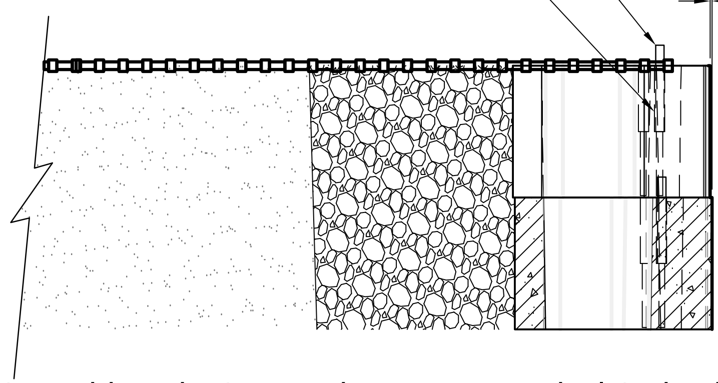




Pin Connection - Near Vertical Setback Section



Compac III Block to Block
Pin Connections Isometrics



Geogrid & Pin Connection - Near Vertical Setback Section

KEYSTONE® RETAINING WALL SYSTEMS
4444 West 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By:	DMT	Title:	Unit Drawing Item 1.2.5	Date:	10/2019
Checked By:	PJS	Project:	IDEA Evaluation	Project No:	IDEA
Scale:	No Scale			Drawing No:	1 of 1

Series # BCGT2533

REPORT

RESULTS OF KEYSTONE COMPAC III WITH MIRAGRID 3XT GEOGRID CONNECTION CAPACITY TESTING

submitted to

Keystone Retaining Wall Systems

CONFIDENTIAL

Distribution:

2 copies Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435
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 performance of the connection between Keystone Compac III® (Light) modular concrete block units and Miragrid 3XT geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 27 July 2009.

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 Keystone Compac III concrete block units and Miragrid 3XT geogrid was investigated using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the 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 Keystone Compac III blocks in combination with Miragrid 3XT geogrid.

Materials

Keystone Compac III blocks are hollow concrete blocks weighing approximately 90 pounds per unit (weight/unit measured in our laboratory) which are normally filled with a select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. The installation arrangement is illustrated in **Figure 1**. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 13 April 2007 and designated as BIC 07-017.

Miragrid 3XT is a bi-directional geogrid composed of 100% polyester multifilament yarn with a tensile strength of 3500 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009). The geogrid specimens used in this series of testing were cut from roll/lot # 032092006/06244-2-4 received at our laboratory on 8 December 2008.

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 description 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. Strips of geogrid reinforcement 39 inches (1 meter) wide were attached to a roller clamp and the geogrid extended over the facing block. The next course was then placed over the geogrid simulating the technique that would be used in the field. The hollow portions of each block and spaces between blocks were infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 2** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the geogrid to measure geogrid displacement at the back of the block. Wall heights were simulated by placing one block course over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. A gum rubber mat was placed over the top layer of blocks to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inches/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 strength due to longitudinal geogrid member failure. Following each test, the blocks were removed and the geogrid examined to confirm failure modes. A virgin specimen of geogrid 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 and after 3/4 inch displacement is given in **Figure 3**.

The peak connection strength between Keystone Compac III units and Miragrid 3XT for walls between 3.1 and 20.0 feet in height ranged between 36 and 66% of the index tensile strength of 3500 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009).

Two repeat tests were performed and the results in **Figure 3** illustrate that there is minor variability in connection capacity between nominal identical tests. This variability is less than ± 10% of the mean peak load criterion required by the NCMA (e.g. maximum variability is 2.6%) and is likely the result of small differences in the setting up of the blocks, compaction of the granular infill, and laying out of the geogrid reinforcement. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves. The reduced connection capacity at lower surcharge loads may be due to the combined effect of lower surcharge pressure and more grid slippage.

There was evidence of slippage of the geogrid within the concrete block-geogrid interface in all tests. Geogrid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces. The amount of slippage was seen to diminish with an increase in wall height.

Implications to Keystone Compac III design and construction with Miragrid 3XT geogrid

The long-term design connection strength 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 4** is controlled by the 3/4 inch connection capacity criterion.

The design capacity envelope illustrated in **Figure 4** 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 geogrid and blocks in order to minimize abrasion to the geogrid and to maximize the frictional resistance that is developed at the concrete block-geogrid 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-geogrid interface, pinching of the geogrid 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 connection performance of Keystone Compac III modular block facing units in combination with Miragrid 3XT geogrid. The following conclusions can be drawn:

1. The peak connection strength between Keystone Compac III units and Miragrid 3XT geogrid for walls between 3.1 and 20.0 feet in height ranged between 36 and 66% of the index tensile strength of 3500 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009).
2. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves.
3. Care must be taken during the installation of Keystone Compac III units in order to prevent accumulation of soil and rock debris at the concrete block-geogrid interface surfaces. This debris may significantly reduce the capacity of the Keystone Compac III facing unit-geogrid system.

4. The design envelope in **Figure 4** 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 4**.

P. Clarabut

R. J. Bathurst, Ph.D., P. Eng.

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:
Keystone III (Light) modular block unit - Miragrid 3XT geogrid connection

Test number	normal load (lb/ft)	approximate wall height (feet)	approximate number of blocks	tensile capacity (lb/ft) at 3/4 inch displacement	peak tensile capacity (lb/ft)
1	1013	9.0	13.5	1108	1858
2	346	3.1	4.6	797	1245
3	2252	20.0	30.1	1570	2298
4	1013	9.0	13.5	1130	1913
5	676	6.0	9.0	1024	1644
6	1344	12.0	17.9	1305	2160
7	1013	9.0	13.5	1152	1954
8	1688	15.0	22.5	1525	2264

LEGEND

1	Keystone Compac III	6	guide rail	11	platform
2	Miragrid 3XT geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamp	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

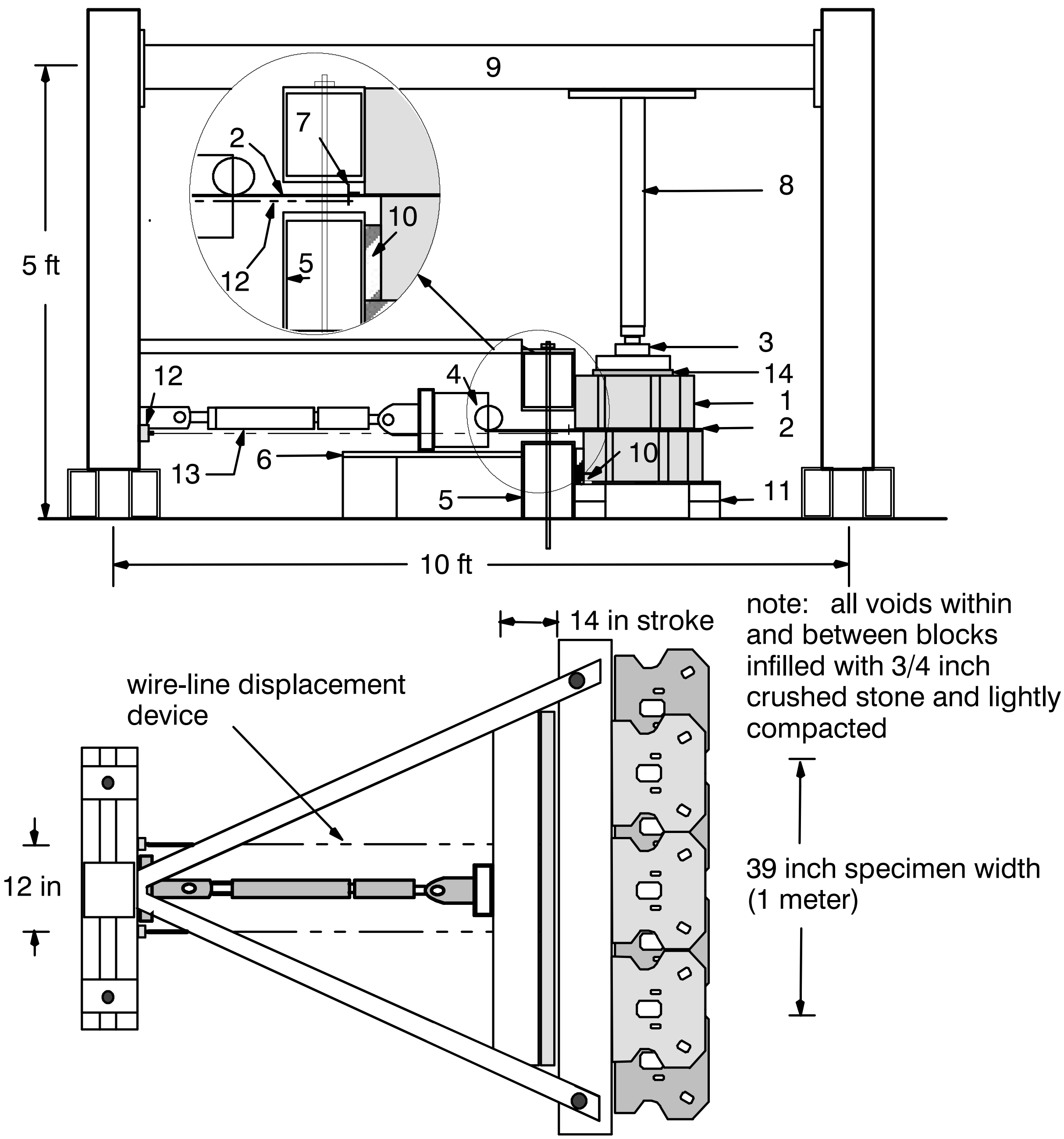


Figure 1: Schematic of connection test apparatus showing Keystone Compac III block units and Miragrid 3XT geogrid reinforcement

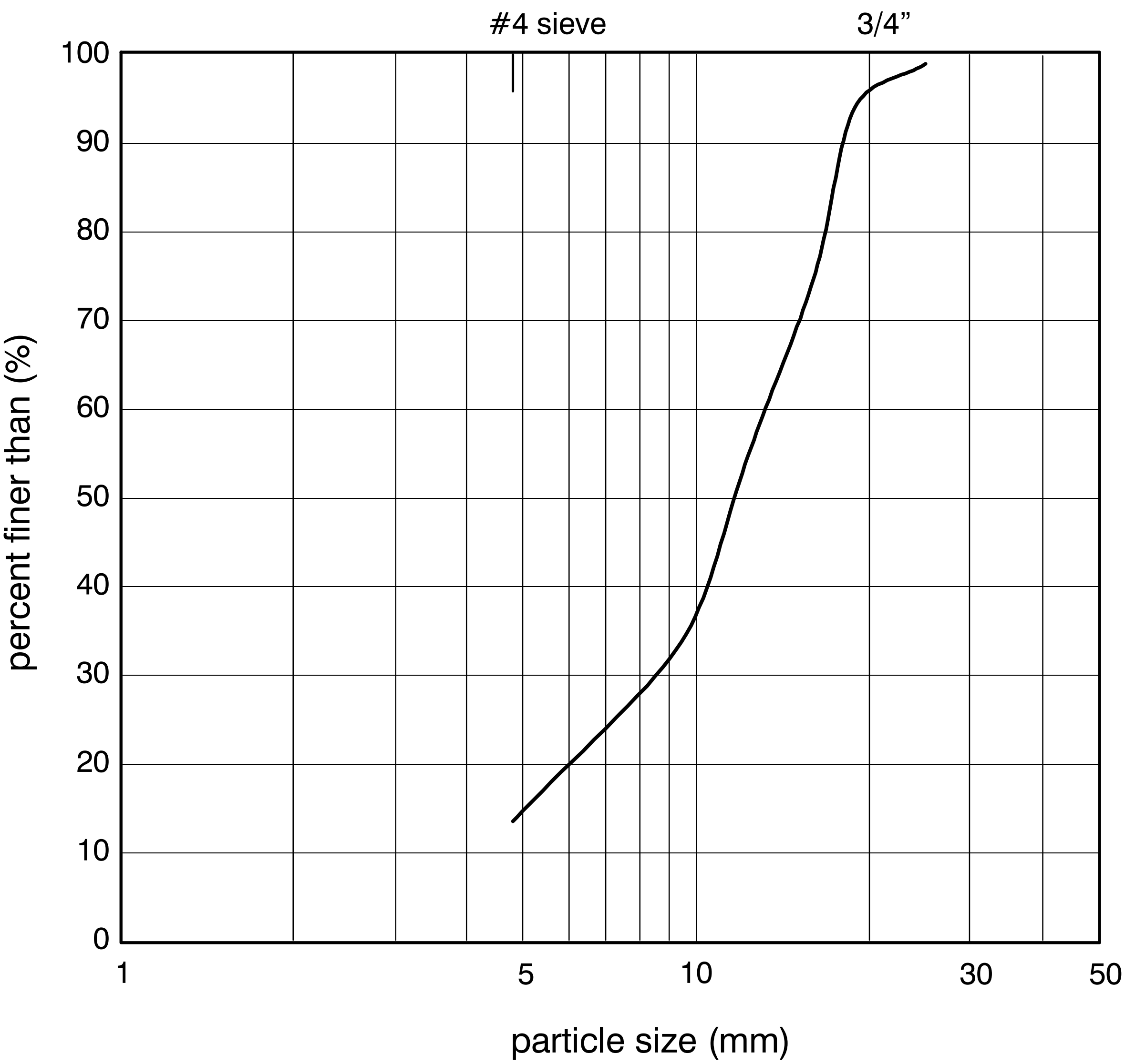


Figure 2: Particle size distribution for 100% crushed granular stone used in Keystone Compac III block tests

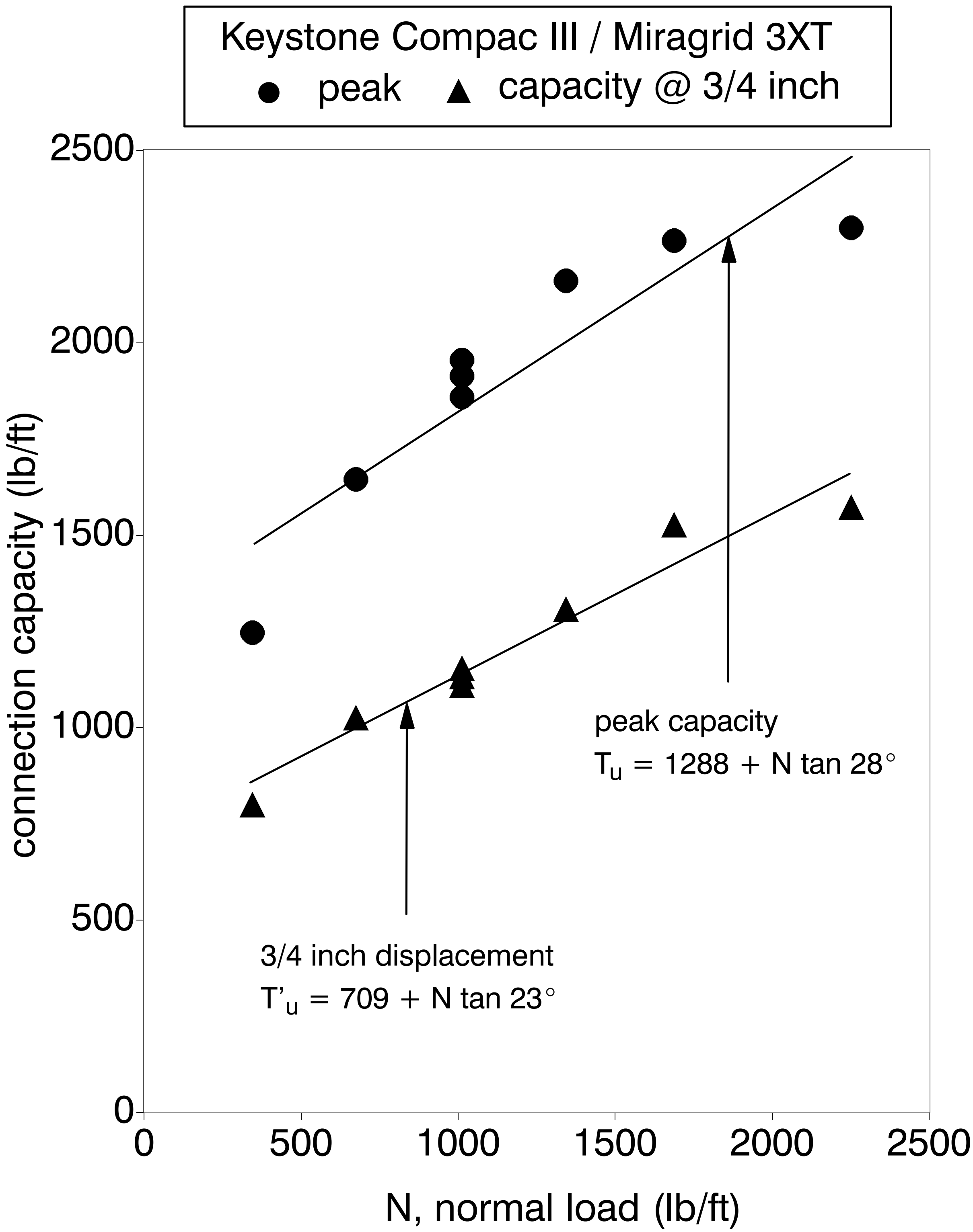


Figure 3: Summary of connection capacities for Keystone Compac III and Miragrid 3XT geogrid combination

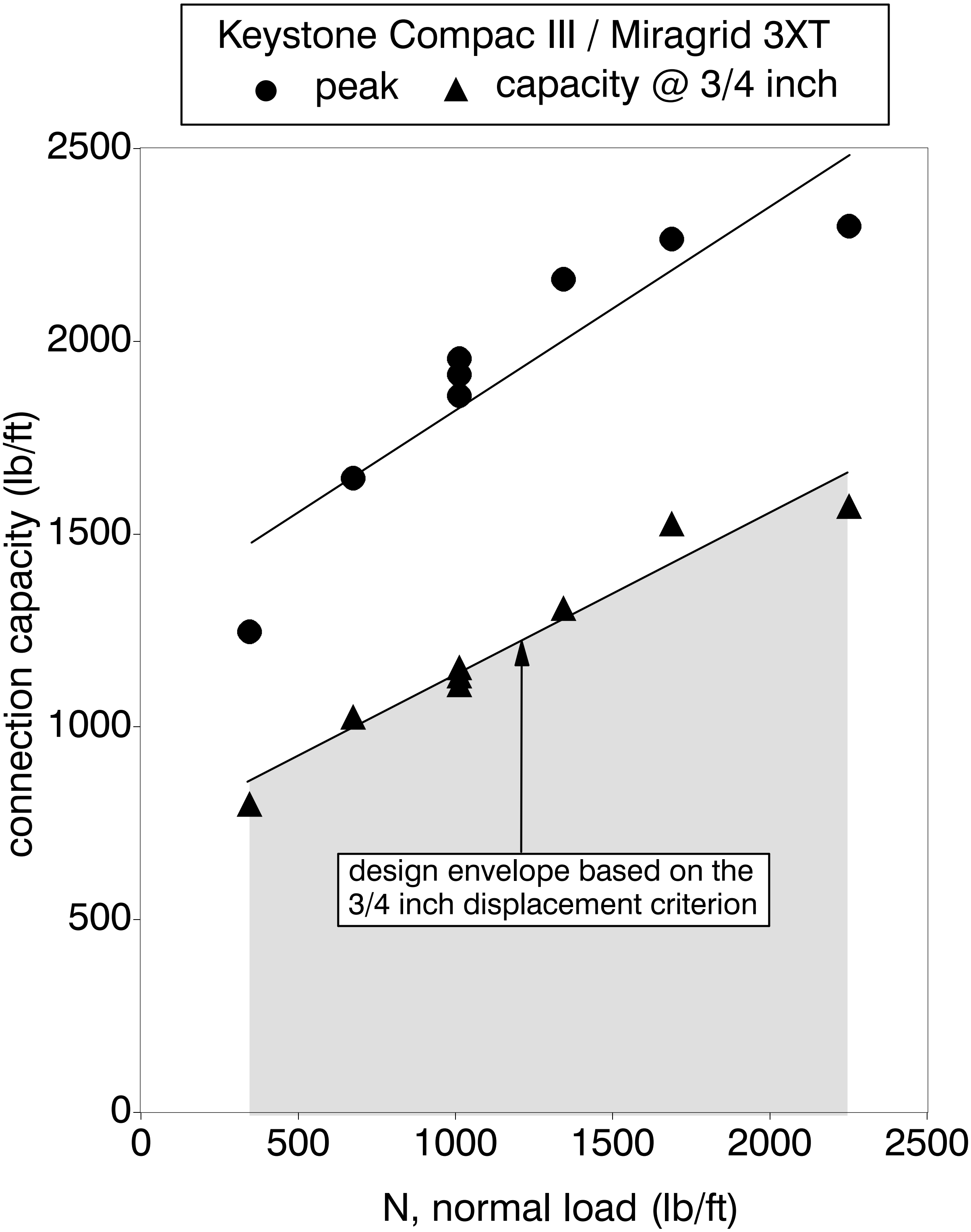


Figure 4: Preliminary design capacity envelope for Keystone Compac III / Miragrid 3XT geogrid combination

Series # BCGT2534

REPORT

RESULTS OF KEYSTONE COMPAC III WITH MIRAGRID 5XT GEOGRID CONNECTION CAPACITY TESTING

submitted to

Keystone Retaining Wall Systems

CONFIDENTIAL

Distribution:

2 copies Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435
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 performance of the connection between Keystone Compac III® (Light) modular concrete block units and Miragrid 5XT geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 27 July 2009.

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 Keystone Compac III 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 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 Keystone Compac III blocks in combination with Miragrid 5XT geogrid.

Materials

Keystone Compac III blocks are hollow concrete blocks weighing approximately 90 pounds per unit (weight/unit measured in our laboratory) which are normally filled with a select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. The installation arrangement is illustrated in **Figure 1**. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 13 April 2007 and designated as BIC 07-017.

Miragrid 5XT is a bi-directional geogrid 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 27 October 2009). The geogrid specimens used in this series of testing were cut from roll/lot # 031106986 / 08234-1-4 received at our laboratory on 1 June 2009.

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 description 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. Strips of geogrid reinforcement 39 inches (1 meter) wide were attached to a roller clamp and the geogrid extended over the facing block. The next course was then placed over the geogrid simulating the technique that would be used in the field. The hollow portions of each block and spaces between blocks were infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 2** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the geogrid to measure geogrid displacement at the back of the block. Wall heights were simulated by placing one block course over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. A gum rubber mat was placed over the top layer of blocks to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inches/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 strength due to longitudinal geogrid member failure. Following each test, the blocks were removed and the geogrid examined to confirm failure modes. A virgin specimen of geogrid 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 and after 3/4 inch displacement is given in **Figure 3**.

The peak connection strength between Keystone Compac III units and Miragrid 5XT for walls between 5.0 and 30.1 feet in height ranged between 35 and 63% of the index 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 27 October 2009).

Two repeat tests were performed and the results in **Figure 3** illustrate that there is minor variability in connection capacity between nominal identical tests. This variability is less than ± 10% of the mean peak load criterion required by the NCMA (e.g. maximum variability is 1.8%) and is likely the result of small differences in the setting up of the blocks, compaction of the granular infill, and laying out of the geogrid reinforcement. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves. The reduced connection capacity at lower surcharge loads may be due to the combined effect of lower surcharge pressure and more grid slippage.

There was evidence of slippage of the geogrid within the concrete block-geogrid interface in all tests. Geogrid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces. The amount of slippage was seen to diminish with an increase in wall height.

Implications to Keystone Compac III design and construction with Miragrid 5XT geogrid

The long-term design connection strength 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 4** is controlled by the 3/4 inch connection capacity criterion.

The design capacity envelope illustrated in **Figure 4** 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 geogrid and blocks in order to minimize abrasion to the geogrid and to maximize the frictional resistance that is developed at the concrete block-geogrid 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-geogrid interface, pinching of the geogrid 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 connection performance of Keystone Compac III modular block facing units in combination with Miragrid 5XT geogrid. The following conclusions can be drawn:

1. The peak connection strength between Keystone Compac III units and Miragrid 5XT geogrid for walls between 5.0 and 30.1 feet in height ranged between 35 and 63% of the index 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 27 October 2009).
2. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves.
3. Care must be taken during the installation of Keystone Compac III units in order to prevent accumulation of soil and rock debris at the concrete block-geogrid interface surfaces. This debris may significantly reduce the capacity of the Keystone Compac III facing unit-geogrid system.

4. The design envelope in **Figure 4** 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 4**.

P. Clarabut

R. J. Bathurst, Ph.D., P. Eng.

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:

Keystone III (Light) modular block unit - Miragrid 5XT geogrid connection

Test number	normal load (lb/ft)	approximate wall height (feet)	approximate number of blocks	tensile capacity (lb/ft) at 3/4 inch displacement	peak tensile capacity (lb/ft)
1	1681	15.0	22.4	1533	2566
2	559	5.0	7.5	918	1644
3	3380	30.1	45.1	1759	2979
4	1688	15.0	22.5	1507	2484
5	1117	9.9	14.9	1318	2264
6	2245	20.0	30.0	1774	2773
7	1695	15.1	22.6	1615	2511
8	2802	24.9	37.4	2052	2931

LEGEND

1	Keystone Compac III	6	guide rail	11	platform
2	Miragrid 5XT geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamp	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

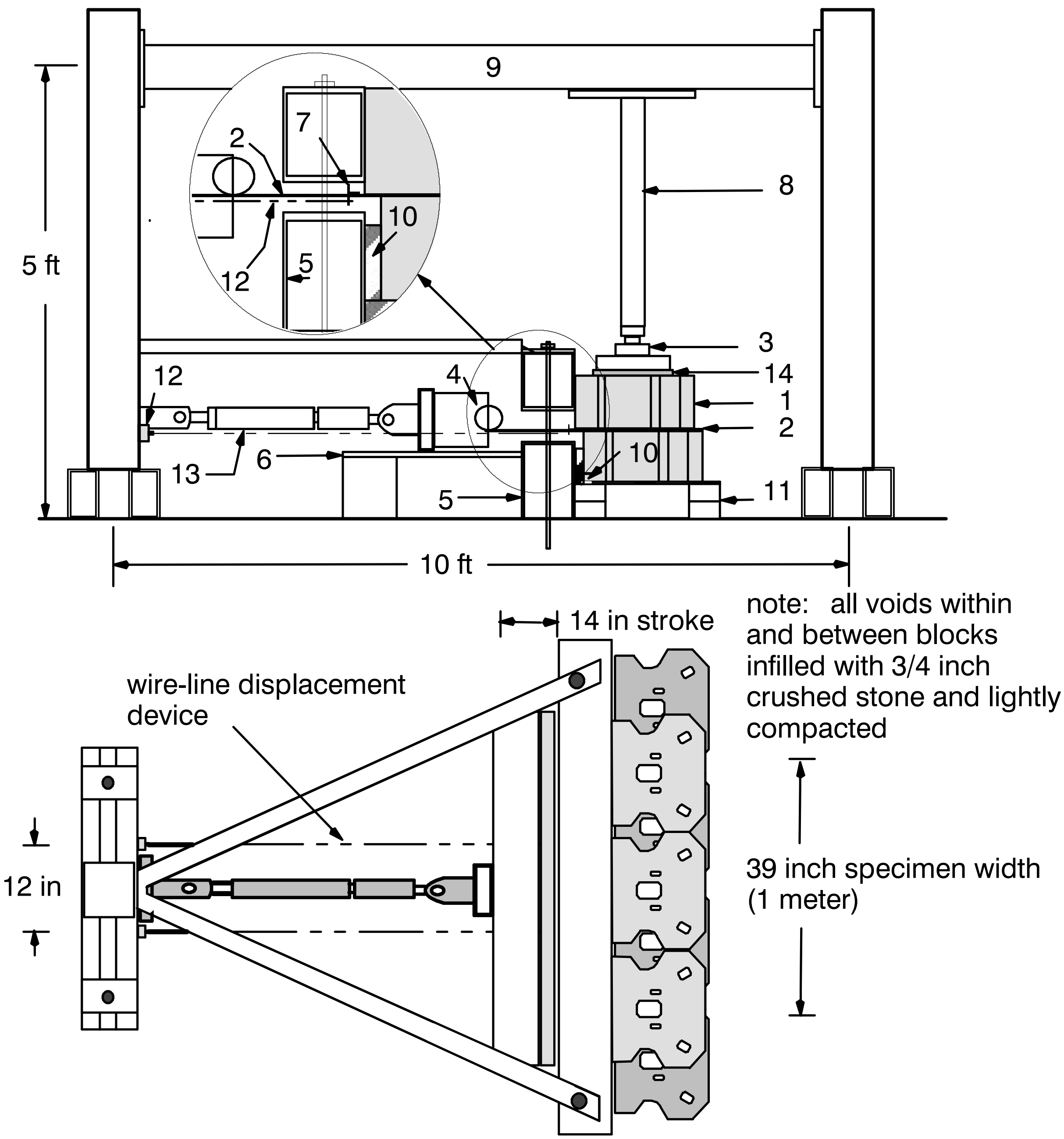


Figure 1: Schematic of connection test apparatus showing Keystone Compac III block units and Miragrid 5XT geogrid reinforcement

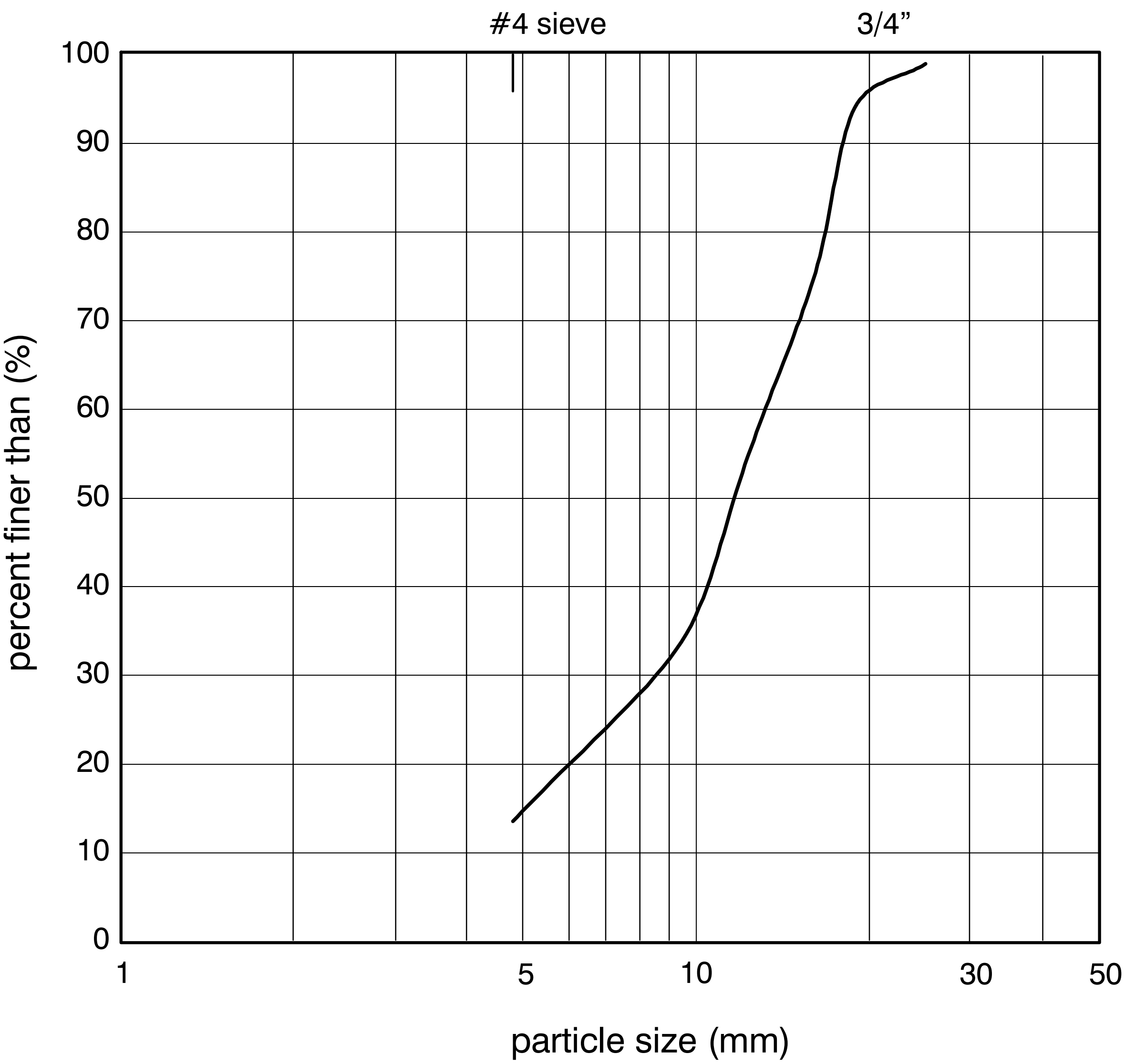


Figure 2: Particle size distribution for 100% crushed granular stone used in Keystone Compac III block tests

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

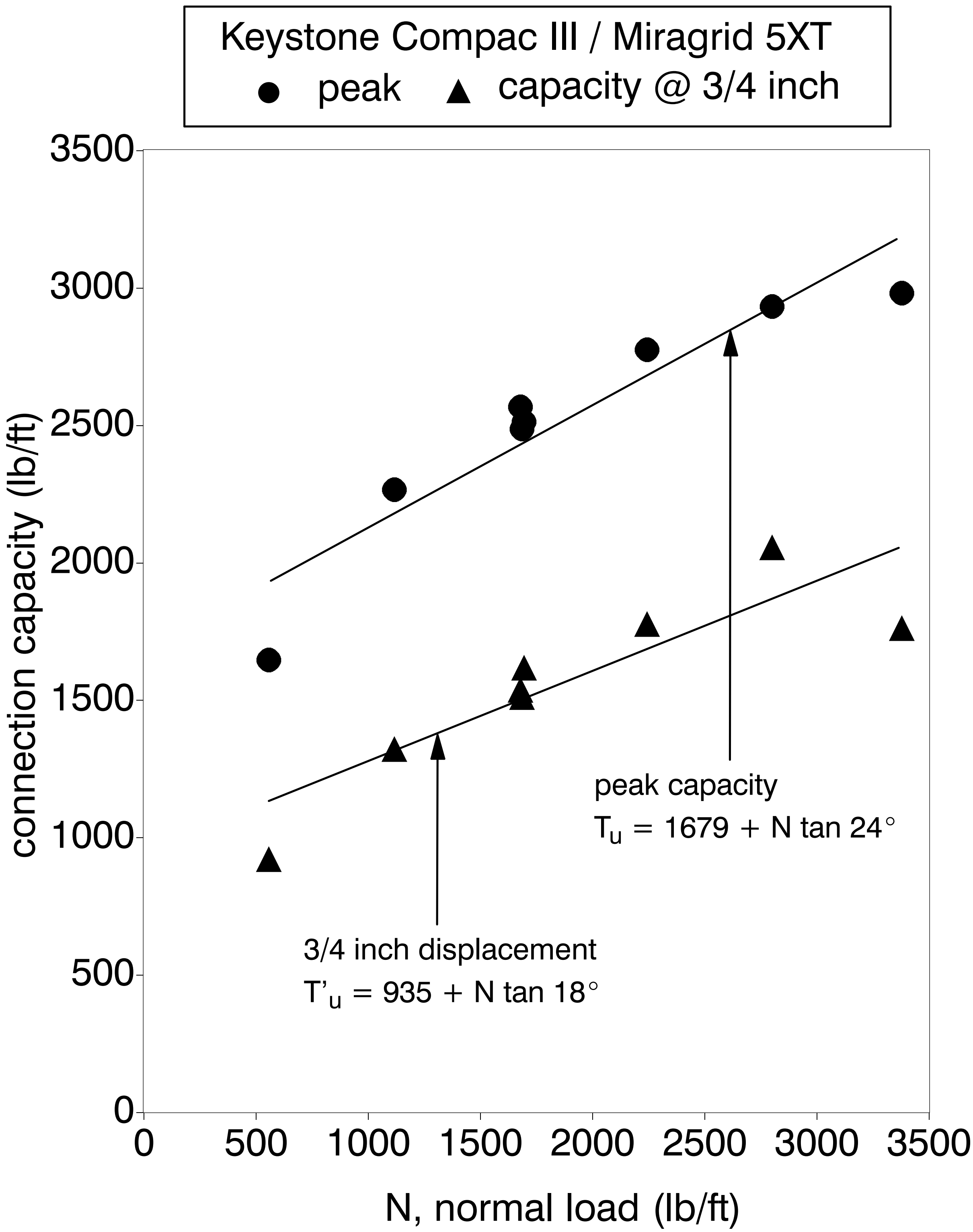


Figure 3: Summary of connection capacities for Keystone Compac III and Miragrid 5XT geogrid combination

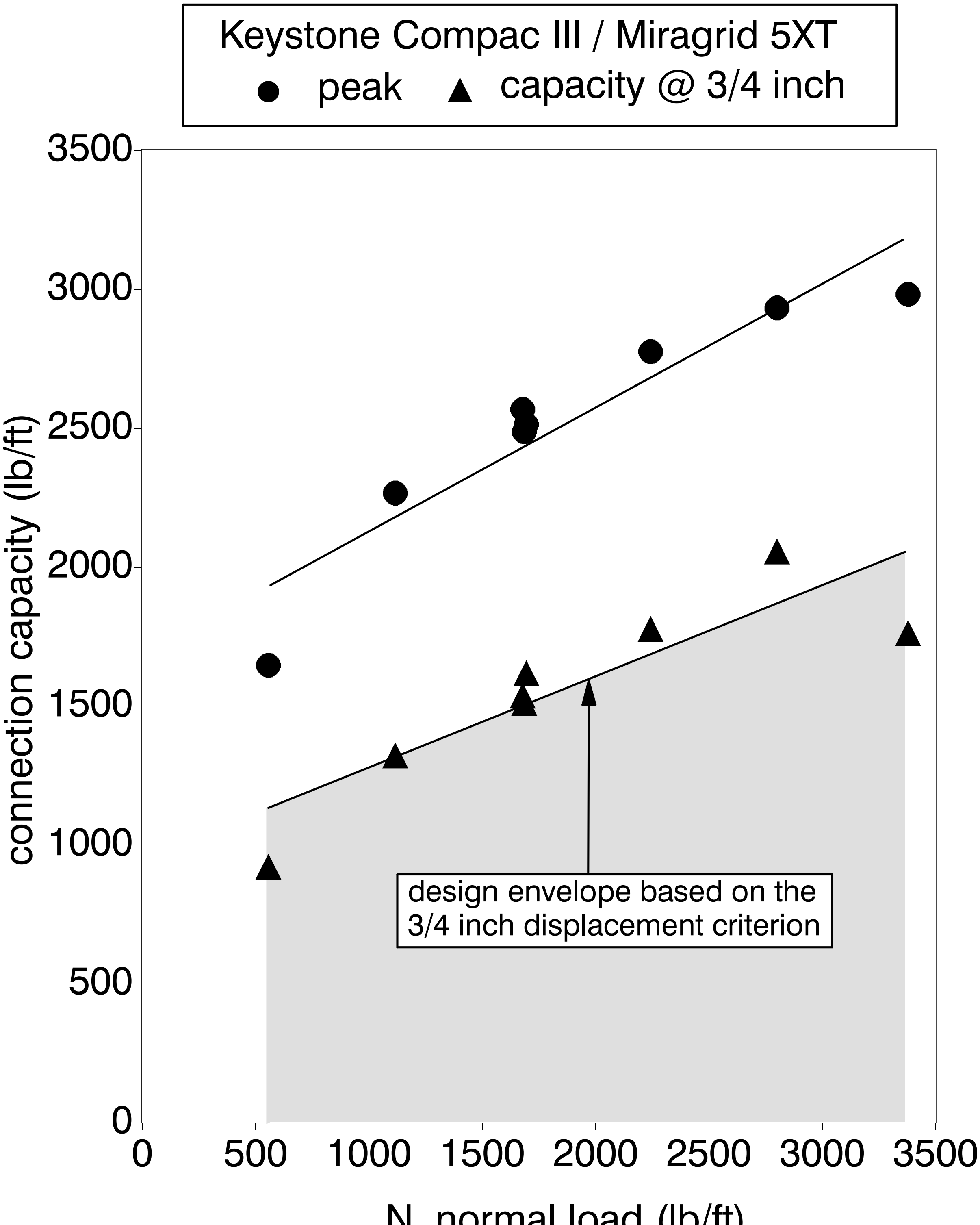


Figure 4: Preliminary design capacity envelope for Keystone Compac III / Miragrid 5XT geogrid combination

Series # BCGT2535

REPORT

RESULTS OF KEYSTONE COMPAC III WITH MIRAGRID 7XT GEOGRID CONNECTION CAPACITY TESTING

submitted to

Keystone Retaining Wall Systems

CONFIDENTIAL

Distribution:

2 copies Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435
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 performance of the connection between Keystone Compac III® (Light) modular concrete block units and Miragrid 7XT geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 27 July 2009.

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 Keystone Compac III concrete block units and Miragrid 7XT geogrid was investigated using a large-scale connection test apparatus.

The principal objective of the testing was to evaluate the 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 Keystone Compac III blocks in combination with Miragrid 7XT geogrid.

Materials

Keystone Compac III blocks are hollow concrete blocks weighing approximately 90 pounds per unit (weight/unit measured in our laboratory) which are normally filled with a select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. The installation arrangement is illustrated in **Figure 1**. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 13 April 2007 and designated as BIC 07-017.

Miragrid 7XT is a bi-directional geogrid composed of 100% polyester multifilament yarn with a tensile strength of 5900 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009). The geogrid specimens used in this series of testing were cut from roll/lot # 031062656 / 06334-1-4 received at our laboratory on 8 December 2006.

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 description 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. Strips of geogrid reinforcement 39 inches (1 meter) wide were attached to a roller clamp and the geogrid extended over the facing block. The next course was then placed over the geogrid simulating the technique that would be used in the field. The hollow portions of each block and spaces between blocks were infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 2** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the geogrid to measure geogrid displacement at the back of the block. Wall heights were simulated by placing one block course over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. A gum rubber mat was placed over the top layer of blocks to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inches/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 strength due to longitudinal geogrid member failure. Following each test, the blocks were removed and the geogrid examined to confirm failure modes. A virgin specimen of geogrid 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 and after 3/4 inch displacement is given in **Figure 3**.

The peak connection strength between Keystone Compac III units and Miragrid 7XT for walls between 4.9 and 30.1 feet in height ranged between 27 and 57% of the index tensile strength of 5900 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009).

Two repeat tests were performed and the results in **Figure 3** illustrate that there is minor variability in connection capacity between nominal identical tests. This variability is less than ± 10% of the mean peak load criterion required by the NCMA (e.g. maximum variability is 3.3%) and is likely the result of small differences in the setting up of the blocks, compaction of the granular infill, and laying out of the geogrid reinforcement. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves. The reduced connection capacity at lower surcharge loads may be due to the combined effect of lower surcharge pressure and more grid slippage.

There was evidence of slippage of the geogrid within the concrete block-geogrid interface in all tests. Geogrid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces. The amount of slippage was seen to diminish with an increase in wall height.

Implications to Keystone Compac III design and construction with Miragrid 7XT geogrid

The long-term design connection strength 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 4** is controlled by the 3/4 inch connection capacity criterion.

The design capacity envelope illustrated in **Figure 4** 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 geogrid and blocks in order to minimize abrasion to the geogrid and to maximize the frictional resistance that is developed at the concrete block-geogrid 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-geogrid interface, pinching of the geogrid 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 connection performance of Keystone Compac III modular block facing units in combination with Miragrid 7XT geogrid. The following conclusions can be drawn:

1. The peak connection strength between Keystone Compac III units and Miragrid 7XT geogrid for walls between 4.9 and 30.1 feet in height ranged between 27 and 57% of the index tensile strength of 5900 lb/ft in the machine direction (based on ASTM D 6637 method of test and reported on the manufacturers' website - www.tencate.com on 27 October 2009).
2. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves.
3. Care must be taken during the installation of Keystone Compac III units in order to prevent accumulation of soil and rock debris at the concrete block-geogrid interface surfaces. This debris may significantly reduce the capacity of the Keystone Compac III facing unit-geogrid system.

4. The design envelope in **Figure 4** 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 4**.

P. Clarabut

R. J. Bathurst, Ph.D., P. Eng.

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.

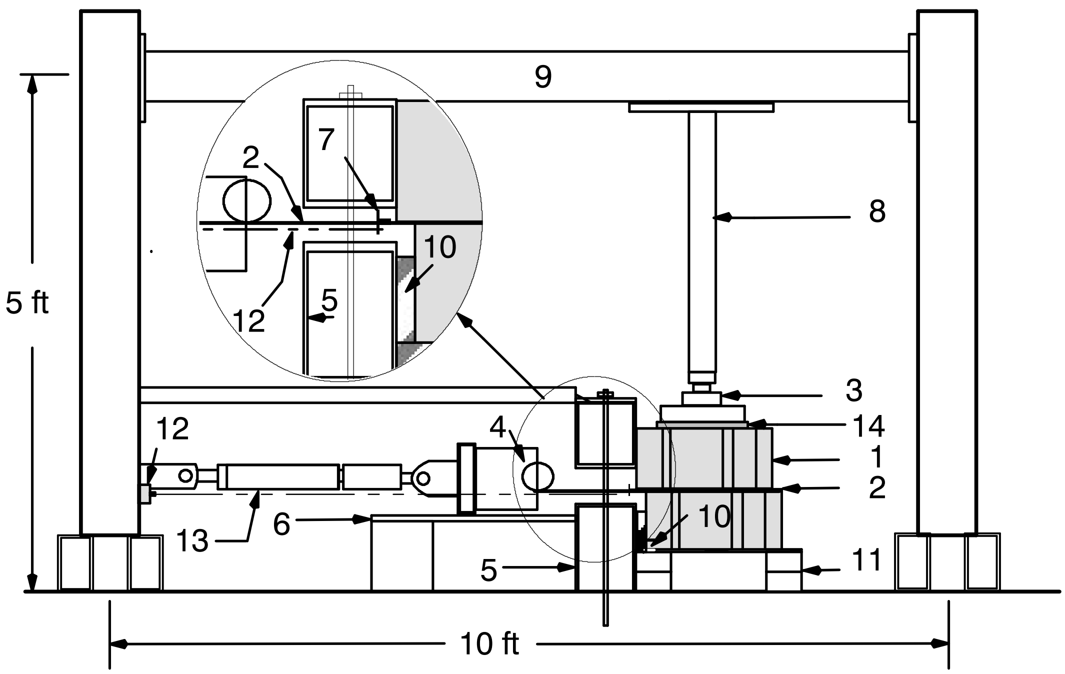
Table 1

Test Program:
Keystone III (Light) modular block unit - Miragrid 7XT geogrid connection

Test number	normal load (lb/ft)	approximate wall height (feet)	approximate number of blocks	tensile capacity (lb/ft) at 3/4 inch displacement	peak tensile capacity (lb/ft)
1	1688	15.0	22.5	1633	2491
2	553	4.9	7.4	1066	1576
3	3380	30.1	45.1	2017	3337
4	1681	15.0	22.4	1528	2394
5	1124	10.0	15.0	1337	2202
6	2245	20.0	30.0	1827	2669
7	1681	15.0	22.4	1656	2539
8	2809	25.0	37.5	1904	2931

LEGEND

1	Keystone Compac III	6	guide rail	11	platform
2	Miragrid 7XT geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamp	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat



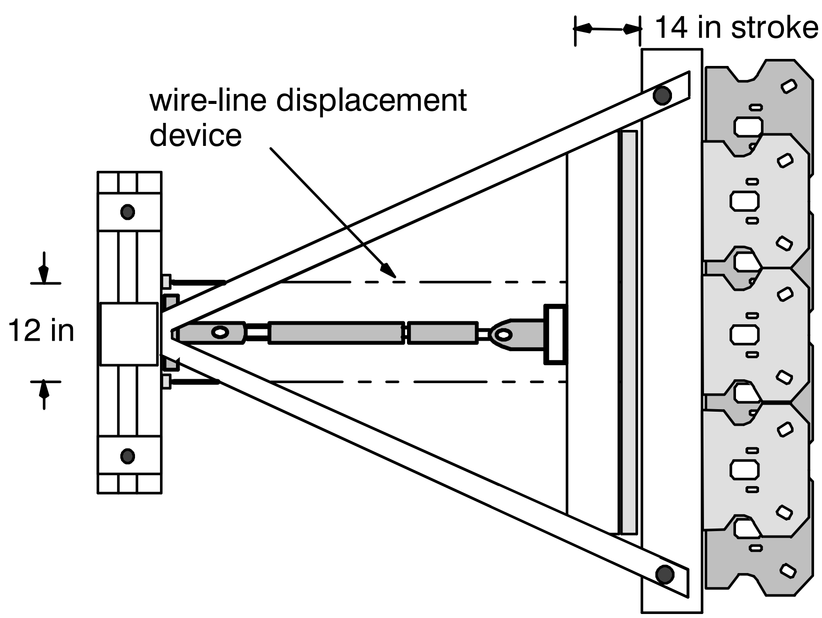


Figure 1: Schematic of connection test apparatus showing Keystone Compac III block units and Miragrid 7XT geogrid reinforcement

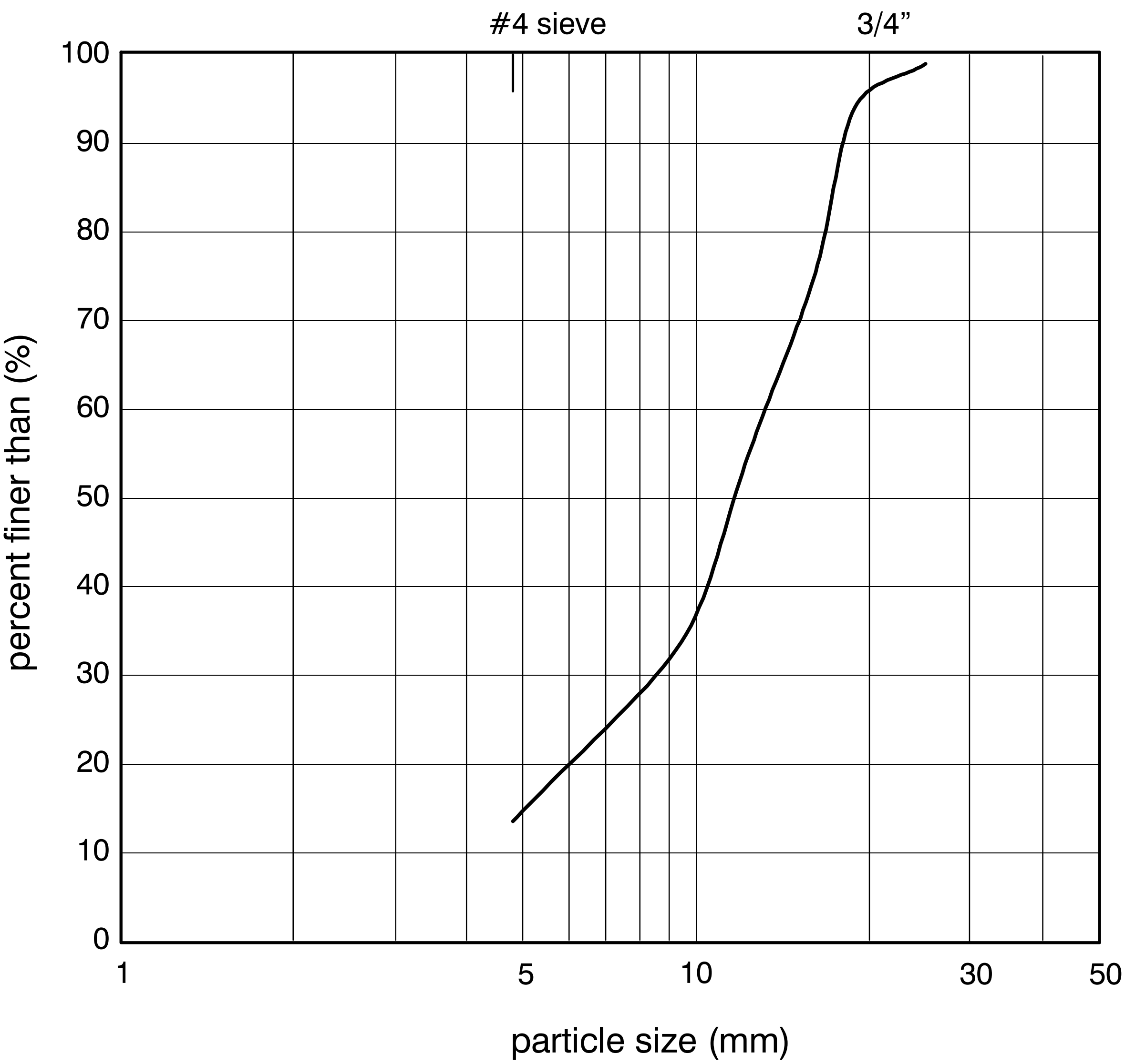


Figure 2: Particle size distribution for 100% crushed granular stone used in Keystone Compac III block tests

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

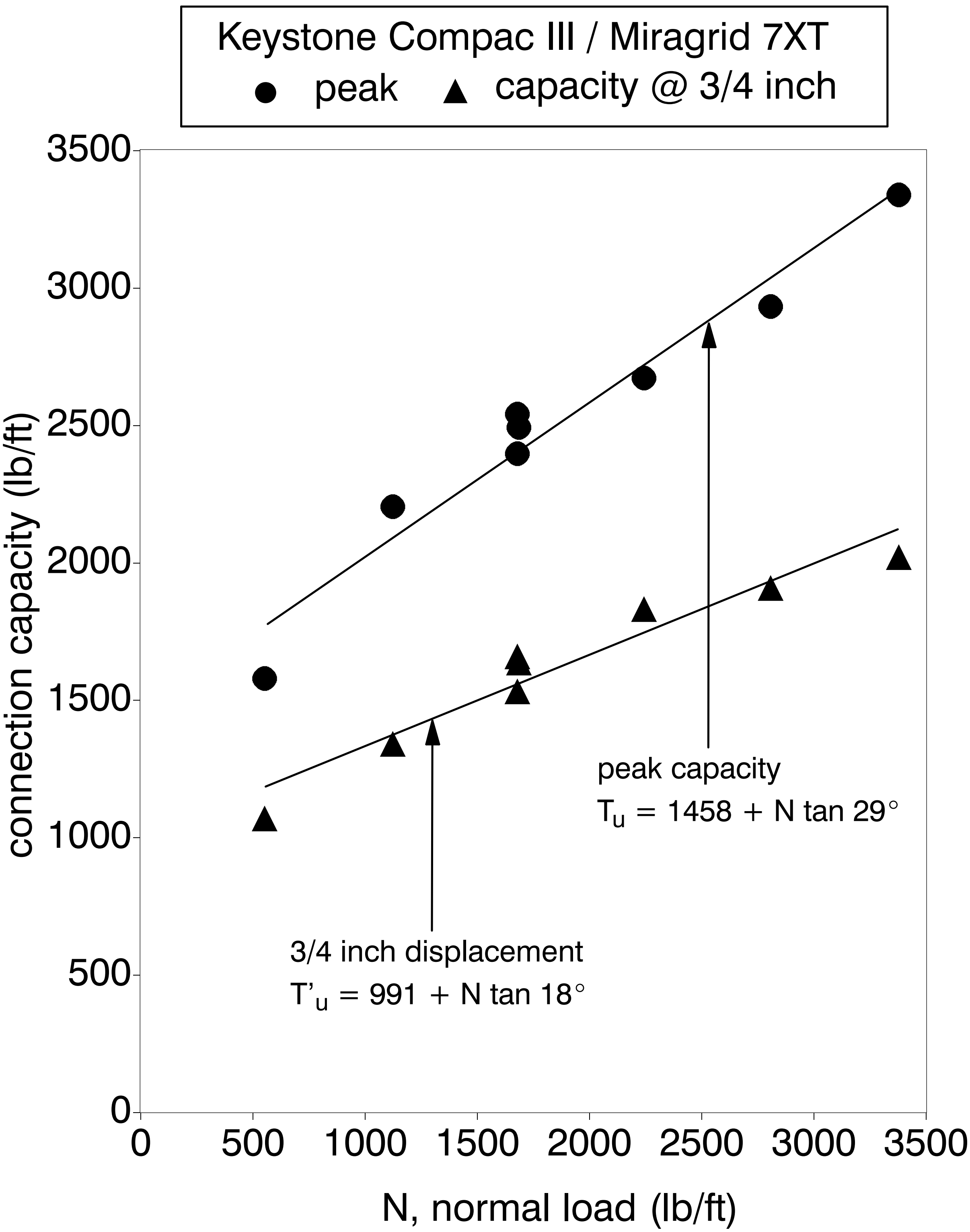


Figure 3: Summary of connection capacities for Keystone Compac III and Miragrid 7XT geogrid combination

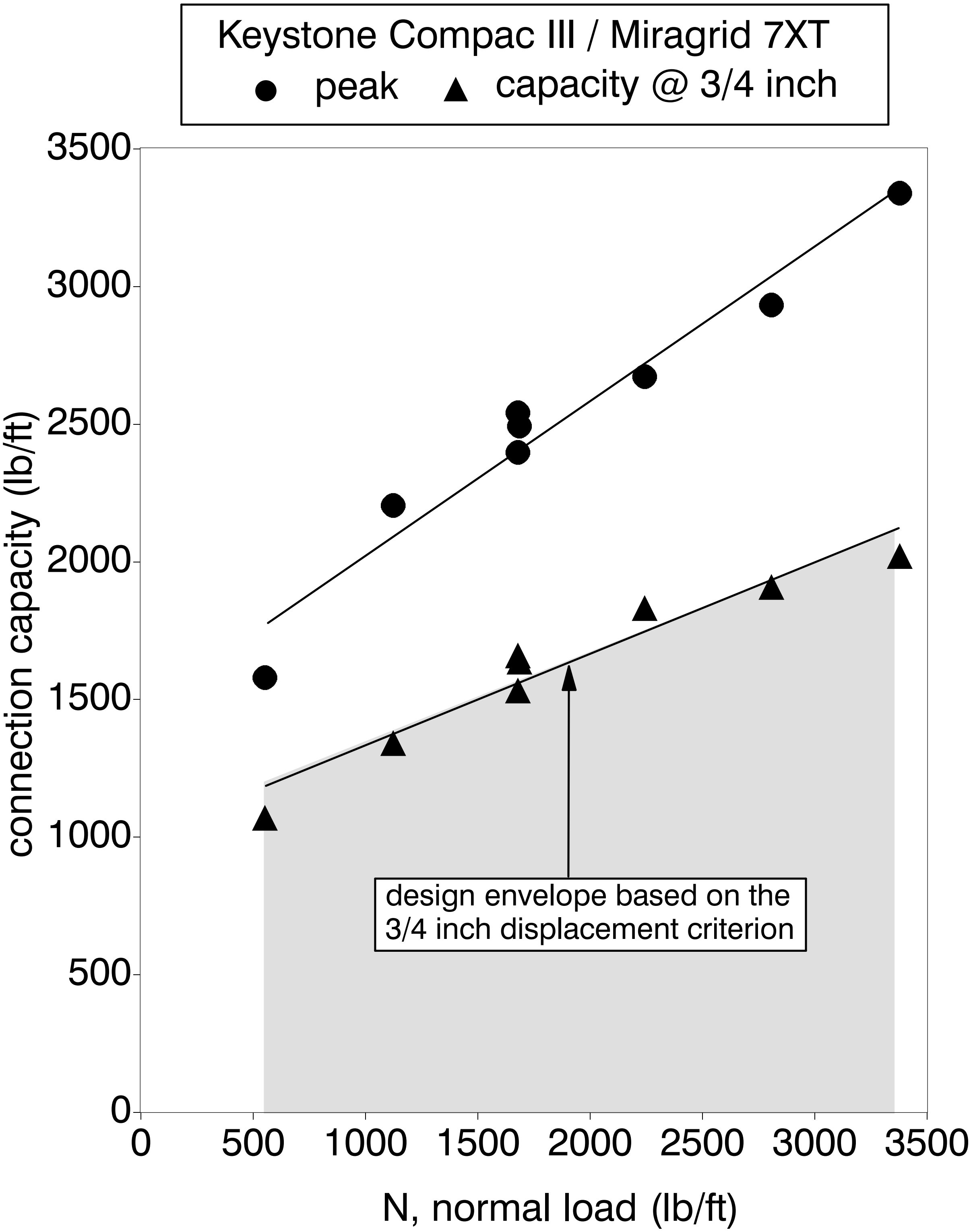


Figure 4: Preliminary design capacity envelope for Keystone Compac III / Miragrid 7XT geogrid combination

REPORT

RESULTS OF
KEYSTONE COMPAC III
WITH MIRAGRID 8XT GEOGRID
CONNECTION CAPACITY TESTING

submitted to

Keystone Retaining Wall Systems

CONFIDENTIAL

Distribution:

2 copies Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435
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 performance of the connection between Keystone Compac III® (Light) modular concrete block units and Miragrid 8XT geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 27 July 2009.

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 Keystone Compac III 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 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 Keystone Compac III blocks in combination with Miragrid 8XT geogrid.

Materials

Keystone Compac III blocks are hollow concrete blocks weighing approximately 90 pounds per unit (weight/unit measured in our laboratory) which are normally filled with a select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. The installation arrangement is illustrated in **Figure 1**. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 13 April 2007 and designated as BIC 07-017.

Miragrid 8XT is a bi-directional geogrid 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 27 October 2009). The geogrid specimens used in this series of testing were cut from roll/lot # 031109345 / 08288-1-1 received at our laboratory on 29 April 2009.

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 description 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. Strips of geogrid reinforcement 39 inches (1 meter) wide were attached to a roller clamp and the geogrid extended over the facing block. The next course was then placed over the geogrid simulating the technique that would be used in the field. The hollow portions of each block and spaces between blocks were infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 2** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the geogrid to measure geogrid displacement at the back of the block. Wall heights were simulated by placing one block course over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. A gum rubber mat was placed over the top layer of blocks to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inches/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 strength due to longitudinal geogrid member failure. Following each test, the blocks were removed and the geogrid examined to confirm failure modes. A virgin specimen of geogrid 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 and after 3/4 inch displacement is given in **Figure 3**.

The peak connection strength between Keystone Compac III units and Miragrid 8XT for walls between 5.0 and 30.1 feet in height ranged between 22 and 49% of the index 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 27 October 2009).

Two repeat tests were performed and the results in **Figure 3** illustrate that there is some variability in connection capacity between nominal identical tests. This variability is less than ± 10% of the mean peak load criterion required by the NCMA (e.g. maximum variability is 3.5%) and is likely the result of small differences in the setting up of the blocks, compaction of the granular infill, and laying out of the geogrid reinforcement. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves. The reduced connection capacity at lower surcharge loads may be due to the combined effect of lower surcharge pressure and more grid slippage.

There was evidence of slippage of the geogrid within the concrete block-geogrid interface in all tests. Geogrid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces. The amount of slippage was seen to diminish with an increase in wall height.

Implications to Keystone Compac III design and construction with Miragrid 8XT geogrid

The long-term design connection strength 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 4** is controlled by the peak connection capacity criterion.

The design capacity envelope illustrated in **Figure 4** 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 geogrid and blocks in order to minimize abrasion to the geogrid and to maximize the frictional resistance that is developed at the concrete block-geogrid 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-geogrid interface, pinching of the geogrid 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 connection performance of Keystone Compac III modular block facing units in combination with Miragrid 8XT geogrid. The following conclusions can be drawn:

1. The peak connection strength between Keystone Compac III units and Miragrid 8XT geogrid for walls between 5.0 and 30.1 feet in height ranged between 22 and 49% of the index 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 27 October 2009).
2. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves.
3. Care must be taken during the installation of Keystone Compac III units in order to prevent accumulation of soil and rock debris at the concrete block-geogrid interface surfaces. This debris may significantly reduce the capacity of the Keystone Compac III facing unit-geogrid system.

4. The design envelope in **Figure 4** 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 4**.

P. Clarabut

R. J. Bathurst, Ph.D., P. Eng.

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:
Keystone III (Light) modular block unit - Miragrid 8XT geogrid connection

Test number	normal load (lb/ft)	approximate wall height (feet)	approximate number of blocks	tensile capacity (lb/ft) at 3/4 inch displacement	peak tensile capacity (lb/ft)
1	1688	15.0	22.5	1873	2580
2	3380	30.1	45.1	2516	3646
3	559	5.0	7.5	1117	1644
4	1695	15.1	22.6	1818	2683
5	1124	10.0	15.0	1510	2181
6	2238	19.9	29.9	2134	3000
7	1688	15.0	22.5	2010	2759
8	2816	25.1	37.6	2338	3461

LEGEND

1	Keystone Compac III	6	guide rail	11	platform
2	Miragrid 8XT geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamp	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

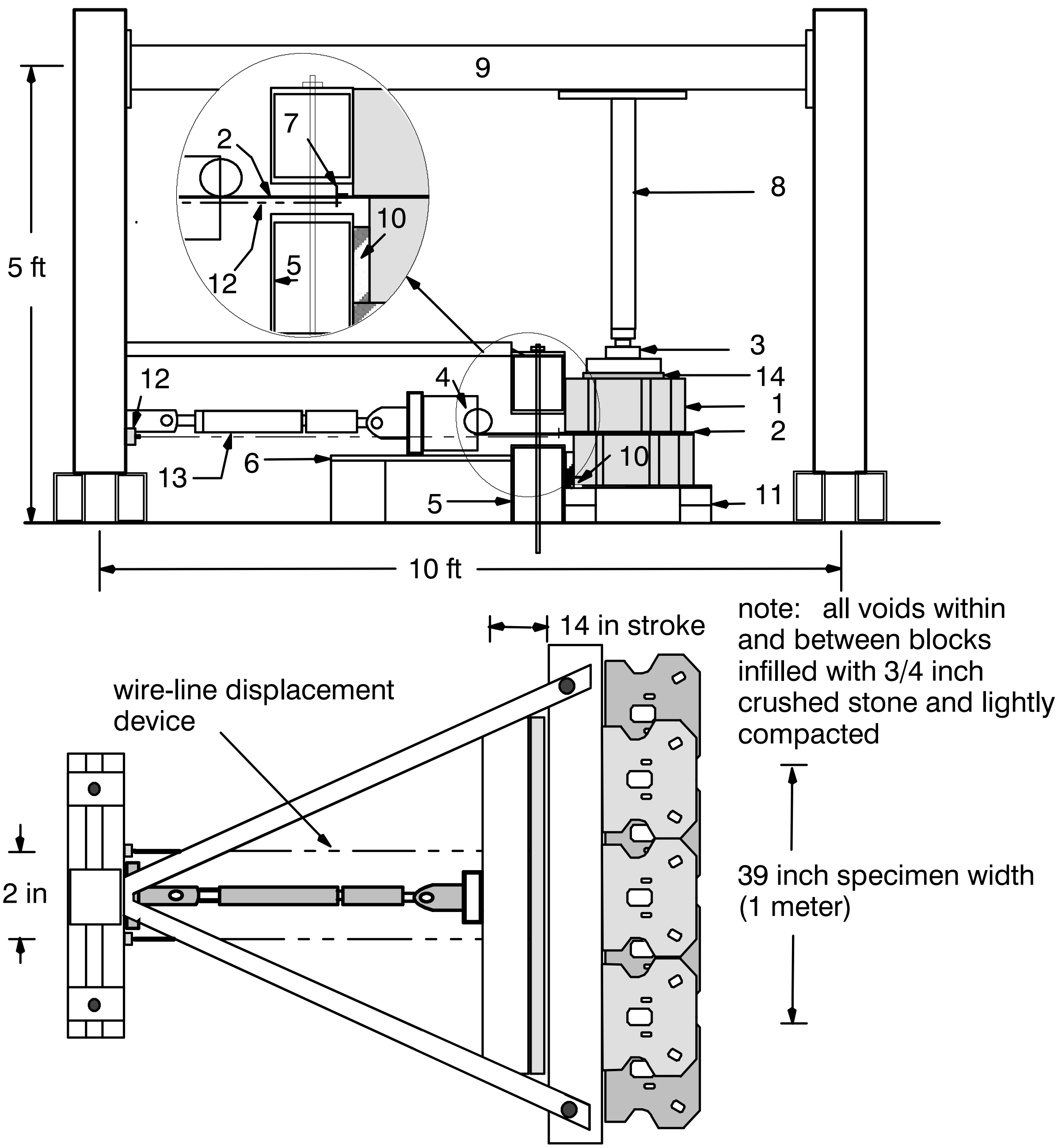


Figure 1: Schematic of connection test apparatus showing Keystone Compac III block units and Miragrid 8XT geogrid reinforcement

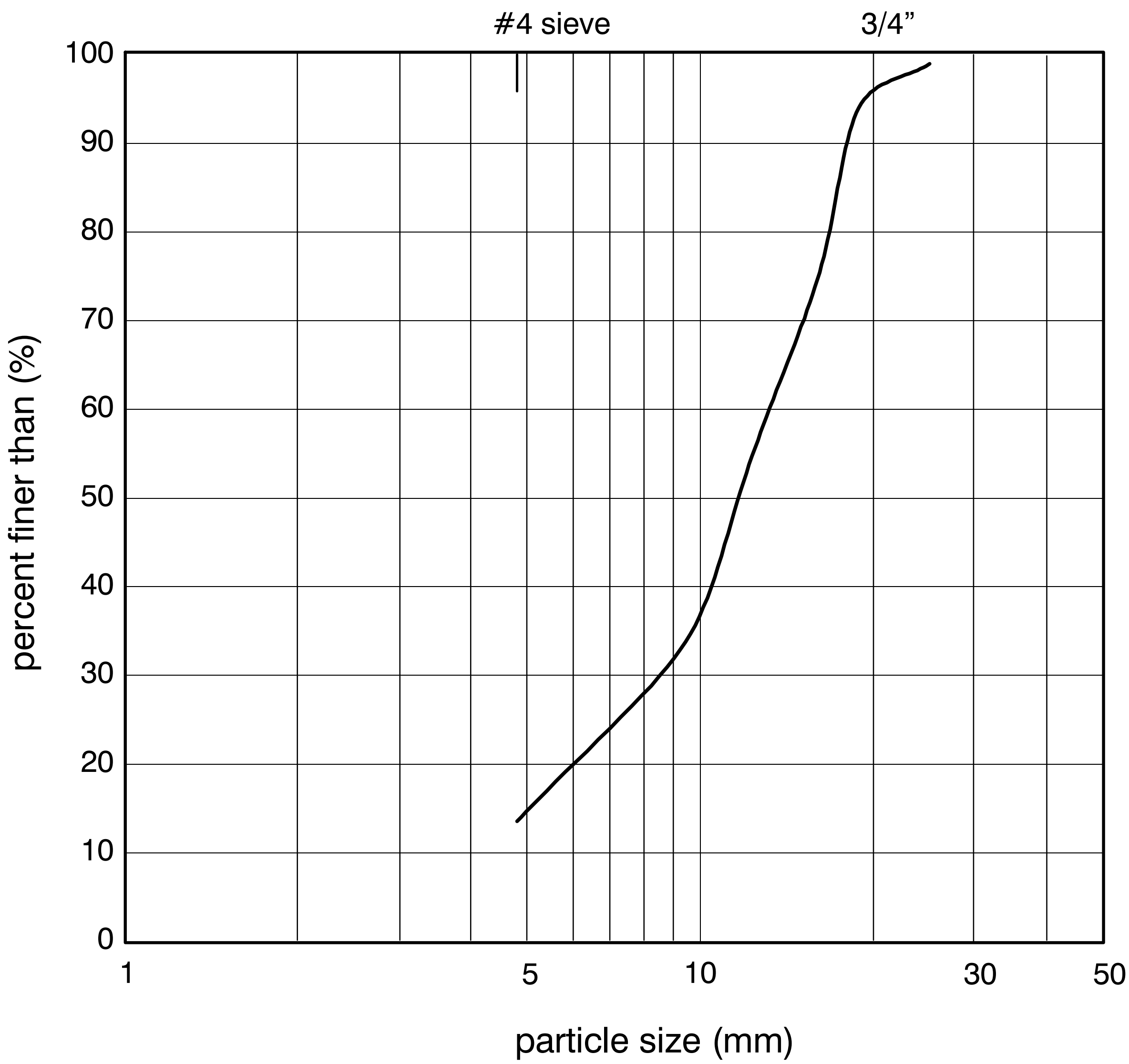


Figure 2: Particle size distribution for 100% crushed granular stone used in Keystone Compac III block tests

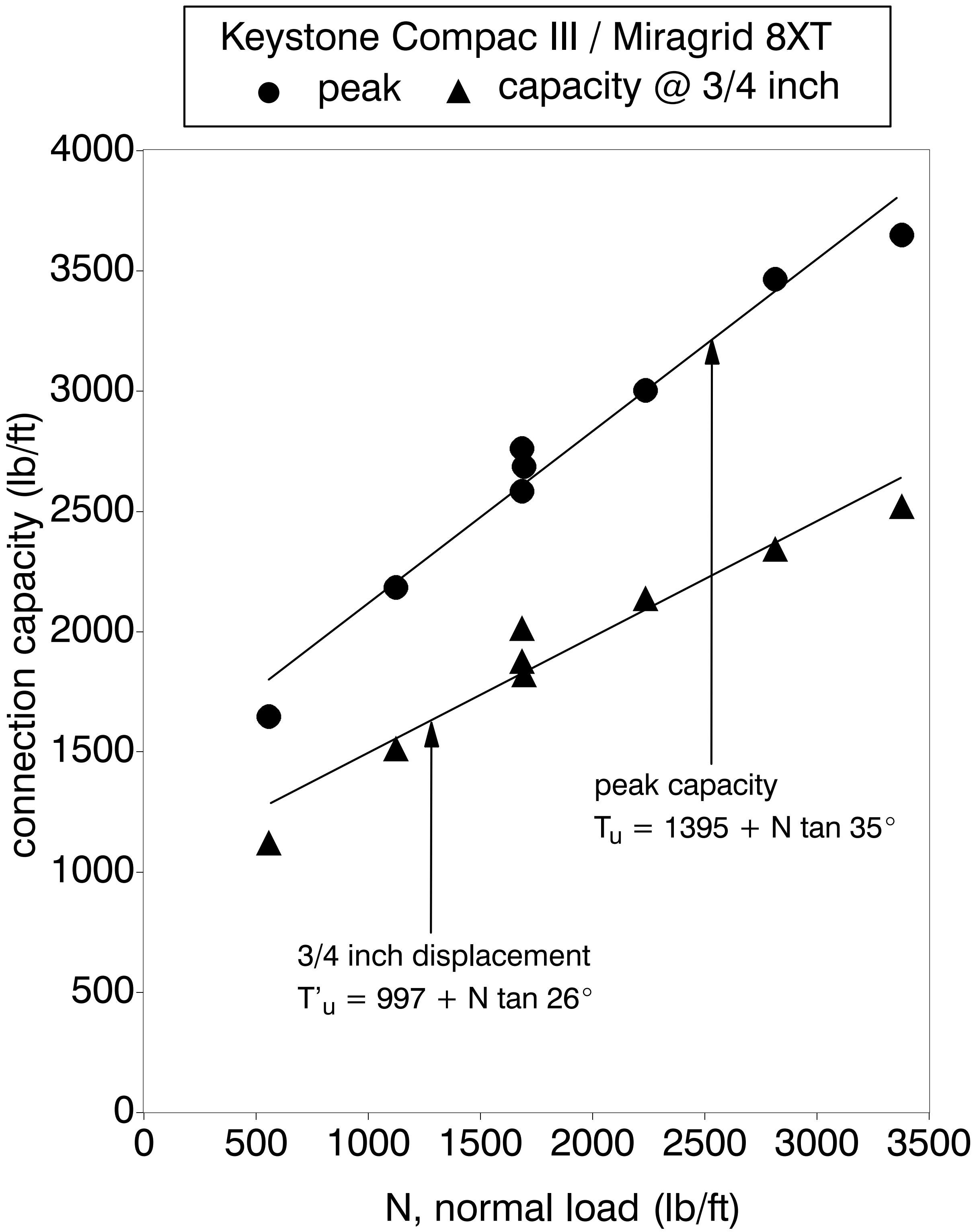


Figure 3: Summary of connection capacities for Keystone Compac III and Miragrid 8XT geogrid combination

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

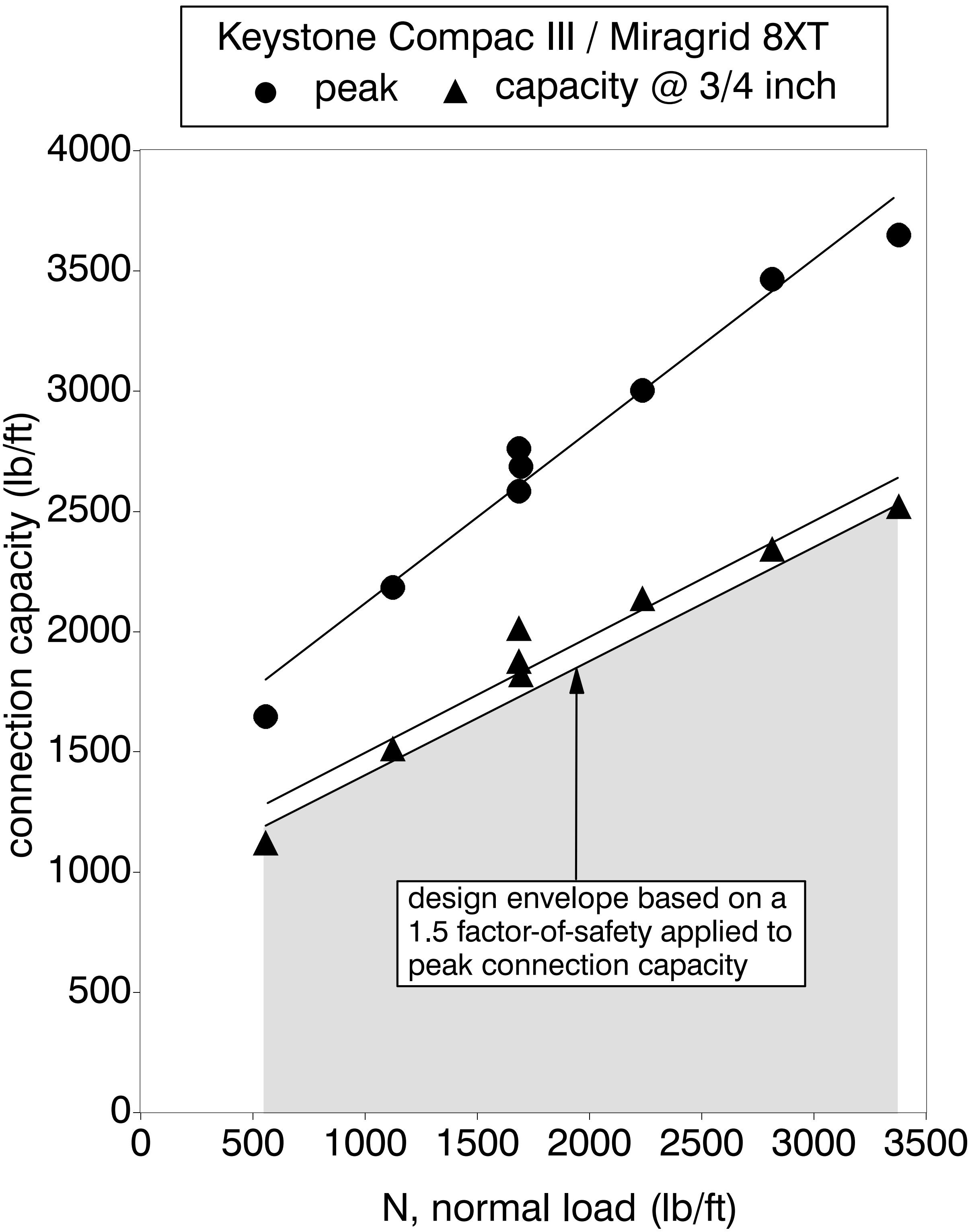


Figure 4: Preliminary design capacity envelope for Keystone Compac III / Miragrid 8XT geogrid combination

REPORT

RESULTS OF KEYSTONE COMPAC III WITH MIRAGRID 10XT GEOGRID CONNECTION CAPACITY TESTING

submitted to

Keystone Retaining Wall Systems

CONFIDENTIAL

Distribution:

2 copies Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435
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 performance of the connection between Keystone Compac III® (Light) modular concrete block units and Miragrid 10XT geogrid.

The test program was initiated in response to a verbal authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 27 July 2009.

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 Keystone Compac III 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 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 Keystone Compac III blocks in combination with Miragrid 10XT geogrid.

Materials

Keystone Compac III blocks are hollow concrete blocks weighing approximately 90 pounds per unit (weight/unit measured in our laboratory) which are normally filled with a select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. The installation arrangement is illustrated in **Figure 1**. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 13 April 2007 and designated as BIC 07-017.

Miragrid 10XT is a bi-directional geogrid 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 27 October 2009). The geogrid specimens used in this series of testing were cut from roll/lot # 031109615 / 08296-1-3 received at our laboratory on 6 August 2009.

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 description 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. Strips of geogrid reinforcement 39 inches (1 meter) wide were attached to a roller clamp and the geogrid extended over the facing block. The next course was then placed over the geogrid simulating the technique that would be used in the field. The hollow portions of each block and spaces between blocks were infilled with a 3/4 inch, 100% crushed limestone aggregate and lightly compacted. **Figure 2** illustrates the particle size distribution of the infill used in this test series. Two wire-line LVDT(s) were connected to the geogrid to measure geogrid displacement at the back of the block. Wall heights were simulated by placing one block course over the interface and applying an additional surcharge load using the vertically-oriented hydraulic jack shown in **Figure 1**. A gum rubber mat was placed over the top layer of blocks to ensure a uniform distribution of vertical surcharge pressure. The connection force was applied at a constant rate of displacement (i.e. 0.75 inches/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 strength due to longitudinal geogrid member failure. Following each test, the blocks were removed and the geogrid examined to confirm failure modes. A virgin specimen of geogrid 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 and after 3/4 inch displacement is given in **Figure 3**.

The peak connection strength between Keystone Compac III units and Miragrid 10XT for walls between 5.0 and 30.0 feet in height ranged between 17 and 41% of the index 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 27 October 2009).

Two repeat tests were performed and the results in **Figure 3** illustrate that there is minor variability in connection capacity between nominal identical tests. This variability is less than ± 10% of the mean peak load criterion required by the NCMA (e.g. maximum variability is 2.6%) and is likely the result of small differences in the setting up of the blocks, compaction of the granular infill, and laying out of the geogrid reinforcement. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves. The reduced connection capacity at lower surcharge loads may be due to the combined effect of lower surcharge pressure and more grid slippage.

There was evidence of slippage of the geogrid within the concrete block-geogrid interface in all tests. Geogrid straining and slippage caused abrasion of longitudinal members as the geogrid was pulled across the concrete surfaces. The amount of slippage was seen to diminish with an increase in wall height.

Implications to Keystone Compac III design and construction with Miragrid 10XT geogrid

The long-term design connection strength 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 4** is controlled by the peak connection capacity criterion.

The design capacity envelope illustrated in **Figure 4** 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 geogrid and blocks in order to minimize abrasion to the geogrid and to maximize the frictional resistance that is developed at the concrete block-geogrid 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-geogrid interface, pinching of the geogrid 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 connection performance of Keystone Compac III modular block facing units in combination with Miragrid 10XT geogrid. The following conclusions can be drawn:

1. The peak connection strength between Keystone Compac III units and Miragrid 10XT geogrid for walls between 5.0 and 30.0 feet in height ranged between 17 and 41% of the index 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 27 October 2009).
2. The trends in data for connection capacities at 3/4 inches of displacement and at peak capacities have been plotted using linear curves.
3. Care must be taken during the installation of Keystone Compac III units in order to prevent accumulation of soil and rock debris at the concrete block-geogrid interface surfaces. This debris may significantly reduce the capacity of the Keystone Compac III facing unit-geogrid system.

4. The design envelope in **Figure 4** 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 4**.

P. Clarabut

R. J. Bathurst, Ph.D., P. Eng.

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:
Keystone III (Light) modular block unit - Miragrid 10XT geogrid connection

Test number	normal load (lb/ft)	approximate wall height (feet)	approximate number of blocks	tensile capacity (lb/ft) at 3/4 inch displacement	peak tensile capacity (lb/ft)
1	1695	15.1	22.6	1959	2800
2	559	5.0	7.5	1132	1589
3	1124	10.0	15.0	1622	2339
4	1688	15.0	22.5	2036	2793
5	3373	30.0	45.0	2703	3894
6	2238	19.9	29.9	2255	3089
7	1695	15.1	22.6	2017	2690
8	2809	25.0	37.5	2488	3433

LEGEND

1	Keystone Compac III	6	guide rail	11	platform
2	Miragrid 10XT geogrid	7	LVDT clamp	12	wire-line LVDT
3	loading platen	8	surcharge actuator	13	computer controlled hydraulic actuator
4	roller clamp	9	loading frame		
5	lateral restraining system	10	spacers	14	stiff gum rubber mat

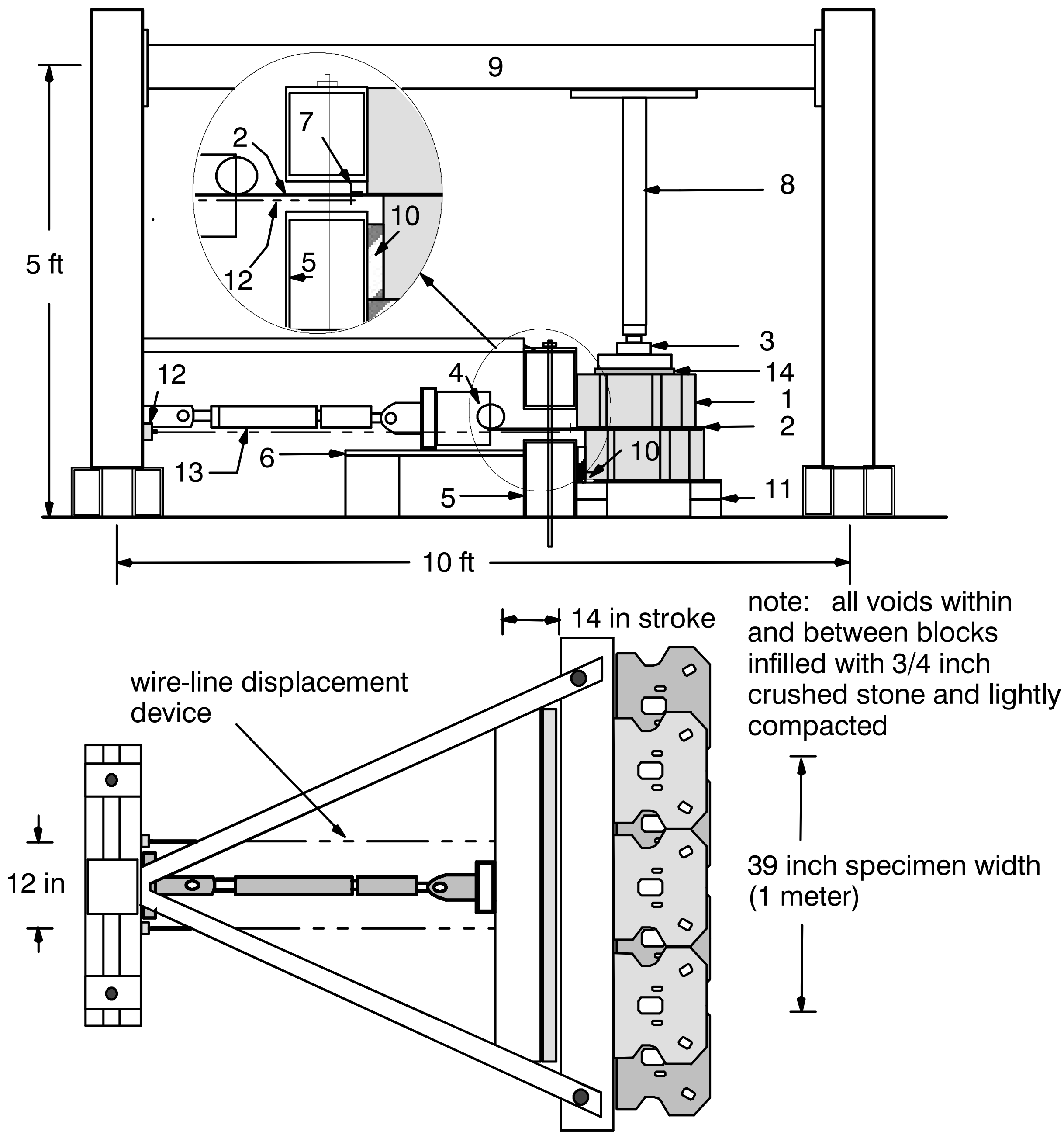


Figure 1: Schematic of connection test apparatus showing Keystone Compac III block units and Miragrid 10XT geogrid reinforcement

Bathurst, Clarabut Geotechnical Testing, Inc. 27 October 2009

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

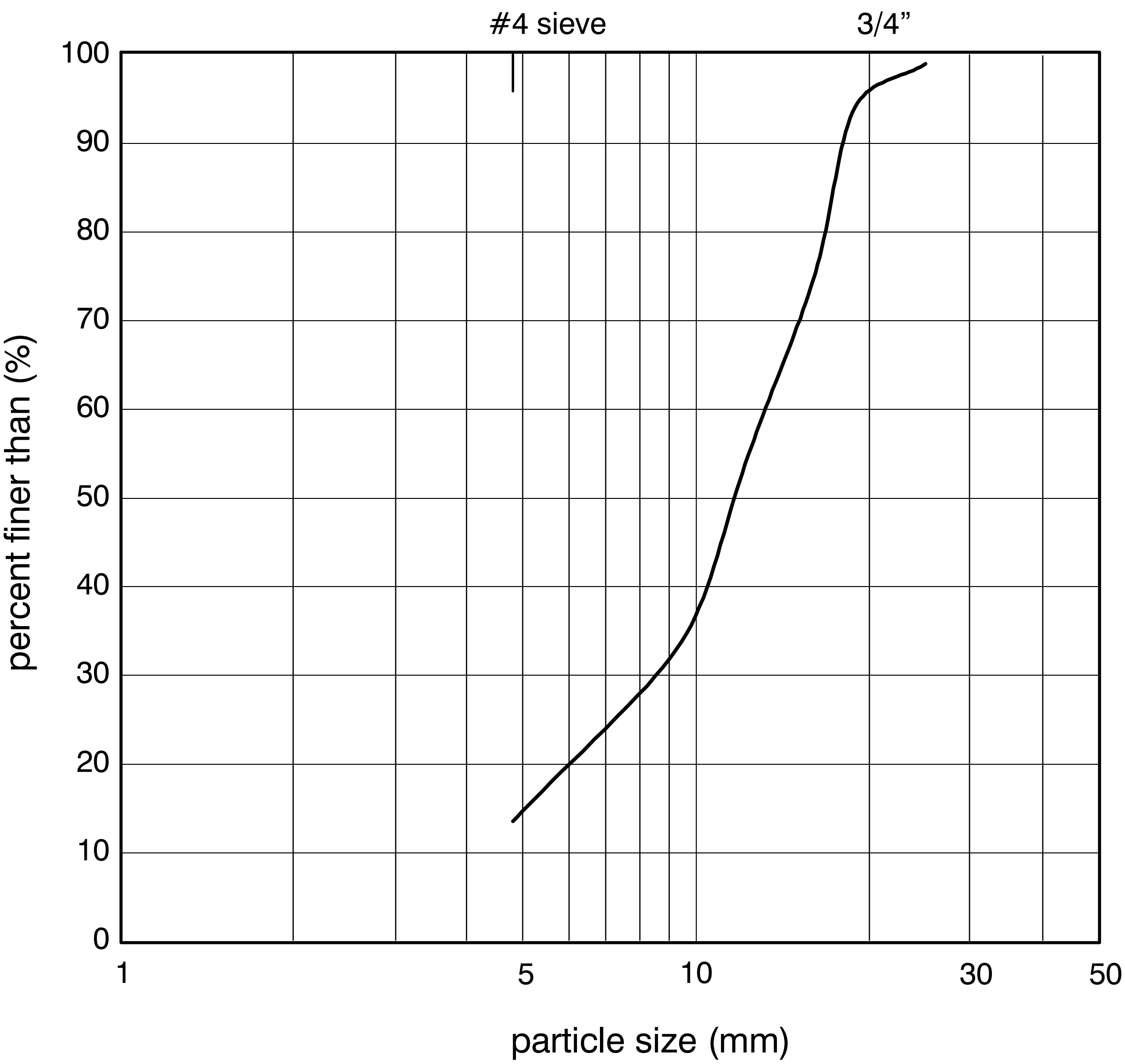


Figure 2: Particle size distribution for 100% crushed granular stone used in Keystone Compac III block tests

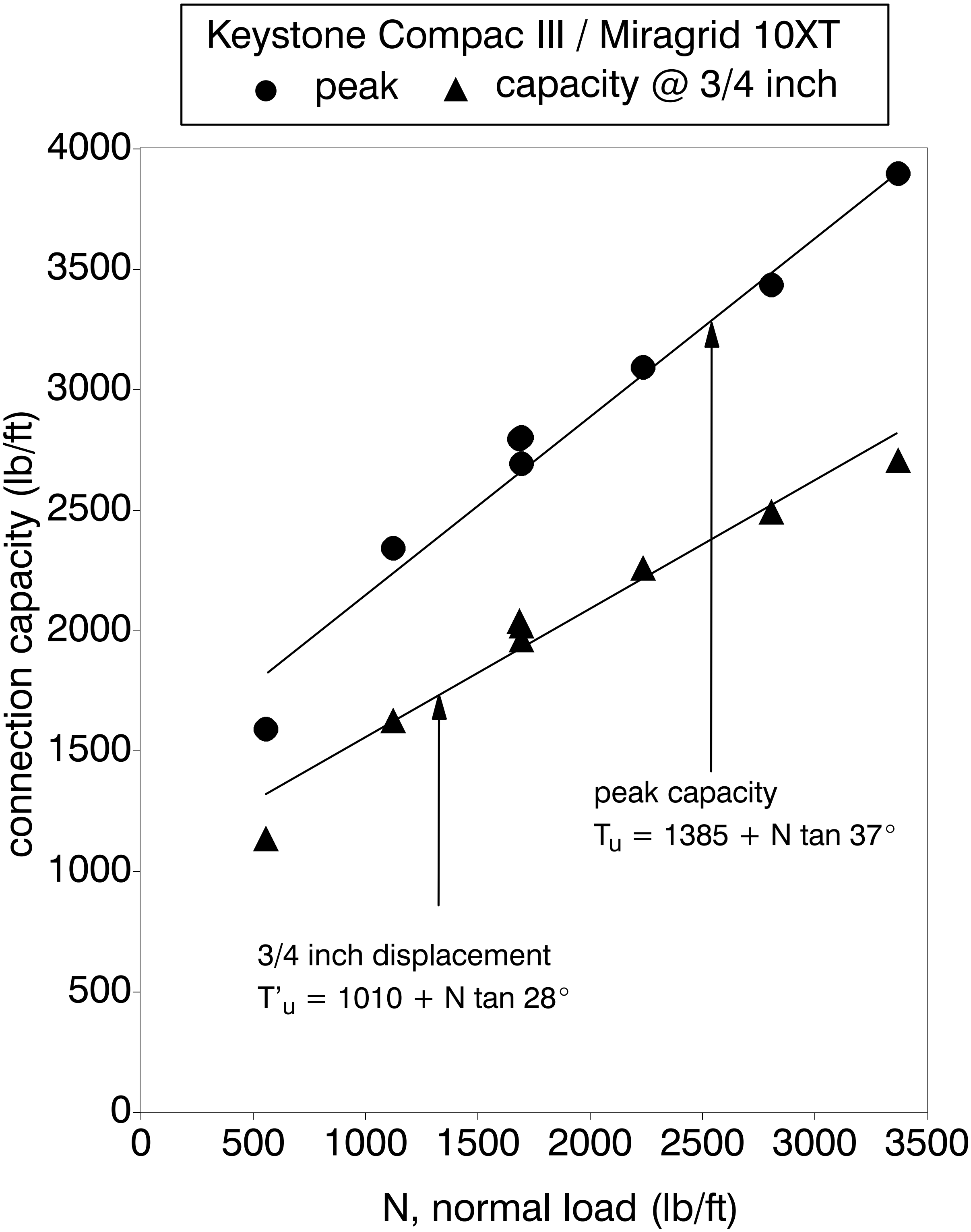


Figure 3: Summary of connection capacities for Keystone Compac III and Miragrid 10XT geogrid combination

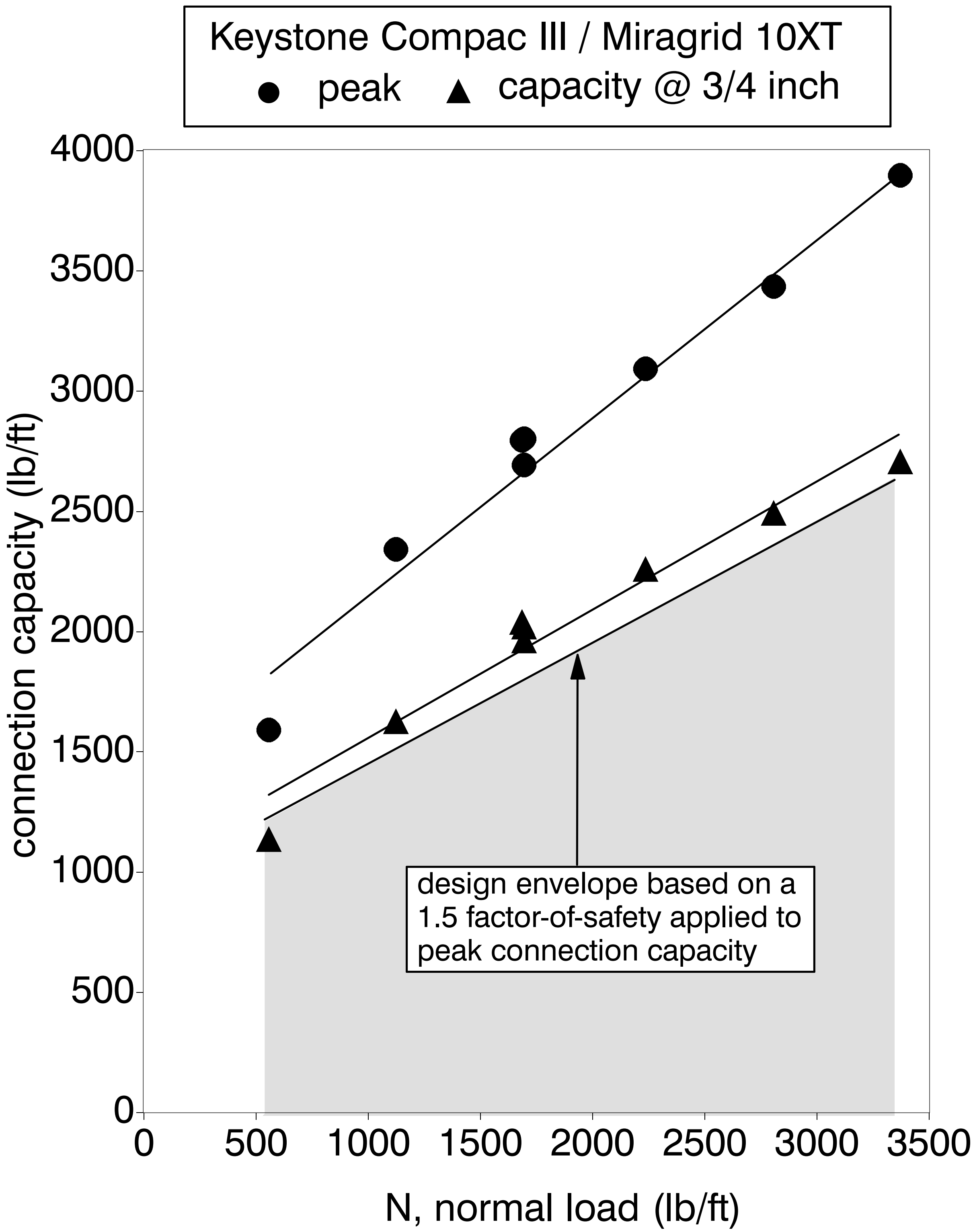


Figure 4: Preliminary design capacity envelope for Keystone Compac III / Miragrid 10XT geogrid combination

REPORT

RESULTS OF

SUSTAINED LOAD CONNECTION TESTING

WITH KEYSTONE COMPAC 3 WALL UNITS

AND MIRAGRID 3XT GEOGRID

Submitted to

KEYSTONE WALL SYSTEMS

CONFIDENTIAL

Distribution:
Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435-5406
USA

TRI Environmental, Inc.
9063 Bee Caves Road
Austin, Texas 78733

October 22, 2014

1. Introduction

This report gives the results of a sustained (constant) load (creep) connection testing program carried out to evaluate the creep mechanical performance of the connection system between Keystone Compac 3 modular concrete blocks and Miragrid 3XT geogrid. The test program was initiated in response to an email authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 15 November 2013. The tests were carried out at the laboratories of TRI Environmental, Inc. in Austin Texas.

2. Methodology

The test program was carried out in general accordance with the procedures outlined by the Federal Highway Administration (2009).

2.1 Index connection tests

A series of reference index connection tests were first carried out using Keystone Compac 3 modular block units in combination with specimens of Miragrid 3XT geogrid. A one block over two block arrangement was used and grid specimens measured 18 inches wide. The results of these tests were used to determine a regressed reference (index) peak capacity for each series of sustained tensile load tests described below.

2.2 Constant load connection tests

A series of constant tensile load tests were carried out under normal loads of 500 lb/ft, 1000 lb/ft and 2000 lb/ft. Different percentages of the reference connection peak load capacity were applied as a tensile load to block-geogrid specimens configured to conform to the index test setup described above. The tensile loads ranged from 88.7 to 102.0% of the reference connection strength at each normal load level. The time to rupture/pullout was recorded for each test (if applicable) and results of the test series plotted as connection load versus log-time to failure. The data was regressed to estimate a linear load-log time creep rupture curve and the regressed line was used to extrapolate test data to an elapsed time corresponding to design lives of 75 and 100 years.

3. Materials

Keystone Compac 3 blocks are hollow concrete blocks weighing approximately 67.0 pounds per unit (weight/unit measured in our laboratory), which are filled with select granular material. A photograph of a Keystone Compac 3 block is shown in **Figure 1**. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. In this investigation the pins were positioned to provide approximately a 1/8 inch wall batter. The installation arrangement is illustrated in **Figure 2**. The hollow portions between the blocks were in-filled with a poorly graded (GP) crushed limestone gravel (AASHTO Classification A-1-a), the particle size distribution curve for this aggregate is presented in **Figure**

3. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 25 November 2013 and designated as TRI-13-009.

Miragrid 3XT is a bi-directional geogrid composed of 100% polyester multifilament yarn with a tensile strength of 3883 lb/ft in the machine direction (based on ASTM D6638 method of test and provided by TRI Environmental on 20 December 2013). The geogrid specimens used in this series of testing were cut from Roll number 031148337 received at our laboratory on 25 November 2013.

4. Test equipment and test procedures

4.1 Reference index tests

The method of test used in this investigation follows in general accordance the guidelines established in ASTM D6638 and FHA (2009). A brief description of the apparatus and test methodology is presented here. The test apparatus used to perform the tests is illustrated in **Figure 4**. 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 bottom blocks were laterally restrained to prevent horizontal movement and the system was surcharged vertically. The hollow sections of the bottom blocks were filled with ¾ inch crushed stone and lightly compacted (**Figure 5**). Strips of grid reinforcement, 18 inches wide (16 longitudinal strands), were attached to a roller clamp and the grid extended over two lower blocks. The geogrid reinforcement was then laid flat over the bottom blocks (**Figure 6**). A single block was then placed over the grid and centered on the joint between the two underlying units as shown in **Figure 7**. An infill containment barrier was placed around the top block allowing the hollow sections to be filled and compacted with crushed stone (**Figures 4** and **8)**. Two wire-line LVDT(s) were connected to the grid to measure grid displacement at the back of the block. Wall heights were simulated by applying an additional surcharge load using the vertically oriented hydraulic jack shown in **Figure 4**. 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 inches/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/pullout. Following each test, the blocks were removed and the grid and blocks examined to confirm failure modes. A virgin specimen of grid was used for each test and any damaged blocks were replaced. Aggregate fill was reused from test to test.

The only variable in this series of connection tests was the magnitude of surcharge load. Block units used in the reference connection load tests and in the sustained load tests were taken from the same pallet of blocks supplied by Keystone Retaining Wall Systems. Specimens of Miragrid 13XT geogrid were trimmed from the same longitudinal section of the roll of grid supplied by Mirafi.

4.2 Sustained load (creep) connection testing

The connection configuration used in the reference index test program was replicated in the constant load connection creep apparatus illustrated in **Figure 9**. The test apparatus has the following features:

- A lever-arm loading arrangement to apply normal loads up to 3600 lb/ft to the connection system,
- A roller clamp to apply a constant tensile load to the geosynthetic specimen,
- A dead weight arrangement to apply a constant tensile load to the geosynthetic specimen/connection with loads in excess of 3000 lb/ft,
- Two (2) LVDT displacement devices to monitor geosynthetic displacements at a clamp connected across the geosynthetic reinforcement specimen close to the connection,
- A load cell to record tensile load applied to the connection, and
- Electronic data acquisition system with battery back-up for uninterrupted data acquisition.

The normal load was applied to the top block using the lever-arm arrangement illustrated in **Figure 9**. A tray of pre-weighed rectangular stock steel sections was prepared to match the target tensile load to be applied to each geogrid test specimen. The dead weight was supported by a hydraulic lift truck during grid specimen alignment. The lift truck was released smoothly to apply the tensile load over a period of 20 to 30 seconds.

The displacement at the connection, load cell reading and temperature were recorded continuously until the specimen ruptured or until the test was manually terminated. The temperature in the laboratory for both index and sustained load tests was maintained at 20°C +/- 2°C.

4.3 Results

Photographs of exhumed tests for both Index Connection and Sustained Load Testing are shown in **Figures 10** through **17**.

The results for the index connection and sustained load creep data are presented in **Appendix A** of this report.

References

ASTM D6637-11. 2011, "Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method, American Society for Testing and Materials", *Annual Book of ASTM Standards*, Vol. 4.13, ASTM International, West Conshokocken, PA.

ASTM D6638-11. 2011, "Standard Test Method for Determining Connection Strength between Geosynthetic Reinforcement and Segmental Concrete Units (Modular Concrete Blocks)," *Annual Book of ASTM Standards*, Vol. 4.13, ASTM International, West Conshokocken, PA.

Federal Highway Administration, 2009, "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Volume I and II," *U.S. Department of Transportation*, Washington, D.C., FHWA-NHI-10-025, Appendix B, pp. B-5-B18.

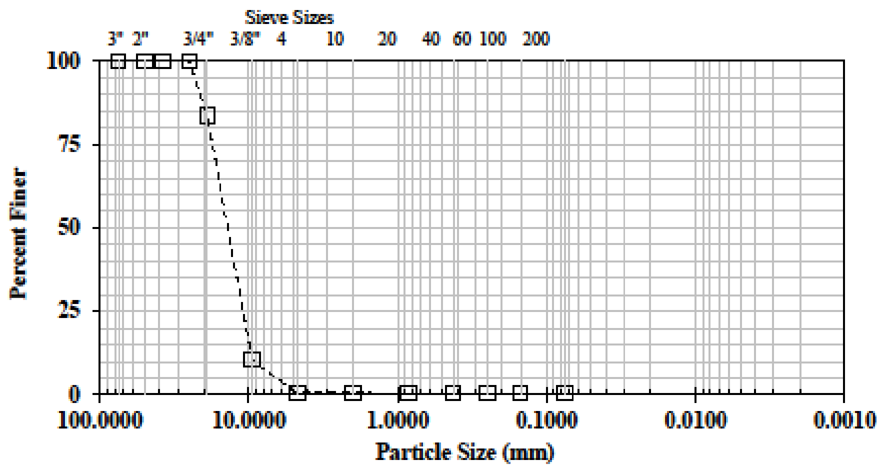
Figure 1: Photograph of a Keystone Compac 3 block.

Figure 2: Photograph of the test set-up.

TRI/ENVIRONMENTAL, INC.
A Texas Research International Company

Particle Size Analysis for Soils

Client:	TRI	TRI Log#:	E2377-25-08
Project:	Internal Testing	Test Method:	D422
Sample:	No.57 Stone	Test Date:	06/26/13



Sieve Analysis	
Sieve Size	Percent Passing
3 in.	100.0
2 in.	100.0
1.5 in.	100.0
1 in.	100.0
3/4 in.	83.6
3/8 in.	10.5
No. 4 (4.75 mm)	0.5
No. 10 (2.00 mm)	0.5
No. 20 (850 µm)	0.5
No. 40 (425 µm)	0.5
No. 60 (250 µm)	0.5
No. 100 (150 µm)	0.5
No. 200 (75 µm)	0.4
Hydrometer Analysis	
Particle Size	Percent Passing
0.074 mm	- -
0.005 mm	- -
0.001 mm	- -

USCS Classification (ASTM D2487)	Poorly Graded Gravel (GP)	
As-Received Moisture Content (%)	(ASTM D2216)	- -
Atterberg Limits (ASTM D 4318)	Liquid Limit	- -
	Plastic Limit	- -
	Plastic Index	- -
Notes: Specimen was air dried, 3 point Liquid Limit procedure was used. (NL = No Liquid Limit, NP = No Plastic Limit)		
Specific Gravity	(ASTM D854)	- -
Organic Content (%)	(ASTM D2974)	- -
Carbonate Content (%)	(ASTM 4373)	- -

Jeffrey A. Kuhn, Ph.D., P.E., 6/27/2013
Quality Review/Date
Tested by: Kahlil Hart & Tierra Jackson

9063 Bee Caves Road · Austin, TX 78733-6201 · (512) 263-2101 · (512) 263-2558 · 1-800-880-TEST

Figure 3: Particle size distribution curve for the poorly graded gravel (GP) (AASHTO A-1-a) used in this investigation.

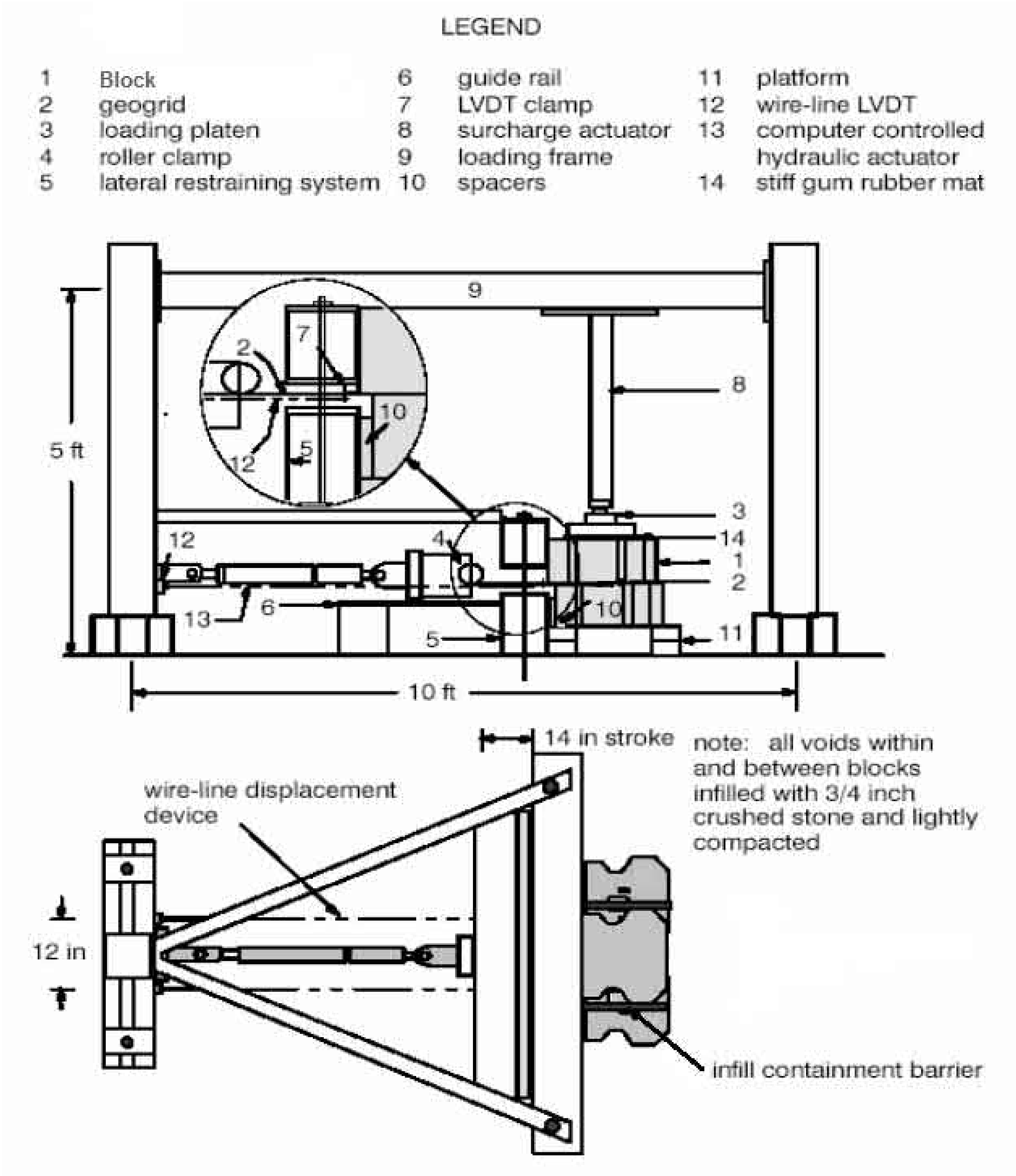


Figure 4: Schematic of test apparatus to carry out reference (index) connection tests.

Figure 5: Photograph of the bottom row of blocks and granular fill.

Figure 6: Photograph of the geogrid placed flat over the two bottom blocks.

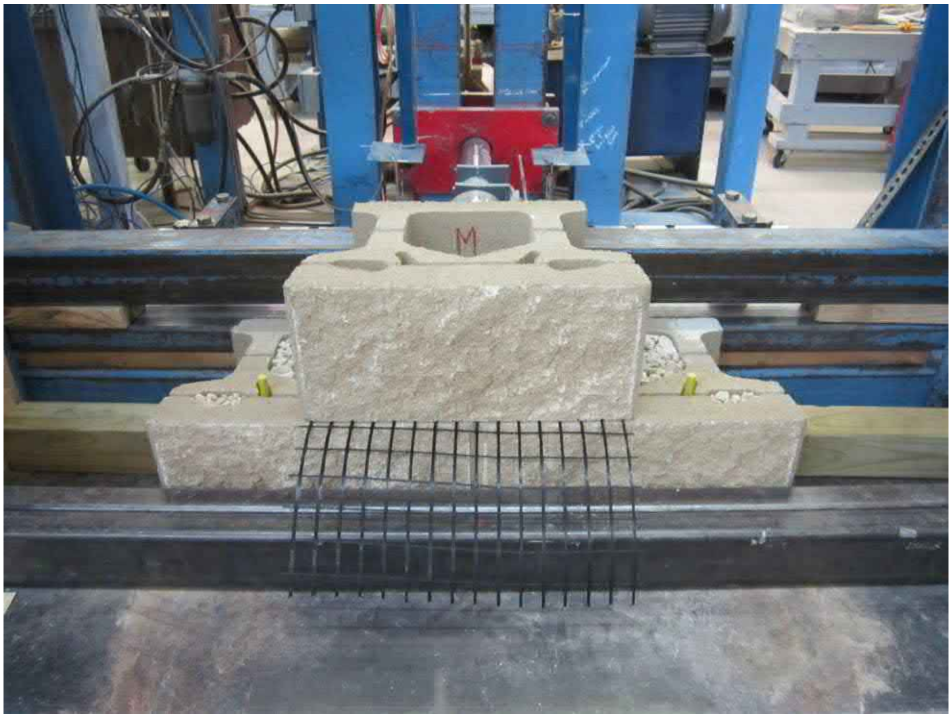


Figure 7: Photograph of a Keystone Compac 3 block centered above the geogrid and the two underlying blocks.

Figure 8: Photograph showing the infill of the top block and containment barriers.

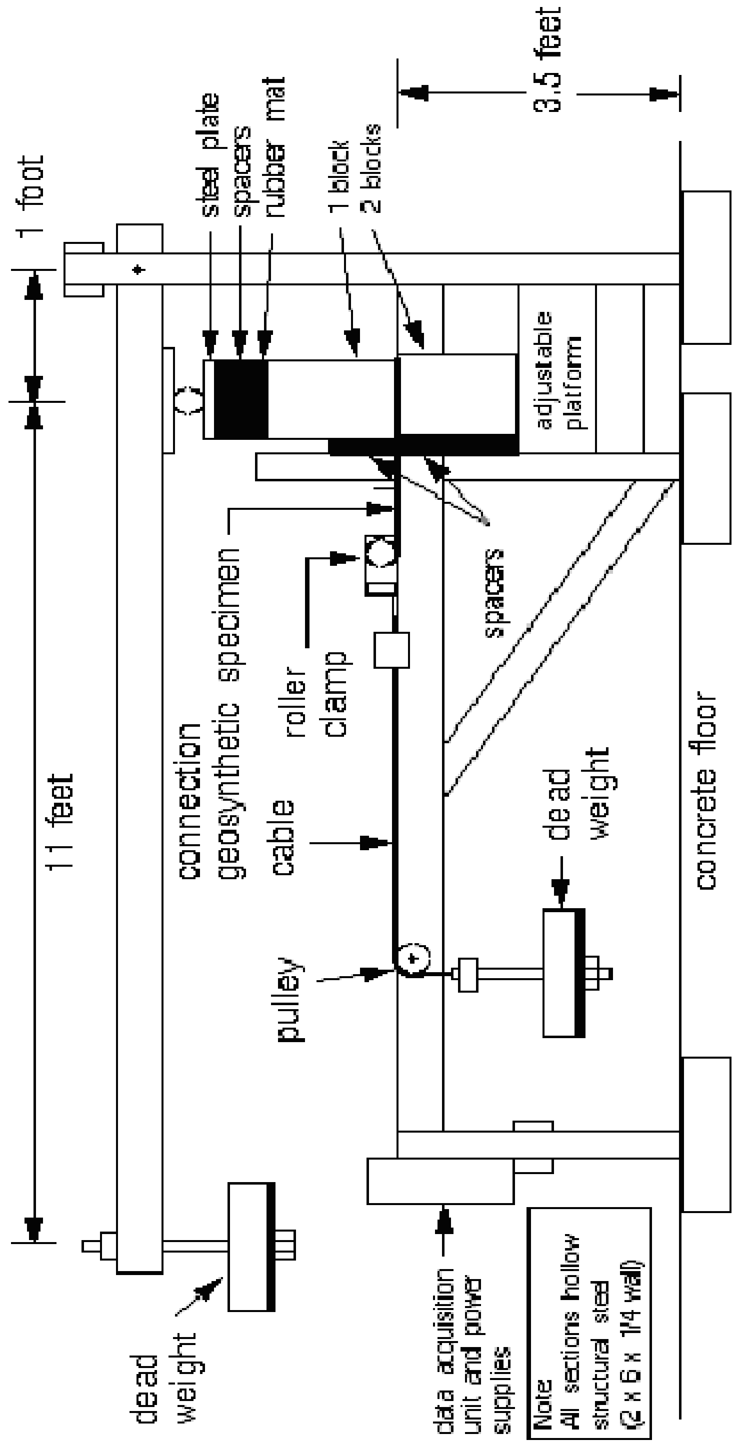


Figure 9: Schematic of sustained load (creep) connection test apparatus.

Figure 10: Photograph of exhumed grid specimen from Test 3 of index connection testing.

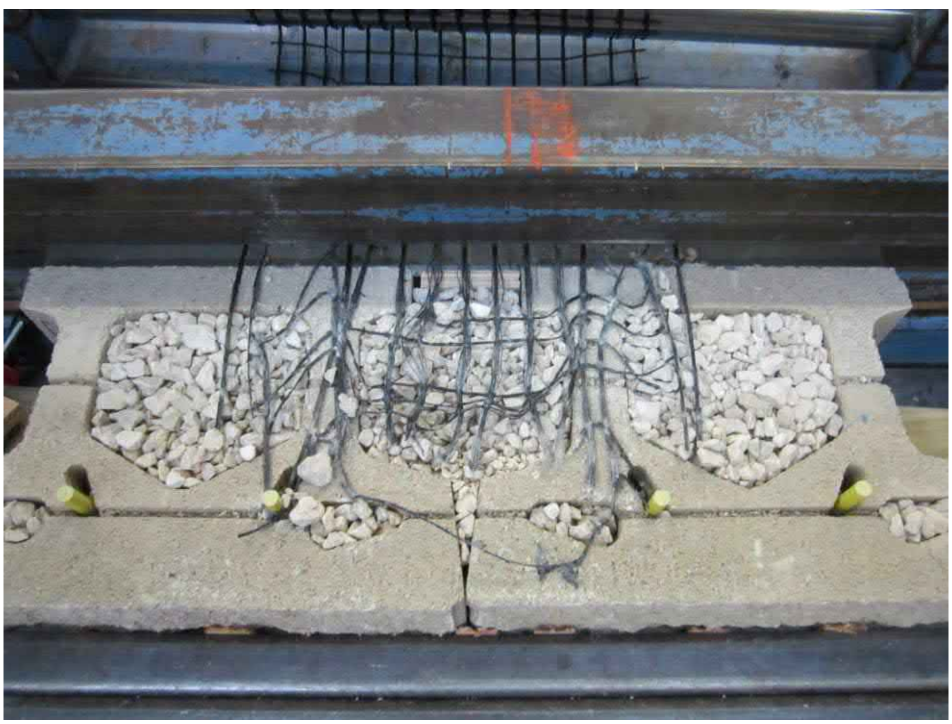


Figure 11: Photograph of the exhumed grid specimen from Test 5.

Figure 12: Photograph of the exhumed grid specimen from Test 7.

Figure 13: Photograph of the exhumed grid specimen from Test 12

Figure 14: Photograph of exhumed grid specimen from Test 1 of Sustained Load Testing (Normal Load = 500 lb/ft).

Figure 15: Another photograph of the exhumed grid specimen from Test 1.

Figure 16: Photograph of exhumed grid specimen from Test 5 of Sustained Load Testing (Normal Load = 1000 lb/ft).

Figure 17: Photograph of exhumed grid specimen from Test 7 of Sustained Load Testing (Normal Load = 2000 lb/ft).

Index Connection Testing: one block over two with in-fill

Client: Keystone
Reinforcement: Mirafi 3XT
Tensile Strength: 3500
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 57-Stone
Block Wt* (lb): 99.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

TRI Log#: E2371-03-05
Test Method: ASTM D 6637-01
Test Dates(s): December 12-30, 2013

Jt. Configuration: running bond
Set-up: 1/4" batter

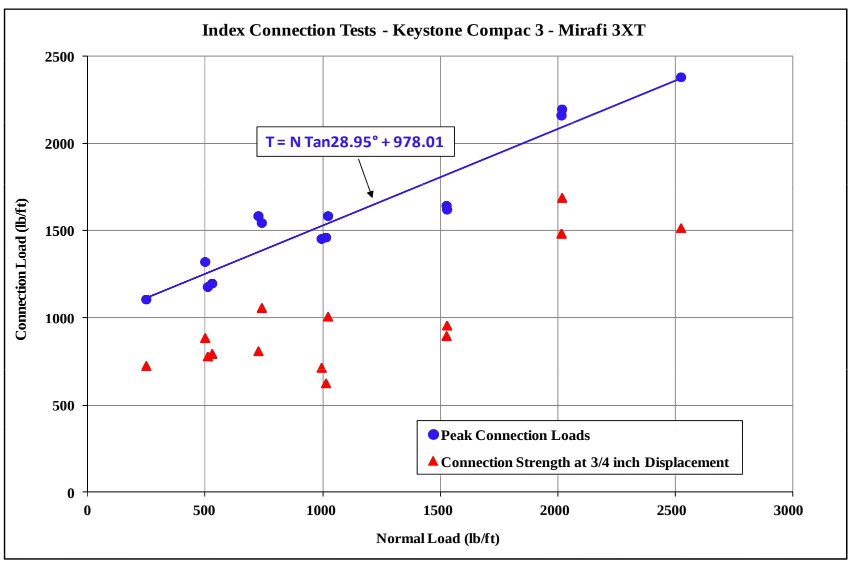
Series 1: Tests 1 - 5
Blocks: A, B, C

Series 2: Tests 6 -10
Blocks: M, N, O

Series 3: Tests 11- 15
Blocks: X, Y, Z

Test Number	Normal Load (lb/ft)	Approximate wall height (ft)**	Approximate number of blocks tall	Connection capacity (lb/ft) at 0.75 inches displacement	Peak connection capacity (lb/ft)
1	250	2.5	3.8	725	1105
2	512	5.2	7.8	779	1177
3	530	5.4	8.0	794	1197
4	500	5.1	7.6	884	1321
5	741	7.5	11.2	1057	1544
6	727	7.3	11.0	809	1584
7	1023	10.3	15.5	1007	1584
8	1014	10.2	15.4	625	1461
9	995	10.1	15.1	714	1453
10	1526	15.4	23.1	896	1643
11	1529	15.4	23.2	956	1621
12	2015	20.4	30.5	1483	2160
13	2017	20.4	30.6	1688	2195
14	2015	20.4	30.5	1483	2160
15	2523	25.5	38.2	1514	2379

* With In-Fill **Wall Height Calc: Normal Load / (Block Wt*/Block Width) *Block Height



Reference (Index) Peak Connection Capacitiy

	Normal Load (lb/ft)***	Peak Connection (lb/ft)***
Series 1	**500**	**1255**
Series 2	**1000**	**1531**
Series 3	**2000**	**2084**

***calculated using linear regression

John M. Allen, P.E., 10/22/14
Quality Review/Date
Analysis by: Mike Domingo
Specimens prepared by: Mike Domingo

Sustained Load Testing Series 1: Normal Load = 500 lb/ft

Client: Keystone
Reinforcement: Mirafi 3XT
Tensile Strength: 3500
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 57-Stone
Block Wt* (lb): 99.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

TRI Log#: E2371-03-05
Test Method: ASTM D 6637-01
Test Dates(s): Apr 11 -Sept 10, 2014

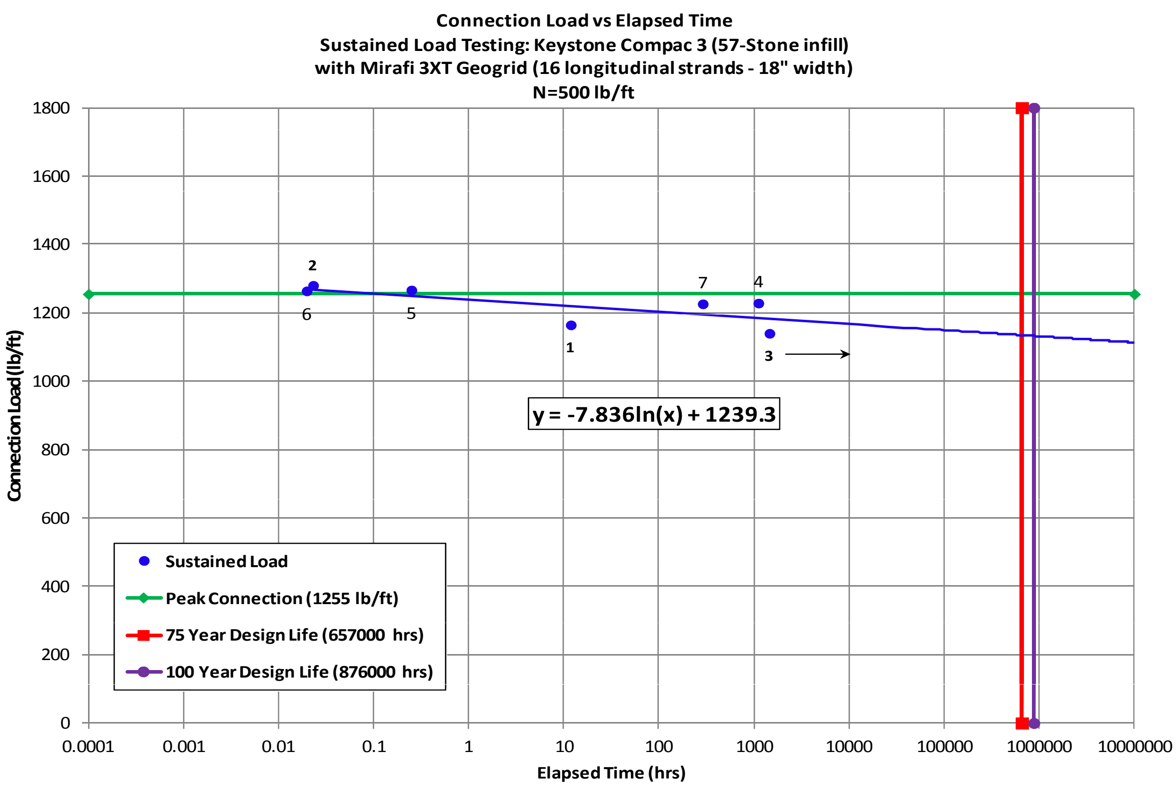
Jt. Configuration: running bond
Set-up: 1/4" batter

Series 1: **Tests 1 - 5**

Blocks: A, B, C

Test Number	Start Date	File Name	% of Peak Connection	Connection Load (lb/ft)	Time to Rupture h/m/s	Time to Rupture (hrs)
1	Apr 11/14	C3M3S1T3	92.8	1165	11:50:00	11.833
2	Apr 11/14	C3M3S1T4	102.0	1280	0:01:23	0.0231
3	Apr 17/14	C3M3S1T5	90.8	1140	test terminated	1453.9
4	Jul 14/14	G2T6	97.9	1228	1195:00:42	1112.3
5	Sept 5/14	G2T8	100.9	1267	0:14:57	0.2492
6	Sept 9/14	G2T9	100.7	1264	0:01:10	0.0197
7	Sept 10/14	G2T10	97.7	1226	289:11:17	289.19

* With In-Fill



John M. Allen, P.E., 10/22/14
Quality Review/Date
Analysis by: Mike Domingo
Specimens prepared by: Mike Domingo

Sustained Load Testing Series 2: Normal Load = 1000 lb/ft

Client: Keystone
Reinforcement: Mirafi 3XT
Tensile Strength: 3500
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 57-Stone
Block Wt* (lb): 99.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

TRI Log#: E2371-03-05
Test Method: ASTM D 6637-01
Test Dates(s): Apr 11 -Sept 24, 2014

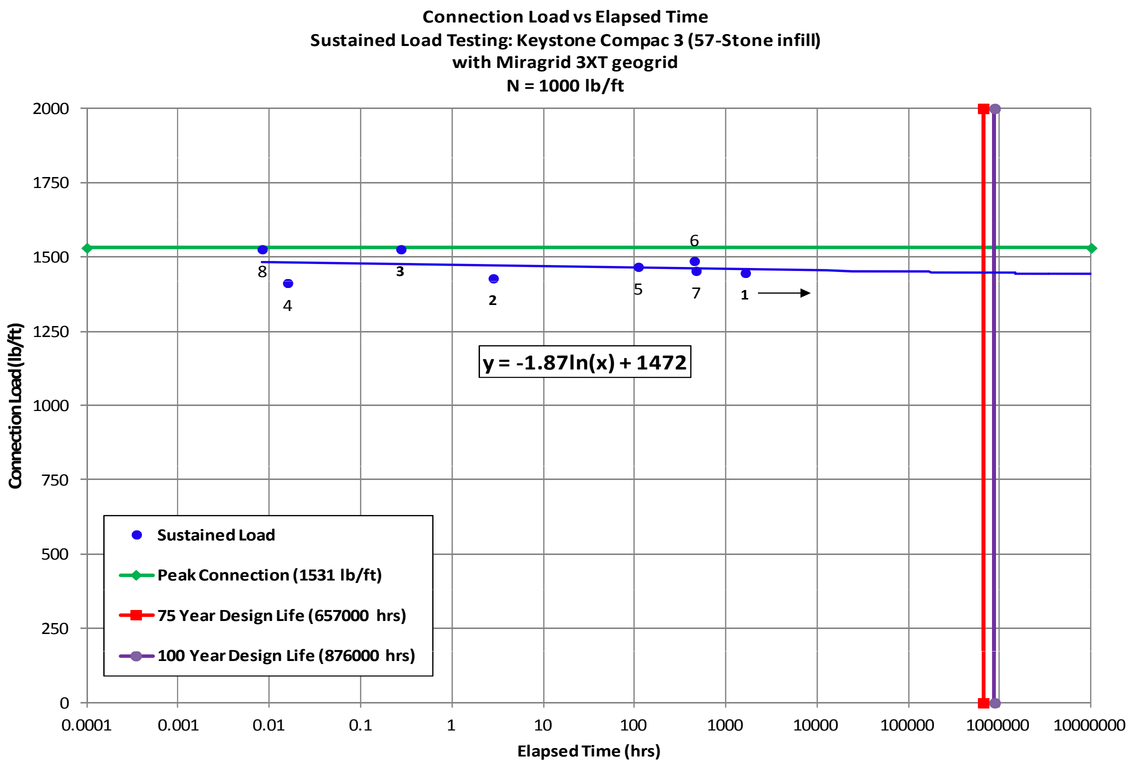
Jt. Configuration: running bond
Set-up: 1/4" batter

Series 1: Tests 1 - 5

Blocks: M, N, O

Test Number	Start Date	File Name	% of Peak Connection	Connection Load (lb/ft)	Time to Rupture h/m/s	Time to Rupture (hrs)
1	Apr 11/14	C3M3S2T2	94.5	1446	test terminated	1631.2
2	Jul 11/14	YT5	93.3	1428	2:49:39	2.8275
3	Jul 18/14	YT12	99.7	1526	0:16:31	0.2753
4	Jul 19/14	YT14	92.3	1413	0:00:57	0.0158
5	Jul 24/14	YT17	95.8	1467	109:33:43	109.56
6	Jul 31/14	YT18	97.1	1487	450:22:45	450.38
7	Aug 20/14	YT19	94.9	1453	470:36:24	470.61
8	Sept 24/14	YT21	99.7	1526	0:00:30	0.0083

* With In-Fill



John M. Allen, P.E., 10/22/14
Quality Review/Date
Analysis by: Mike Domingo
Specimens prepared by: Mike Domingo

Sustained Load Testing Series 3: Normal Load = 2000 lb/ft

Client: Keystone
Reinforcement: Mirafi 3XT
Tensile Strength: 3500
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 57-Stone
Block Wt* (lb): 99.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

TRI Log#: E2371-03-05
Test Method: ASTM D 6637-01
Test Dates(s): Apr 10 -Sept 23, 2014

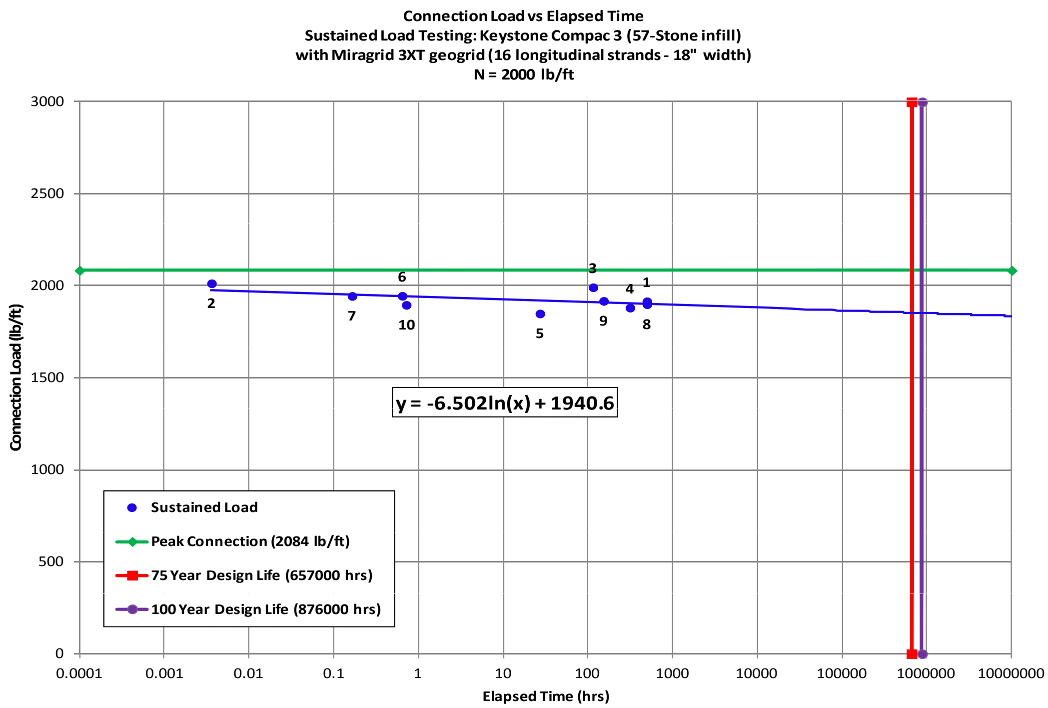
Jt. Configuration: running bond
Set-up: 1/4" batter

Series 1: **Tests 1 - 5**

Blocks: X, Y, Z

Test Number	Start Date	File Name	% of Peak Connection	Connection Load (lb/ft)	Time to Rupture h/m/s	Time to Rupture (hrs)
1	Apr 10/14	C3M3S3T3	91.9	1916	494:54:09	494.90
2	May 6/14	C3M3S3T4	96.6	2014	0:00:13	0.0036
3	May 12/14	C3M3S3T5	95.6	1992	114:34:04	114.57
4	Jul 9/14	C3M3S3T6	90.3	1881	312:35:03	312.58
5	Jul 24/14	C3M3S3T7	88.7	1849	27:04:07	27.069
6	Jul 28/14	G1T8	93.4	1946	0:38:30	0.6417
7	Aug 1/14	G1T9	93.3	1945	0:09:52	0.1644
8	Aug 4/14	G1T10	91.2	1900	495:51:12	495.85
9	Sept 9/14	G1T13	92.0	1918	152:42:01	152.70
10	Sept 23/14	G1T14	91.0	1896	0:42:59	0.7167

* With In-Fill



John M. Allen, P.E., 10/22/14
Quality Review/Date
Analysis by: Mike Domingo
Specimens prepared by: Mike Domingo

Summary of Estimated 75-year Reduced-Connection Strength Data
Keystone Compac 3 blocks - Mirafi 3XT Connection

Normal Load N (lb/ft)	Index peak Capacity Tconn (lb/ft)	75-year creep-reduced connection strength Tconn75 (lb/ft)*	Connection creep reduction factor (RFconncr = Tconn/Tconn75)
500	1255	1134	1.11
1000	1531	1447	1.06
2000	2084	1854	1.12

* calculated using the trend in creep-rupture data which has been approximated by a linear regressed line for each series plot. The regressed creep connection line has been used to estimate the creep-reduced connection strength at a desighn life of 75 years assuming the linear trend in the data is preserved.

Summary of Estimated 100-year Reduced-Connection Strength Data
Keystone Compac 3 blocks - Mirafi 3XT Connection

Normal Load N (lb/ft)	Index peak Capacity Tconn (lb/ft)	100-year creep-reduced connection strength Tconn100 (lb/ft)*	Connection creep reduction factor (RFconncr = Tconn/Tconn100)
500	1255	1132	1.11
1000	1531	1446	1.06
2000	2084	1852	1.13

* calculated using the trend in creep-rupture data which has been approximated by a linear regressed line for each series plot. The regressed creep connection line has been used to estimate the creep-reduced connection strength at a desighn life of 100 years assuming the linear trend in the data is preserved.

John M. Allen, P.E., 10/22/14
Quality Review/Date
Analysis by: Mike Domingo
Specimens prepared by: Mike Domingo

REPORT

RESULTS OF

SUSTAINED LOAD CONNECTION TESTING

WITH KEYSTONE COMPAC 3 RETAINING WALL UNITS

AND MIRAGRID 7XT GEOGRID

Submitted to

KEYSTONE RETAINING WALL SYSTEMS

CONFIDENTIAL

Distribution:
Keystone Retaining Wall Systems
4444 West 78th Street
Minneapolis, MN 55435-5406
USA

TRI Environmental, Inc.
9063 Bee Caves Road
Austin, Texas 78733

1. Introduction

This report gives the results of a sustained (constant) load (creep) connection testing program carried out to evaluate the creep mechanical performance of the connection system between Keystone Compac 3 modular concrete block and Miragrid 7XT geogrid. The test program was initiated in response to an email authorization to proceed from Mr. Craig Moritz of Keystone Retaining Wall Systems received 5 September 2012. The tests were carried out at the laboratories of TRI Environmental, Inc. in Kingston, Ontario.

2. Methodology

The test program was carried out in accordance with recommendations found in the FHWA-NHI-00-043 guidance document dated March 2001.

2.1 Index connection tests

A series of reference index connection tests were first carried out using Keystone Compac 3 modular block units in combination with specimens of Miragrid 7XT geogrid. The test arrangement and methodology were in accordance with the NCMA SRWU-1 protocol with the exception that the connection width was reduced to match the one block over two-block configuration used in the creep connection tests. The results of these tests were used to determine a regressed reference (index) peak capacity for each series of sustained tensile load tests described below.

2.2 Constant load connection tests

A series of constant tensile load tests were carried out under normal loads of 1000 lb/ft, 2000 lb/ft and 3000 lb/ft. Different percentages of the reference connection peak load capacity were applied as a tensile load to block-geogrid specimens configured to conform to the index test setup described above. The tensile loads ranged from 85.1 to 96.4% of the reference connection strength at each normal load level. The time to rupture was recorded for each test (if applicable) and results of the test series plotted as connection load versus log-time to rupture. The load-log time data was fit with a linear regression estimate to generate a creep rupture curve and extrapolated to an elapsed time corresponding to a design life of 75 years.

3. Materials

Keystone Compac 3 blocks (Figure 1) are hollow concrete blocks weighing approximately 77.0 pounds per unit (weight/unit measured in our laboratory), which are filled with select granular material. The nominal dimensions of the block are 12 inches wide (toe to heel) by 8 inches high by 18 inches long. Construction alignment and wall batter is achieved by means of fiberglass pins inserted into the top surface of the units. In this investigation the pins were positioned to provide approximately a 1/8 inch wall batter. The blocks used in this series of tests were supplied by Keystone and were received at our laboratory on 28 September 2012 and designated as TRI-12-009.

Miragrid 7XT is a bi-directional geogrid composed of 100% polyester multifilament yarn with a tensile strength of 6023 lb/ft in the machine direction (based on ASTM D6638 method of test and provided by TenCate Geosynthetics Americas on 7 September 2012). The geogrid specimens used in this series of testing were cut from Roll/Lot number 031141808/20111202-1-2 received at our laboratory on 29 March 2012. All index connection tests were carried out using the specimens trimmed from this same roll/lot. The particle size distribution curve for the block infill soil used in this investigation is shown in Figure 2.

4. Test equipment and test procedures

4.1 Reference index tests

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 description of the apparatus and test methodology is presented here. The test apparatus used to perform the tests is illustrated in Figure 3. 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. The hollow sections of both the top and bottom blocks were filled with ¾ inch crushed stone and lightly compacted (Figure 4). Strips of grid reinforcement, 18 inches wide (17 longitudinal strands), were attached to a roller clamp and the grid extended over two lower blocks. The geogrid reinforcement was then laid flat over the bottom blocks (Figure 5). A single block was then placed over the grid and centered on the joint between the two underlying units as shown in Figure 6. An infill containment barrier (Figures 3 & 4) was placed around the top block allowing the hollow sections to be filled and compacted with crushed stone. Two wire-line LVDT(s) were connected to the grid to measure grid displacement at the back of the block. Wall heights were simulated by applying an additional surcharge load using the vertically oriented hydraulic jack shown in Figure 3. 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 inches/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 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, with the exception of tests in excess of 3000 hours which were terminated prior to rupture. Following each test, the blocks were removed and the grid and blocks examined to confirm failure modes. A virgin specimen of grid was used for each test and any damaged blocks were replaced.

The only variable in this series of connection tests was the magnitude of surcharge load. Block units used in the reference connection load tests and in the sustained load tests were taken from the same pallet of blocks supplied by Keystone Retaining Wall Systems. Specimens of Miragrid 7XT geogrid were trimmed from the same longitudinal section of the roll of grid supplied by Mirafi.

4.2 Sustained load (creep) connection testing

The connection configuration used in the reference index test program was replicated in the constant load connection creep apparatus illustrated in Figure 7. The test apparatus has the following features:

- A lever-arm loading arrangement to apply normal loads up to 3000 lb/ft to the connection system,
- A roller clamp to apply a constant tensile load to the geosynthetic specimen,
- A dead weight arrangement to apply a constant tensile load to the geosynthetic specimen/connection with loads in excess of 3000 lb/ft,
- Two (2) LVDT displacement devices to monitor geosynthetic displacements at a clamp connected across the geosynthetic reinforcement specimen close to the connection,
- A load cell to record tensile load applied to the connection, and
- Electronic data acquisition system with battery back-up for uninterrupted data acquisition.

The normal load was applied to the top block using the lever-arm arrangement illustrated in Figure 7. A tray of pre-weighed rectangular stock steel sections was prepared to match the target tensile load to be applied to each geogrid test specimen. The dead weight was supported by a hydraulic lift truck during grid specimen alignment. The lift truck was released smoothly to apply the tensile load over a period of 20 to 30 seconds.

The displacement at the connection, load cell reading and temperature were recorded continuously until the specimen ruptured or until the test was manually terminated. The temperature in the laboratory for both index and sustained load tests was maintained at 20°C +/- 2°C.

4.3 Results

The results for the index connection and sustained load creep data are presented in standalone appendix to this report.

References

ASTM D6637-01. Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method, American Society for Testing and Materials, West Conshohocken, PA 19428-2958 USA.

ASTM D6638-01. 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., Laboratory Testing of Modular Concrete Block Geogrid Facing Connections, ASTM Symposium on Geosynthetic Soil Reinforcement Testing, San Antonio, Texas, January 19, 1993, ASTM STP 1190.

Simac, M.R., Bathurst, R.J., Berg, R.R. and Lothspeich, S.E., National Concrete Masonry Association Segmental Retaining Wall Design Manual, Earth Improvement Technologies, pp. 250, March 1993 (First Edition)

FHWA-NHI-00-043.Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., March 2001

Sustained Load Connection Test Report: Keystone Compac II Blocks and Mirafi 7XT Geogrid, BCGT Project Number 26141 Series Number 1937 (March 18, 2008)

Figure 1: Photograph of a Keystone Compac 3 modular block with fiberglass pins.

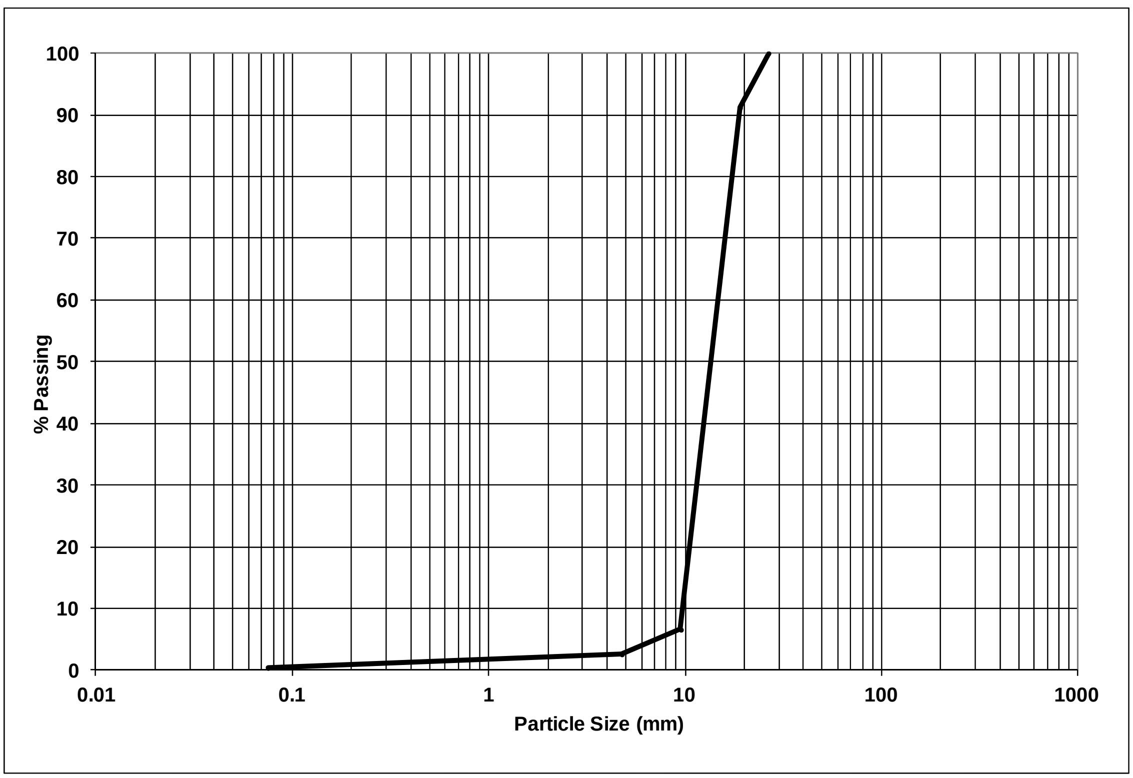


Figure 2: Particle size distribution curve for the soil used in this investigation.

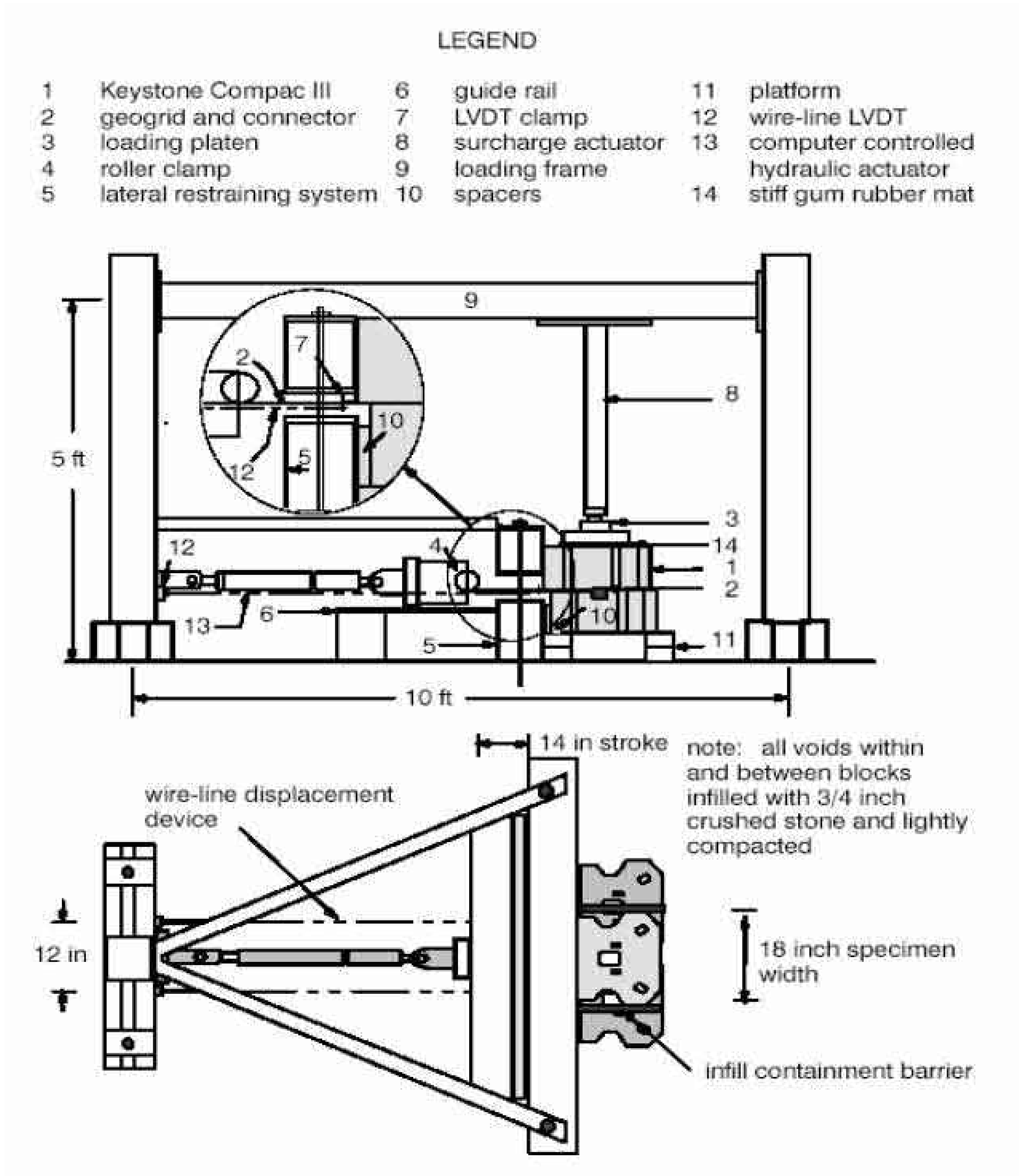


Figure 3: Schematic of test apparatus to carry out reference (index) connection tests.

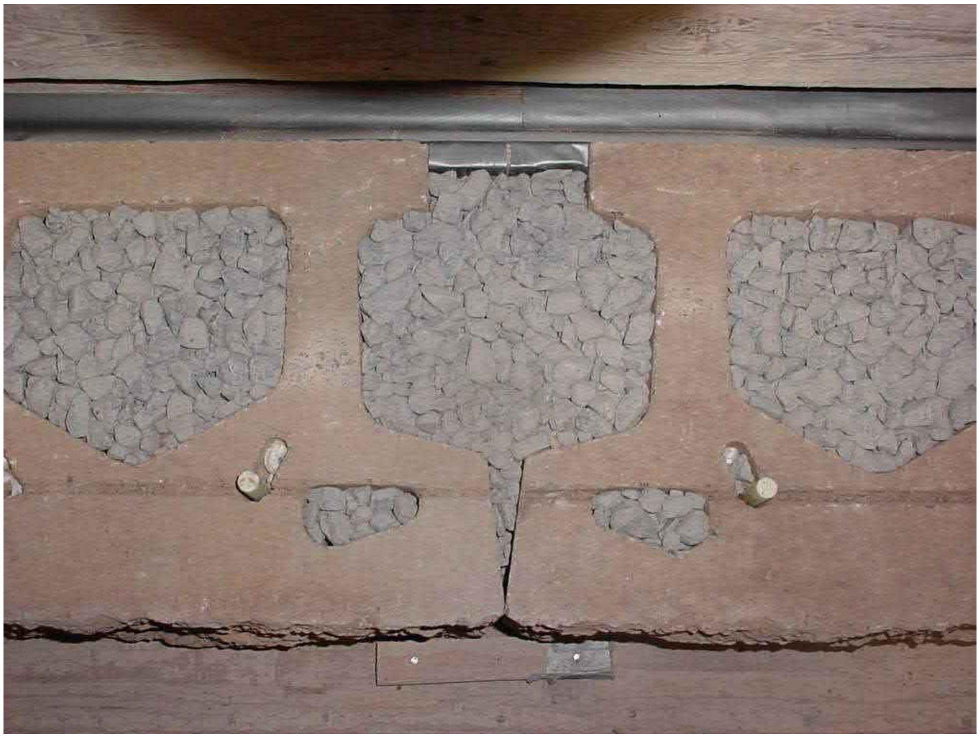


Figure 4: Photograph of the bottom row of blocks and granular fill.

Figure 5: Photograph of the geogrid placed flat over the two bottom blocks.

Figure 6: Photograph of a Keystone Compac 3 block centered above the geogrid and the two underlying blocks.

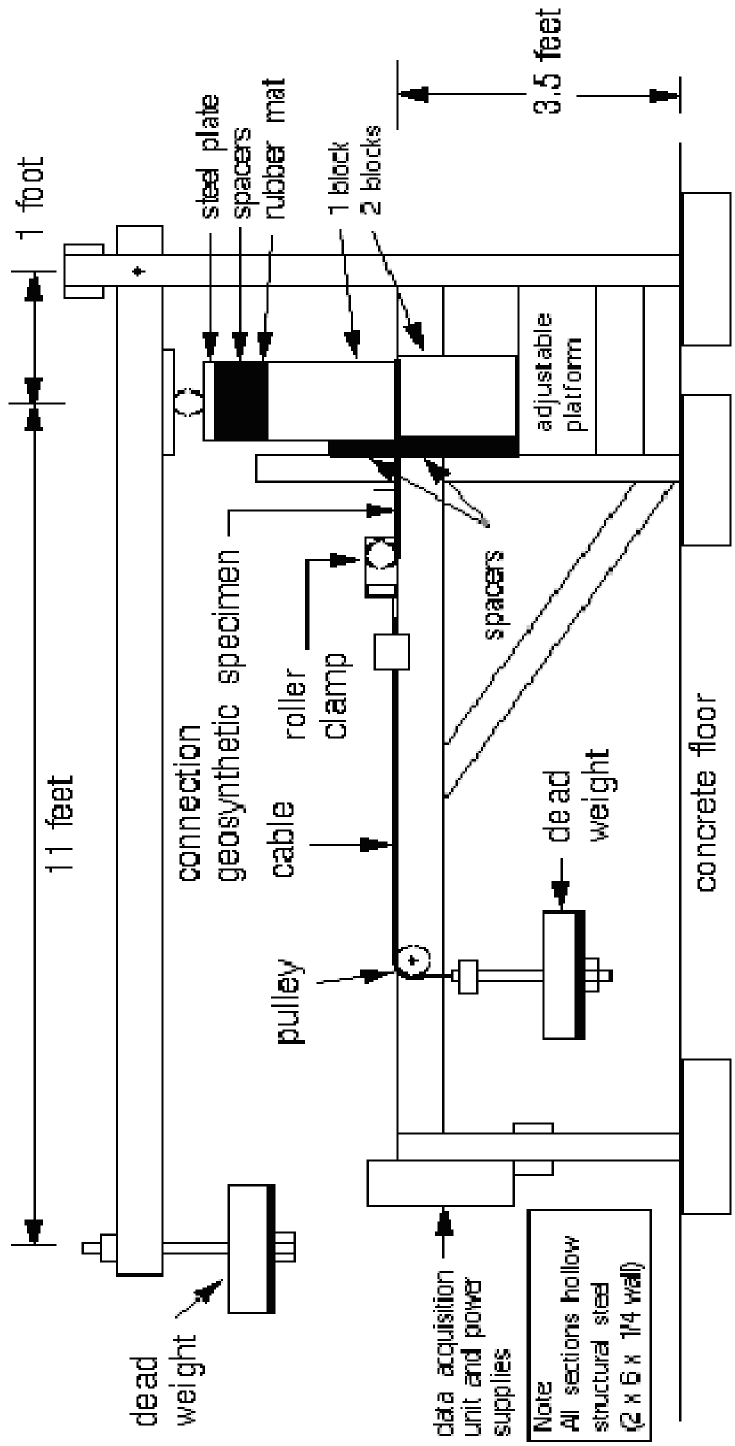


Figure 7: Schematic of sustained load (creep) connection test apparatus.

TRI/Environmental, Inc.
A Texas Research International Company

Index Connection Testing: one block over two with in-fill

Client: Keystone
Reinforcement: Mirafi 7XT
Tensile Strength: 5900
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 3/4" crushed stone
Block Wt* (lb): 118.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

TRI Log#: E2368-01-02
Test Method: ASTM D 6637-01
Test Dates(s): Oct 1/12 - Oct 9/12

Jt. Configuration: running bond
Set-up: 1/8" batter

Series 1: Tests 1 - 8
Blocks: A, B, C

Series 2: Tests 9 - 16
Blocks: D, E, F

Series 3: Tests 17 - 24
Blocks: X, Y, Z

Test Number	Normal Load (lb/ft)	Approximate wall height (ft)**	Approximate number of blocks tall	Connection capacity (lb/ft) at 0.75 inches displacement	Peak connection capacity (lb/ft)
1	1000	8.5	12.7	1203	2013
2	512	4.3	6.5	1128	1784
3	992	8.4	12.6	1437	2024
4	1493	12.7	19.0	1580	2462
5	1009	8.5	12.8	1317	1844
6	1000	8.5	12.7	1377	1800
7	997	8.4	12.7	1472	1775
8	1000	8.5	12.7	1476	1830
9	2000	17.0	25.4	1649	2388
10	1505	12.8	19.1	1380	2076
11	2018	17.1	25.7	1686	2381
12	2494	21.1	31.7	1880	2613
13	2003	17.0	25.5	1509	2502
14	2015	17.1	25.6	1763	2687
15	2000	17.0	25.4	1581	2582
16	1999	16.9	25.4	1754	2489
17	2989	25.3	38.0	2124	2867
18	2500	21.2	31.8	1958	2627
19	2995	25.4	38.1	2022	2642
20	3479	29.5	44.2	2168	2850
21	3007	25.5	38.2	2357	2939
22	2987	25.3	38.0	1941	2874
23	3005	25.5	38.2	2120	3035
24	2996	25.4	38.1	1925	2808

* With In-Fill **Wall Height Calc: Normal Load / (Block Wt*/Block Width) *Block Height

John M. Allen, P.E., 07/18/13
Quality Review/Date
Testing by: Mike Domingo
Specimens prepared by: Mike Domingo

9063 Bee Caves Road □ Austin, TX 78733-6201 □ (512) 263-2101 □ (512) 263-2558 □ 1-800-880-TEST

Index Connection Testing: one block over two with in-fill

Client: Keystone
Reinforcement: Mirafi 7XT
Tensile Strength: 5900
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 3/4" crushed stone
Block Wt* (lb): 118.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

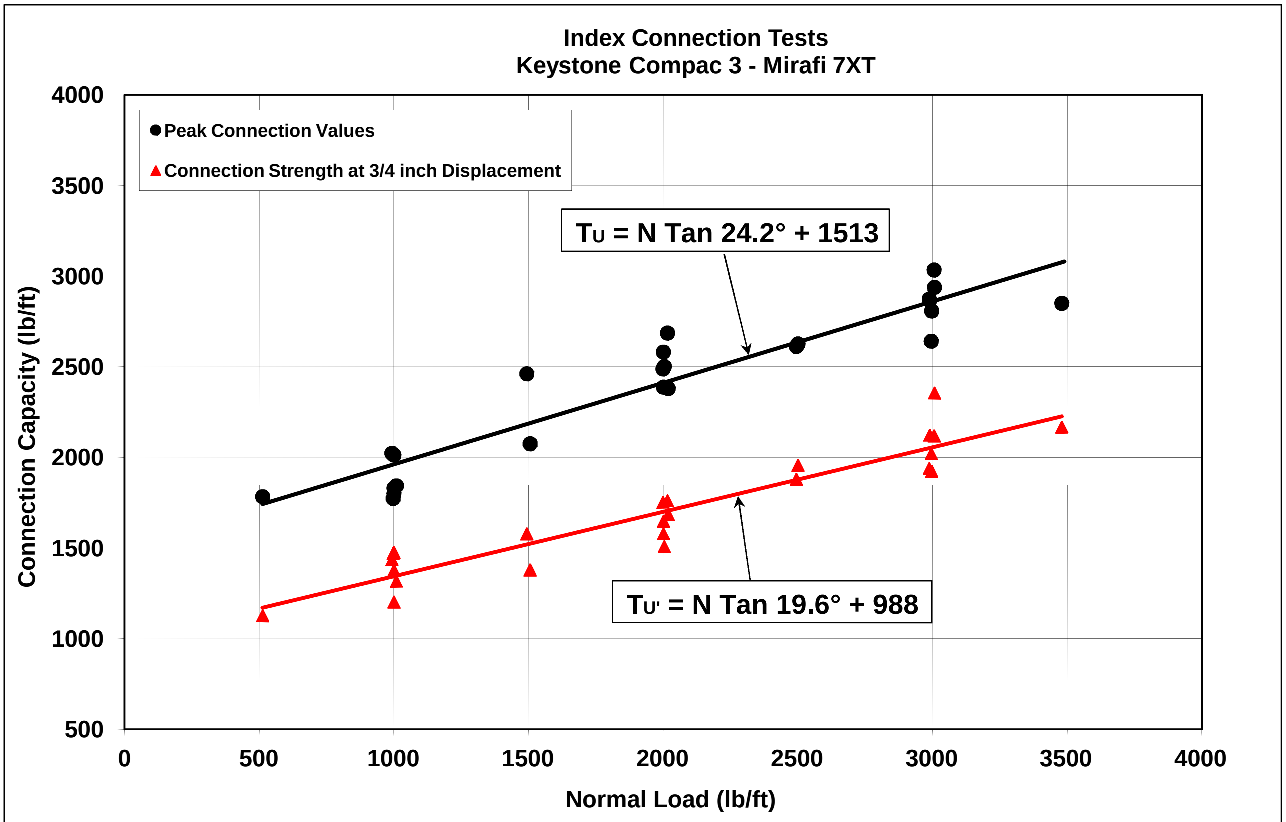
TRI Log#: E2368-01-02
Test Method: ASTM D 6637-01
Test Dates(s): Oct 1/12 - Oct 9/12

Jt. Configuration: running bond
Set-up: 1/8" batter

Series 1: Tests 1 - 5, 16
Blocks: A, B, C

Series 2: Tests 6 -10
Blocks: D, E, F

Series 3: Tests 11- 15
Blocks: G, H, I



Reference (Index) Peak Connection Capacitiy

	Normal Load (lb/ft)	Peak Connection (lb/ft)***
Series 1	**1000**	**1962**
Series 2	**2000**	**2412**
Series 3	**3000**	**2862**

***calculated using the equation from the linear regression

John M. Allen, P.E., 07/18/13
Quality Review/Date
Testing by: Mike Domingo
Specimens prepared by: Mike Domingo

Sustained Load Testing Series 1: Normal Load = 1000 lb/ft

Client: Keystone
Reinforcement: Mirafi 7XT
Tensile Strength: 5900
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 3/4" crushed stone
Block Wt* (lb): 118.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

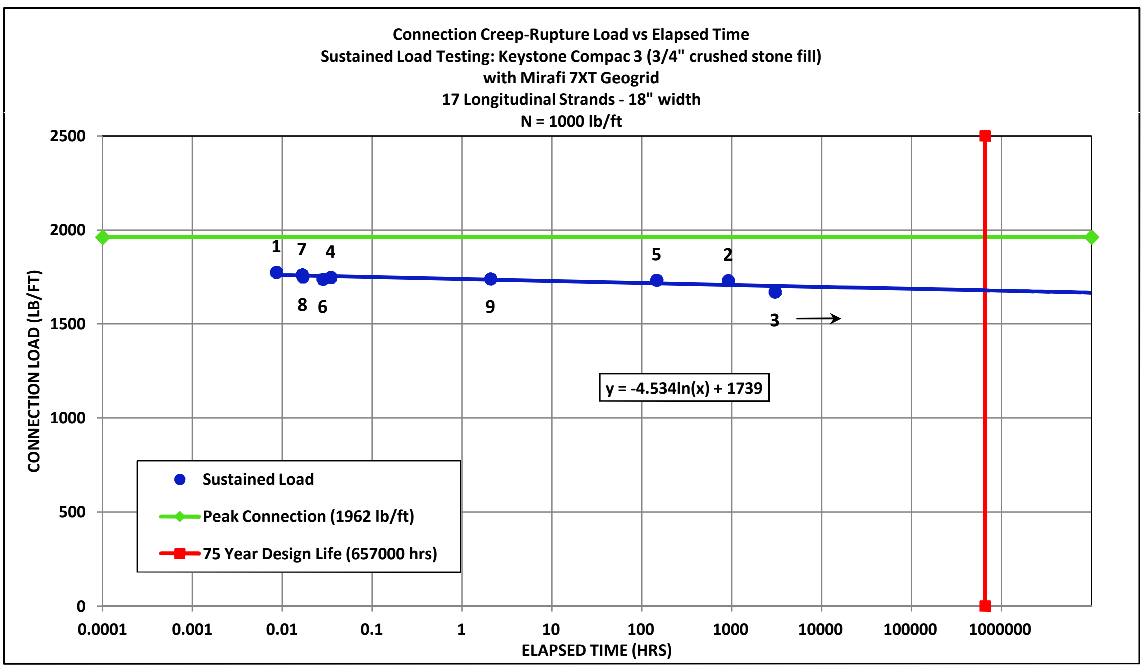
TRI Log#: E2368-01-02
Test Method: ASTM D 6637-01
Test Dates(s): Dec 7/12 - Feb 1/13
Jt. Configuration: running bond
Set-up: 1/8" batter

Series 1: N = 1000 lb/ft, Peak Connection = 1962 lb/ft

Blocks: A, B, C

Test Number	Start Date	File Name	% of Peak Connection	Connection Load (lb/ft)	Time to Rupture h/m/s	Time to Rupture (hrs)
1	Dec 7/12	C3M7S1A1	90.5	1775	0:00:31	0.0086
2	Dec 7/12	C3M7S1A2	88.2	1730	912:41:48	912.70
**3	Jan 8/13	C3M7S1T1	85.1	1670	test terminated	3019.6
4	Jan 15/13	C3M7S1A3	89.1	1748	0:02:05	0.0347
5	Jan 15/13	C3M7S1A4	88.3	1733	146:04:16	146.07
6	Jan 29/13	C3M7S1A5	88.6	1738	0:01:42	0.0283
7	Feb 1/13	C3M7S1A6	89.8	1762	0:01:00	0.0167
8	Feb 1/13	C3M7S1A7	89.2	1751	0:01:01	0.0169
9	Feb 1/13	C3M7S1A8	88.7	1740	2:04:34	2.0761

* With In-Fill **Note: Test 3 was terminated after more than 3000 hrs of sustained load



John M. Allen, P.E., 07/18/13
Quality Review/Date
Testing by: Mike Domingo
Specimens prepared by: Mike Domingo

Sustained Load Testing Series 2: Normal Load = 2000 lb/ft

Client: Keystone
Reinforcement: Mirafi 7XT
Tensile Strength: 5900
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 3/4" crushed stone
Block Wt* (lb): 118.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

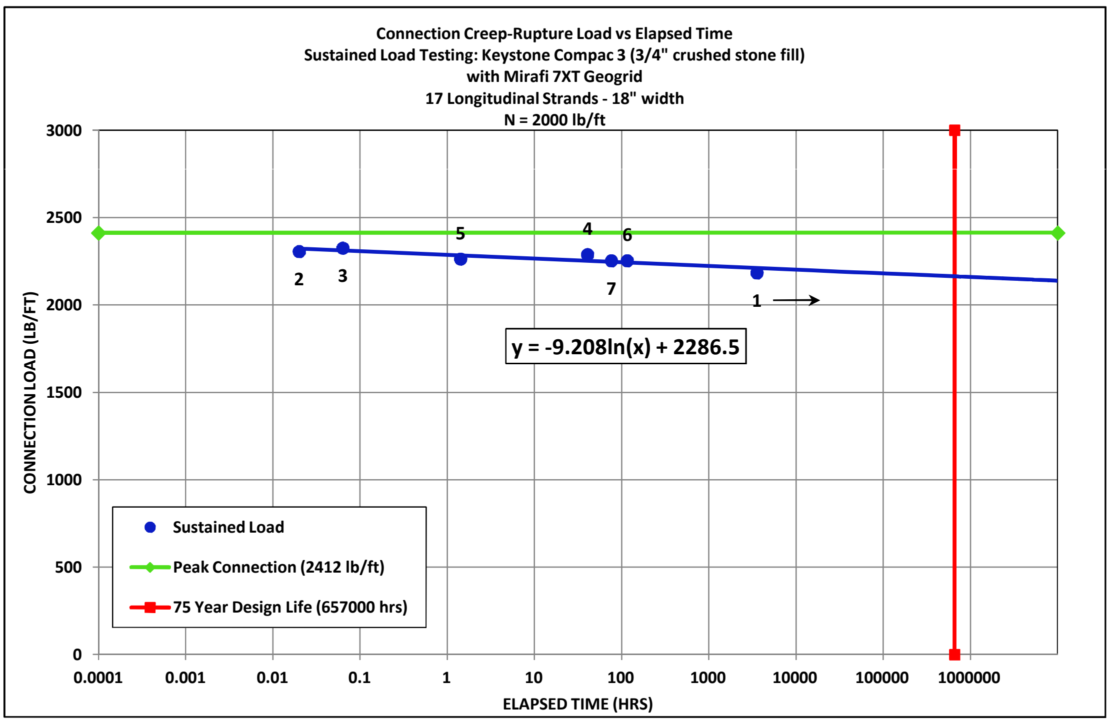
TRI Log#: E2368-01-02
Test Method: ASTM D 6637-01
Test Dates(s): Dec 6/12 - Jan 8/13
Jt. Configuration: running bond
Set-up: 1/8" batter

Series 1: N = 2000 lb/ft, Peak Connection = 2412 lb/ft

Blocks: D, E, F

Test Number	Start Date	File Name	% of Peak Connection	Connection Load (lb/ft)	Time to Rupture h/m/s	Time to Rupture (hrs)
**1	Dec 6/12	C3M7S2A1	90.5	2183	test terminated	3549.2
2	Dec 18/12	C3M7S2T1	95.6	2306	0:01:12	0.0200
3	Dec 18/12	C3M7S2T2	96.4	2325	0:03:48	0.0633
4	Dec 18/12	C3M7S2T3	94.9	2288	40:34:23	40.573
5	Dec 21/12	C3M7S2T4	93.8	2263	1:25:13	1.4203
6	Jan 3/13	C3M7S2T5	93.4	2253	115:34:00	115.57
7	Jan 8/13	C3M7S2T6	93.4	2253	76:04:00	76.067

* With In-Fill **Note: Test 1 was terminated after more than 3500 hrs of sustained load



John M. Allen, P.E., 07/18/13
Quality Review/Date
Testing by: Mike Domingo
Specimens prepared by: Mike Domingo

Sustained Load Testing Series 3: Normal Load = 3000 lb/ft

Client: Keystone
Reinforcement: Mirafi 7XT
Tensile Strength: 5900
(lbs/ft, ASTM D6637): (MARV per Mfr.)
Specimen Width (ft): 1.50

Block Type: Compac 3
In-Fill: 3/4" crushed stone
Block Wt* (lb): 118.00
Block Width (ft): 1.50
Block Depth (ft): 1.00
Block Height (ft): 0.67

TRI Log#: E2368-01-02
Test Method: ASTM D 6637-01
Test Dates(s): Dec 6/12 - Jan 8/13

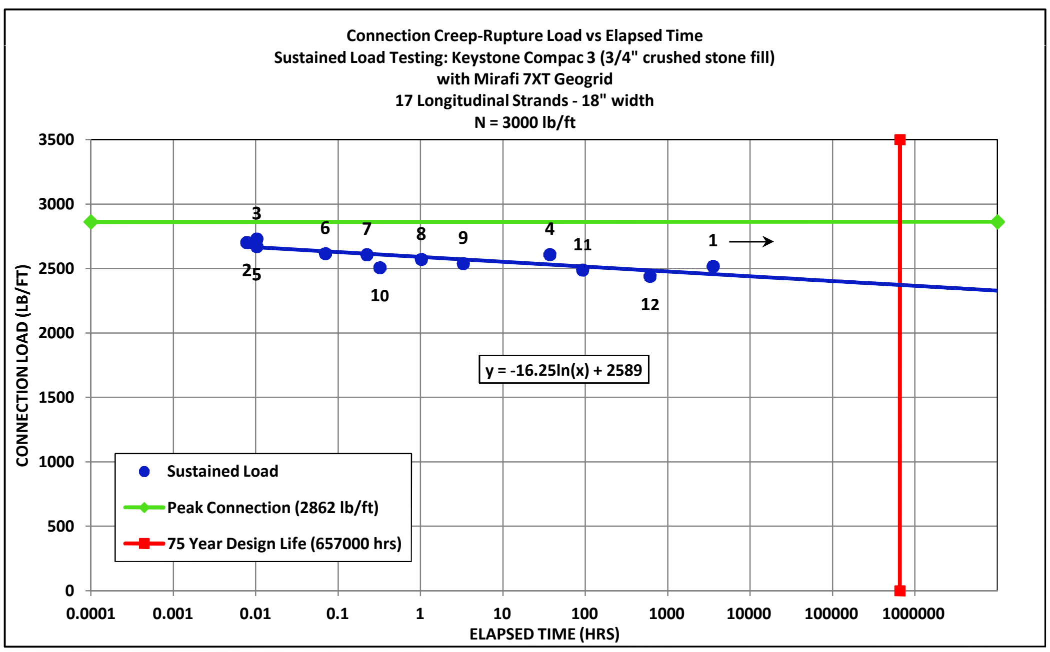
Jt. Configuration: running bond
Set-up: 1/8" batter

Series 1: N = 3000 lb/ft, Peak Connection = 2862 lb/ft

Blocks: X, Y, Z

Test Number	Start Date	File Name	% of Peak Connection	Connection Load (lb/ft)	Time to Rupture h/m/s	Time to Rupture (hrs)
**1	Dec 6/12	C3M7S3A1	88.0	2517	test terminated	3551.7
2	Dec 13/12	C3M7S3T6	94.4	2701	0:00:28	0.0078
3	Dec 14/12	C3M7S3T7	95.3	2729	0:00:37	0.0103
4	Dec 17/12	C3M7S3T11	91.1	2608	37:04:14	37.071
5	Dec 20/12	C3M7S3T12	93.3	2671	0:00:37	0.0103
6	Dec 20/12	C3M7S3T13	91.4	2616	0:04:12	0.0700
7	Dec 20/12	C3M7S3T14	91.1	2607	0:13:23	0.2231
8	Dec 21/12	C3M7S3T15	89.8	2571	1:01:20	1.0222
9	Dec 21/12	C3M7S3T16	88.7	2538	3:18:38	3.2942
10	Jan 3/13	C3M7S3T17	87.6	2507	0:19:13	0.3203
11	Jan 3/13	C3M7S3T18	86.9	2488	92:34:14	92.571
12	Jan 8/13	C3M7S3T19	85.2	2439	608:40:30	608.68

* With In-Fill **Note: Test 1 was terminated after more than 3500 hrs of sustained load



John M. Allen, P.E., 07/18/13
Quality Review/Date
Testing by: Mike Domingo
Specimens prepared by: Mike Domingo

Summary of Estimated 75-year Reduced-Connection Strength Data
Keystone Compac 3 - Mirafi 7XT Connection

Normal Load N (lb/ft)	Index peak Capacity Tconn (lb/ft)	75-year creep-reduced connection strength Tconn75 (lb/ft)*	Connection creep reduction factor (RFconncr = Tconn/Tconn75)
1000	1962	1678	1.17
2000	2412	2163	1.12
3000	2862	2371	1.20

* calculated using the trend in creep-rupture data which has been approximated by a linear regressed line for each series plot. The regressed creep connection line has been used to estimate the creep-reduced connection strength at a desighn life of 75 years assuming the linear trend in the data is preserved.

John M. Allen, P.E., 07/18/13
Quality Review/Date
Testing by: Mike Domingo
Specimens prepared by: Mike Domingo

3/10/15
pjs

HITEC CONNECTION EVALUATION

Keystone Unit: Compac III
Manufacturer: Mirafi
Geogrid Type: 3XT
Laboratory: BCGT 10/27/09

Normalized Peak Connection Equation Fit

	English	Metric
Intercept (plf)	975	14.23
Slope1	42.3	42.3
Break - Normal	1300	18.97
Slope2	8.1	8.1
Maximum (plf)	2293	33.47

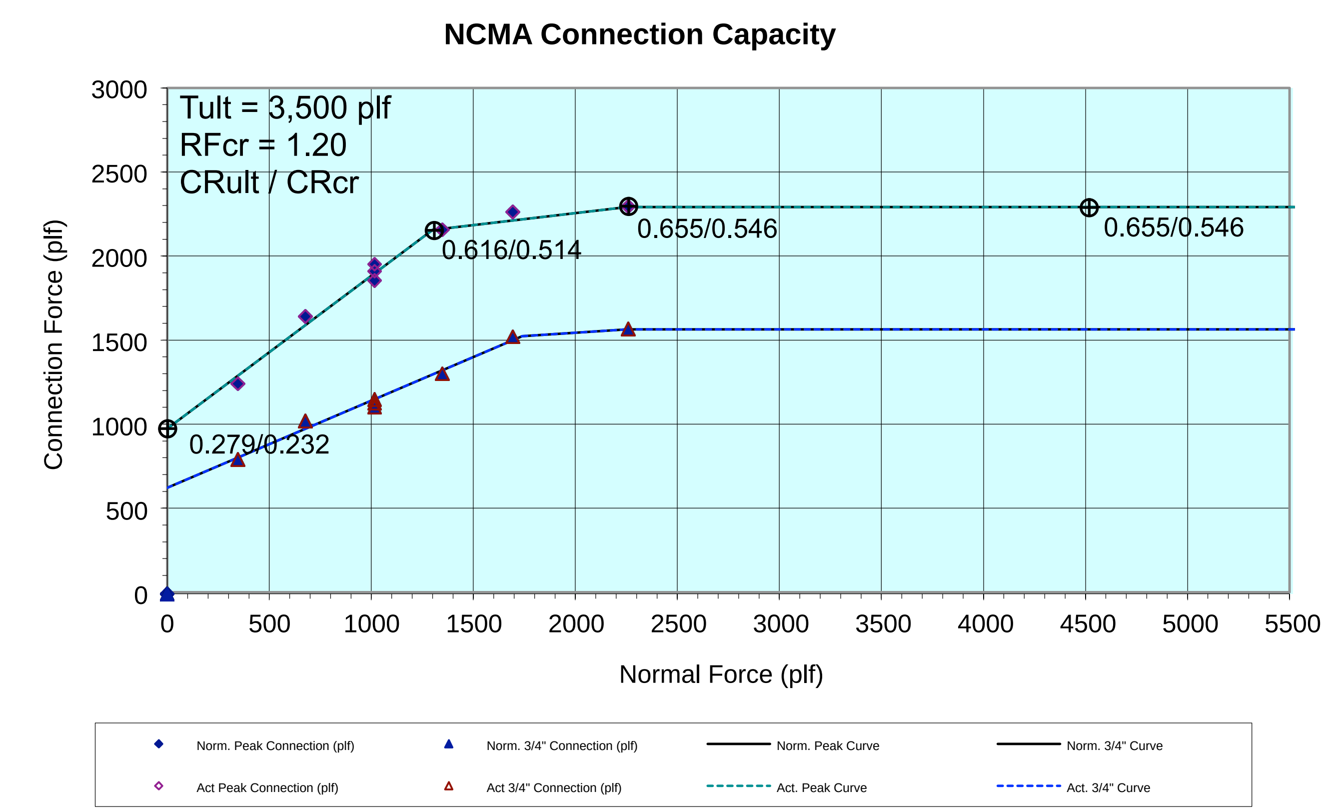
Normalized 3/4" Serviceability Equation Fit

Intercept (plf)	625	9.12
Slope1	27.4	27.4
Break - Normal	1740	25.39
Slope2	4.6	4.6
Maximum (plf)	1568	22.89

Normalized Laboratory Test Data

T_{lot}/T_{ult}=1.00

Normal Load (plf)	Peak Connection (plf)	3/4" Connection (plf)
346	1245	797
676	1644	1024
1013	1858	1108
1013	1913	1130
1013	1954	1152
1344	2160	1305
1688	2264	1525
2252	2298	1570



3/10/15
pjs

HITEC CONNECTION EVALUATION

Keystone Unit: Compac III
Manufacturer: Mirafi
Geogrid Type: 5XT
Laboratory: BCGT 10/27/09

Normalized Peak Connection Equation Fit

	English	Metric
Intercept (plf)	938	13.69
Slope1	45.5	45.5
Break - Normal	1100	16.05
Slope2	20.2	20.2
Maximum (plf)	2684	39.17

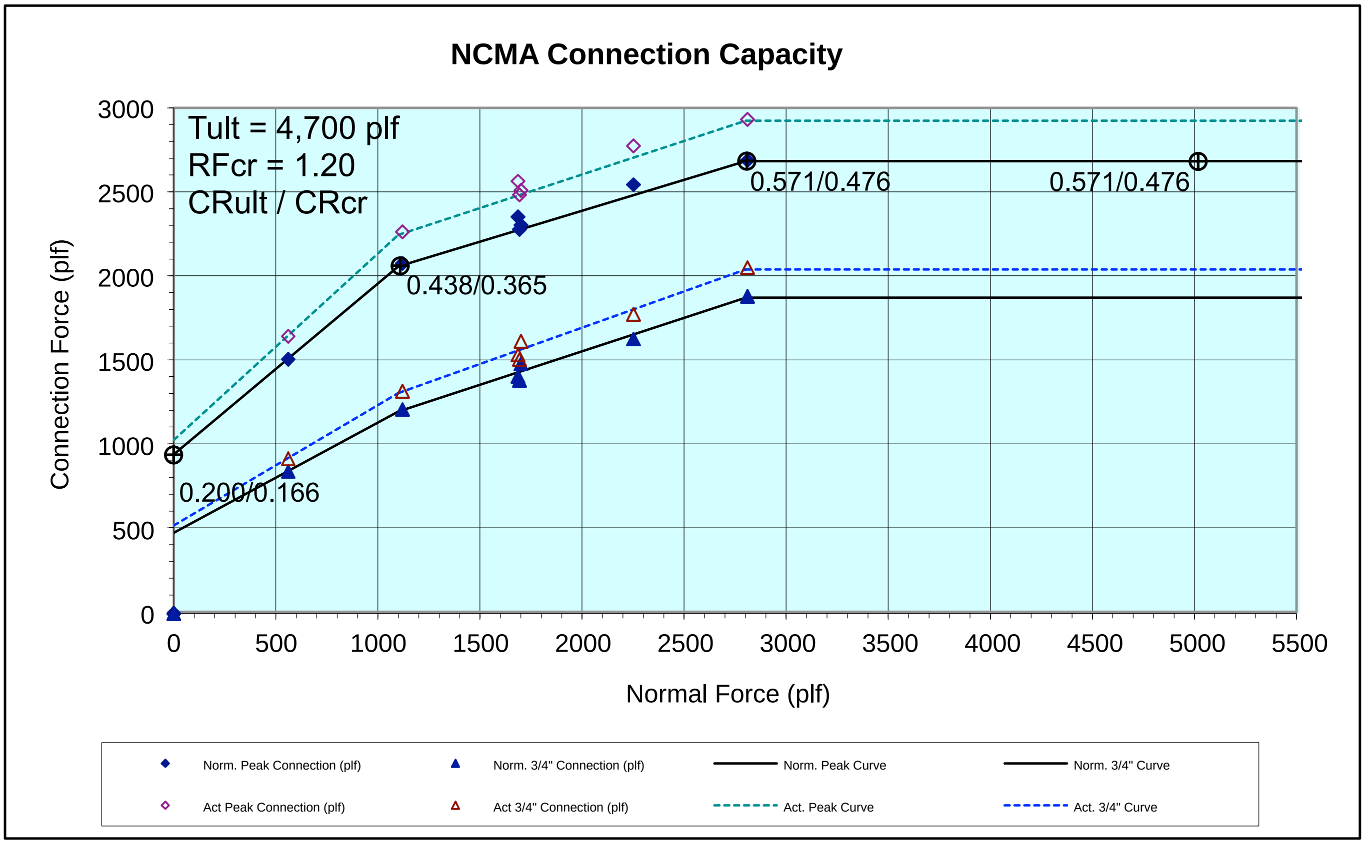
Normalized 3/4" Serviceability Equation Fit

Intercept (plf)	474	6.92
Slope1	33.3	33.3
Break - Normal	1100	16.05
Slope2	21.7	21.7
Maximum (plf)	1874	27.35

Normalized Laboratory Test Data

T_{lot}/T_{ult}=1.09

Normal Load (plf)	Peak Connection (plf)	3/4" Connection (plf)
559	1508	842
1117	2077	1209
1681	2354	1406
1688	2279	1383
1695	2304	1482
2245	2544	1628
2802	2689	1883



3/10/15
pjs

HITEC CONNECTION EVALUATION

Keystone Unit: Compac III
Manufacturer: Mirafi
Geogrid Type: 7XT
Laboratory: BCGT 10/27/09

Normalized Peak Connection Equation Fit

	English	Metric
Intercept (plf)	907	13.24
Slope1	45.7	45.7
Break - Normal	1100	16.05
Slope2	24.1	24.1
Maximum (plf)	3054	44.57

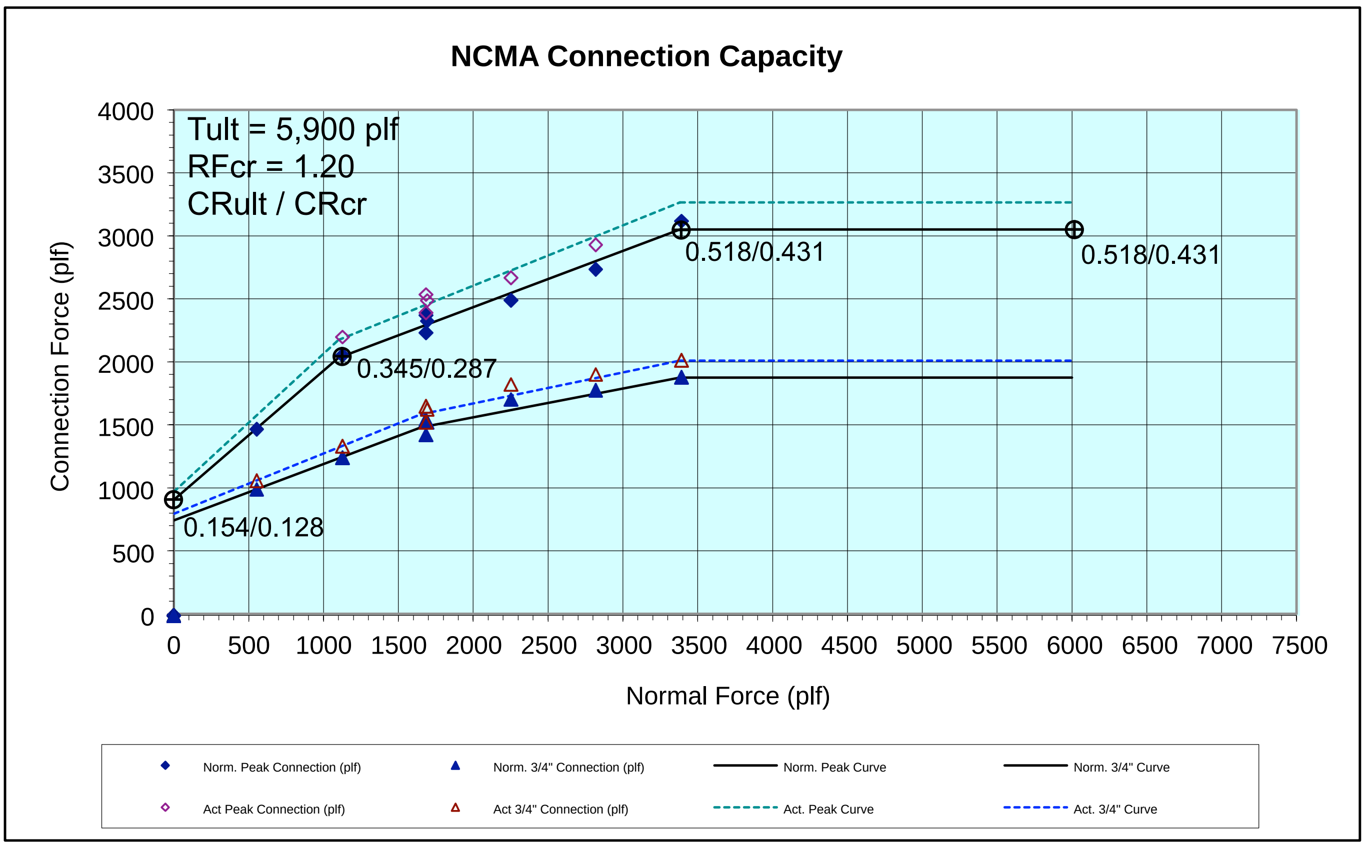
Normalized 3/4" Serviceability Equation Fit

Intercept (plf)	748	10.92
Slope1	24.1	24.1
Break - Normal	1650	24.08
Slope2	12.9	12.9
Maximum (plf)	1882	27.47

Normalized Laboratory Test Data

T_{lot}/T_{ult}=1.07

Normal Load (plf)	Peak Connection (plf)	3/4" Connection (plf)
553	1473	996
1124	2058	1250
1681	2237	1428
1681	2373	1548
1688	2328	1526
2245	2494	1707
2809	2739	1779
3380	3119	1885



3/10/15
pjs

HITEC CONNECTION EVALUATION

Keystone Unit: Compac III
Manufacturer: Mirafi
Geogrid Type: 8XT
Laboratory: BCGT 10/27/09

Normalized Peak Connection Equation Fit

	English	Metric
Intercept (plf)	1065	15.54
Slope1	40.3	40.3
Break - Normal	1680	24.52
Slope2	27.6	27.6
Maximum (plf)	3378	49.31

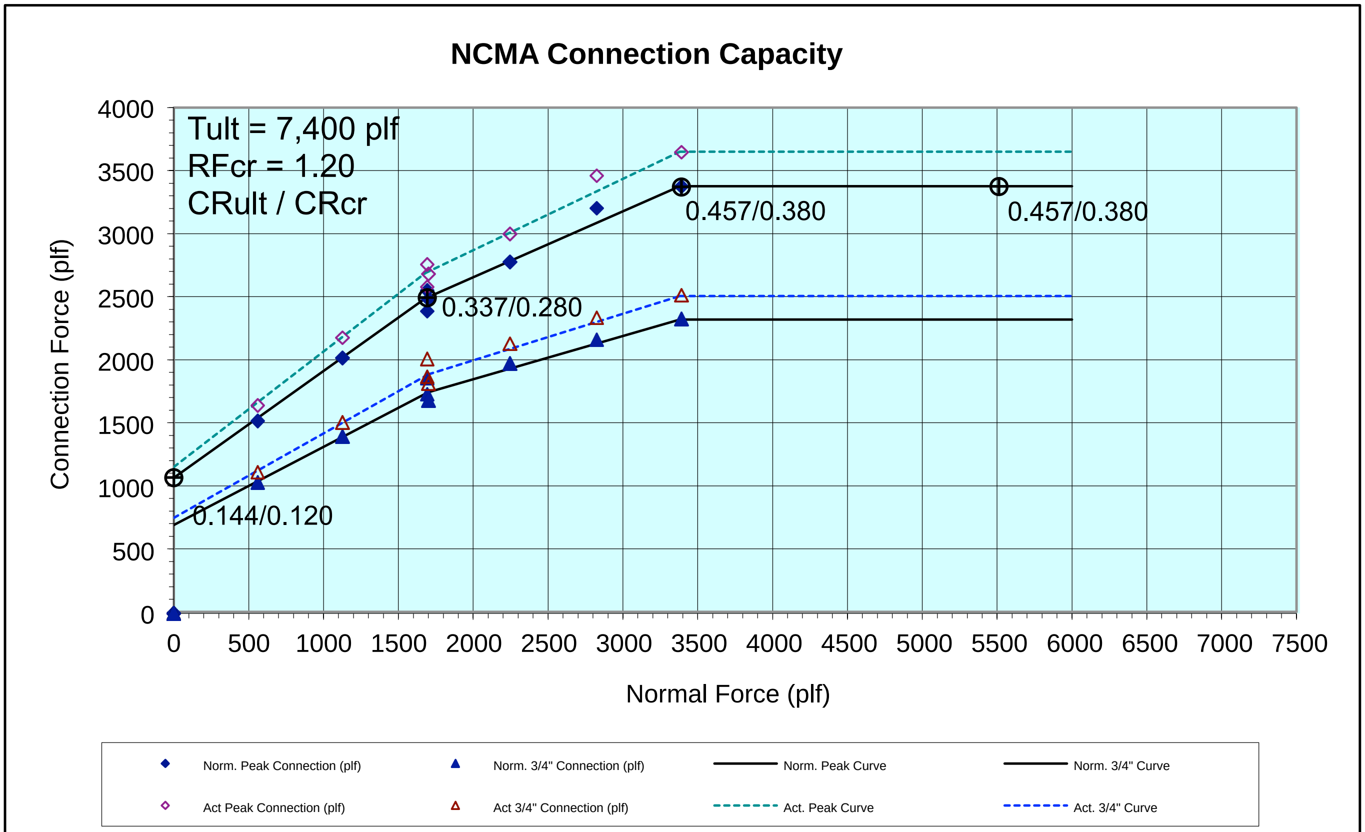
Normalized 3/4" Serviceability Equation Fit

Intercept (plf)	694	10.13
Slope1	31.8	31.8
Break - Normal	1700	24.81
Slope2	18.9	18.9
Maximum (plf)	2323	33.91

Normalized Laboratory Test Data

T_{lot}/T_{ult}=1.08

Normal Load (plf)	Peak Connection (plf)	3/4" Connection (plf)
559	1522	1034
1124	2019	1398
1688	2389	1734
1688	2555	1861
1695	2484	1683
2238	2778	1976
2816	3205	2165
3380	3376	2330



3/10/15
pjs

HITEC CONNECTION EVALUATION

Keystone Unit: Compac III
Manufacturer: Mirafi
Geogrid Type: 10XT
Laboratory: BCGT 10/27/09

Normalized Peak Connection Equation Fit

	English	Metric
Intercept (plf)	733	10.70
Slope1	48.8	48.8
Break - Normal	1150	16.78
Slope2	29.5	29.5
Maximum (plf)	3304	48.23

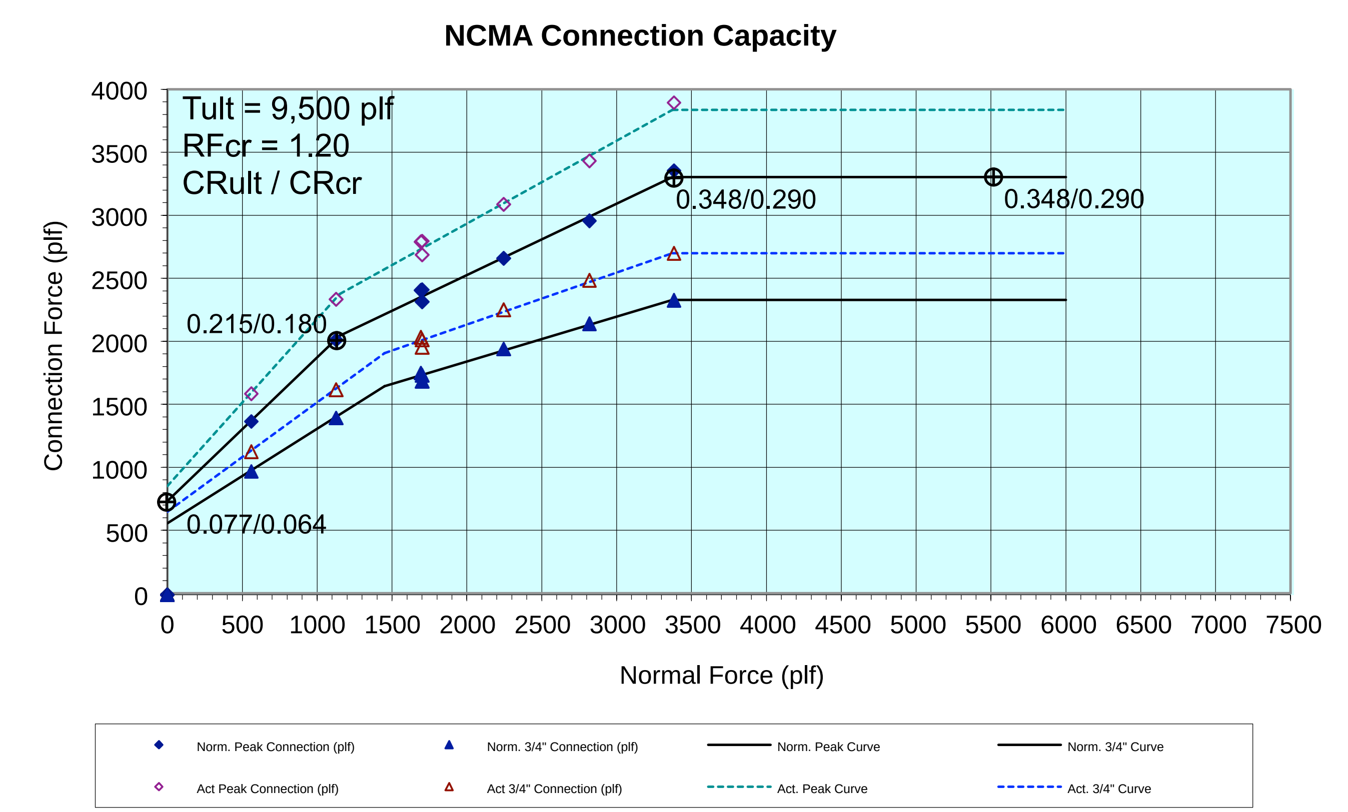
Normalized 3/4" Serviceability Equation Fit

Intercept (plf)	560	8.17
Slope1	36.9	36.9
Break - Normal	1450	21.16
Slope2	19.6	19.6
Maximum (plf)	2333	34.06

Normalized Laboratory Test Data

T_{lot}/T_{ult}=1.16

Normal Load (plf)	Peak Connection (plf)	3/4" Connection (plf)
559	1370	976
1124	2016	1398
1688	2408	1755
1695	2414	1689
1695	2319	1739
2238	2663	1944
2809	2959	2145
3373	3357	2330



Mirafi XT - Compac III Connection Strength Normalization (lbs/ft) 1/29/15

	MARV	INDEX	Tlot/Tult	Lot
3XT	3,500	3,484	1.00	032092006/06244-2-4
5XT	4,700	5,130	1.09	031106986/08234-1-4
7XT	5,900	6,317	1.07	031062656/06334-1-4
8XT	7,400	7,987	1.08	031109345/08288-1-1
10XT	9,500	10,973	1.16	031109615/08296-1-3

MARV - Mean Average Roll Value
INDEX - Strength of roll used
Tlot/Tult = INDEX/MARV
Lot - Manufacturer Roll Identification

AASHTO specifications require that connection test data be normalized to the actual strength of the geogrid tested to conservatively address statistical variation based on the MARV value.

Short term connection tests shall be reduced by the Tlot/Tult factors to adjust to the lowest statistical geogrid strength as determine by the MARV analysis.

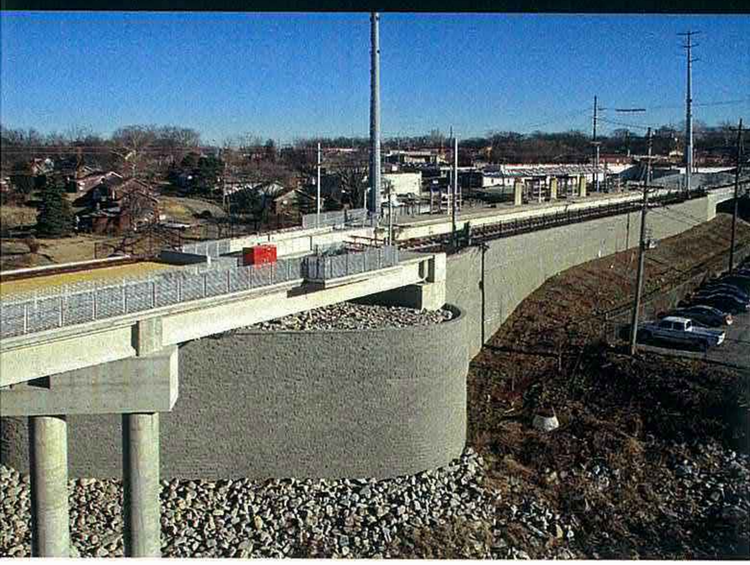
Technical Evaluation Report

EVALUATION OF

THE KEYSYSTEM™ II RETAINING WALL

BY KEYSTONE RETAINING WALL SYSTEMS, INC. WITH
TENCATE GEOSYNTHETICS GEOGRID REINFORCEMENT

FINAL REPORT



HITEC

Prepared by the
Highway Innovative Technology
Evaluation Center (HITEC)

MAY 2012

EVALUATION OF
THE KEYSYSTEM™ II RETAINING WALL
By Keystone Retaining Wall Systems, Inc. with
TenCate Geosynthetics Geogrid Reinforcement

FINAL REPORT

The Highway Innovative Technology Evaluation Center (HITEC) was created through a cooperative agreement with the Federal Highway Administration (FHWA) to expedite the introduction of innovative products into the US highway and bridge markets. By providing impartial evaluation of technologies, HITEC hopes to encourage state and local governments to implement innovative products in the highway system more quickly, thereby enhancing the incentives for private industry to invest in highway-oriented research and development. HITEC was organized not only to provide a service to specific clients, but also to serve as a clearinghouse for information useful to the highway community at large, particularly public sector officials.

To guide the overall process, HITEC assembles a unique, multi-disciplinary panel of experts for each evaluation. The panel works with the manufacturer of the innovative product or technology to devise a plan for comprehensively evaluating the performance of the product. The panelists selected to direct the evaluation typically include experts from the county, state, and federal transportation agencies, academia, and the private sector.

The information found in this report is neither an endorsement nor an approval of a technology. Instead, the information is intended to provide the reader with accurate information and/or credible analysis. Also, where appropriate, HITEC hopes to feed the development of national standards for innovative technologies through its published reports.

For further information on HITEC, please contact 703-295-6392.

Disclaimer

The Highway Innovative Technology Evaluation Center (HITEC) program was launched through Federal Highway Administration support under Cooperative Agreement No. DTFH61-93-X-00011, and is currently operational under private funding. The Federal Highway Administration has not reviewed, sponsored, or endorsed this document in any manner and bears no responsibility for its contents. Any opinions, findings, conclusions, or recommendations expressed in this publication are those HITEC and do not necessarily reflect the view of the Federal Highway Administration.

This report is the result of an impartial, consensus-based approach to evaluating innovative highway technology in accordance with the HITEC Technical Protocol. The data presented are believed accurate and the analyses credible. The statements made and conclusions drawn regarding the product evaluated do not, however, amount to an endorsement or approval of the product in general or for any particular application.

Abstract

The Highway Innovative Technology Evaluation Center (HITEC) serves as a clearinghouse for implementing highway innovation by conducting nationally focused, collaborative evaluations of new products and technologies. This report, *Evaluation of the KeySystem™ II Retaining Wall*, was prepared as part of the HITEC evaluation for earth retaining systems (ERS). This evaluation was performed on the KeySystem™ II Retaining Wall System with TenCate XT geogrid reinforcement (KeySystem II/TenCate XT geogrids), a mechanically stabilized earth (MSE) structure developed, designed, and supplied by Keystone Retaining Wall Systems, Inc.

This report describes a HITEC evaluation designed to determine the basic capabilities and limitations of KeySystem II for use as a technically viable precast MSE retaining wall system. The evaluation was conducted based on design, construction, performance, and quality assurance information outlined in the HITEC Protocol.

KeySystem II/Tencate XT geogrids features modular block facing (MBW) to which PET grid reinforcement is connected. The PVC coated PET geogrid reinforcement is a high strength, high tenacity polyester yarn product produced by Tencate Geosynthetics.

Library of Congress Cataloguing-in-Publication Data

Highway Innovative Technology Evaluation Center (U.S.)
Evaluation of the Keysystem II retaining wall by Keystone Retaining Wall Systems, Inc. with TenCate Geosynthetics' geogrid reinforcement / prepared by the Highway Innovative Technology Evaluation Center.
p. cm. – (Technical evaluation report)
Includes bibliographical references and index.
ISBN 978-0-7844-1214-5
1. Retaining walls--Testing. 2. Retaining walls--Materials--Evaluation. 3. Geogrids. I. Keystone Retaining Wall Systems, Inc. II. TenCate Geosynthetics. III. Title.
TA770.H54 2012
624.1'64--dc23
2012002966

Library of Congress Catalog Card No: 2012002966
ISBN 978-0-7844-1214-5
Manufactured in the United States of America.

Technical Evaluation Panel Key Contacts

Product: KeySystem II MSE Retaining Walls with TenCate XT geogrid reinforcement

Panelists:

Tony Allen
State Geotechnical Engineer
Washington State Department of Transportation

Randy Cannon
Director of Structural & Geotechnical Engineering
Civil Engineering Consulting Services

Todd Dickson
Civil Engineer II
New York State Department of Transportation

Jerry DiMaggio
Principal
Jerry A. DiMaggio Consulting LLC

David Dundas
Senior Foundation Engineer
Ministry of Transportation, Ontario

Dov Leshchinsky
Professor of Civil Engineering
University of Delaware

HITEC Project Manager: **Muhammad Amer**

Client:

Keystone® Retaining Wall Systems, Inc.
4444 West 78th Street
Minneapolis, MN 55435
Phone: 952.897.1040
Fax: 952.897.3858
Web: www.keystonewalls.com

Consultant: **D'Appolonia**
Ryan R. Berg, P.E., D.GE
Barry R. Christopher, Ph.D., P.E.
Fatma Ozkahriman, P.E.
James L. Withiam, Ph.D., P.E., D.GE

Acknowledgments

The Highway Innovative Technology Evaluation Center (HITEC) prepared this report and wishes to acknowledge the contributions of individuals whose efforts and suggestions have significantly influenced the content of this report. Notably, this report is based on work by members of a technical evaluation panel (Panel) who volunteered to develop the evaluation plan for this project and carry out its objectives. The HITEC Panel is composed of Tony Allen, Washington State Department of Transportation; Randy Cannon, Civil Engineering Consulting Services; Todd Dickson, New York State Department of Transportation; Jerry DiMaggio, Jerry A. DiMaggio Consulting, LLC; David Dundas, Ontario Ministry of Transportation; and Dov Leshchinsky, University of Delaware. Additionally, D'Appolonia served as the consultant to the Panel and was instrumental in producing this report.

HITEC also wishes to thank the employees of Keystone Retaining Walls Systems, Inc. and TenCate Geosynthetics for their cooperation during the evaluation process.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This evaluation was performed on the KeySystem™ II Retaining Wall System (KeySystem II), a mechanically stabilized earth (MSE) structure, based on data submitted by the developer and designer, Keystone Retaining Wall Systems, Inc. (Keystone) of Minneapolis, MN.

The evaluation was conducted based on design, construction, performance, and quality assurance information provided by Keystone. This information was evaluated for conformance with the latest state-of-practice criteria as outlined in the HITEC Protocol.

As shown in Figure 1, KeySystem II features a modular concrete block facing (MBW) (segmental precast concrete blocks) connected to geogrid soil reinforcement. Keystone Compac II MBW units, which are available in a variety of aesthetic finishes, and TenCate Miragrid XT PVC coated, woven polyester geogrids are used in the design and construction of this wall system. The Compac II modular block units have a face area of 1 ft^2 (0.09 m^2) and are 1 ft (300 mm) long (front to back). A pair of fiberglass pins are used to align and vertically connect adjacent facing units. The locations, strengths, and lengths of the soil reinforcement geogrids are designed to meet individual project requirements. The design of this type of structure is fully governed by Article 11.10 of the AASHTO LRFD Bridge Design Specifications (AASHTO, 2010a).

The design methods submitted for external and internal stability are in accordance with the requirements in AASHTO (2010a, 2010b).

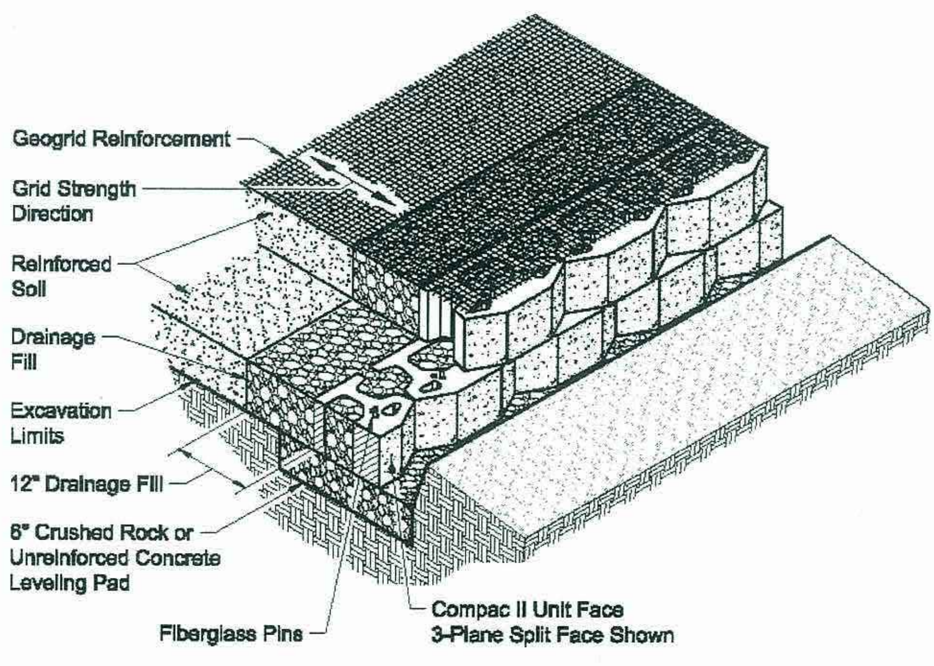


Figure 1
Oblique View of KeySystem Showing Block Face and Connection with Reinforcement

The construction materials specification submitted is in general accordance with current practice and AASHTO (2010a) and FHWA (2009) with the following exceptions.

- The submittal did not include internal stability analysis for MSE wall support of a bridge abutment spread footing; therefore, this system has not been reviewed for support of bridge structures. KeySystem II walls should not be used for support of a bridge abutment spread footing without a detailed review.

- The details of the specification included with the precaster's license agreement are not in conformance with AASHTO/FHWA, however the precaster must meet AASHTO/FHWA specifications and/or local agency requirements if required in the project-specific specifications. QA of modular block face units and geogrid reinforcement should be addressed in the specifying agency's special provisions.

Keystone relies on their geosynthetic supplier to provide quality control of the materials in accordance with specification requirements and maintains a copy of all mill certificates. Keystone relies on their licensed MBW precasters to provide quality control of facing units in accordance with the QC/QA program described herein. The QC/QA requirements are included in Keystone's license agreements with precasters along with Keystone's right to review records, inspect the production and shipping facilities, and randomly sample and test the product. Keystone relies on TenCate Geosynthetics to provide quality control of the geogrid materials in accordance with specification requirements, but does not maintain a copy of certificates of compliance. TenCate Geosynthetics performs in-house quality control tests on the geogrids in accordance with the TenCate QC/QA program described herein.

KeySystem II retaining walls have been widely used on private works in California, New York, Georgia, and North Carolina. Information on twenty-nine projects were contained within the submittal, representing over 475,000 ft^2 (44,000 m^2) of constructed walls. Information on three transportation related projects was contained within the submittal, representing 150,000 ft^2 (13,900 m^2) of constructed walls. The highest KeySystem II wall constructed to date is 55 ft (16.8 m), at the Rocky Mountain Metropolitan Airport in Broomfield, Colorado.

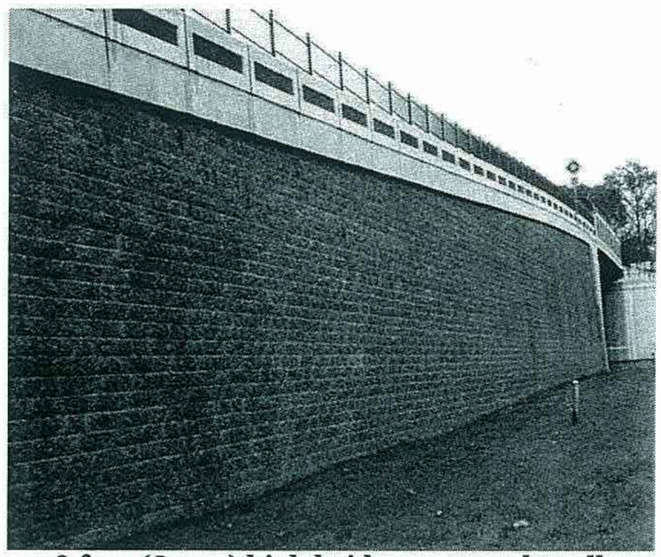
The potential height limit of this KeySystem II is approximately 55 ft (16.8 m), based on the good performance reported for the Rocky Mountain Metropolitan Airport wall and for the geogrids and test data submitted.

KeySystem is a technically viable MSE retaining wall system. The in-place costs for KeySystem have been estimated by Keystone.

1 INTRODUCTION

1.1 Purpose, Scope and Basis for Evaluation

This evaluation was conducted for the KeySystem™ II Retaining Wall System (KeySystem II) developed by Keystone Retaining Wall Systems, Inc. (Keystone), of Minneapolis, Minnesota. The primary components of this mechanically stabilized earth (MSE) structure include:



28 foot (8.5 m) high bridge approach wall

- zero-slump (dry cast) concrete modular block facing units (MBW);
- continuous high tenacity polyester (PET) woven yarn and PVC coated geogrid reinforcing elements;
- fiberglass "alignment/shear" pins between facing units; and
- select granular wall fill.

Figure 1 in the Executive Summary shows an oblique view of the face block and reinforcement connection for KeySystem II.

The evaluation was conducted using material, design, construction, performance, and quality assurance information provided by Keystone, and evaluated for conformance to the latest state-of-the-practice criteria outlined in the HITEC Protocol. The Protocol document substantially incorporates the AASHTO LRFD Bridge Design Specifications (AASHTO 2010a), AASHTO LRFD Bridge Construction Specifications (AASHTO, 2010b), and FHWA guidelines for Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes (FHWA, 2009). Where no applicable criteria exist in the referenced documents, evaluations were based on state-of-the-practice as indicated in the technical literature or documentation submitted by Keystone.

This evaluation is intended for readers who have a working knowledge of the design and construction specification requirements in AASHTO (2010a) Article 11.10 for MSE Walls, and the FHWA design and construction guidelines manual (FHWA, 2009). Understanding the test methods and interpreting procedures in the Appendices of the FHWA manual is essential to understanding the test data submitted by Keystone in support of product-specific design parameters.

The submittal by Keystone for this KeySystem II (see CERF Report #40478 for KeySystem I with steel grid soil reinforcements) was evaluated relative to the Protocol developed by the HITEC Panel and the Consultant. The Protocol (Appendix A) is an updated (to LRFD) version of the original (ASD based) HITEC Protocol which was further reviewed and commented on by industry in a public forum prior to being finalized.

The results of this evaluation do not constitute an approval or a rejection of the system and/or its components. Further, any recommendations for modifications and/or conformance to specific evaluation criteria should not be construed as mandatory. The potential effects are noted, and each approval agency must determine its own requirements for implementation. It is suggested that manufacturers note any deviation from their HITEC submittal when submitting their system for acceptance by an approving agency.

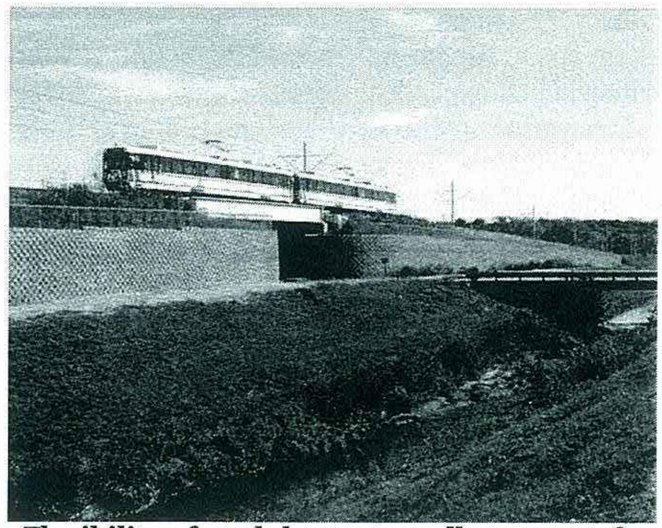
1.2 Documents Reviewed

The documents that support this report were initially submitted in September 2009. During the course of this evaluation additional information or clarification was requested twice, and was subsequently submitted for the record in August 2010 and December 2011.

A complete set of the submitted data is available from HITEC, which maintains the chain-of-custody for all data reviewed and used in this evaluation, including revisions to the initial submittals.

2 HISTORY AND SYSTEM CONCEPT

This KeySystem is an MSE retaining wall system comprised of zero-slump modular concrete block facing units and extensible PET grid type reinforcements. The design of this type of structure is therefore fully governed by applicable design and construction criteria in AASHTO (2010a).



Flexibility of modular system allows ease of construction around bridge foundation piers.

The system features modular concrete blocks (segmental precast concrete blocks) identified as Compac II units. The Compac II units are 8 in. (203 mm) high, 18 in. (457 mm) wide, and 12 in. (305 mm) long as measured from front to back. (Note: this latter dimension is the width W_u in AASHTO, 2010a). The exposed area of the facing block unit is 1 ft^2 (0.09 m^2). Two modular block capping units, identified as Half Cap and Full Cap units are also available, are sometimes used on wall structures. Full Cap units are 8 in. (203 mm) high, 18 in. (457 mm) wide, and 10.5 in (267 mm) long. Half Cap units are 4 in (102 mm) high and the same width and length as the Full Cap unit. Refer to Appendix C for information regarding the dimensional features of the facing units.

Cap units are manufactured with a smooth top surface and are used to cap the wall and to vary the face appearance for aesthetics. The modular blocks are dry-stacked (i.e., without mortar) in a running-bond configuration (Figure 1). Two pins connect vertically adjacent blocks to inhibit relative horizontal displacement. These pins are constructed of fiberglass with a diameter of 0.5 in. (12.7 mm) and a length of 5.25 in (133 mm). Compac II units are manufactured with two sets of pin receiving holes (front and rear pin holes), as shown in Appendix C. When the connection pins are installed in front pin holes, the effective setback is approximately 1/4-in. per 8-in. unit, a batter of 1H:32V, which is approximately 2 degrees from the vertical plane. When the pins are installed in the rear pin holes, the effective unit setback is 1-1/4-in. per 8-in. unit, a batter of 1H:6.4V, which is approximately 8.8 degrees from the vertical plane.

The earth reinforcing elements consist of TenCate Geosynthetics' XT polyester (PET) geogrids of various strength and dimensions as required by the design. The XT geogrids are manufactured by weaving high tenacity polyester (PET) yarns (Type 811) and coating the finished grid with polyvinyl chloride (PVC) to maintain the integrity of the geogrid during handling and placement and to protect it during construction. The geogrid reinforcements are placed with the machine direction perpendicular to the block units and extending over the surface of the block beyond the fiberglass alignment pins to achieve the connection through friction between the block facing units and interlock with infill gravel contained within the block. All components are illustrated in Appendix C.

KeySystem II is a retaining wall system marketed and serviced by Keystone Retaining Wall Systems, Inc. The system is specifically designed for use in highway and heavy construction industries. Keystone Retaining Wall Systems, Inc. is responsible for the system performance, excluding construction issues. Keystone Retaining Wall Systems, Inc., their local manufacturers, and TenCate (geogrid manufacturer) are responsible for the retaining wall materials. Keystone Retaining Wall Systems, Inc. is the Engineer of Record for KeySystem II projects designed by their engineering department. Projects are also designed locally by private consultants, with technical support by Keystone Retaining Wall Systems, Inc.

KeySystem II retaining walls have been widely used on private works in California, New York, Georgia, and North Carolina since introduced in 2002. Information on twenty-nine projects were contained within the submittal, representing over 475,000 ft^2 (44,000 m^2) of constructed walls. Information on three transportation related projects was contained within the submittal, representing 150,000 ft^2 (13,900 m^2) of constructed walls. The highest KeySystem II wall constructed to date is 55 ft (16.8 m), at the Rocky Mountain Metropolitan Airport in Broomfield, CO.

3 DESIGN METHOD EVALUATIONS

3.1 Performance Criteria

The methodology submitted, and supported by typical computations, indicates a design practice that conforms to AASHTO (2010a) and FHWA NHI-09-024/025 (Berg et al., 2009) criteria with respect to load and resistance factors for external and internal stability, foundation embedment, bearing pressure computations, maximum vertical spacing and minimum reinforcement length.

Tiered retaining wall structure with 55-ft (17-m) finished total height

With respect to overall vertical tolerances during erection, the KeySystem II Installation Guide includes tolerances of 3/4-in. over 10 ft (19 mm over 3 m) which is in conformance with FHWA (2009) requirements erection tolerances. No specific project data was submitted to demonstrate that the system could be erected to the specified tolerances.

Regarding the facing unit(s) tolerance to differential settlement, Keystone recommends a maximum differential settlement limit of 1/200, which is in conformance with the FHWA NHI-09-024/025 recommendation of 1/200 limit for dry cast modular lock facings. Keystone states that differential settlements in excess of the 1/200 value may be tolerated with the use of slip joints (detail presented in Appendix C).

3.2 External Stability

The submitted methodology for external stability computations under static and transient loading (dead and live load) conforms to AASHTO (2010a) criteria.

The project owner is responsible for providing strength parameters for the retained fill as well as allowable foundation bearing pressures, anticipated foundation settlement, and global stability determinations for each structure.

3.2.1 Global and Compound Stability

Global: Agency engineers or their consultant geotechnical engineers who have experience with local geological conditions should perform the analysis of potential deep-seated failure planes. Evaluation of global stability is typically performed by the contracting agency/owner or by the owner's geotechnical engineer and, therefore, is usually beyond the scope of services provided by Keystone. Keystone does provide consultation regarding appropriate methods to incorporate KeySystem components in global stability analyses.

Compound: Agency engineers or their consultant geotechnical engineers who have experience with local geological conditions should perform the analysis of potential compound failure planes. Alternatively, the contracting agency could provide detailed subsurface profiles, soil shear strengths, soil unit weights and groundwater information for wall vendors to use in compound stability analyses. Evaluation of compound stability is typically beyond the scope of services provided by Keystone, and is performed by the contracting agency/owner or by the owner's geotechnical engineer. Keystone does provide consultation regarding appropriate methods to incorporate KeySystem components in global stability analyses. Keystone will incorporate agency defined and specified reinforcement requirements, for compound stability, into their wall design.

3.3 Internal Stability

The submitted methodology for internal stability computations under static and seismic loading conforms to AASHTO (2010a) criteria with respect to:

- Assumed failure surface for internal stability calculations and calculations for effective length, L_e.
- Horizontal stress computations using K_r.
- Distribution of surcharge and concentrated loads.
- Development of seismic loads and calculations to preclude pullout or rupture.
- Distribution of supplemental loads due to traffic barrier impact.

Submittal did not include internal stability analysis for MSE wall support of a bridge abutment spread footing. Therefore, conformance to AASHTO (2010a) and FHWA (2009) requirements were not reviewed.

The vertical reinforcement spacing for Key System II is controlled by the height of the block, i.e., 8-in. (203 mm) increments. The KeySystem II maximum vertical spacing of soil reinforcement is 24 in. (610 mm). This spacing is less than 32 in. (800 mm) maximum limit per AASHTO (2010a) and FHWA (2009) and meets the requirements for segmental concrete facing block that the vertical spacing be no greater than twice the front to back width, W_u, of the facing unit (i.e., for the KeySystem II facing unit with W_u = 12 in. (300 mm), the maximum vertical spacing = 24 in. (600 mm) or every third block) as recommended in Article 11.10.2.3.1 of AASHTO (2010a). Vertical spacing is reduced to every other block or every block where needed for loading conditions, and at the top and the base of the wall, to meet AASHTO (2010a) requirements. A soil reinforcement coverage ratio of 100 percent is utilized.

With respect to design parameters needed to determine spacing and sizing of the reinforcement to preclude pullout or rupture, the submitted data for interaction coefficients and allowable strength are described in the following sections.

3.3.1 Interaction Coefficient (F*)

Specific reinforcement-soil interaction coefficients used in design are not stated by TenCate Geosynthetics, but a range of values were provided. These values were based on pullout tests performed on Mirafi XT geogrids by an independent laboratory in general accordance with the methods outlined in Appendix B of FHWA (2009). Tests on a range of geogrid grades were performed with a concrete sand type soil with the normalized pullout resistance factor, F*, and scale factor, α, used in AASHTO (2010a) and FHWA (2009) reported. The reported F* and α values are listed in Table 1.

Table 1
Reinforcement-Soil Interaction Coefficients for Mirafi Geogrids

Soil Type	$\phi_{residual}$ (degrees)	F*	α
Poorly graded sand (SP)	34	0.64 – 0.87	1.0

Submitted test reports in support of these coefficients are presented in Appendix B. The default value recommended by FHWA (2009) of $F^* = 0.66 \tan\phi$ and $\alpha = 0.8$ should be used in the absence of test data on project-specific or project-representative soil.

The recommended F* and α values are consistent with those recommended for Mirafi XT geogrids in a February 2005 HITEC Technical Evaluation Report (#40708).

3.3.2 Ultimate Strengths, PET Geogrids

The KeySystem uses soil reinforcement elements that are PVC-coated, woven high tenacity PET geogrids of various configurations and strengths, and are identified as Mirafi Miragrid™ XT geogrids.

In accordance with AASHTO (2010a) criteria, the long-term nominal geosynthetic material strength (T_{al}) is defined as the ultimate strength (T_{ult}) tests based on minimum average roll values (MARV) for each product, divided by reduction factors to account for creep (RF_{CR}), durability (RF_D), and installation damage (RF_{ID}) that can be anticipated over a design life of either 100 or 75 years. Reduction factors are determined by laboratory or field tests in accordance with methods outlined in the appendices to FHWA (2009). The factored reinforcement resistance must be greater than (or equal to) the maximum factored tension in each layer of reinforcement for retaining wall design. The values of T_{ult} by TenCate recommended for use in design are listed Table 2, and are based on the ASTM D6637 test method.

Table 2
Values of T_{ult} for Mirafi Geogrids

Product	T_{ult} lb/ft (kN/m)
Miragrid 3XT	3,500 (51)
Miragrid 5XT	4,700 (69)
Miragrid 7XT	5,900 (86)
Miragrid 8XT	7,400 (108)
Miragrid 10XT	9,500 (139)

Note that minimum average roll value (MARV) T_{ult} is defined as the mean production strength minus two standard deviations. The 2009 manufacturer's production T_{ult} MARV values and representative data were submitted. The 2009 T_{ult} MARV values for the 3XT, 5XT, 7XT and 8XT grades are 3% to 5% higher than the values presented in Table 2. The 2009 T_{ult} MARV value for the 10XT is 10% higher than the value presented in Table 2.

The reduction factors submitted for the Mirafi XT geogrids are discussed in the following section. The factors are supported by laboratory and/or field test data developed in conformance to AASHTO (2010a) and FHWA (2009) criteria except as noted.

The T_{ult} values listed in Table 2 are significantly higher (31% and 19%, respectively) than those listed for the two Mirafi (5XT and 8XT) geogrids addressed in the February 2005 HITEC Technical Evaluation Report (#40708). The T_{ult} values in Table 2 for the Mirafi 10XT geogrid is the same value as listed in the March 2008 National Transportation Product Evaluation Program (NTPEP) Report #8501.1 Laboratory Testing of Geosynthetic Reinforcement, (2005) – 03 Product Submissions (NTPEP, 2008). The T_{ult} values in Table 2 are 4% to 11% higher than those listed for Mirafi 3XT, 5XT, 7XT and 8XT in the March 2008 NTPEP Report #8501.1 (NTPEP, 2008). The ASTM D6637 tensile strength test procedure was used to define the NTPEP values. As noted in the submittal, the increases are primarily due to the amount of data now available (from a comprehensive testing program in 2007) and use of more effective hydraulic clamping grips (which provide better load transfer across the specimen width and reduces stress concentrations) for tensile testing.

The ultimate tensile strengths listed in Table 2 are recommended. As previously noted, these values are equal or slightly lower than the values listed in the NTPEP report (NTPEP, 2008)[1]. The reduction factors submitted for Mirafi XT geogrids are discussed in the following section. The factors are supported by laboratory and/or field data developed in conformance with AASHTO (2010a) and FHWA (2009) criteria except as noted.

3.3.3 Installation Damage (RF_{ID}) Reduction Factors, PET Geogrids

Damage during reinforced fill placement and compaction operations is a function of the severity of loading imposed on the geosynthetic during construction operations and the size and angularity of the reinforced fill. For MSE wall construction, lightweight, low strength geotextiles and geogrids should be avoided to minimize damage with ensuing loss of strength. Protocols for field testing for this reduction factor are detailed in the FHWA Corrosion/Degradation document (Elias et al., 2009) and in ASTM D5818 (see also WSDOT T925 and PP66-10 [AASHTO, 2010c]). These protocols require that the geosynthetic material be subjected to a reinforced fill placement and compaction cycle, consistent with field practice. The ratio of the initial strength, to the strength of retrieved samples defines this reduction factor. In general, RF_{ID} is strongly dependent on the backfill soil gradation characteristics and its angularity, especially for lighter weight geosynthetics. Regarding geosynthetic characteristics, the geosynthetic weight/thickness or tensile strength may have a significant effect on RF_{ID}. However, for coated polyester geogrids, the coating thickness may overwhelm the effect of the product unit weight or thickness on RF_{ID}. (FHWA, 2009)

[1] An updated NTPEP report is scheduled for 2012.

A significant amount of damage reduction factor test data was submitted by TenCate. A range of RF_{ID} values was presented for two soil types. The submitted values were independent of the geogrid grade. However, interpretation of the data and rational for the submitted values were not provided. Specifically, MSE wall gradation, angularity of soils, laboratory testing procedures (e.g., fill placement, spreading, compaction) and methods consistency (or inconsistency) with field practice, geosynthetic weight, coating values on tested specimens and typical values, and coating versus grade of geogrid were not addressed.

Therefore, it is recommended that:

- An RF_{ID} value of 1.15 to 1.3 may be used for 5XT, 7XT, 8XT and 10XT geogrids with MSE fills with a maximum 3/4-in. (19 mm) aggregate size limit. The upper end of the range value is recommended in absence of site specific or representative tests due to the less aggressive placement techniques used in the laboratory tests.

- An RF_{ID} value of 1.2 to 1.4 may be used for 3XT geogrids with MSE fills with a maximum 3/4-in. (19 mm) aggregate size limit. The upper end of the range value is recommended in absence of site specific or representative tests due to the less aggressive placement techniques used in the laboratory tests.

- Project-specific or representative installation damage testing and RF_{ID} quantification be performed for 3XT, 5XT, 7XT, 8XT and 10XT geogrids with MSE fills with a maximum aggregate size greater than 3/4-in. (19 mm).

3.3.4 Durability (RF_D) Reduction Factors, PET Geogrids

The durability reduction factor is primarily focused on potential strength losses due to hydrolysis of the polymer during in-ground use over the design life. The Mirafi XT geogrid reinforcements are manufactured with with a high molecular weight of more than 25,000 grams/mol (3.4 oz/mol), and low carboxyl end group number (≤ 30) as supported by data submitted by TenCate. Although no direct aging studies were submitted for the Mirafi geogrids, they should offer good resistance to hydrolysis when used within the AASHTO non aggressive reinforced fills with a pH of 5 to 9 based on: 1) a review of the polymer literature; 2) molecular weight and carboxyl end group results from independent tests performed for Mirafi on their polymer; 3) preliminary testing developed by FHWA on the durability of geosynthetics (Elias, et al., 2001).

The submitted information supports the use of a $RF_D = 1.15$ in a pH range of 5 to 8, a $RF_D = 1.3$ in a pH of 8 to 9, and a $RF_D = 1.3$ in a pH range of 4.5 to 5 in accordance with the minimum requirement specified in AASHTO (2010a) and FHWA (2009).

A FHWA-sponsored field study to examine pH conditions within MBW units showed that the pH occasionally increased above 9, but then only for the first few years. For cases where the modular block facing is anticipated to be wet for an extended period of time, the higher reduction factor of 1.3 should be considered for connection evaluation. Certain natural soil conditions (e.g., some limestone backfills) may also require the use of the higher reduction factor. PET geogrid reinforcement should not be used in an environment with a pH > 9 or pH < 4.5 as recommended in Chapter 3 of FHWA (2009), unless product specific tests in accordance with FHWA (2009b) are performed on the reinforcement to verify the suitability of its use and determine the appropriate short and long-term reduction factor(s).

The molecular weight and carboxyl end group values reported in the March 2008 NTPEP Report #8501.1 (NTPEP, 2008) suports the use of the above recommended RF_D values.

3.3.5 Creep (RF_{CR}) Reduction Factors, PET Geogrids

Laboratory creep rupture data and interpretation on Miragrid XT products were submitted in support of the determination of a creep limiting long-term strength reduction factors. All creep testing was performed in-isolation (i.e., not confined in soil). Baseline testing was performed on the Miragrid 8XT grade of geogrid and consists of a combination of conventional creep testing and Stepped Isothermal Method (SIM) creep testing. The SIM data was consistent with the conventional data. The submitted SIM and conventional creep data points meets the minimum requirements of data points within rupture time limits listed in Appendix D of FHWA (2009).

Laboratory creep rupture data and interpretation on other Miragrid XT products were also submitted in support of the determination of product line creep limiting long-term strength reduction factors. Conventional and SIM creep rupture data were submitted for Miragrid 3XT, 5XT, and 10XT grades. The submitted reduction factors are based upon the baseline 8XT mean creep rupture values and a regression of all (3XT, 5XT, 8XT, and 10XT) creep rupture values. Review of the product line evaluation noted a slight variation of projected long-term rupture data for family of products.

Evaluation of the long-term creep rupture data for the baseline product and the product line indicates a RF_{CR} based on creep-rupture of 1.60 and 1.65 for 75-year and 100-year design life, respectively, for Miragrid 3XT, 5XT, 8XT and 10XT geogrids. These reduction factors are valid for routine in-ground use, where the temperature is no greater than 20 °C (68 °F).

3.3.6 Nominal Long-Term Strengths (T_{al}), PET Geogrids

The nominal long-term strength, T_{al}, used for TenCate Miragrid series geogrids design depends on:

- Design life desired
- Specific geogrid used
- Predominant reinforced fill size
- Chemistry (i.e., pH) of reinforced fill

T_{al} is expressed by:

$$T_{al} = \frac{T_{ult}}{RF} = \frac{T_{ult}}{RF_{ID} \times RF_{CR} \times RF_D}$$

where:

T_{ult} = the ultimate tensile strength based on the minimum average roll value, MARV, in Table 2.
RF_{ID} = installation damage reduction factor, see Section 3.3.3
RF_{CR} = creep reduction factor of 1.60 for 75-year and 1.65 for 100-year design life, respectively
RF_D = durability reduction factor of 1.15 for a pH range of 5 to 8, 1.3 in a pH of 8 to 9, and 1.3 in a pH range of 4.5 to 5

The total reduction factor, RF, will generally be approximately 2.4 for reinforced wall fill with a maximum aggregate size of 3/4-in. (19 mm) and pH < 8, and be based on supporting data submitted in accordance with AASHTO (2010a) and FHWA (2009). A lower RF value may be obtained with project-specific installation damage testing. Project specific, or representative, installation damage testing and RF_{ID} is recommended for reinforced wall fills with maximum aggregate size greater than 3/4-in. (19 mm).

3.3.7 Connection Capacity

The connection detail for the KeySystem II requires filling block openings with unit fill gravel and placing the geogrid over the alignment pins, then placing the next row of units on top of the geogrid, and then pulling the geogrid taut and placement of wall fill. The connection capacity between the Keystone Compac II units and Miragrid geogrid is developed by: interface friction between the MBW units and geogrid; granular interlock of the unit fill and geogrid; and interlock with the alignment pins. The pins provides a construction control to prevent slippage of the geogrid during wall construction; however, the submittal did not address durability of the fiberglass necessary to consider these as structural elements. The reinforcement placed over the pins provides a minimum of 8 in. (200 mm) embedment between the rows of MBW units and full overlap of the aggregate unit fill. Connections are 100% continuous along any one elevation of geogrid coverage (i.e., 100% reinforcement coverage).

Connection capacity has been tested for all combinations of blocks and geogrids in general accordance with National Concrete Masonry Association (NCMA) Test Method SRWU-1 for ultimate connection strength definition, as required by AASHTO (2010a). Sustained connection capacity has been tested for the Keystone Compac II units with 3XT and 7XT geogrids in general accordance with FHWA (2009) Appendix B.3.

With respect to the design connection capacity of the Miragrid XT geogrids and the connection to Keystone Compac II MBW units, application of the AASHTO (2010a) and FHWA (2009) connection design criteria requires that the capacity be the lesser of:

- the nominal long-term strength of the geogrid; or
- the connection strength obtained by long-term connection testing in accordance with the testing protocol in Appendix A-3 in FHWA NHI-10-024/025 (2009), divided by the long term environmental aging reduction factor.

Creep rupture connection test values were submitted for Miragrid 3XT and 7XT and the Keystone Compac II unit. Creep rupture tests were conducted with specimen widths equal to one block width and various normal loads, and with 3/4-in. (19 mm) [max.] crushed stone unit fill, lightly compacted, and alignment pins installed. The test data submitted indicate that a rupture of the geogrid occurred for most tests. Tests which were terminated prior to rupture were conservatively assumed to be rupture points for the long-term strength evaluation. Companion quick tests were conducted with the same width and normal loads, with 3/4-in. (19 mm) [max.] crushed stone unit fill (lightly compacted), and alignment pins installed. The width used in these tests is significantly narrower than used in SRWU-1, as required by AASHTO (2010a). Ratios of long-term to short-term rupture for different normal loads were submitted. The ratio of long-term strength to ultimate reinforcement strength, CR_{CR}, and supporting long-term and representative short-term test results are summarized in Table 3. The geogrid for both the long-term and the short-term testing were trimmed from the same longitudinal section of a single roll of grid (3XT and 7XT) supplied by TenCate.

Table 3
Keystone Compac II/Miragrid
Long-Term and Index Connection Testing Summary

Miragrid Product	Normal Load lb/ft (kN/m)	Index, Short-Term Connection Strength lb/ft (kN/m)	Long-Term (75 yr) Connection Strength lb/ft (kN/m)	Ratio of Strengths (T_{conn}/T_{conn75})
3XT	500	1103	1107	1.00
	1000	1735	1535	1.13
	2000	2355	2117	1.11
7XT	500	1295	1578	0.82
	1000	2070	1907	1.09
	2000	2945	2558	1.15
	3000	3390	3032	1.12
NOTE: Width of geogrid in long-term and short-term index tests equal to one block width.				

Additional short-term (i.e., quick) connection capacity tests were conducted in accordance with SRWU-1, as required by AASHTO (2010a) and FHWA (2009), at various normal loads. Testing width was 1 m (39 in.). Results of this testing are summarized in Table 4 in terms of general equations to compute ultimate connection strengths as a function of normal load and reinforcement grade.

The connection creep reduction factor, RF_{ccr}, is applied to the short-term connection strengths summarized in Table 4. These short term strengths are a function of normal load. A connection creep reduction factor, RF_{ccr}, of 1.15 is recommended for 3XT, 5XT, 7XT, 8XT and 10XT, based upon the ratio of strength values from the long-term test results in Table 3 and supporting test reports.

The ultimate strengths of the specimens used in the testing, T_{LOT}, were reported for the 3XT, 5XT, 7XT and 8XT geogrid specimens. The test specimen strengths were higher than

MARV strengths for the 5XT, 7XT and 8XT geogrids. Therefore, a reduction factor to account for this difference must be applied to compute long-term connection strength. Recommended T_{ULT} to T_{MARV} reduction factors are listed in Table 5, and are based upon data submitted. The recommended value of 1.10 for the 10XT is based upon production MARV value (Section 3.3.2).

Table 4
Keystone Compac II/Miragrid Short-Term Connection Testing Summary

Miragrid Product	Range of Normal Load lb/ft (kN/m)	Ultimate, Short-Term Connection Strength, $T_{ultconn}$ lb/ft (kN/m)
3XT	N ≤ 1000	$T_{ULT,S-T}$ = 915 + N tan 45°
	1000 < N ≤ 2270	$T_{ULT,S-T}$ = 1465 + N tan 26°
5XT	N ≤ 1700	$T_{ULT,S-T}$ = 1456 + N tan 27°
	1700 < N ≤ 3425	$T_{ULT,S-T}$ = 2101 + N tan 9°
7XT	1000 < N ≤ 3425	$T_{ULT,S-T}$ = 1279 + N tan 33°
8XT	1000 < N ≤ 3400	$T_{ULT,S-T}$ = 1219 + N tan 39°
10XT	500 < N ≤ 3000	$T_{ULT,S-T}$ = 1625 + N tan 34°
NOTE (from Lab Test Reports): These values are based upon laboratory controlled construction. Actual capacity could be lower if the quality of construction or uniformity of blocks in the field is less than that of the laboratory. Connection strength could be significantly less than shown if the geogrid is not placed as specified.		

An additional reduction factor to account for durability must be applied. A reduction factor of 1.15 was submitted, and appears appropriate for dry conditions and a soil pH of 5 to 8. However, for cases were the modular block facing is anticipated to be wet for an extended period of time or if the soil pH is 8 to 9, a higher reduction factor of 1.30 should be considered.

Long-term Keystone Compac II/Miragrid connection capacities are summarized in Table 5. The factored connection capacity is computed by multiplying the nominal long-term connection design load, T_{crc}, and a resistance factor. A resistance factor of 0.90 for static loading is recommended in AASHTO (2010a). The connection capacity controls factored load on the geogrids.

3.3.8 Reinforced Zone Fill

The KeySystem II construction specifications reviewed by HITEC require the use of select granular fill in accordance with the grain size and soundness requirements in AASHTO (AASHTO, 2010a,b). Keystone notes that the maximum aggregate size should be limited to 3/4-in. (19 mm) unless installation damage field tests are performed, as recommended in AASHTO (2010a) and FHWA (2009).

In addition to the reinforced fill, Keystone includes select unit fill within and behind the wall face units to facilitate placement in the facing unit voids and compaction directly behind (a minimum of 1 ft (300 mm) the block facing units. The unit fill is identified by Keystone as "drainage rock" as it also facilitates drainage of water behind the wall facing units and the gradation of this fill is included in Section 3.6.3 on wall drainage.

Table 5
Keystone Compac II and Mirafi
Long-Term Connection Testing Summary

Miragrid Grade	Reduction Factors on Ultimate Connection Strength[a,b]			Nominal Long-Term (75 Year) Connection Strength[c,d], T_{alc} lb/ft (kN/m)
	CR_{cr}, Creep Rupture	RF_d, Durability[e]	T_{LOT} to T_{MARV}	
3XT	1.15	1.15	1.00	$N \leq 1000$ lb/ft
				$T_{ULT,L-T} = (1/1.32)(915 + N \tan 45°)$
				1000 lb/ft $< N \leq 2270$ lb/ft
				$T_{ULT,L-T} = (1/1.32)(1465 + N \tan 26°)$
5XT	1.15	1.15	1.05	$N \leq 1700$ lb/ft
				$T_{ULT,L-T} = (1/1.39)(1456 + N \tan 27°)$
				$1700 < N \leq 3425$ lb/ft
				$T_{ULT,L-T} = (1/1.39)(2101 + N \tan 9°)$
7XT	1.15	1.15	1.07	$1000 < N \leq 3425$ lb/ft
				$T_{ULT,L-T} = (1/1.42)(1279 + N \tan 33°)$
8XT	1.15	1.15	1.07	$1000 < N \leq 3400$ lb/ft
				$T_{ULT,L-T} = (1/1.42)(1219 + N \tan 39°)$
10XT	1.15	1.15	1.10	$500 < N \leq 3000$ lb/ft
				$T_{ULT,L-T} = (1/1.45)(1625 + N \tan 34°)$

NOTES:
a. See Table 4 for ultimate connection strength relationships.
b. Relationships are based upon laboratory controlled construction. Actual capacity could be lower if the quality of construction or uniformity of blocks in the field is less than that of the laboratory.
c. N = normal load on connection
d. The factored connection capacity is computed by multiplying the nominal long-term connection design load, T_{crc}, and a resistance factor.
e. For cases where the modular block facing is anticipated to be wet for an extended period of time or if soil pH is 8 to 9, a higher reduction factor of 1.3 should be considered.

3.4 Design Computations

Design computations for typical walls with horizontal and sloping backfill (i.e., HITEC Protocol problems 1, 2, and 3) were checked for compliance to AASHTO (2010a) and FHWA (2009) criteria. Typical computations for a horizontal backfill case are presented in Appendix B. The design computations were performed using the Keystone Keywall (Version 3.6.3, 2010) computer program, an in-house detailed spreadsheet format, and the MSEW (Version 3.0) computer program with excellent correlation.

External stability calculations for static and seismic design comply with the methodology for the typical cases submitted.

Internal stability methodology is in compliance with respect to AASHTO (2010a) and FHWA (2009).

Keystone's computational and design methodology related to sloped backfill, seismic, traffic, and concentrated loads complies with AASHTO (2010a) and FHWA (2009) criteria.

Input design parameters for the MSEW computer program, in accordance with recommendations within this report, are summarized in Table 6.

3.4.1 Coverage Ratios

As stated in the KeySystem II Installation specification the geogrid reinforcement coverage ratio is always 100 percent.

3.5 Limitations

Keystone recommends that the following practices or limitations for the use of the KeySystem II:

- KeySystem II walls constructed in deicing salt spray zones should be periodically coated with a sealer specifically designed for use with zero-slump concrete products.

- KeySystem II walls should not be constructed in submerged salt-water environments.

- A maximum practical height limit of a KeySystem II wall is 55 ft (16.8 m). [Section 3.6.5 for discussion of FHWA recommended height limit for MBW unit faced MSE walls.]

- MSE walls generally should not have utilities running parallel to the wall face within the reinforced fill volume.

- Special design (and construction) considerations are required in areas of unpredictable erosion or uncontrollable scour depth below the reinforced fill zone.

- Geosynthetic reinforcements should not be used in areas of extremely low or high pH as specified in the sample specifications.

The use of a KeySystem to support a bridge abutment spread footing was not submitted and, therefore, was not reviewed and evaluated within this report. Therefore, it is recommended that:

- KeySystem II walls should not be used for support of a bridge abutment spread footing without a detailed review.

Furthermore, as discussed under Section 3.6.5, FHWA (2009) recommends a maximum height limit for MBW faced MSE walls of 32 ft unless setbacks, bearing pads, and/or vertical joints. The KeySystem has a vertical joint detail (Appendix C) and can be setback for taller walls. Bearing pads are not used with the KeySystem II (Section 3.6.5). Therefore, it is recommended that:

- The design and detailing of KeySystem II walls taller than 32 ft should incorporate setbacks, bearing pads, and/or vertical joints to address bearing between units and possible stress concentrations due to geometric variations along the length of the wall.

Table 6
Summary of *MSEW* Program Input Parameters for Keystone Compac II/Miragrid

Geogrid Soil Reinforcement:						
Data\Geogrid		3XT	5XT	7XT	8XT	10XT
T_{ult} (lb/ft)		3,500	4,700	5,900	7,400	9,500
Durability reduction factor, RF_D	$5 < pH < 8$	1.15 [a]	1.15 [a]	1.15 [a]	1.15 [a]	1.15 [a]
	$4.5 \leq pH \leq 5$	1.3	1.3	1.3	1.3	1.3
	$8 \leq pH \leq 9$	1.3	1.3	1.3	1.3	1.3
Installation damage reduction factor, RF_{ID}	¾″ max aggregate	1.2 to 1.4[b]	1.15 to 1.3[b]	1.15 to 1.3[b]	1.15 to 1.3[b]	1.15 to 1.3[b]
	> ¾″ aggregate	c	c	c	c	c
Creep reduction factor, RF_{CR}	75-year	1.60	1.60	1.60	1.60	1.60
	100-year	1.65	1.65	1.65	1.65	1.65
Coverage Ratio		1.0	1.0	1.0	1.0	1.0
Friction coefficient along geogrid-soil interface, ρ	Fine to medium sands[d]	0.8	0.8	0.8	0.8	0.8
	Well-graded sands[d], sand & gravel[d]	0.9	0.9	0.9	0.9	0.9
Pullout resistance factor, F*	Sands[d]	0.6	0.6	0.6	0.6	0.6
	Gravels[d]	0.67 tanφ	0.67 tanφ	0.67 tanφ	0.67 tanφ	0.67 tanφ
Scale-effect correction factor, α	Sands[d]	1.0	1.0	1.0	1.0	1.0
	Gravels[d]	0.8	0.8	0.8	0.8	0.8
Facia Geometry and Unit Weight:		Depth/height = 1.0 ft / 0.667 ft.				
		Horizontal distance to center of gravity = 0.50 ft.				
		Average unit weight of block = 120 lb/ft³				
Connection Strengths:		CR_{ult}[e]				
	$\sigma^{e,f}$ (lb/ft²)	3XT	5XT	7XT	8XT	10XT
	0	0.26	0.31	–	–	–
	500	–	–	–	–	0.21
	1000	0.55		0.33	0.27	
	1700	–	0.49	–	–	–
	2270	0.73	–	–	–	–
	3000	–	–	–	–	0.38
	3400	–	–	–	0.54	–
	3425	–	0.56	0.59	–	–
Connection strength reduction factor, RF_d [a,e]		1.15	1.15	1.15	1.15	1.15
Creep reduction factor, RF_c [e,g]		1.15	1.21	1.23	1.23	1.27

[a] Increase value to 1.3 for cases where the MBW facing is anticipated to be wet for an extended period of time; [b] The upper end of the range value is recommended in absence of site specific (or representative) tests; [c] Project-specific (or representative) installation damage testing and RF_{ID} quantification should be performed for MSE fills with a maximum aggregate size greater than 3/4-in. (19 mm); [d] Predominant material; [e] MSEW program term; [f] Normal pressure (lb/ft²) value equal to N (lb/ft) value for the 1.0-foot deep Compac II unit; [g] Value is the product of CR_{cr}, Creep Rupture and T_{LOT}/T_{MARV} ratio in Table 5.

3.6 Design Details

3.6.1 Facing Units (MBW)

Structural design of facing units, is based on the ability of facing blocks to resist compression and shear stresses imposed on the face by the wall. Minimum compressive strength and water absorption should be specified to ensure durable units in accordance with AASHTO (2010b). Keystone facing units are produced locally, therefore, concrete density and absorption vary with aggregate sources and manufacturing processes. The KeySystem Compac II facing units are designed to have a minimum compressive strength of 4,000 psi (28 MPa) at 28 days, as sampled and tested in accordance with ASTM C140 (2010), which is in compliance with Article 7.3.1.4 of AASHTO (2010b). The KeySystem Compac II facing units are typically produced with maximum water absorption limit of 5 percent for normal weight aggregates, as sampled and tested in accordance with ASTM C140 (2010), which is in accordance with the 5% or less requirement in Article 7.3.1.4 of AASHTO (2010b). The dimensions of the modular block facing units are shown in Appendix C.

Additional freeze-thaw restrictions should be required where site conditions warrant them. Freeze thaw durability of modular units is governed by the AASHTO (2010b), Article 7.3.1.4, which has been modified by FHWA (2009) Section 10.9. The applicable test method is ASTM C1262 (ASTM, 2010). The current specification requires that specimens comply with either or both of the following:

- The weight loss of four out of five specimens at the conclusion of 150 cycles shall not exceed 1% of its initial weight when tested in water.

- The weight loss of each of four of the five test specimens at the conclusion of 50 cycles shall not exceed 1.5% of its initial mass when tested in a saline (3% sodium chloride by weight) solution.

As stated in FHWA (2009), the agency may require that either or both acceptance criteria be met depending on the severity of the project location. Additionally, AASHTO (2010b) Article 7.3.1.4 requires that facing blocks directly exposed to spray from deiced pavements shall be sealed after erection with a water-resistant coating or be manufactured with a coating or additive to increase freeze-thaw resistance.

Standard colors of KeySystem facing units include concrete gray, buff or light tan, and dark brown. Available face textures include Sculpterra™ molded finish, Tri-Plane split face, straight face split finish, KeyKut™ abraded finish, and Soft-Split™ finish. Graffiti treatments are available for the modular block facing units from local manufacturers. Keystone does not recommend their use because they are paraffin based and reduce vapor transfer from the units. The experience of Keystone is that split rock finish does not provide an acceptable media for "street art" and discourages graffiti application.

Details that show standard modular block facing units, wall copings, and traffic barriers are provided in Appendix C. The modular block configuration allows for the construction of acute corners and special details are not required. For non-standard facing requirements, such as slip joints or obstruction spanning, special wet-cast facing units can be made as shown in Appendix C.

Keystone notes that for extremely acute angles, zero slump or no-fines concrete is used for wall fill. However, use of concrete reinforced fill with PET geogrids is not recommended as noted in FHWA (2009).

3.6.2 Leveling Pad

The standard leveling pad used for KeySystem II is a 6-in. (150 mm) unreinforced concrete leveling pad with a minimum compressive strength of 2500 psi (17 MPa). An alternative gravel pad is permitted by Keystone for less critical structures such as landscaping walls. It should be noted that granular leveling pads requires continuous monitoring of horizontal control during base unit placement to preclude uneven horizontal joints.

3.6.3 Wall Drainage

Drainage of water from the reinforced soil zone is primarily through joints between facing units. According to Keystone, the installation of weep holes is not required. To facilitate movement of water to the face, drainage aggregate identified by Keystone as "drain rock" is placed in facing unit voids, between units, and for a distance of 2 ft (600 mm) as measured from the wall face. This exceeds the minimum of 1 ft^3/ft^2 of wall face of drainage fill within and/or behind the face block, as recommended by FHWA (2009). The material specified by Keystone as unit fill/drainage aggregate conforms with the specification requirement in Section 10.9 (FHWA, 2009, but is on the coarser side of the gradation range, as follows:

Sieve Size	Percent Passing	
	FHWA (2009)	Keystone II
1-1/2 in. (38 mm)	100	–
1 in. (25 mm)	75 - 100	100
3/4 in. (19 mm)	50 - 75	50 - 75
No. 4 (4.74 mm)	0 - 60	0 - 10
No. 40 (425 μm)	0 - 50	–
No. 50 (300 μm)	–	0 - 5
No. 200 (75 μm)	0 - 5	–

Keystone recommends that a design check should be made of grain size compatibility between the drain aggregate and reinforced fill using standard geotechnical filter criteria as provided in the submittal document, where there may be water flow through the reinforced wall fill to the face that could cause piping or loss of fines. Where filter criteria cannot be achieved with a graded filter, or where wave action on the wall would cause inward and outward flow, Keystone recommends that a geotextile filter be installed between the drain rock and reinforced fill. The geotextile is required to conform to the requirements of AASHTO M288 (2006).

If a groundwater source is known or suspected to exist in the retained zone, then a chimney drain is installed at the face of the cut excavation to intercept groundwater flow. The toe of the chimney drain terminates in a French drain constructed around a perforated pipe. An illustration of possible drainage provisions is provided in Appendix C.

Flow of surface water into the reinforced zone is inhibited by capping the reinforced zone with an 8-in. (200 mm) thick layer of low-permeability soil or with pavement. In addition, water should be diverted away from the wall and/or drainage swales or catch basins should be used as needed to collect water and remove surface water to a point outside the reinforced zone as shown in Appendix C.

3.6.4 Copings and Barriers

Coping details have been developed and are presented in Appendix C. Cast-in-place copings or barriers are preferred for commercial and highway applications. Cap units glued in place are offered as an alternative for less critical applications; however, longevity of this application has not been demonstrated.

Traffic and pedestrian barrier details have been developed and are also presented in Appendix C. The overturning leg dimension must be designed on a project-specific basis. Although feasible in principle, the performance of traffic barriers under the AASHTO impact traffic loads has not been demonstrated.

3.6.5 Horizontal Joint Bearing Materials

Horizontal joint bearing materials are typically not utilized in KeySystem II, due to the ratio of facing unit depth to width and height. FHWA (2009) recommends that maximum wall height be limited to about 32 ft (10 m) unless setbacks are used to separate wall facing loads, or bearing pads (or other compression members) are used in the lower portion of the wall and/or vertical joints to separate geometric variations.

3.6.6 Obstruction Avoidance Details

Major vertical obstructions to the normal placement of the geogrid reinforcement are designed individually and the reinforcement capacity downgraded as required as shown in the typical detail in Appendix C. Keystone modifies the reinforcement design by one of the following methods: (i) design adjacent reinforcement layers to carry the additional load and add facing support, if needed; (ii) place a structural frame to carry the reinforcement load around the obstruction; or (iii) splay the reinforcement (maximum 15 degree angle) around the obstruction. A structural frame detail is presented in Appendix C.

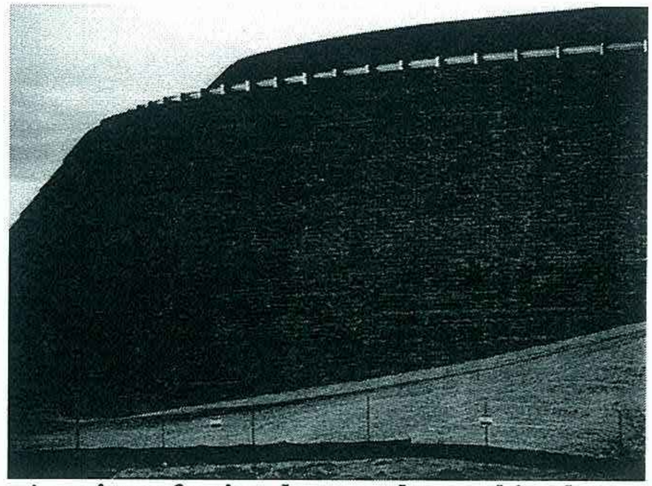
Obstruction avoidance calculations of a typical design were submitted in the KeySystem I (HITEC, 2000) to support the method of designing adjacent reinforcement layers to carry additional load. The KeySystem I submittals (HITEC, 2000) demonstrate a clear understanding of AASHTO requirements.

For horizontal obstructions, the submittal indicated that the wall facing is field cut and designed to fit around obstructions and is free to rotate without bearing against the obstruction. Joints between the facing and the obstruction are designed to retain the fill. A collar is placed around the obstruction where required. Typical details are shown in Appendix C.

A slip joint detail has been developed for use where a KeySystem wall terminates and abuts another structure. The detail is shown in Appendix C.

4 SPECIFICATIONS

The KeySystem II submittal included a material specification and an installation (i.e., construction) specification. These specifications are in substantial conformance with the applicable provisions of the specification for MSE Walls, Section 10.9 of NHI-10-024/025 (FHWA, 2009).



A variety of unit colors can be combined to create images in wall face.

4.1 Description

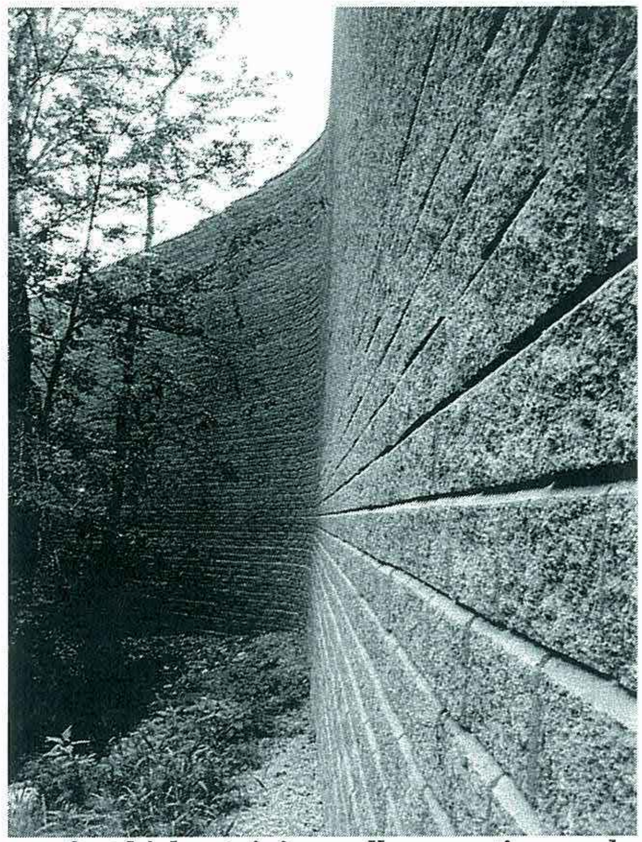
The following sections list editorial and technical revisions to the KeySystem II specifications that would be necessary to produce a specification that conforms to FHWA (2009) Section 10.9, and is appropriate for agencies to incorporate into their specifications. FHWA references below note specification part, of the specification presented in Section 10.9 (FHWA, 2009).

4.2 KeySystem II Material Specification

- 1.05 Unit Drainage Fill:
  - RETAIN the coarser (than FHWA) KeySystem II gradation

5 QUALITY CONTROL/QUALITY ASSURANCE SYSTEMS

QC/QA programs have been developed for the manufacture of all supplied materials, design, and construction. A copy of the QC/QA submittal for each element is included in Appendix D. Each plan was separately reviewed as discussed in the following subsections.



45 foot high retaining wall supporting road and parking areas

5.1 Modular Block Face Units

An undated Quality Control/Quality Assurance plan for highway work for the zero-slump concrete modular block face units was provided as part of the submittal. Keystone relies on its licensed precasters to provide quality control of facing units in accordance with the QC/QA program. Schedule D of Keystone's Standard License Agreement with its precasters require compression and absorption testing of block face units each calendar quarter using a recognized independent testing laboratory. The Standard License Agreement also requires measurement of mold wear on each calendar quarter. (Note: Only that portion of the License Agreement applying to QC/QA was provided for review.) The QC/QA requirements are included in Keystone's License Agreement along with Keystone's right to review records, inspect the production and shipping facilities, and randomly sample and test the product, however, no information was provided to evidence QA oversight of these requirements by Keystone. The License Agreement by reference requires that all modular block face units meet the requirements presented in the QC/QA plan. Keystone requires that records of production shall be kept for each day's production or each lot, whichever is less, and specifies the report requirements.

5.2 Geosynthetic Manufacturing

An undated Quality Control Plan was submitted for Miragrid and Basxgrid geogrid products which identifies all testing and acceptance limits required by their manufacturer, TenCate Nicolon.

Manufacturer certification of product delivered is based on meeting all of the requirements and tolerances specified in this document and summarized in the production specification and process control data sheets enclosed in Appendix D. There is no description or evidence of how Keystone monitors compliance of the Quality Control Plan as part of KeySystem II system.

5.3 Fiberglass Pins

The Quality Assurance requirements for the pultruded fiberglass pins used for alignment and connection are included as part of the Fiberglass Pin Specification rather than a standalone QC/QA plan. The Keystone specifications prescribed the type and frequency of QA tests to be conducted. The pin is a matrix of isophthalic polyester resin with Type "E" glass reinforcement. A sample quality control test report from the manufacturer, for a production lot, was provided for review, as documentation on how Keystone monitors compliance of these QA requirements as part of KeySystem II system. The longevity of fiberglass has not be documented and is questionable; therefore, and the pins are not considered to be long-term structural elements and are not relied upon for shear resistance.

5.4 Design QC/QA

An undated Design Quality Control/Quality Assurance plan was provided as part of the submittal. System design for internal stability only (size, length, and spacing of geogrids) is the responsibility of Keystone. Quality control is the responsibility of Keystone's Director of Engineering who is a registered Professional Engineer. All calculations are checked by an engineer other than the designer. Final plans are reviewed by the Director of Engineering or designated Senior Engineer and verified by initialing and dating all plan sheets. A registered Professional Engineer seals all drawings and calculations. Keystone maintains a permanent record of all projects designed.

5.5 Construction and Quality Control Manual

An undated installation manual was submitted and reviewed. The KeySystem II Installation Manual substantially complies guidelines in FHWA (2009), and sound construction practice. A copy of the manual is included in Appendix D.

As with all MSE wall systems, it is important that the construction specifications be enforced. Specifically under backfill placement, it is important to follow the sequence of placing no more than one course of MBW units and backfilling with drainage aggregate and reinforced backfill prior to placement of the next course. With hollow core units like those used in KeySystem, this sequence allows complete and uniform filling of the voids inside, between, and behind units. Failure to obtain complete and uniform filling can lead to future settlement of the drainage aggregate, which in turn creates a vertical stress on wall components that is not anticipated in the wall design methodology. Dense drainage aggregate is also required to provide an effective filter for the reinforced fill.

The KeySystem II Installation Manual includes an appendix to aid in identifying the cause and effect of construction and in-service structure problems, and means for repairs. The manual would be improved with the addition of a contractor QC/QA checklist to help ensure that wall construction conforms to the requirements of the manual. Keystone is neither involved in nor responsible for the construction QC process.

5.6 Warranties and Insurance

Keystone warrants that each unit, when manufactured strictly in accordance with the specifications, will meet or exceed current ASTM standards on compression, strength, and absorption for concrete masonry units for 15 years after proper installation. The warranty does not apply to units which are damaged or defective or fail to meet the warranty statement due to the manner of installation, chemicals coming into contact with the unit, the design of the structure in which the unit was installed, excessive of unforeseen site conditions, soil condition, manufacturing defects, or other conditions beyond Keystone's control. The warranty applies to replacement of units not meeting this warranty, including units damaged beyond Keystone's control, and it is not responsible for installation of replacement units.

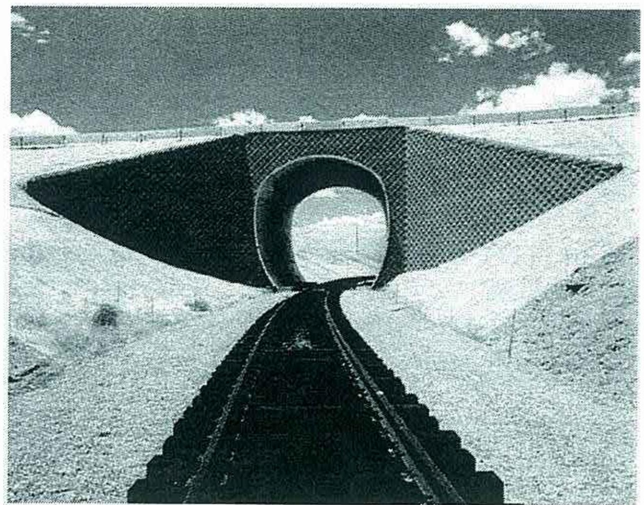
Keystone submitted the following evidence of current Professional Liability (Errors and Omissions) Insurance in force:

Amount:	$5,000,000 Each Occurrence and Annual Aggregate
Deductible:	(not listed)
Basis:	Per Occurrence
Insurer:	ACE American Insurance Company
Renewal:	Annual

Keystone indicates that their licensed precasters and TenCate Geosynthetics maintain product liability insurance, but evidence of these insurances were not provided.

6 PERFORMANCE REVIEW

As noted in Section 2, the KeySystem II wall system has been widely used on private works in California, New York, Georgia, and North Carolina. Information on twenty-nine projects were contained within the submittal, representing over 475,000 ft^2 (44,000 m^2) of constructed walls. Information on three transportation related projects was contained within the submittal, representing 150,000 ft^2 (13,900 m^2) of constructed walls. The highest KeySystem II wall constructed to date is 55 ft (16.8 m), at the Rocky Mountain Metropolitan Airport in Broomfield, CO.



33-ft (10 m) High Headwall/Wingwall Application

The submittal notes that there is no project documentation on: (i) projects experiencing maximum measured settlement; (ii) measurements of lateral movements; (iii) numerical modeling studies; (iv) instrumented structures; or (v) field testing of geogrid pullout, crash-barrier load test, or seismic load test.

The submittal notes that KeySystem II walls constructed to date do not have any reported in-service structural problems. It is also noted that walls constructed to date have not required any reported maintenance other than basic maintenance for surficial erosion.

6.1 Costs

Keystone indicates typical in-place costs varying from \$21/ft^2 to \$33/ft^2 (\$170/m^2 to \$275/m^2) of wall face including materials, labor, engineering, and drain rock unit fill materials, but excluding the cost of imported wall fill. However, actual cost data (i.e., bid prices) from projects to support the unit costs was not provided as requested in the HITEC protocol.

7 REFERENCES

AASHTO (2010a). *LRFD Bridge Design Specifications*. 5th Edition, American Association of State Highway and Transportation Officials, Washington, D.C.

AASHTO (2010b). *LRFD Bridge Construction Specifications*, 3rd Edition, American Association of State Highway and Transportation Officials, Washington, D.C.

AASHTO (2010c). PP66-10 Standard Practice for Determination of Long-Term Strength for Geosynthetic Reinforcement, *Standard Specifications for Transportation Materials of Sampling and Testing*, 31st Edition, American Association of State Transportation and Highway Officials, Washington, D.C.

AASHTO (2006). Standard Specifications for Geotextiles - M 288, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 26th Edition, American Association of State Transportation and Highway Officials, Washington, D.C.

ADAMA Engineering, Inc. (2010). MSEW (3.0). Mechanically Stabilized Earth Walls, http://www.geoprograms.com/mseindex.htm, Newark, DE.

ASTM (2010). *Annual Books of ASTM Standards, Volume 4.05, Chemical-Resistant Nonmetallic Materials; Vitrified Clay Pipe; Concrete Pipe; Fiber-Reinforced Cement Products; Mortars and Grouts; Masonry; Precast Concrete*, ASTM International, West Conshohocken, PA.

ASTM (2010). *Annual Books of ASTM Standards, Volume 4.08 Soil and Rock (I)*, ASTM International, West Conshohocken, PA.

ASTM (2010). *Annual Books of ASTM Standards, Volume 4.13 Geosynthetics*, ASTM International, West Conshohocken, PA.

ASTM (2010). *Annual Books of ASTM Standards, Volume 7.01 Textiles (I)*, ASTM International, West Conshohocken, PA.

ASTM (2010). *Annual Books of ASTM Standards, Volume 8.02, Plastics (II)*, ASTM International, West Conshohocken, PA.

FHWA (2009). Berg, R.R., Christopher, B.R. and Samtani, N.C., *Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, FHWA NHI-10-024 Vol I and NHI-10-025 Vol II, U.S. DOT, Federal Highway Administration, Washington, D.C., pp 306 (Vol I) and pp. 378 (Vol II).

Elias, V., Fishman, K.L., Christopher, B.R. and Berg, R.R. (2009). *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, FHWA NHI-09-087, U.S. DOT, Federal Highway Administration, Washington, D.C.

Highway Innovation Technology Evaluation Center (HITEC) (2005). *Technical Evaluation Report, Evaluation of the Versa-Lok®/Miragrid® Reinforced Soil Wall System, CERF Report: #40708,* Washington, DC.

Highway Innovation Technology Evaluation Center (HITEC) (2000). *Technical Evaluation Report, Evaluation of the KeySystem™I Retaining Wall System, CERF Report: #40478,* Washington, DC.

National Concrete Masonry Association (NCMA) (1997). *Design Manual for Segmental Retaining Walls,* Second Edition, Herndon, VA.

NTPEP (2008). Laboratory Testing of Geosynthetic Reinforcement, (2005) – 03 Product Submissions, Submitting Manufacturer: TenCate Geosynthetics, National Transportation Product Evaluation Program (NTPEP) Report 8501.1, American Association of State Highway and Transportation Officials (AASHTO), 92p.

APPENDICES

Appendix A
- Submittal Protocol Check List

Appendix B
- Connection Test Results
- Connection Capacity Calculations
- Calculations of Pullout Resistance Factor F* based on Laboratory Testing
- Typical Wall Design Computations

Appendix C
- System Components and Standard Modular Block Details
- Pin and Pin Connection Details and Isometrics
- Wall Section and Conceptual Drainage Details and Isometrics
- C-I-P Concrete Coping Details
- C-I-P Traffic Barrier and Details
- Wall Slip Joint Details
- Obstruction Avoidance Details
- Acute Corner Details and Isometrics
- Outside and Inside Corner Details and Isometrics
- Details for Outlets Through Walls
- Wall System and Connection Details
- Outside and Inside Curve Plans and Geogrid Layout Plans and Isometrics

Appendix D
- Manufacturing Quality Control/Quality Assurance Procedures
- Design Quality Control/Quality Assurance Systems
- Construction Installation Manual

APPENDIX A

Submittal Protocol Check List

HITEC Earth Retaining Systems Evaluation for MSE Wall Systems Submittal Requirements

INSTRUCTIONS
To expedite the HITEC evaluation process for MSE earth retaining system technologies, the Applicant are requested to furnish the following list of detailed information as a supplement to the descriptive materials in the standard HITEC Application Form. The requested information expands on Section E.3 of the Application Form ("Performance History") to include queries bearing on each of the technical issues/evaluation elements that will be considered in the overall assessment of the product by the HITEC Technical Evaluation Panel (Panel). *To help the Panel understand the functioning and performance of the technology and thereby facilitate the Technical Audit, Applicants are urged to spend the time necessary to provide clear, complete and detailed responses. A response on all items that could possibly apply to the system or its components, even those where evaluation protocol has not been fully established, is expected by the Panel. Any omissions should be noted and explained.* ***Responses should be organized in the order shown and referenced to the given numbering system.*** *Additionally, duplication of information is not needed or wanted. A simple statement referencing another section is adequate.* *When providing the completed submittal, include a cover letter stating that either the submittal is consistent with your current nationwide design practices or state the exceptions.*

Part One: Materials and Material Properties

Provide a sample of the reinforcement material and material specifications describing the material type, quality, certifications, lab and field testing, acceptance and rejection criteria along with support information for each of the following material items. Include representative test results (lab and/or field) clearly referencing the date, source and method of test, and, where required, the method of interpretation and/or extrapolation. Along with the source of the supplied information, include a listing of facilities normally used for testing (i.e., in-house and independent).

Part One: Materials and Material Properties

1.1 Facing Unit

Yes No N/A

☑ ☐ ☐ • standard dimensions and tolerances

☑ ☐ ☐ • joint sizes and details

☑ ☐ ☐ • concrete strength (minimum)

Yes	No	N/A		
☐	☐	☑	•	wet cast concrete % air (range)
☑	☐	☐	•	dry cast concrete density (minimum or range)
☑	☐	☐	•	moisture absorption (percent and by weight)
☐	☐	☑	•	salt scaling
☐	☑	☐	•	freeze thaw durability factor
☑	☐	☐	•	facing unit to facing unit shear resistance
☐	☐	☑	•	bearing pads (joints)
☑	☐	☐	•	spacers (pins, etc.)
☑	☐	☐	•	joint filter requirements: geotextile or graded granular
☑	☐	☐	•	aesthetic choices (texture, relief, color, graffiti treatment)
☐	☐	☑	•	other facing materials

1.2 Earth Reinforcement

1.2.1 Metallic

			•	manufacturing sizes, tolerances and lengths
☐	☐	☑		- ultimate and yield strength of steel
☐	☐	☑		- minimum galvanization thickness for 75 year design life
☐	☐	☑	•	sacrificial steel thickness for 75 and 100 year design life
☐	☐	☑	•	corrosion resistance test data
☐	☐	☑	•	pullout interaction coefficients for range of backfill

1.2.2 Geosynthetics

			•	polymer type and grade
☐	☐	☑		- HDPE: resin type, class, grade & category
☐	☐	☑		- PP: resin type, class, grade & category
☑	☐	☐		- PET: minimum intrinsic viscosity correlated to number average molecular weight and maximum carboxyl end groups
☐	☑	☐		- post-consumer recycled material, if any
☑	☐	☐		- weight per unit area
			•	minimum average roll value for ultimate strength
☑	☐	☐		- coefficient of variation for ultimate strength
☑	☐	☐	•	minimum average roll value for QC strength (e.g. single rib, grab, or strip)
☑	☐	☐	•	creep reduction factor for 75 and 100 year design life, including effect of temperature (20°C to 40°C)
☑	☐	☐	•	durability reduction factor (chemical, hydrolysis, oxidative) for 75 and 100 year design life
☐	☑	☐	•	additional durability reduction factor for high biologically active environments
☑	☐	☐	•	installation damage reduction factor for range of backfill (i.e., sand, sandy gravel, gravel, coarse gravel)
☐	☑	☐	•	junction strength for quality control
☐	☐	☑	•	seam strength
☑	☐	☐	•	pullout interaction coefficients for range of backfills
☑	☐	☐	•	embedment scale factor

Yes No N/A

☑ ☐ ☐ • coatings (type and amount)
☑ ☐ ☐ • UV inhibitors, coatings, etc.
☑ ☐ ☐ • UV resistance

1.3 Facing Connection(s)

☑ ☐ ☐ • mode (i.e., structural, frictional or combined)
☑ ☐ ☐ • connection strength as a % of reinforcement strength at various confining pressures for each reinforcement product and connection type submitted
☑ ☐ ☐ • composition of devices, dimensions, tolerances
☑ ☐ ☐ • full scale connection test method/results

1.4 Range of Backfill

• reinforced
☑ ☐ ☐ - soil classification, gradation, unit weight, friction angle
• facing
☑ ☐ ☐ - soil classification, gradation, unit weight, friction angle

1.5 Leveling Pad

☑ ☐ ☐ • cast-in-place
☐ ☑ ☐ • precast
☑ ☐ ☐ • granular

1.6 Drainage Elements

☐ ☐ ☑ • weep holes
☑ ☐ ☐ • base
☑ ☐ ☐ • backfill
☑ ☐ ☐ • surface

1.7 Coping

☐ ☐ ☑ • precast
☐ ☐ ☑ • precast attachment method/details
☑ ☐ ☐ • cast-in-place

1.8 Traffic Railing/Barrier

☑ ☐ ☐ • precast
☑ ☐ ☐ • cast-in-place

1.9 Connections to Appurtenances

☐ ☐ ☑ • precast

1.10 Other Materials

☑ ☐ ☐ • corner elements
☑ ☐ ☐ • slip-joint elements

1.11 Quality Control/Quality Assurance Systems

- material suppliers

Yes	No	N/A	
☐	☐	☑	- metallic reinforcement
☑	☐	☐	- polymeric reinforcement
☑	☐	☐	- concrete products
☐	☑	☐	- backfill
☑	☐	☐	• fabricator(s)
☐	☑	☐	• test facilities (internal and external)

Part Two: Design

Provide design assumptions and procedures with specific references (e.g., design code section) for each of the following items. Clearly show any deviations from the 5th Edition of the AASHTO LRFD Bridge Design Specifications, along with theoretical or empirical information which support such deviations.

2.1 External Stability

☑	☐	☐	• sliding
☑	☐	☐	• overturning (including traffic impact)
☑	☐	☐	• bearing capacity (overall and local)
☑	☐	☐	• seismic
☑	☐	☐	• settlement (total and differential)
☑	☐	☐	• recommended wall embedment

2.2 Internal Stability

☑	☐	☐	• assumed failure surface
☑	☐	☐	• distribution of horizontal stress
			• surcharge
☐	☑	☐	- concentrated dead load
☑	☐	☐	- sloped surcharge
☑	☐	☐	- broken-back surcharge
☑	☐	☐	- live load
☑	☐	☐	- traffic impact
☑	☐	☐	- lateral loads from piles, drilled shafts within reinforced backfill
☑	☐	☐	• allowable tensile strength of the reinforcement
☑	☐	☐	• pullout
☑	☐	☐	• facing connections
☑	☐	☐	• vertical and horizontal spacing (including traffic impact requirements)
			• facing design
☑	☐	☐	- connections
☑	☐	☐	- concrete strength requirements
☑	☐	☐	• effective face batter
☑	☐	☐	• compound/global stability
☑	☐	☐	• seismic considerations
☑	☐	☐	• design modification for tiered structures and acute corners

Yes	No	N/A	
☑	☐	☐	• full design details to overcome obstructions in reinforced zones (e.g., drainage structures, deep foundations, etc.)

2.3 Performance Criteria

Yes	No	N/A	
☑	☐	☐	• ultimate strength of reinforcement
			• service limit
☐	☐	☑	- for steel, F_y
☐	☑	☐	- for polymeric, strength at % strain
☑	☐	☐	• long-term allowable design strength
☑	☐	☐	• material properties, requirements and test standards
☑	☐	☐	• horizontal/vertical deflection limits

2.4 Plan Sheets

Provide representative plan sheets showing all standard details along with any alternate details, including the following:

Yes	No	N/A	
☑	☐	☐	• details for wall elements
☑	☐	☐	• connection details
☐	☑	☐	• appurtenance connection details
☑	☐	☐	• obstruction detail (utilities, parapet/sidewalk connection, light standard and box)
☐	☐	☑	• corrosion/durability protection details
☑	☐	☐	• construction details
☑	☐	☐	• optional details

2.5 Specifications

Provide sample specifications for:

Yes	No	N/A	
☑	☐	☐	• materials
☑	☐	☐	• installation
☑	☐	☐	• construction
☑	☐	☐	• maintenance

2.6 Aesthetic Compliance

Detail the provisions in material specifications for aesthetics compliance, including:

Yes	No	N/A	
☑	☐	☐	• texture
☑	☐	☐	• color
☐	☑	☐	• graffiti treatment for facing panels
☐	☑	☐	• durability of aesthetic features

2.7 Limitations

List any and all design limitations, including:

Yes	No	N/A	
☑	☐	☐	• seismic loading
☑	☐	☐	• environmental restraints
☑	☐	☐	• wall height, external loading
☑	☐	☐	• other: True bridge abutment

2.8 Example Calculations

Provide detailed (hand) design calculations for the four problems shown in Figure 1 in conformance with your practice or to the 2010 provisions to the 5th Edition of the AASHTO LRFD Bridge Design Specifications. The calculations should address the technical review items listed above. List deviations from the 2010 AASHTO 5th Edition provisions.

Yes No N/A

☑ ☑ ☐ Calculations not provided for Problem No. 4

2.9 Computer Support

If a computer program is used for design or distributed to customers, provide representative computer printouts of design calculations for the above typical applications demonstrating the reasonableness of computer results.

☑ ☐ ☐

2.10 Quality Control/Quality Assurance Systems

Include the system designer's Quality Assurance program for evaluation of conformance to the quality control program.

☑ ☐ ☐

Part Three: Construction

Provide the following information related to the construction of the system. Clearly show any deviations from the 2010 provisions to the 3rd Edition of the AASHTO LRFD Bridge Construction Specifications, along information which supports such deviations.

3.1 Fabrication of Facing Units

☐ ☐ ☑ • curing times

☐ ☐ ☑ • form removal

☐ ☐ ☑ • concrete surface finish requirements

3.2 Field Construction Manual

Provide a documented field construction manual describing in detail and with illustrations as necessary the step-by-step construction sequence, including requirements for:

☑ ☐ ☐ • foundation preparation

☑ ☐ ☐ • special tools required

☑ ☐ ☐ • leveling pad

☑ ☐ ☐ • facing erection

☑ ☐ ☐ • facing batter for alignment

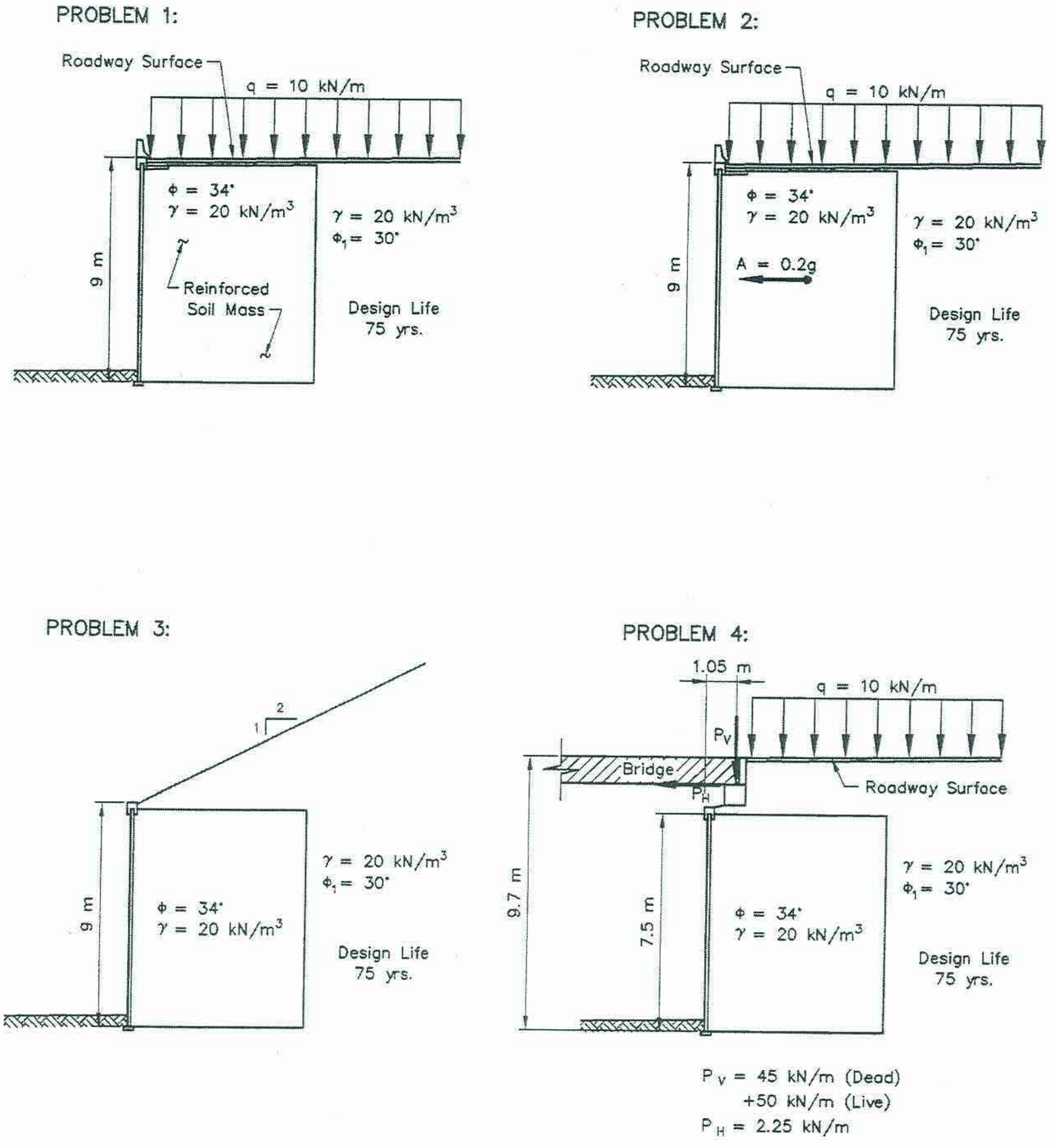
☑ ☐ ☐ • steps to maintain horizontal and vertical alignment

☑ ☐ ☐ • retained and backfill placement/compaction

☑ ☐ ☐ • erosion mitigation

☑ ☐ ☐ • all equipment requirements

Figure 1



Example MSE Wall Design Problems

3.3 Construction Specifications

Include sample construction specifications, showing field sampling, testing and acceptance/rejection requirements.

Yes No N/A

☑ ☐ ☐

3.4 Construction Case Histories

Provide construction case histories and photos/videotapes from projects illustrating the construction process.

☑ ☐ ☐

3.5 Contractor or Subcontractor Prequalification Requirements

List any contractor or subcontractor prequalifications.

☑ ☐ ☐

3.6 List of Contractors and Subcontractors

Provide a list of installation contractors who have constructed this system, including contact persons, addresses and telephone numbers.

Provide a list of precasters.

☑ ☐ ☐

3.7 Quality Control/Quality Assurance of Construction

Describe the quality control and quality assurance measurements required during construction to assure consistency in meeting performance requirements.

☑ ☐ ☐

Part Four: Performance

Provide the following information related to the performance of the system:

4.1 Warranties

Provide a copy of any system warranties.

☑ ☑ ☐ warranty provided for MBW face unit, but not for geogrid reinforcement or overall "system"

4.2 Designated Responsible Party

☑ ☐ ☐ • system performance

☑ ☐ ☐ • material performance

☑ ☐ ☐ • project-specific design (in-house, consultant)

4.3 Insurance Coverage for Responsible Party

List insurance coverage types (e.g., professional liability, product liability, performance) limits, basis (i.e., per occurrence, claims made) provided by each responsible party

☑ ☐ ☐

4.4 Project Performance History

Provide a well-documented history of performance (with photos, where available), including

Yes No N/A

☐ ☑ ☐ • oldest

☑ ☐ ☐ • highest

☐ ☑ ☐ • projects experiencing maximum measured settlement (total and differential)

☐ ☑ ☐ • measurements of lateral movement/tilt

☑ ☐ ☐ • demonstrated aesthetics

☑ ☐ ☐ • project photos

☐ ☑ ☐ • maintenance history

4.5 Numerical Model Studies

Provide case histories on numerical model studies.

☐ ☑ ☐

4.6 Instrumented Structures

Provide case histories of instrumented structures.

☐ ☑ ☐

4.7 Field Tests

☐ ☐ ☑ • construction testing

☐ ☑ ☐ • pullout testing

☐ ☑ ☐ • crash-barrier testing

☐ ☑ ☐ • seismic load test

4.8 Construction/In-Service Structure Problems

Provide case histories of structures where problems have been encountered, including an explanation of the problems and methods of repair.

☐ ☑ ☐

4.9 Unit Costs

Provide typical unit costs in $\$/m^2$ of vertical face, supported by data from projects.

☑ ☐ ☐

4.10 Maintenance

Provide a listing of maintenance requirements to maintain performance and repair damage. If available, provide a maintenance manual.

☑ ☐ ☐

4.11 Quality Control History

Provide the history for the system and material quality along with improvements that have been made based on the experience with the system.

☑ ☐ ☐

4.12 List of Users

Provide a list of users, including contact persons, addresses and telephone numbers (ensure correct and current project information).

Yes No N/A

☑ ☐ ☐

APPENDIX B

1.3 Facing Connection(s)

Mode

The connection capacity generated between the Compac II units and Miragrid reinforcing elements is developed by both frictional and structural mechanisms. The three components of the connection between Compac II units and Miragrid are through the interface friction created by the unit to unit contact at geogrid locations, the granular interlock of the unit drainage fill and geogrid and the fiberglass alignment pins. The pin connection is especially significant at lower normal loads as a means to prevent slippage of the Miragrid during installation operations.

Capacity

The ultimate connection capacity of the Compac II Units and Miragrid is determined through laboratory testing according to NCMA Tests Method SRWU-1 for ultimate connection strength and the procedures in NHI-10-025, Appendix B.3 for sustained load connection capacity. The results of these tests are summarized below. The full test reports are included in appendix B. Tables 1 and 2 provide a summary of the quick index connection testing and the sustained load connection testing performed with the Compac II unit and Miragrid 3XT and 7XT geogrids. The two testing programs were performed with Miragrid from the same roll; therefore a normalization of the ultimate strength (MARV) to the lot strength is not required.

Normal Load N, (lb/ft)	Index Peak Capacity T_{conn} (lb/ft)	75-year Creep-reduced Connection Strength T_{conn75} (lb/ft)	Connection Creep Reduction Factor $RF_{connCR} = T_{conn} / T_{conn75}$
500	1103	1107	1.00
1000	1735	1535	1.13
2000	2355	2117	1.11

Table 1: Miragrid 3XT Sustained Load Connection Factors

Normal Load N, (lb/ft)	Index Peak Capacity T_{conn} (lb/ft)	75-year Creep-reduced Connection Strength T_{conn75} (lb/ft)	Connection Creep Reduction Factor $RF_{connCR} = T_{conn} / T_{conn75}$
500	1295	1578	1.00
1000	2070	1907	1.09
2000	2945	2558	1.15
3000	3390	3032	1.12

Table 2: Miragrid 7XT Sustained Load Connection Factors

Tests were performed at normal forces ranging from 500 pounds per foot to 3000 pounds per foot. The results of the sustained load connection tests performed at 500 pounds per foot were greater than the index test at this normal load. A connection creep reduction factor of 1.0 is conservatively assumed for this normal load. The tests performed at normal loads from 1000 plf to 3000 plf have connection creep reduction factors of 1.09 to 1.15. The calculated connection creep reduction factors do not appear to be directly related to increasing normal loads. The maximum factors were at the intermediate normal loads of 1000 plf for the 3XT and 2000 plf for the 7XT geogrids. The connection creep reduction factors at the maximum normal loads tested were less than the maximum creep reduction factor calculated at the intermediate normal load levels for both Compac II/Miragrid combinations. This indicates that the connection creep reduction factor is not directly normal load dependent and may even decrease with increasing normal load based on the limited testing performed. Additional testing is required to determine if a reduced factor is applicable at higher normal loads. Therefore the maximum measured connection creep reduction factor of 1.15 will be used for all normal loads. A plot of the connection creep reduction factors versus normal loads is shown in Figure 1.

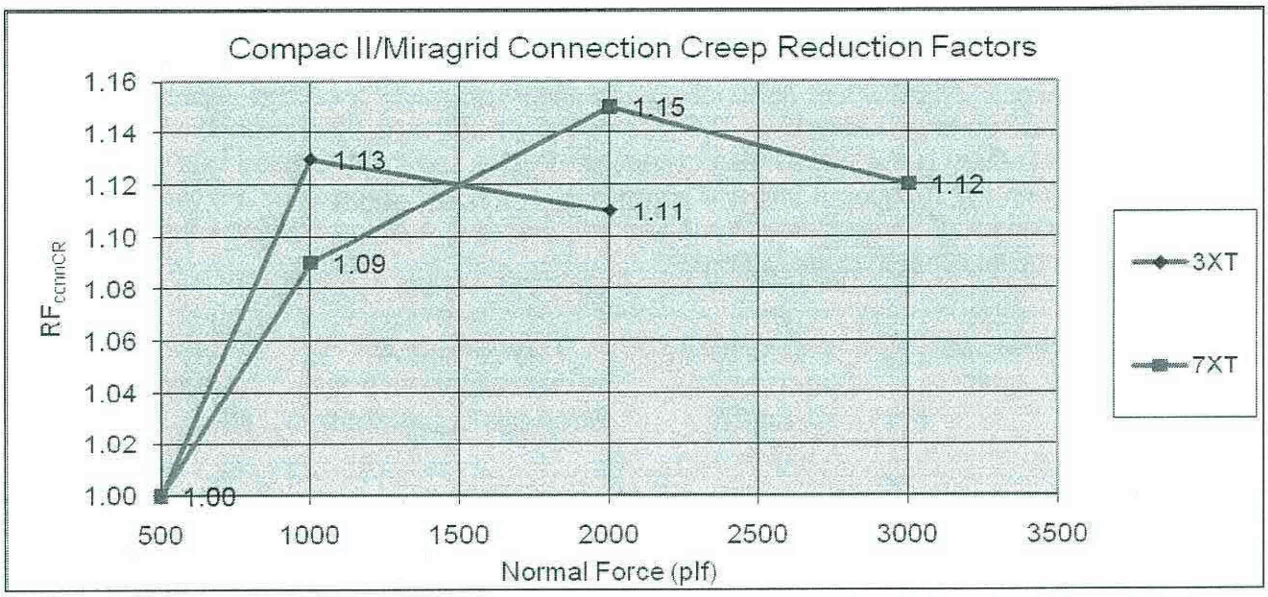


Figure 1: Connection Creep Reduction Factors

The maximum connection creep reduction factor of 1.15 determined from the sustained connection load testing of the Miragrid 3XT and 7XT will also be used for the Miragrid 5XT, 8XT and 10XT geogrids included in this submittal. This reduction factor will be used to determine the connection creep reduction factor for all the miragird geogrids included in this submittal based on NHI-10-025 section *D.5 Use of Creep Data from Similar Products and Evaluation of Similar Product Lines* based on the following.

- The chemical and physical properties of the Miragrid geogrids are the same.

- A comparative plot of connection strength data points, for a range of normal loads for the Compac II and Marigrid 3XT through 10XT geogrids, is provided in figure 2. This graph shows similar connection strength trends for each Compac II and Miragrid combination up to the maximum connection strength for each combination. The maximum connection strength for each combination increases with increasing Miragrid geogrid ultimate strength. This indicates that the connection mechanism is similar for the full range of Compac II and Miragrid combinations submitted.

Therefore, the use of the sustained load connection testing performed for the Compac II and Miragrid 3XT and 7XT is applicable to the Compac II and Miragrid 5XT, 8XT and 10XT combinations.

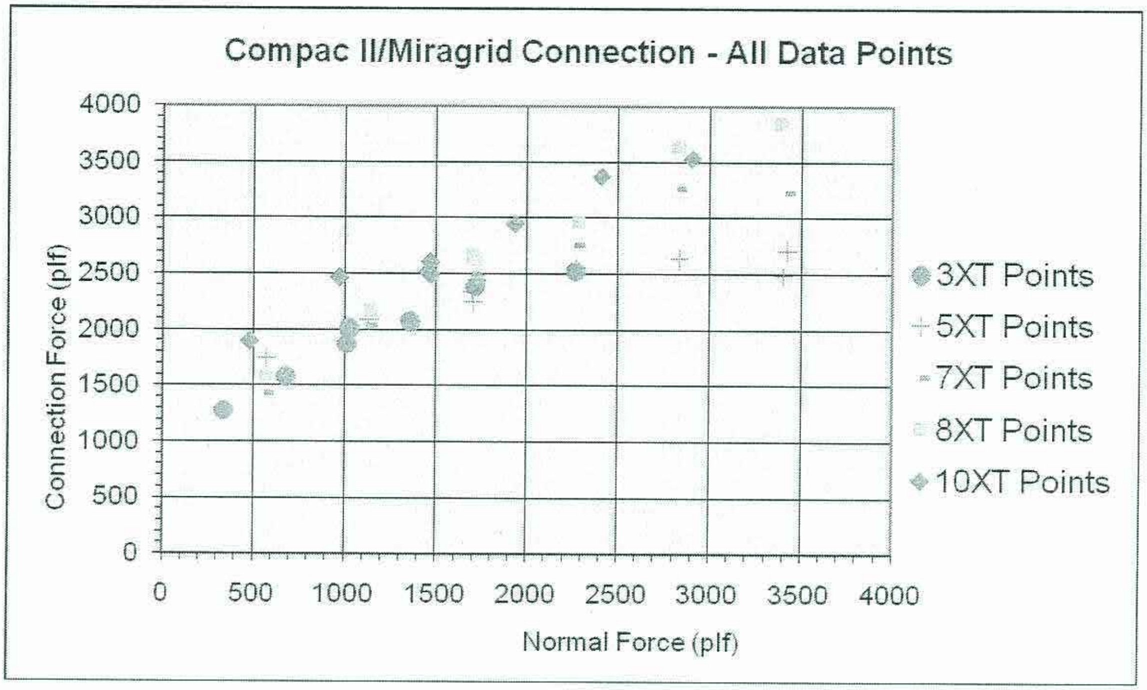


Figure 2: Connection Data Points

The reduction factor for durability at the connection (RF_d) is 1.15 based on NHI-10-024, Table 3-11 and section 3.5.2.e. This durability reduction factor is to be used for a pH environment of 5<pH<8. In situations where Keysystem II walls will be permanently submerged in a pond or stream application, additional pH testing may be required to determine the appropriate durability reduction factor at the connection.

The normalization of Compac II and Miragrid connection strength to account for variations between the ultimate strength of the Miragrid used in the full scale connection testing tests and the published MARV values for each Miragrid submitted is summarized in Table 3. In cases where the lot strength was less than the MARV value, the normalization factor is conservatively assumed to be 1.0.

Miragrid	$T_{ult\text{-}MARV}$ (plf)	T_{lot} (plf)	$T_{lot}/T_{ult\text{-}MARV}$ (plf)	Lot
3XT	3,500	3,484	1.00	031087847/07294-1-3
5XT	4,700	4,927	1.05	031041750/06077-1-2
7XT	5,900	6,317	1.07	031062656/06334-1-4
8XT	7,400	7,897	1.07	031109369/08288-1-1
10XT	9,500	10,795	1.14	031013898/04229-1-3

Table 3: $T_{lot}/T_{ult\text{-}MARV}$ Normalization

The total reduction factor for each combination of Compac II and Miragrid submitted is included in table 4.

Miragrid		Reductions Factors to the Ultimate Connection Strength			Long Term (75 year) Connection Reduction Factor $RF_{ConnTot}$
Type	T_{ult} (lb/ft)	RF_{connCR}, Connection Creep Rupture	RF_d, Durability	T_{Lot} to T_{ult}	
3XT	3500	1.15	1.15	1.00	1.32
5XT	4700	1.15	1.15	1.05	1.39
7XT	5900	1.15	1.15	1.07	1.42
8XT	7400	1.15	1.15	1.07	1.42
10XT	9500	1.15	1.15	1.14	1.51

Table 4: Long Term Connection Reduction Factors

The following are the long term connection strength design equations for the combinations of the Compac II unit and the Miragrids submitted. The equations are based on the short term and sustained load connection strength tests included in appendix B-1. The data for these tests is also summarized with the data points, connection strength equation data and a graphical representation of the data in the HITEC Connection Evaluation sheets for each Compac II and Miragrid combination included in appendix B-1. The short term test results were performed with a non-standard geogrid sample width of thirty-nine inches as noted in the Connection Capacity reports provided in Appendix B-1. ASTM D6638 standard for connection testing requires the sample width to be an exact multiple of unit width. The thirty-nine inch width is three inches longer than the unit multiple for two units of thirty-six inches. This deviation was discussed with the testing laboratory and their explanation was that this is the standard dimension used by them for segmental retaining wall unit/geogrid connection testing. Their experience with indicates that the wider width provides slightly lower results than an even multiple because the 1.5 inch outside edge of the geogrid sample on each side of a whole units engages the edge of adjacent units which typically provide lower connection capacity than the middle third of a unit where there is greater concrete to concrete friction and also connecting devices such as pins.

The following connection equations are based on the laboratory report equations for 3XT, 5XT, 7XT, 8XT and 10XT.

The connection strength equations presented below are a combination of the reduction factors presented in Table 4($RF_{ConnTot}$) and the short term connection equations in the form:

Connection Capacity = $(1/RF_{ConnTot})$(*/ y-intercept + Normal force x tan slope)*

The connection test results and equations are based on full unit to unit contact and preclude the use of shims at unit to geogrid connection locations as noted in ***Section 1.10 Other Materials.***

Miragrid Type	T_{ult} (lb/ft) - Miragrid Ultimate Strength	Normal Load (N) in equivalent wall height (feet)	Long Term Design Capacity, T_{Conn75} (lb/ft)	
3XT	3500	H< 9	N < 1074	$T_{Conn75} = (1/RF_{ConnTot})(915 + N \tan 45)$
		9<H<18.9	1074 < N < 2270	$T_{Conn75} = (1/RF_{ConnTot})(1465 + N \tan 26)$
5XT	4700	H< 15.3	N < 1837	$T_{Conn75} = (1/RF_{ConnTot})(1456 + N \tan 27)$
		15.3<H<28.5	1837 < N < 3424	$T_{Conn75} = (1/RF_{ConnTot})(2101 + N \tan 9)$
7XT	5900	8.33<H<28.5	1000 < N < 3425	$T_{Conn75} = (1/RF_{ConnTot})(1279 + N \tan 33)$
8XT	7400	8.33<H<28.3	1000 < N < 3400	$T_{Conn75} = (1/RF_{ConnTot})(1219 + N \tan 39)$
10XT	9500	4.1<H<25	500 < N < 3000	$T_{Conn75} = (1/RF_{ConnTot})(1625+ N \tan 34)$

Table 5: Design Capacity

Prepared for:

TC Mirafi

365 South Holland Drive
Pendergrass, Georgia 30567

FINAL REPORT
GEOSYNTHETIC PULLOUT TESTING

SELECT MIRAGRID XT GEOGRIDS
WITHIN CONCRETE SAND

Prepared by:

GeoSyntec Consultants
Soil-Geosynthetic Interaction Testing Laboratory
5775 Peachtree Dunwoody Road, Suite 11D
Atlanta, Georgia 30342

Project Number GLI1292

23 April 2001

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

The details of samples submitted for testing to GeoSyntec Consultants' Soil-Geosynthetic Interaction Testing Laboratory (Geosyntec-SGI®), 5775 Peachtree Dunwoody Road, Suite 11D, Atlanta, Georgia 30342, are as follows:

Submitted by: Mr. Michael Koutsourais, P.E.

Client: TC Mirafi

Address: 365 South Holland Drive
Pendergrass, Georgia 30567

Materials tested: Geosynthetic Materials: Miragrid 3XT, 5XT, 7XT, 8XT, and 10XT geogrids
Soil Type: concrete sand

2. TEST PROGRAM

The test procedures and results are described in the following appendices:
Appendix A: Summary of Test Procedures
Appendix B: Summary of Test Results
Appendix C: Geosynthetic Pullout Test Data

3. STORAGE AND DISPOSAL OF MATERIALS

Samples will be stored for 30 days from the date of this report and then discarded unless Geosyntec-SGI® is informed otherwise.

* * * * *

REPORT REVIEW

REPORT PREPARATION BY:

Zehong Yuan, Ph.D., P.E.
Program Manager

TECHNICAL REVIEW BY:

Robert H. Swan, Jr.
Laboratory Manager

APPENDIX A

SUMMARY OF TEST PROCEDURES

SUMMARY OF TEST PROCEDURES

GEOSYNTHETIC PULLOUT TESTING

Test Method

The geosynthetic pullout tests were performed in accordance with the American Society for Testing and Materials (ASTM) Draft Standard Test Method Z2467Z, *"Measuring Geosynthetic Pullout Resistance in Soil"*. The pullout tests were conducted in one of GeoSyntec's pullout testing devices that had plan dimensions of 2 ft by 5 ft (0.6 m by 1.5 m) and an overall depth of 12-in. (300 mm). Following guidelines provided by our client, the test specimens used during the pullout testing were sufficiently large such that the test specimen area within the pullout box had plan dimensions of approximately 18 in. (455 mm) wide by 48 in. (1200 mm) long.

Sample Description and Test Configuration

The testing program consisted of five pullout test series. Each test series consisted of two pullout tests, each conducted at a different normal stress. The configuration of the test specimen for each pullout test is described, from top to bottom, as follows:

- Compacted upper soil layer of concrete sand; and
- Miragrid 3XT geogrid (Test Series 1), Miragrid 5XT geogrid (Test Series 2), Miragrid 7XT geogrid (Test Series 3), Miragrid 8XT geogrid (Test Series 4), and Miragrid 10XT geogrid (Test Series 5); and
- Compacted lower soil layer of concrete sand.

Details concerning the soil properties (i.e., index, compaction, and strength properties) of the concrete sand are provided for reference at the end of this appendix.

Test Procedure

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:

- Concrete sand was placed in the lower half of pullout box and compacted by hand tamping to form a 6-in. thick layer. For each pullout test, the soil was compacted to the initial target compaction conditions (i.e., dry unit weight and moisture content) corresponding to 95% of maximum dry unit weight and the optimum moisture as specified by our client;

- A fresh test specimen was trimmed from the bulk sample of the geosynthetic material provided by our client. One end of each test specimen was cast in a reinforced epoxy resin to form the pullout clamp. After the test specimen was prepared, it was placed on top of the compacted soil in the lower half of the pullout box and attached to the pullout loading harness;

- Four "tell-tail" wires were connected to selected locations along each test specimen. Displacements at these locations were monitored during testing using linear variable differential transformers (LVDTs) attached to each of the "tell-tail" wires;

- Concrete sand was placed in the upper half of pullout box and compacted by hand tamping to form a 6-in. thick layer. For each pullout test, the soil was compacted to the initial target compaction conditions (i.e., dry unit weight and moisture content) corresponding to 95% of maximum dry unit weight and the optimum moisture as specified by our client;

- 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 also fixed to the test specimen clamp to measure the total pullout displacement of the test specimen;

- A specific normal stress was then applied to the test specimen using dead weight or through an air bladder loading system;

- After application of the normal stress, the test specimen was immediately subjected to a pullout load by displacing the pullout test specimen at a constant displacement rate of 0.04 in./min as measured on the specimen clamp. Pullout was continued until a constant or decreasing pullout load was recorded;

- Each pullout test was tested under as-placed moisture conditions; and

- Each test specimen used during this study was tested in the machine direction.

Test Data Presentation

Ten pullout tests were performed in this testing program. The pullout force versus displacement curve for each test is presented in Appendix C. The pullout force is defined as the pullout load measured at the specimen clamp divided by the initial width of the test specimen. The Coefficient of Interaction (C_i) at the maximum pullout load was calculated for each pullout test using the equation given below.

$$C_i = \frac{F}{2(A)(\sigma_n \tan\phi + c)}$$

Where:	F	=	maximum pullout load (lbs)
	2	=	considers both surfaces of specimen in contact with soil;
	A	=	initial embedded area of specimen (in^2)
	σ_n	=	total normal stress applied to the test specimen (psi);
	ϕ	=	residual total-stress friction angle of the soil being used in testing obtained from direct shear testing; and
	c	=	residual total-stress cohesion of the soil being used in testing obtained from the direct shear testing.

The measured pullout resistance and calculated coefficient of interaction for each pullout test are summarized in Table 1 and presented graphically in Appendix B. It is noted that a pullout failure mode was observed during each pullout test. A pullout mode of failure is established when displacements are observed at all four "tell-tail" wire locations along the geosynthetic specimen during a pullout test. The failure mode for each pullout test is also indicated in Table 1.

Additionally, TC Mirafi requested that the friction coefficient (F^*) and the Alpha coefficient (α) be calculated in accordance with current American Association of State Highway and Transportation Officials (AASHTO) guidelines. The F^* was calculated by dividing the maximum shear stress (i.e., maximum pullout load divided by 2 times of initial embedded area of the geogrid specimen) by the applied normal stress as given in Table 1. The (α) was assumed to be equal to 1.0 since each geogrid specimen was observed to have pulled out from within the soil as indicated by movements of the four "tell-tail" wires attached to the geogrid specimen at specific locations for each pullout test. The end of the specimen was observed to have displaced more than 1 in. (25 mm) at the completion of each test. The values of F^* and α are also summarized in Table 1.

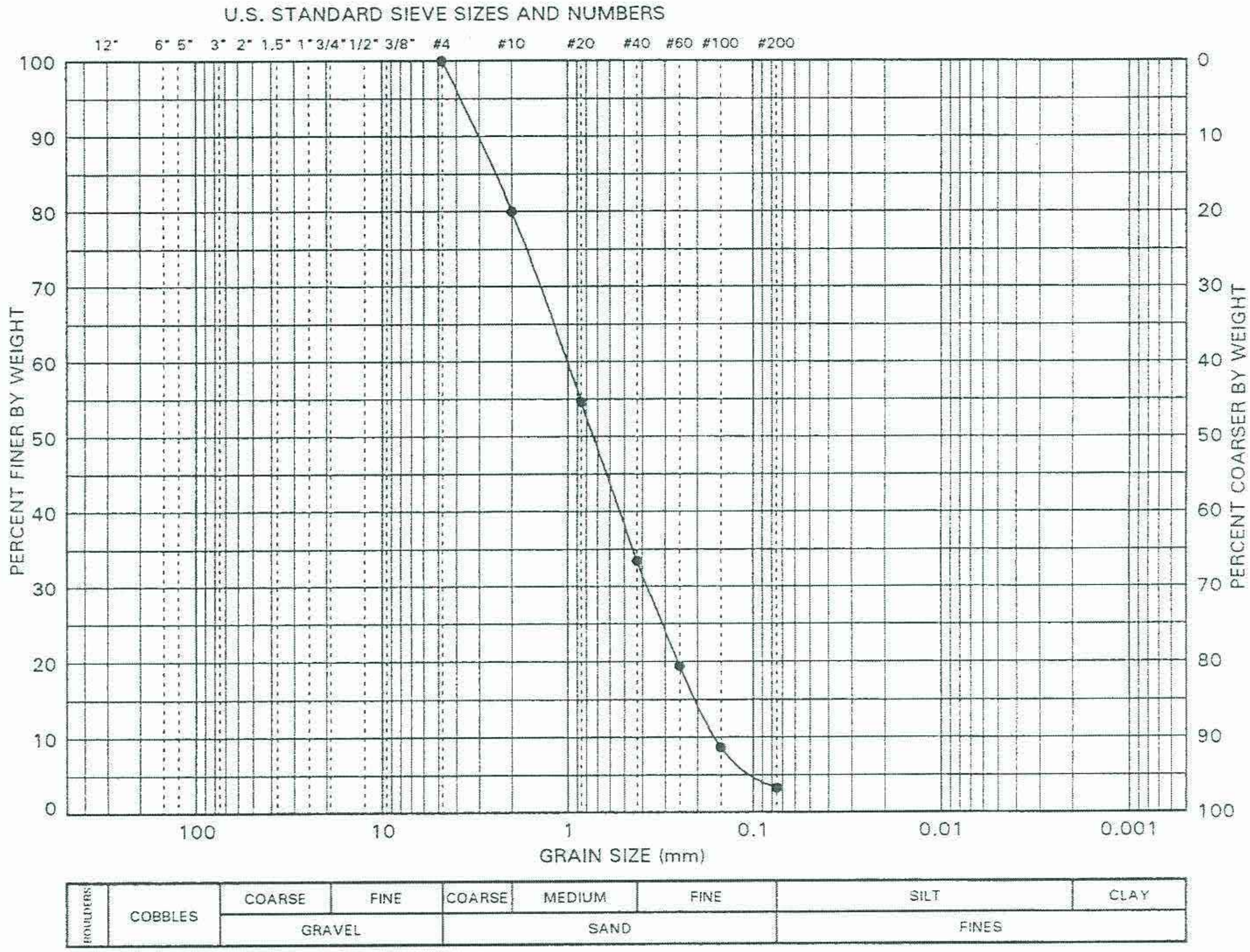
GEO SYNTEC CONSULTANTS
Geomechanics and Environmental Laboratory
Atlanta, Georgia

FIGURE
PROJECT:
PROJECT NO.:
DOCUMENT NO.:

GS FORM: 4PS2 08/25/95

PARTICLE SIZE DISTRIBUTION AND PHYSICAL PROPERTIES

ASTM C 136, D 422, D 2487 D 3042 AND D 4318



SITE SAMPLE ID	AL5012	LIQUID LIMIT (%)		GRAVEL (%)	0.0
LAB. SAMPLE NO.	95H141	PLASTIC LIMIT (%)		SAND (%)	96.7
SAMPLE DEPTH (ft)		PLASTICITY INDEX		FINES (%)	3.3
SOIL CLASSIFICATION: SP - Poorly Graded Sand				SILT (%)	
CONCRETE SAND				CLAY(%)	
				COEFF. UNIFORMITY (Cu)	6.4
				COEFF. CURVATURE (Cc)	0.85

PERCENT PASSING U.S. STANDARD SIEVE SIZES AND NUMBERS / PERCENT FINER THAN HYDROMETER PARTICLE DIAMETER (mm)

3"	2"	1.5"	1"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#60	#100	#200					
75	50	37.5	25	19	12.5	9.5	4.75	2.00	0.850	0.425	0.250	0.150	0.075	0.050	0.020	0.005	0.002	0.001
100	100	100	100	100	100	100	100	80	55	34	19	9	3					

NOTES:

GEO SYNTEC CONSULTANTS

Geomechanics and Environmental Laboratory
Atlanta, Georgia

FIGURE

PROJECT:
PROJECT NO.:
DOCUMENT NO.:

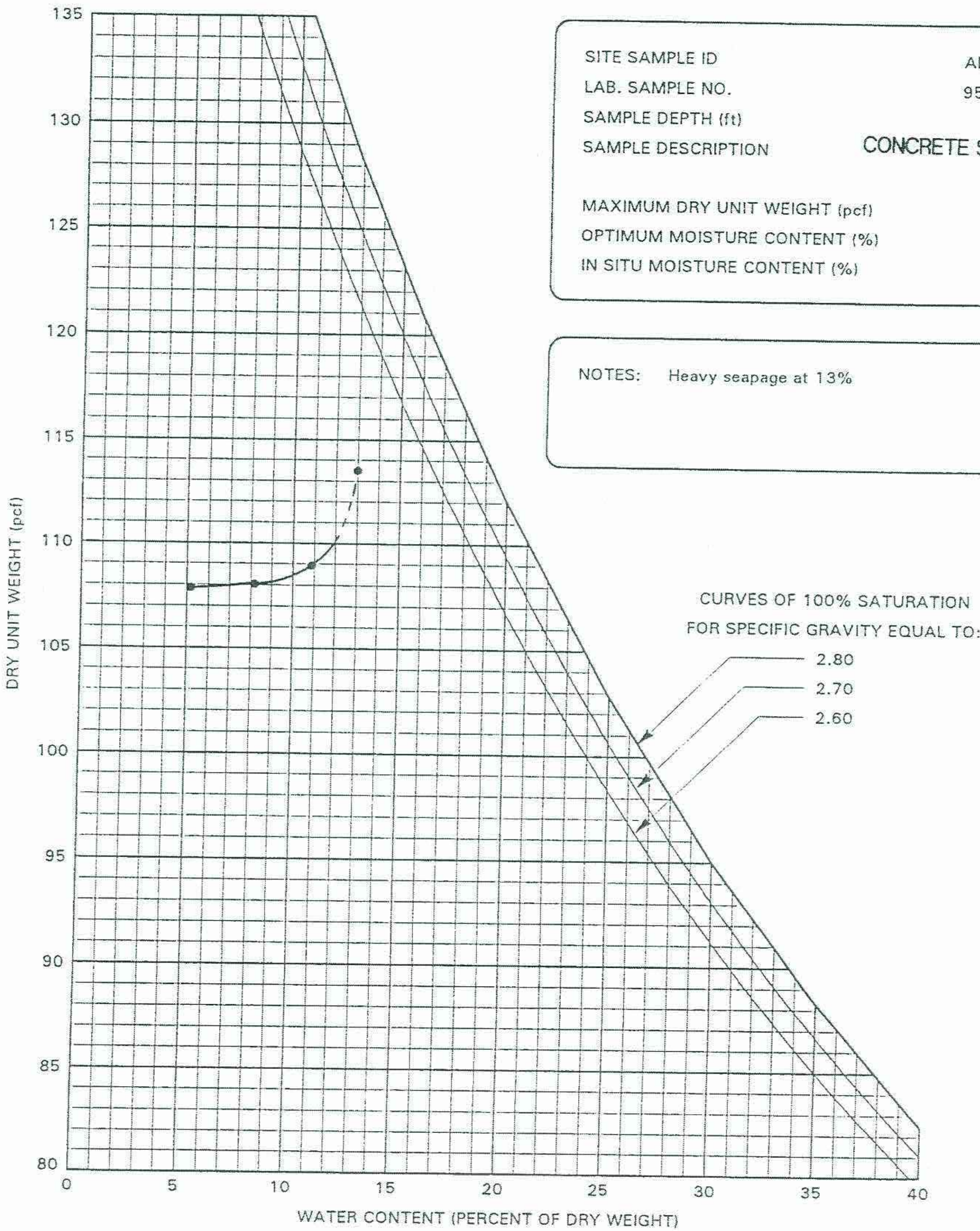
GS FORM:
4MD1 08/25/95

MOISTURE-DENSITY RELATIONSHIP, COMPACTION TESTING

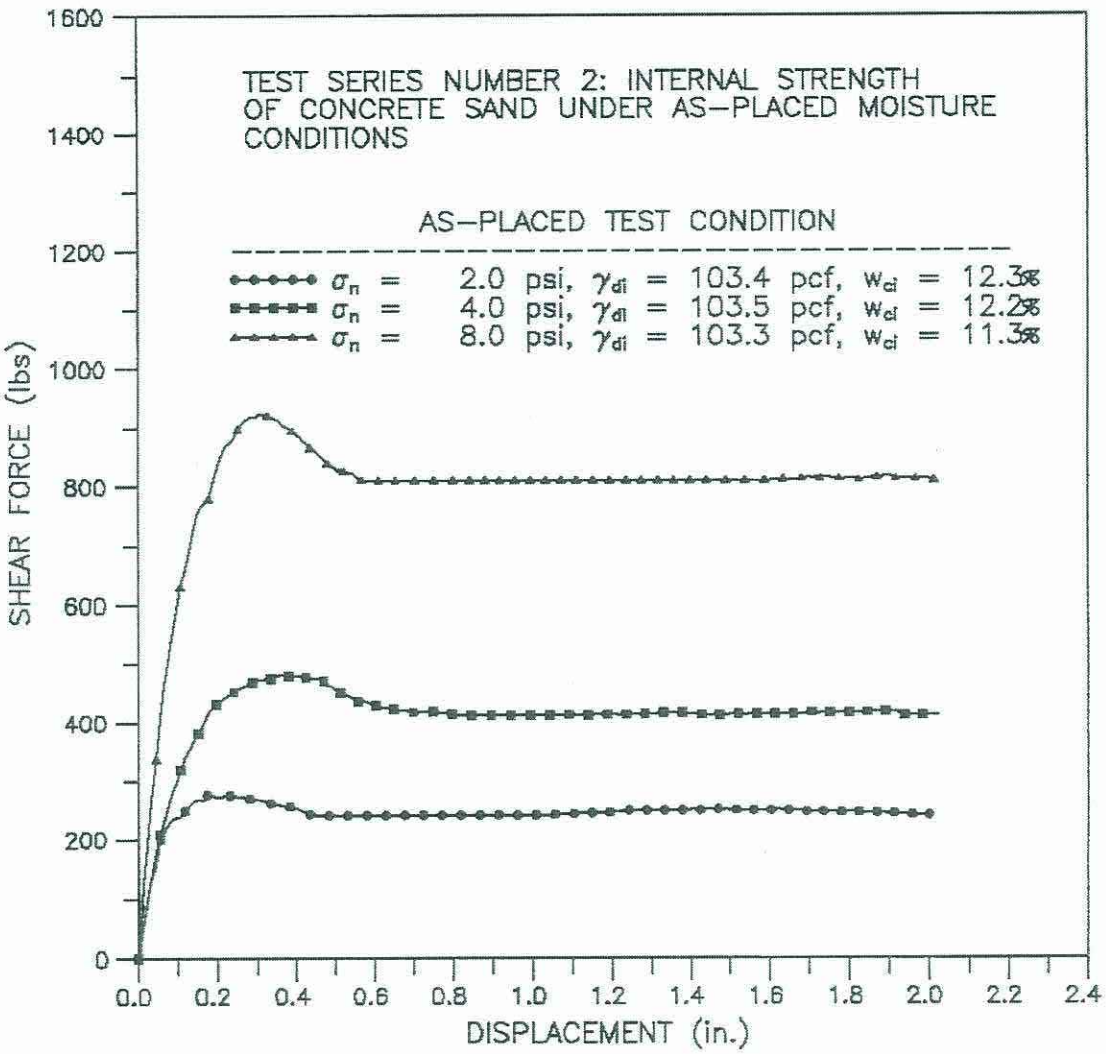
ASTM D-698-A

SITE SAMPLE ID	AL5012
LAB. SAMPLE NO.	95H141
SAMPLE DEPTH (ft)	
SAMPLE DESCRIPTION	CONCRETE SAND
MAXIMUM DRY UNIT WEIGHT (pcf)	109.0
OPTIMUM MOISTURE CONTENT (%)	11.0
IN SITU MOISTURE CONTENT (%)	

NOTES: Heavy seapage at 13%



DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in.(300 mm by 300 mm), and the contact area remained constant throughout the entire test.

DATE TESTED: 6 SEPTEMBER 1995

GEOSYNTEC CONSULTANTS

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

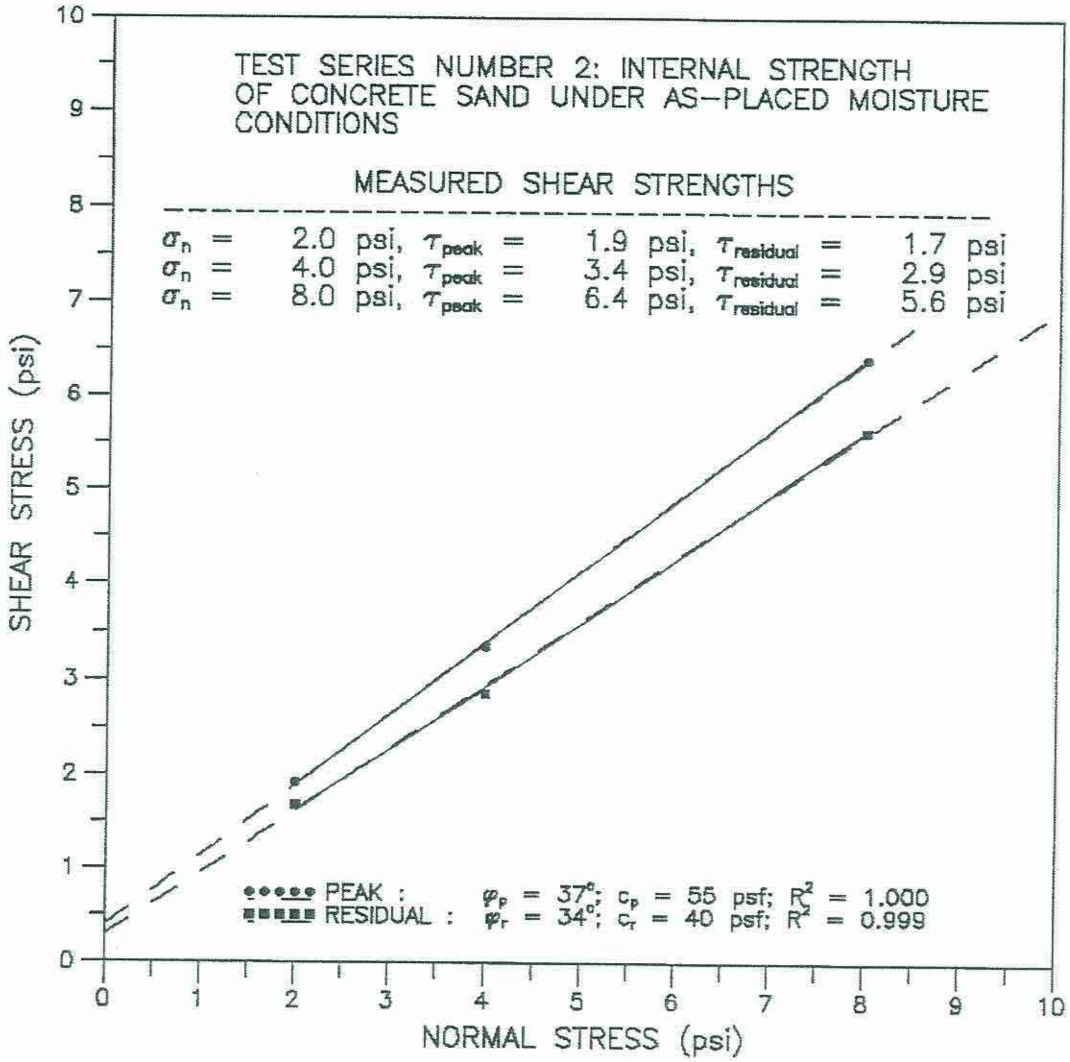
FIGURE NO.

PROJECT NO.

DOCUMENT NO.

FILE NO.

DIRECT SHEAR TESTING



NOTE: The reported value of cohesion may not be the true cohesion of the soil specimen, and caution should be exercised in using this cohesion value for applications involving normal stresses outside the range of stresses covered by the test.

DATE TESTED: 6 SEPTEMBER 1995

GEOSYNTEC CONSULTANTS

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	
PROJECT NO.	
DOCUMENT NO.	
FILE NO.	

APPENDIX B

SUMMARY OF TEST RESULTS

TABLE 1. SUMMARY OF GEOGRID PULLOUT TEST RESULTS
TC MIRAFI

Test Number	Test Specimen	Specimen Width (in)	Specimen Length (in)	Normal Stress (psi)	Residual Shear Strength of Soil Material (ϕ, c)	Maximum Pullout Force (lb/ft)	Coefficient of Interaction	Friction Coefficient (F*)	Alpha Coefficient (α)
1	Miragrid 3XT Geogrid in Machine Direction within Concrete Sand under as-Placed Moisture Conditions	18.0 18.0	48.0 48.0	1.0 3.0	34°,40 psf 34°,40 psf	997 2383	0.91 0.90	0.87 0.69	1.0 1.0
2	Miragrid 5XT Geogrid in Machine Direction within Concrete Sand under as-Placed Moisture Conditions	18.0 18.0	48.0 48.0	2.0 4.0	34°,40 psf 34°,40 psf	1710 3040	0.91 0.89	0.74 0.66	1.0 1.0
3	Miragrid 7XT Geogrid in Machine Direction within Concrete Sand under as-Placed Moisture Conditions	18.0 18.0	48.0 48.0	3.0 5.0	34°,40 psf 34°,40 psf	2390 3750	0.90 0.89	0.69 0.65	1.0 1.0
4	Miragrid 8XT Geogrid in Machine Direction within Concrete Sand under as-Placed Moisture Conditions	18.0 18.0	48.0 48.0	4.0 7.0	34°,40 psf 34°,40 psf	3109 5283	0.91 0.92	0.67 0.66	1.0 1.0
5	Miragrid 10XT Geogrid in Machine Direction within Concrete Sand under as-Placed Moisture Conditions	18.0 18.0	48.0 48.0	5.0 10.0	34°,40 psf 34°,40 psf	3930 7430	0.93 0.92	0.68 0.64	1.0 1.0

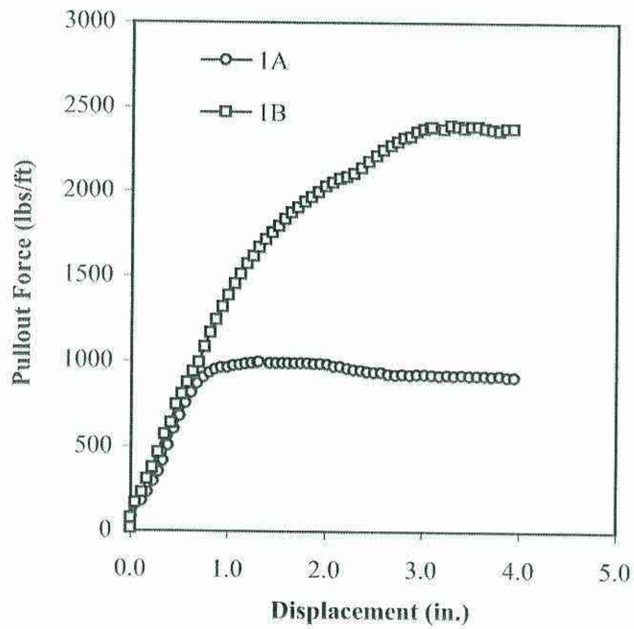
Note: (1) For each test, the geogrid specimen was observed to have pulled out from within soil as indicated by movements of the four "tell-tail" wires attached to the geogrid specimen at specific locations. The end of the specimen was observed to have displaced more than 1 in. (25 mm) at the completion of each test.

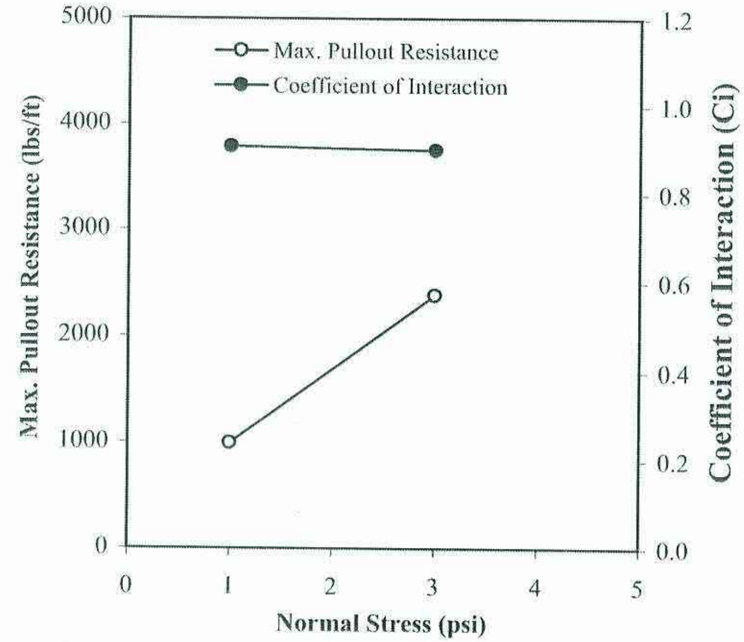
APPENDIX C

GEOSYNTHETIC PULLOUT TEST DATA

TC MIRAFI
GEOGRID PULLOUT TESTING

TEST SERIES NO. 1: Miragrid 3XT geogrid in machine direction within concrete sand under as-placed moisture conditions





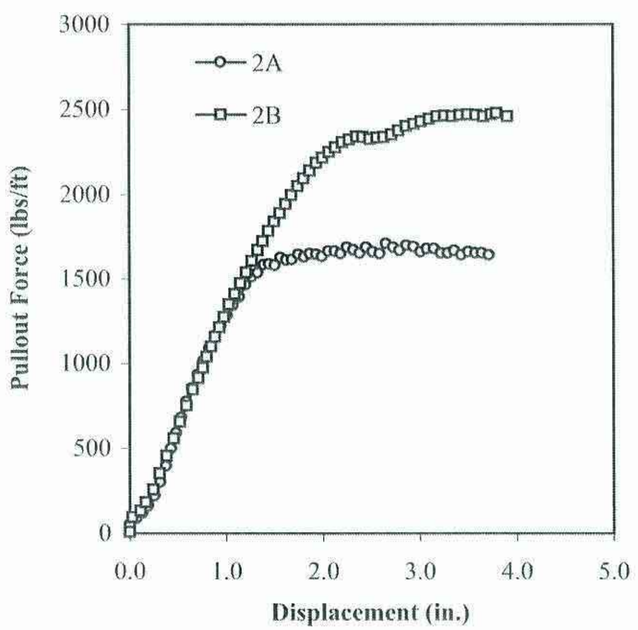
Test No.	Test Specimen Width (in.)	Test Specimen Length (in.)	Normal Stress (psi)	Pullout Rate (in./min)	Residual Soil Shear Strength		Maximum Pullout Resistance (lb/ft)	Coefficient of Interaction	Failure Mode
					φ (degree)	c (psf)			
1A	18.0	48.0	1.0	0.04	34	40	997	0.91	Pullout
1B	18.0	48.0	3.0	0.04	34	40	2383	0.90	Pullout

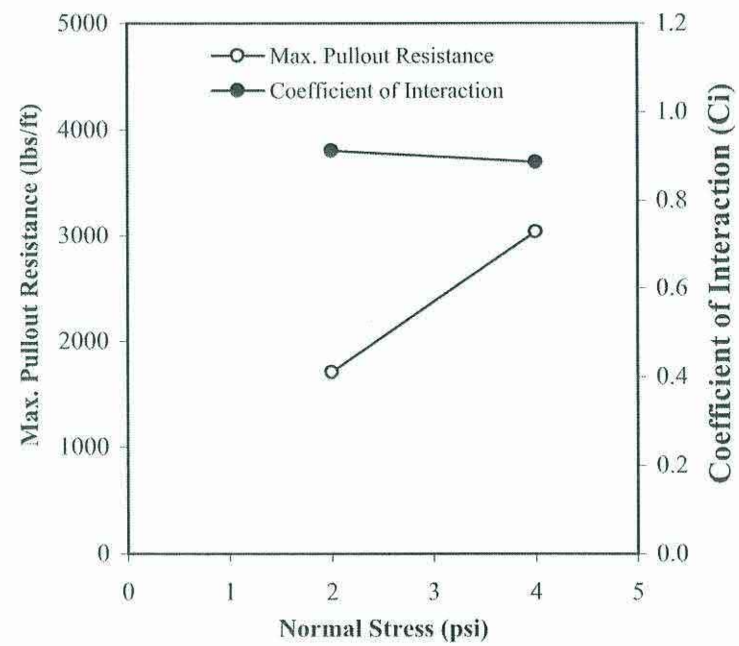
GEOSYNTEC CONSULTANTS
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

DATE TESED:	27 to 28 February 2001
FIGURE NO.	C-1
PROJECT NO.	GLI1292
DOCUMENT NO.	SGI01028
FILE NO.	

TC MIRAFI
GEOGRID PULLOUT TESTING

TEST SERIES NO. 2: Miragrid 5XT geogrid in machine direction within concrete sand under as-placed moisture conditions





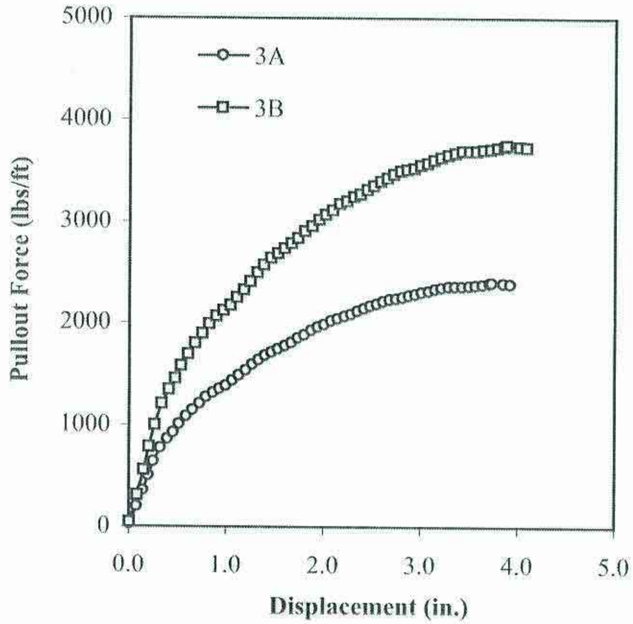
Test No.	Test Specimen Width (in.)	Test Specimen Length (in.)	Normal Stress (psi)	Pullout Rate (in./min)	Residual Soil Shear Strength		Maximum Pullout Resistance (lb/ft)	Coefficient of Interaction	Failure Mode
					φ (degree)	c (psf)			
2A	18.0	48.0	2.0	0.04	34	40	1710	0.91	Pullout
2B	18.0	48.0	4.0	0.04	34	40	3040	0.89	Pullout

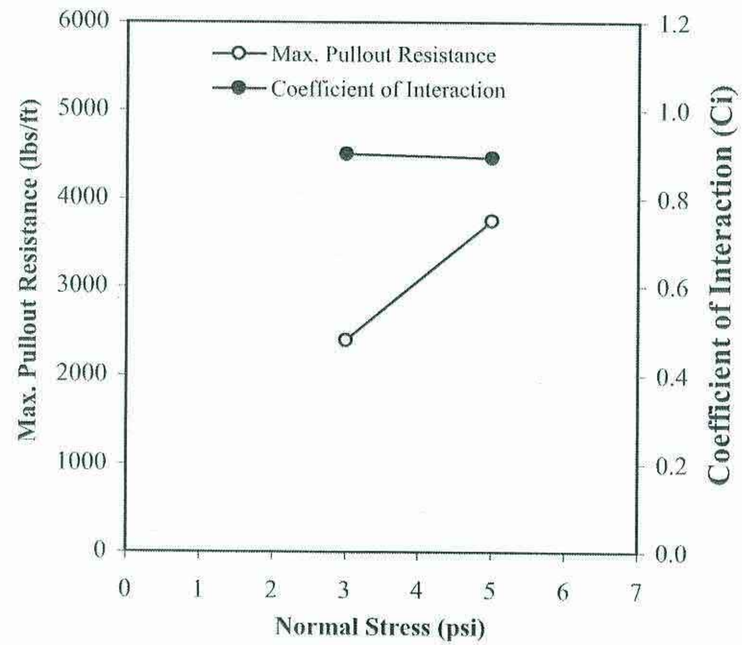
GEOSYNTEC CONSULTANTS
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

DATE TESED:	1 to 3 March 2001
FIGURE NO.	C-2
PROJECT NO.	GLI1292
DOCUMENT NO.	SGI01028
FILE NO.	

TC MIRAFI
GEOGRID PULLOUT TESTING

TEST SERIES NO. 3: Miragrid 7XT geogrid in machine direction within concrete sand under as-placed moisture conditions





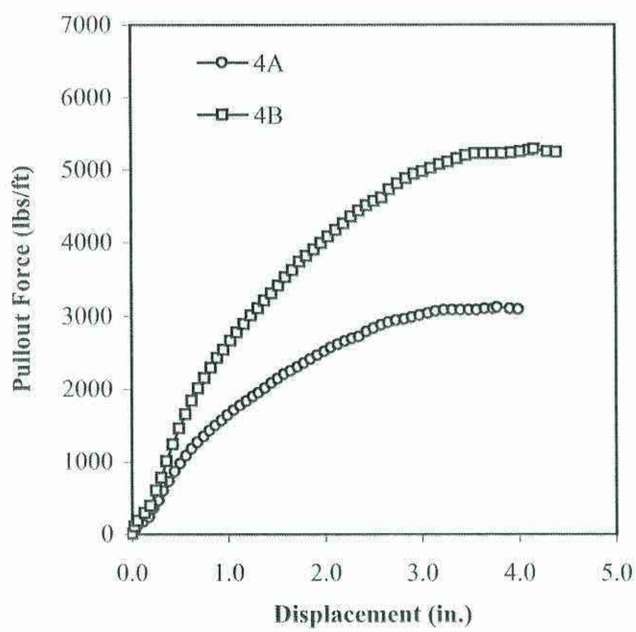
Test No.	Test Specimen Width (in.)	Test Specimen Length (in.)	Normal Stress (psi)	Pullout Rate (in./min)	Residual Soil Shear Strength		Maximum Pullout Resistance (lb/ft)	Coefficient of Interaction	Failure Mode
					φ (degree)	c (psf)			
3A	18.0	48.0	3.0	0.04	34	40	2390	0.90	Pullout
3B	18.0	48.0	5.0	0.04	34	40	3750	0.89	Pullout

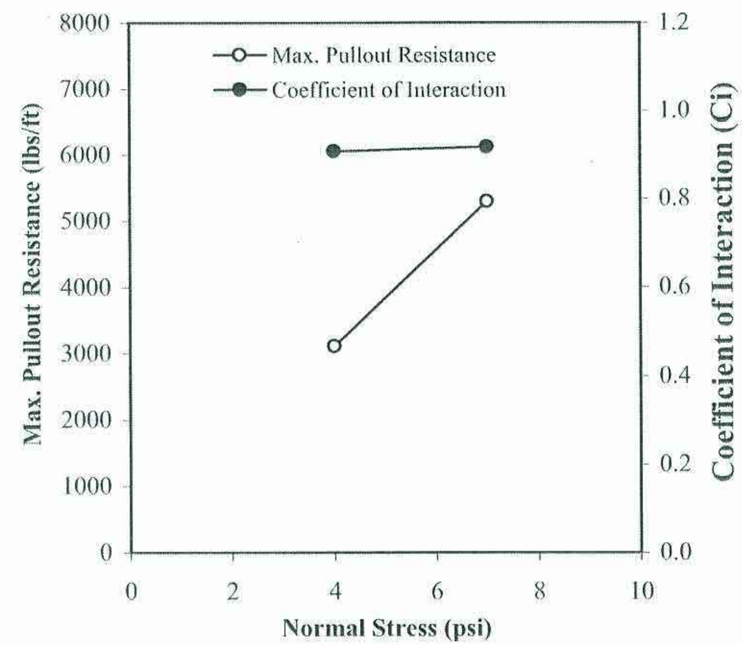
GEOSYNTEC CONSULTANTS
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

DATE TESED:	3 to 7 March 2001
FIGURE NO.	C-3
PROJECT NO.	GLI1292
DOCUMENT NO.	SGI01028
FILE NO.	

TC MIRAFI
GEOGRID PULLOUT TESTING

TEST SERIES NO. 4: Miragrid 8XT geogrid in machine direction within concrete sand under as-placed moisture conditions





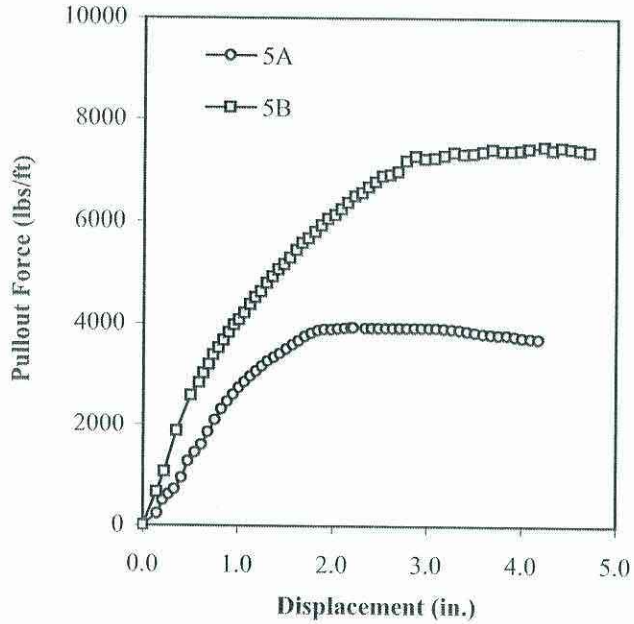
Test No.	Test Specimen Width (in.)	Test Specimen Length (in.)	Normal Stress (psi)	Pullout Rate (in./min)	Residual Soil Shear Strength		Maximum Pullout Resistance (lb/ft)	Coefficient of Interaction	Failure Mode
					φ (degree)	c (psf)			
4A	18.0	48.0	4.0	0.04	34	40	3109	0.91	Pullout
4B	18.0	48.0	7.0	0.04	34	40	5283	0.92	Pullout

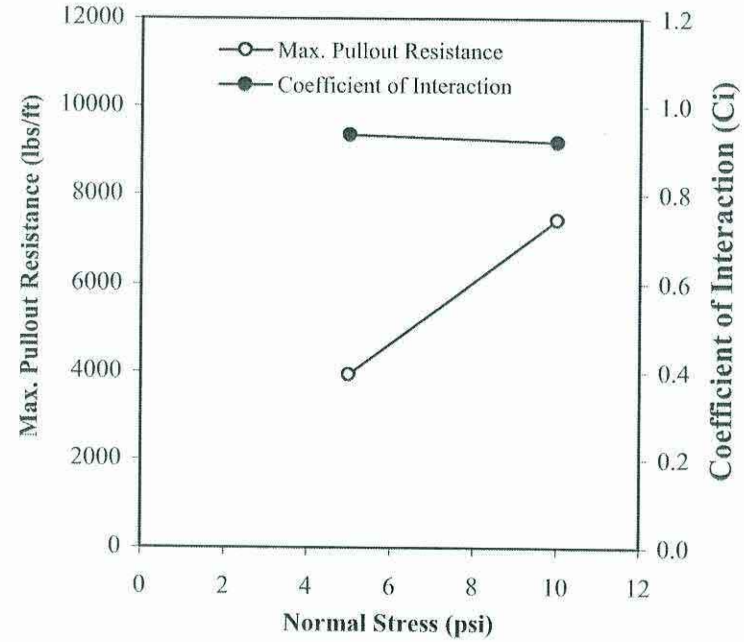
DATE TESED:	8 to 12 March 2001
FIGURE NO.	C-4
PROJECT NO.	GLI1292
DOCUMENT NO.	SGI01028
FILE NO.	

GEOSYNTEC CONSULTANTS
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

TC MIRAFI
GEOGRID PULLOUT TESTING

TEST SERIES NO. 5: Miragrid 10XT geogrid in machine direction within concrete sand under as-placed moisture conditions





Test No.	Test Specimen Width (in.)	Test Specimen Length (in.)	Normal Stress (psi)	Pullout Rate (in./min)	Residual Soil Shear Strength		Maximum Pullout Resistance (lb/ft)	Coefficient of Interaction	Failure Mode
					φ (degree)	c (psf)			
5A	18.0	48.0	5.0	0.04	34	40	3930	0.93	Pullout
5B	18.0	48.0	10.0	0.04	34	40	7430	0.92	Pullout

GEOSYNTEC CONSULTANTS
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

DATE TESED:	13 to 14 March 2001
FIGURE NO.	C-5
PROJECT NO.	GLI1292
DOCUMENT NO.	SGI01028
FILE NO.	

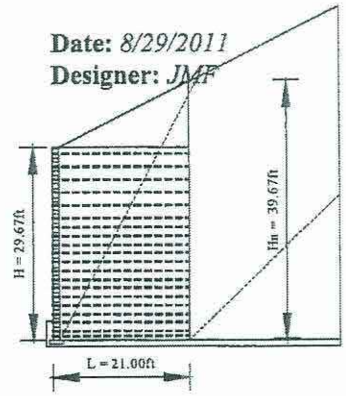
KEYSTONE RETAINING WALL SYSTEMS

RETAINING WALL DESIGN

KeyWall_2010 Version 3.6.3 Build 28

Project: *HITEC Sample Problems*
Project No:
Case: *Case 2*
Design Method: *AASHTO-LRFD (vertical soil interface) Strength I*

Date: *8/29/2011*
Designer: *JMF*



Design Parameters

Soil Parameters:

	φ	c psf	γ pcf
Reinforced Fill	*34*	*0*	*120*
Retained Zone	*30*	*0*	*120*
Foundation Soil	*30*	*0*	*120*

Reinforced Fill Type: *Sand, Silt or Clay*
Unit Fill: *Crushed Stone, 1 inch minus*

Load Factors for Strength I are:
(the larger values are driving (EVd), the lessor values are resisting (EVr)

EH	1.50 to 0.90	RF_bearing	0.65
EV	1.35 to 1.00	RF_pullout	0.90
ES	1.50 to 0.75	RF_sliding	1.00
LL	1.75 to 0.00	RF_tension	0.90

RFcn-d = 1.15 Applied to Peak Connection
RFcn-cr = 1.15 Applied to Peak Connection

Reinforcing Parameters: *Mirafi XT HITEC Geogrids*

	Tult	RFcr	RFd	RFid	LTDS	Tal	Ci	Cds	α
7XT	*5900*	*1.60*	*1.15*	*1.15*	*2788*	*2509*	*0.89*	*0.89*	*0.80*
3XT	*3500*	*1.60*	*1.15*	*1.20*	*1585*	*1427*	*0.89*	*0.89*	*0.80*

Analysis: *Case: Case 2*
HITEC Example 2

Unit Type:	*CompacII / 120.00 pcf*	*Wall Batter: 0.00 deg.*
Leveling Pad:	*Concrete*	
Wall Ht:	*29.67 ft*	*embedment: 3.00 ft*
BackSlope:	*26.56 deg. slope,*	*100.00 ft long*
Surcharge:	*LL: 250 psf uniform surcharge*	*DL: 0 psf uniform surcharge*
	Load Width: 100.00 ft	*Load Width: 100.00 ft*

Results:	Sliding	Overturning	Bearing	Shear	Bending
CDR	*1.03*	*1.86*	*1.66*	*2.80*	*1.19*

Calculated Bearing Pressure: *10289 / Unfactored bearing = 7161 psf*
Eccentricity at base: 3.17 ft
Reinforcing: (ft & lbs/ft)

Layer	Height	Length	Calc. Tension	Reinf. Type	Allow Ten Tal	Pk Conn Tcl	Serv Conn Tsc	Pullout CDR
20	*28.67*	*21.0*	*545*	*3XT*	*1427 ok*	*705 ok*	*N/A*	*8.88 ok*
19	*26.67*	*21.0*	*728*	*3XT*	*1427 ok*	*868 ok*	*N/A*	*9.58 ok*
18	*24.67*	*21.0*	*911*	*3XT*	*1427 ok*	*1031 ok*	*N/A*	*>10 ok*
17	*22.67*	*21.0*	*1094*	*3XT*	*1427 ok*	*1195 ok*	*N/A*	*>10 ok*
16	*20.67*	*21.0*	*1277*	*3XT*	*1427 ok*	*1356 ok*	*N/A*	*>10 ok*
15	*18.67*	*21.0*	*1204*	*3XT*	*1427 ok*	*1435 ok*	*N/A*	*>10 ok*
14	*17.33*	*21.0*	*1055*	*3XT*	*1427 ok*	*1488 ok*	*N/A*	*>10 ok*
13	*16.00*	*21.0*	*1137*	*3XT*	*1427 ok*	*1542 ok*	*N/A*	*>10 ok*

Layer	Height	Length	Calc. Tension	Reinf. Type	Allow Ten Tal	Pk Conn Tcl	Serv Conn Tsc	Pullout CDR
12	14.67	21.0	1218	3XT	1427 ok	1595 ok	N/A	>10 ok
11	13.33	21.0	1299	3XT	1427 ok	1648 ok	N/A	>10 ok
10	12.00	21.0	1381	3XT	1427 ok	1701 ok	N/A	>10 ok
9	10.67	21.0	1462	7XT	2509 ok	1757 ok	N/A	>10 ok
8	9.33	21.0	1544	7XT	2509 ok	1823 ok	N/A	>10 ok
7	8.00	21.0	1625	7XT	2509 ok	1889 ok	N/A	>10 ok
6	6.67	21.0	1706	7XT	2509 ok	1955 ok	N/A	>10 ok
5	5.33	21.0	1788	7XT	2509 ok	2022 ok	N/A	>10 ok
4	4.00	21.0	1869	7XT	2509 ok	2088 ok	N/A	>10 ok
3	2.67	21.0	1951	7XT	2509 ok	2154 ok	N/A	>10 ok
2	1.33	21.0	1516	7XT	2509 ok	2220 ok	N/A	>10 ok
1	0.67	21.0	1562	7XT	2509 ok	2230 ok	N/A	>10 ok

Reinforcing Quantities (no waste included):
7XT 21.00 sy/ft
3XT 25.67 sy/ft

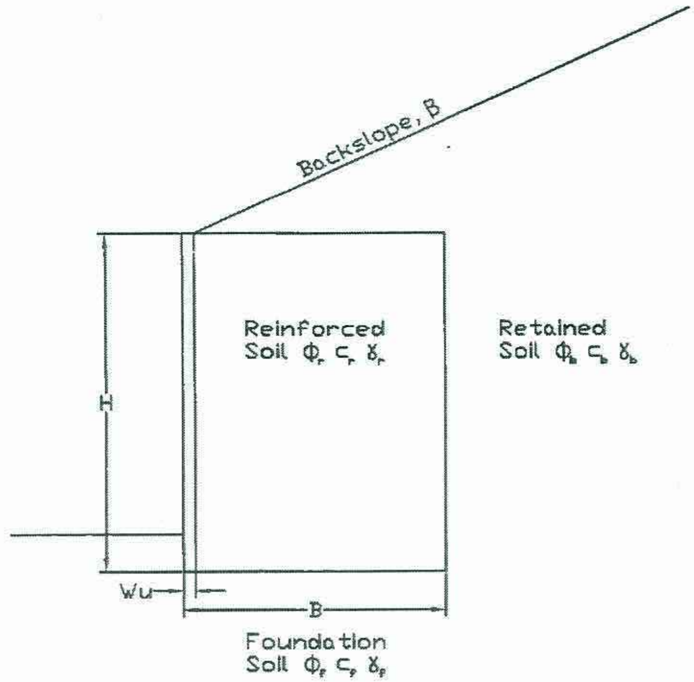
NOTE: THESE CALCULATIONS ARE FOR PRELIMINARY DESIGN ONLY AND SHOULD NOT BE USED FOR CONSTRUCTION WITHOUT REVIEW BY A QUALIFIED ENGINEER

Example 2 Evaluate a 29.67 ft tall MSE Keystone Compac II retaining wall that has a near vertical batter and a 2H:1Vbackslope using Mirafi 3XT and 7XT geogrid based on AASHTO LRFD Interim 2009 design specifications.

Data

1) Geometry and Loads

Design Height	H =	29.67	ft
Wall Embedment	D =	3.00	ft
Backslope	beta =	26.6	°
Wall Batter	theta =	90	°
Wall Friction Angle	delta =	26.6	°
Live Load	ql =	0	psf
Dead Load	qd =	0	psf
Seismic Coefficient	A =	0	g



2) Soil Properties

	phi °	c (psf)	gamma (pcf)
Reinforced Soil, r	34	0	120
Retained Soil, b	30	0	120
Foundation Soil, f	30	0	120

3) Load Factors - Strength 1

Driving Factors (d)	Resisting Factors (r)	Resistance Factors	
EHd = 1.50	EHr = 0.90	Sliding, RFsl = 1.00	EH, EV, ES
EVd = 1.35	EVr = 1.00	Bearing, RFb = 0.65	*AASHTO Table 3.4.1-2*
ESd = 1.50	ESr = 0.75	Tension, RFt = 0.90	LLd
LLd = 1.75		Pullout, RFpo = 0.90	*AASHTO Table 3.4.1-1*
			RF's
			AASHTO Table 11.5.6-1

RFcn-d = 1.15 Applied to Peak Connection
RFcn-cr = 1.15 Applied to Peak Connection

4) Reinforcement Parameters

		Tult		RFcr	RFd	RFid*	Tal		RFt	Ta		Ci	Cds	alpha
Mirafi	3XT	3500	plf	1.60	1.15	1.20	1585	plf	0.90	1427	plf	0.89	0.89	1.00
Mirafi	7XT	5900	plf	1.60	1.15	1.15	2788	plf	0.90	2509	plf	0.89	0.89	1.00

* RFid based on 3/4" Material

5) Unit Data

Compac II Properties

Hu =	0.6667	ft
Wu =	1.00	ft
gammau =	120	pcf

Connection Data   Tc = Peak   Tsc=3/4" Serviceability

	Grid	Min.-Inter.(T)		Slope 1			Break(N)		Slope 2			Max-Inter.(T)	
Tc	3XT	915	plf	tan	45.0	°	1074	plf	tan	26.0	°	2571	plf
	7XT	764	plf	tan	46.1	°	1000	plf	tan	31.3	°	3256	plf
Tsc	3XT	638	plf	tan	27.0	°	888	plf	tan	10.0	°	1334	plf
	7XT	643	plf	tan	33.7	°	1265	plf	tan	10.3	°	1878	plf

Inter-Unit Shear Data
Tunit = N x tan (29 °) + 1250.00 plf

Summary of Results
(See Following Pages)
External Stability

Specify Grid Length — *AASHTO 11.10.2.1*
Minimum Grid Length — B = 0.7 x H = 0.7 x 29.67 ft = 20.77 ft
User Defined Grid Length — B = 21.00 ft (Must be Greater than Minimum)

1) Sliding at Base

$$CDRsl = RFsl \times \frac{RF}{DF} = 1.00 \times \frac{69700 \text{ plf}}{67947 \text{ plf}} = 1.03$$

CDRsl = 1.03 > 1.00 OK

2) Sliding at Lowest Reinforcement Level

$$CDRsl' = RFsl \times \frac{RF}{DF} = 1.00 \times \frac{71874 \text{ plf}}{65682 \text{ plf}} = 1.09$$

CDRsl' = 1.09 > 1.00 OK

3) Overturning

$$CDRot = \frac{RM}{OM} = \frac{1670231 \text{ ft-lb/ft}}{898364.2 \text{ ft-lb/ft}} = 1.86$$

CDRot = 1.86 > 1.00 OK

4) Bearing

$$CDRb = RFb \times \frac{qult}{sigmav} = 0.65 \times \frac{26317 \text{ psf}}{10313 \text{ psf}} = 1.66$$

CDRb = 1.66 > 1.00 OK

5) Eccentricity

e = 4.11 ft < B / 4 = 21.00 ft / 4 = 5.25 ft OK

Note: Maximum e from Case 1 shown

Internal Stability * Max Grid Spacing = 2 x Wu = 2 x 1.00 ft = 2.00 ft which equals 3 block spacing *AASHTO 11.10.2.3*

Layer	* Blocks	Depth (ft)	Length (ft)	Tmax (plf)	Reinf. Type	Ta (plf)		Tc (plf)		Tsc (plf)		CDRpo CDR> 1.00	?
1	1.5	1.00	21.00	549	3XT	1427	OK	704	OK	NA	--	11.01	OK
2	3	3.00	21.00	733	3XT	1427	OK	868	OK	NA	--	11.89	OK
3	3	5.00	21.00	916	3XT	1427	OK	1031	OK	NA	--	12.94	OK
4	3	7.00	21.00	1099	3XT	1427	OK	1194	OK	NA	--	14.08	OK
5	3	9.00	21.00	1282	3XT	1427	OK	1356	OK	NA	--	15.26	OK
6	3	11.00	21.00	1209	3XT	1427	OK	1435	OK	NA	--	19.98	OK
7	2	12.33	21.00	1058	3XT	1427	OK	1488	OK	NA	--	25.94	OK
8	2	13.67	21.00	1140	3XT	1427	OK	1541	OK	NA	--	27.18	OK
9	2	15.00	21.00	1221	3XT	1427	OK	1595	OK	NA	--	28.43	OK
10	2	16.33	21.00	1303	3XT	1427	OK	1648	OK	NA	--	29.69	OK
11	2	17.67	21.00	1384	3XT	1427	OK	1701	OK	NA	--	30.95	OK
12	2	19.00	21.00	1466	7XT	2509	OK	1757	OK	NA	--	32.22	OK
13	2	20.33	21.00	1547	7XT	2509	OK	1823	OK	NA	--	33.49	OK
14	2	21.67	21.00	1628	7XT	2509	OK	1889	OK	NA	--	34.77	OK
15	2	23.00	21.00	1710	7XT	2509	OK	1955	OK	NA	--	36.05	OK
16	2	24.33	21.00	1791	7XT	2509	OK	2022	OK	NA	--	37.33	OK
17	2	25.67	21.00	1873	7XT	2509	OK	2088	OK	NA	--	38.61	OK
18	2	27.00	21.00	1954	7XT	2509	OK	2154	OK	NA	--	39.89	OK
19	2	28.33	21.00	1519	7XT	2509	OK	2216	OK	NA	--	55.18	OK
20	1	29.00	21.00	1565	7XT	2509	OK	2216	OK	NA	--	55.49	OK

Solution - General Information Required

1) Determine Active Earth Pressure Coefficients of Reinforced and Retained Soil Zones

Reinforced Zone (Internal Ka), use Rankine *AASHTO C11.10.6.2.1*

$Kr = \tan^2(45 - phir / 2) = \tan^2(45 - 34 / 2) = 0.283$

$\underline{Kr = 0.283}$

Retained Zone (External Ka), Use Coulomb *AASHTO C3.11.5.3*

$$Ka = \frac{\overbrace{\sin^2(\Theta + \Phi)}^{A}}{\underbrace{\sin^2\Theta \cdot \sin(\Theta - \delta)}_{B} \underbrace{\left[1 + \sqrt{\frac{\sin(\Phi + \delta) \cdot \sin(\Phi - \beta)}{\sin(\Theta - \delta) \cdot \sin(\Theta + \beta)}}\right]^2}_{C}}$$

$A = \sin^2(phib + theta)$

$A = \sin^2(30 + 90) = 0.75$

$B = \sin^2(theta) \times \cos(theta - delta)$

$B = \sin^2(90) \times \sin(90 - 26.6) = 0.89$ Note: Delta=Beta

$$C = 1 + \sqrt{\frac{\sin(delta + phib) \times \sin(phib - beta)}{\sin(theta - delta) \times \sin(theta + beta)}}$$

$$C = 1 + \sqrt{\frac{\sin(26.6 + 30) \times \sin(30 - 26.6)}{\sin(90 - 26.6) \times \sin(90 + 26.6)}} = 1.25$$

$$Ka = \frac{A}{B \times C^2} = \frac{0.75}{0.89 \times 1.25^2} = 0.536$$

$\underline{Ka = 0.536}$

2) Determine Foundation Soil Bearing Capacity Factors

Bearing Capacity Factor for Embedment, Nq

$Nq = [e \wedge (pi \times \tan(phif))] \times \tan^2(45 + phif / 2)$

$Nq = [e \wedge (3.14 \times \tan(30))] \times \tan^2(45 + 30 / 3) = 18.40$

$\underline{Nq = 18.40}$

Bearing Capacity Factor for Cohesion, Nc

$Nc = (Nq - 1) \times \cot(phif)$

$Nc = (18.401 - 1) \times \cot(30) = 30.14$

$\underline{Nc = 30.14}$

Bearing Capacity Factor for Footing Width, Ng

$Ng = 2 \times (Nq + 1) \times \tan(phif)$

$Ng = 2 \times (18.401 + 1) \times \tan(30) = 22.40$

$\underline{Ng = 22.40}$

3) Find L given B

$L = B - Wu = 21.00$ ft $- 1.00$ ft $= 20.00$ ft

$\underline{L = 20.00 \text{ ft}}$

4) Find Height of Backslope, h

$h = H + L \times \tan(beta) = 29.67$ ft $+ 20.00$ ft $\times \tan(26.6) = 39.66$ ft

$\underline{h = 39.66 \text{ ft}}$

External Stabilty Solution - Calculation of Weights, External Forces, and Moment Arms

1) Determine Weights Vf, V1, V2

Weight of Face, Vf

Vf = (H x Wu) x gammau

Vf = (29.67 ft x 1.00 ft) x 120.00 pcf = 3560 plf — **Vf = 3560 plf**

Weight of Reinforced Zone, V1

V1 = (H x L) x gammar

V1 = (29.67 ft x 20.00 ft) x 120.00 pcf = 71200 plf — **V1 = 71200 plf**

Weight of Backslope, V2

V2 = (((h - H) x L) / 2) x gammab

V2 = (((39.66 ft - 29.67 ft) x 20.00 ft) / 2) x 120 pcf = 11997 — **V2 = 11997 plf**

2) Determine External Force, Ft

Active Earth Pressure Force, Ft

Ft = 0.5 x (h x gammab) x h x Ka

Ft = 0.5 x (39.66 ft x 120 pcf) x 39.66 ft x 0.536 = 50643 plf — **Ft = 50643 plf**

Find X and Y Components, Ftx and Fty

Ftx = Ft x cos (beta) = 50643 plf x cos (26.6) = 45298 plf — **Ftx = 45298 plf**

Fty = Ft x sin (beta) = 50643 plf x sin (26.6) = 22644 plf — **Fty = 22644 plf**

3) Determine Weights above the Lowest Reinforcement Level Vf', V1'

Find H' if Lowest Reinforcement Level is 1 Block from the Top of the Leveling Pad

H' = H - (# Blocks x Hu)

H' = 29.67 ft - (1 Blocks x 0.67 ft) = 29.00 ft — **H' = 29.00 ft**

Weight of Face, Vf'

Vf' = (H' x Wu) x gammau

Vf' = (29.00 ft x 1.00 ft) x 120.00 pcf = 3480 plf — **Vf' = 3480 plf**

Weight of Reinforced Zone, V1'

V1' = (H' x L) x gammar

V1' = (29.00 ft x 20.00 ft) x 120.00 pcf = 69600 plf — **V1' = 69600 plf**

4) Determine External Force Ft' above the Lowest Reinforcement Level

Find h' if Lowest Reinforcement Level is 1 Block from the Top of the Leveling Pad

h' = h - (# Blocks x Hu)

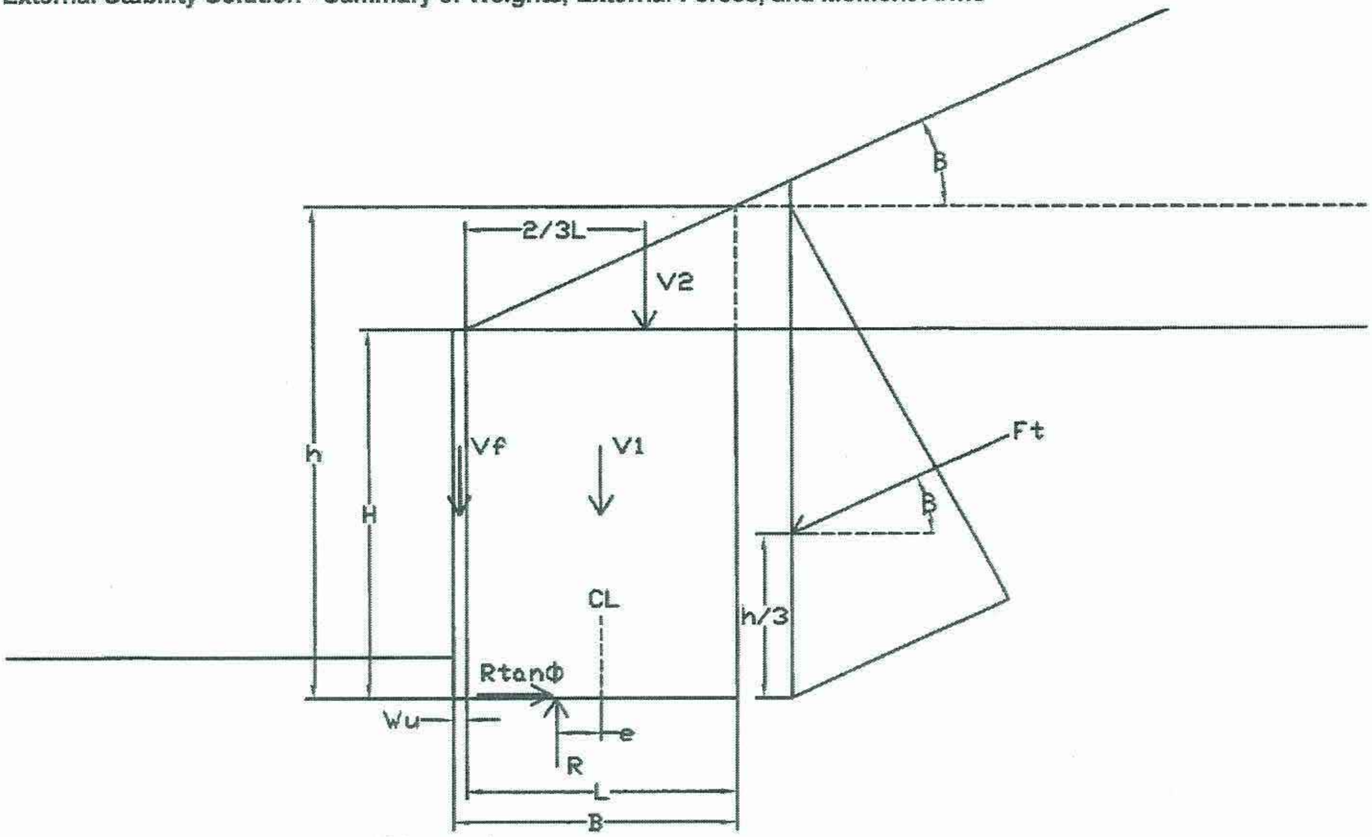
h' = 39.66 ft - (1 Blocks x 0.67 ft) = 39.00 ft — **h' = 39.00 ft**

Active Earth Pressure Force, Ft'

Ft' = 0.5 x (h' x gammab) x h' x Ka

Ft' = 0.5 x (39.00 ft x 120 pcf) x 39.00 ft x 0.536 = 48955 plf — **Ft' = 48955 plf**

External Stability Solution - Summary of Weights, External Forces, and Moment Arms



Weights, External Forces, and Moment Arms

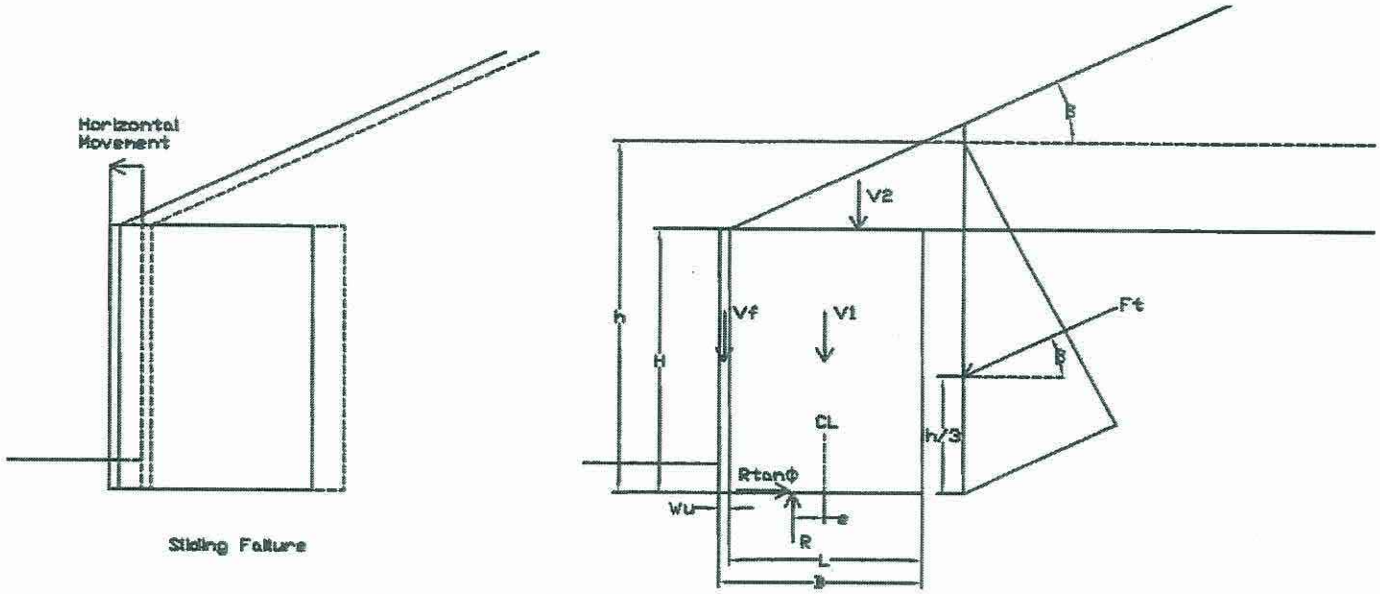
Weights	Forces	Force		X-Arm		Y-Arm		Moment		Type
Vf		3560	plf	Xf = 0.50	ft			1780	ft-lb/ft	RM
V1		71200	plf	X1 = 11.00	ft			783200	ft-lb/ft	RM
V2		11997	plf	X2 = 14.33	ft			171962	ft-lb/ft	RM
	Ftx	45298	plf			Y1 = 13.22	ft	598909	ft-lb/ft	RM
	Fty	22644	plf			B = 21.00	ft	475526	ft-lb/ft	OM

RM = Resisting Moments
OM = Overturning Moments

Weights and External Forces Above Lowest Reinforcement Layer

Weights	Forces	Force	
Vf'		3480	plf
V1'		69600	plf
	Ft'	48955	plf

External Stabilty Solution - External Failure Modes



1) Check Sliding at Base Failure Mode *AASHTO 11.10.5.3*

Driving Force, DF

DF = EHd x Ftx = 1.50 x 45298 plf = 67947 plf — **DF = 67947 plf**

Resisting Force, RF

RF = R x tan (phi)

R = EVr x (Vf + V1 + V2) + EHd x Fty

R = 1.00 x (3560 plf + 71200 plf + 11997 plf) + 1.50 x 22644 plf

R = 120724 plf — **R = 120724 plf**

phi = min (phir , phif) = min (34 , 30) = 30 ° — **phi = 30 °**

RF = R x tan (30)

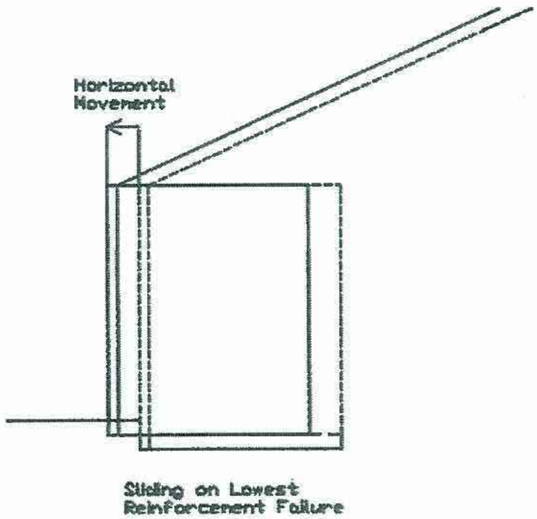
RF = 120724 plf x tan (30) = 69700 plf — **RF = 69700 plf**

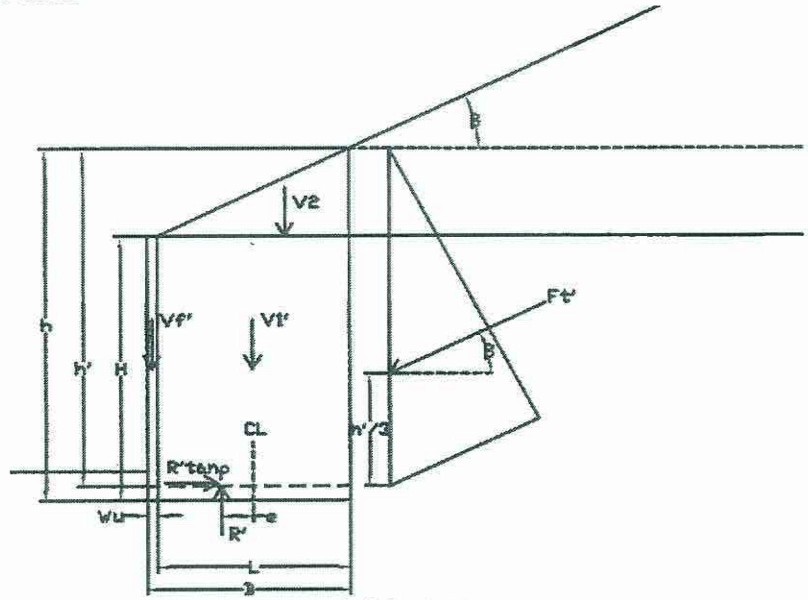
Sliding Capacity Demand Ratio

$$CDRsl = RFsl \times \frac{RF}{DF} = 1.00 \times \frac{69700 \text{ plf}}{67947 \text{ plf}} = 1.03$$

CDRsl = 1.03

External Stabilty Solution - External Failure Modes cont.





2) Check Sliding on Top of Lowest Reinforcement Level Failure Mode *AASHTO 11.10.5.3*

Driving Force, DF

DF = EHd x Ft' x cos (beta)

DF = 1.50 x 48955 plf x cos (26.6) = 65682 plf

DF = 65682 plf

Resisting Force, RF

Find the Sliding Resistance at the Blocks, Va

Va = EVr x N x tan (29) + 1250 plf

N = Vf' = 3480 plf

Va = 1.00 x 3480 plf x tan (29) + 1250 plf = 3179 plf

Va = 3179 plf

Find the Sliding Resistance at the Grid, R' x tan(rho)

R' = EVr x (V1' + V2) + EHd x Ft' x sin (beta)

R' = 1.00 x (69600 plf + 11997 plf) + 1.50 x 48955 plf x sin (26.6)

R' = 114431 plf

R' = 114431 plf

tan(rho) = Cds x tan (phir)

tan(rho) = 0.89 x tan (34) = 0.6003

tan(rho) = 0.6003

RF = Va + R' x tan(rho)

RF = 3179 plf + 114431 plf x 0.6003 = 71874 plf

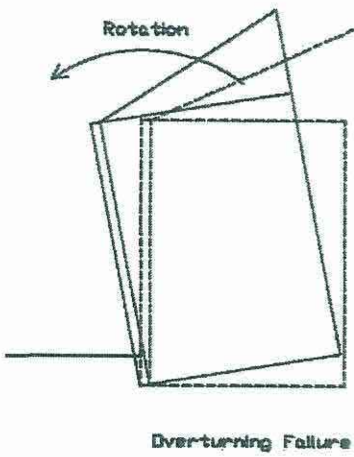
RF = 71874 plf

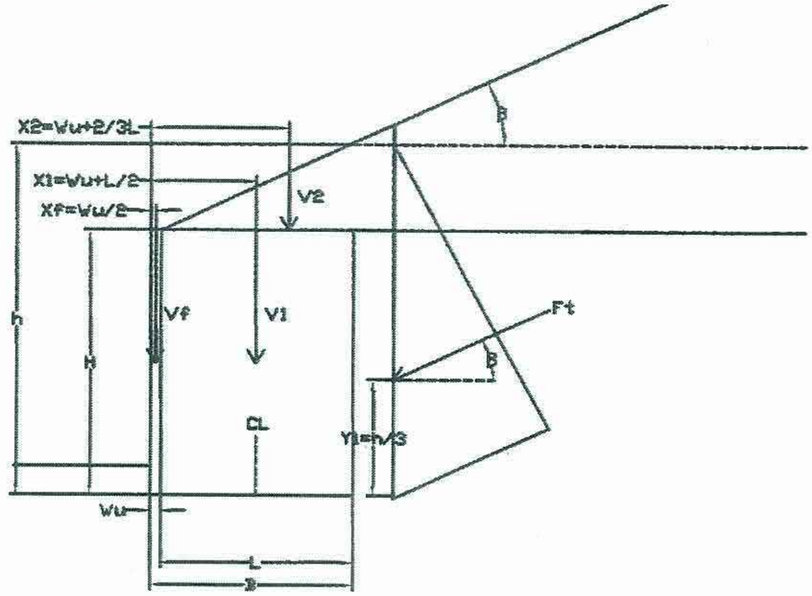
Sliding Capacity Demand Ratio

$$CDRsl' = RFsl \times \frac{RF}{DF} = 1.00 \times \frac{71874 \text{ plf}}{65682 \text{ plf}} = 1.09$$

CDRsl' = 1.09

External Stabilty Solution - External Failure Modes cont.





3) Check Overturning Failure Mode *AASHTO 11.6.3.3*

Determine Moment Arms

Y1 = h / 3 = 39.66 ft / 3 = 13.22 ft — **Y1 = 13.22 ft**

Xf = Wu / 2 = 1.00 ft / 2 = 0.50 ft — **Xf = 0.50 ft**

X1 = Wu + L / 2 = 1.00 ft + 20.00 ft / 2 = 11.00 ft — **X1 = 11.00 ft**

X2 = Wu + (2 / 3) x L = 1.00 ft + (2 / 3) x 20.00 ft = 14.33 ft — **X2 = 14.33 ft**

Overturning Moment, OM

OM = EHd x Ftx x Y1

OM = 1.50 x 45298 plf x 13.22 ft = 898364.2 ft-lb/ft — **OM = 898364.2 ft-lb/ft**

Resisting Moment, RM

RM = EVr x (Vf x Xf + V1 x X1 + V2 x X2)
+ EHd x Fty x B

RM = 1.00 x (3560 plf x 0.50 ft + 71200 plf x 11.00 ft + 11997 plf x 14.33 ft)
+ 1.50 x 22644 plf x 21.00 ft

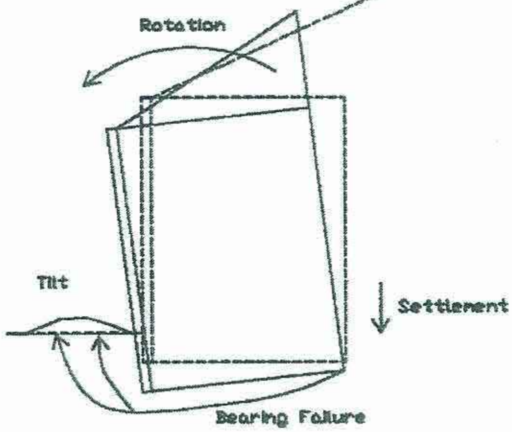
RM = 1670231 ft-lb/ft — **RM = 1670231 ft-lb/ft**

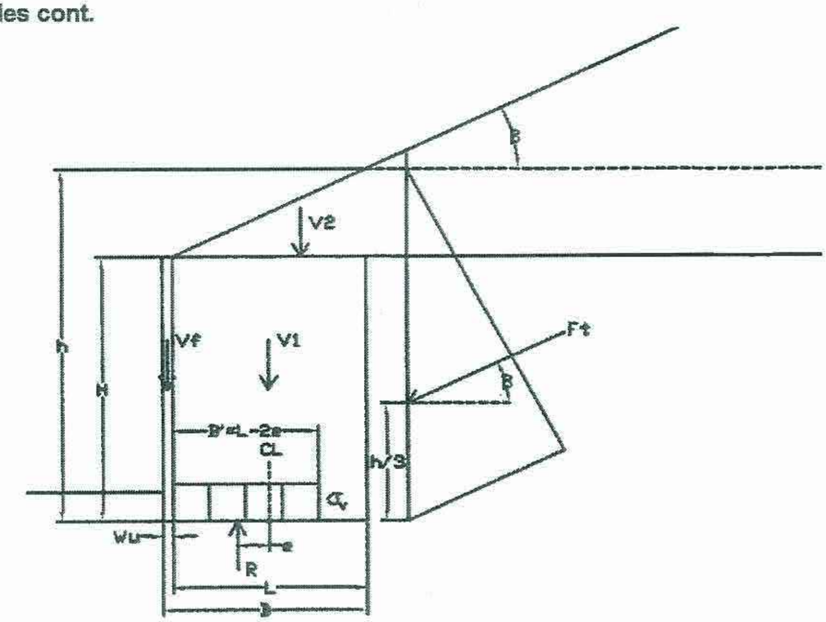
Overturning Capacity Demand Ratio

$$CDRot = \frac{RM}{OM} = \frac{1670231 \text{ ft-lb/ft}}{898364 \text{ ft-lb/ft}} = 1.86$$

CDRot = 1.86

External Stabilty Solution - External Failure Modes cont.





4) Check Bearing Failure Mode　　*AASHTO 11.10.5.4*

Calculate the Applied Bearing Pressure for each of the 3 cases listed below:

Case 1　Use Resisting Factors, except in Overturning Moment Calculation
Case 2　Use Driving Factors
Case 3　Actual Bearing Pressure

Find the Resisting Moments for each case, RM

Case 1
RM = EVr x (MVf + MV1 + MV2) + EHd x MFty
RM = 1.00 x (1780 ft-lb/ft + 783200 ft-lb/ft + 171962 ft-lb/ft) + 1.50 x 475526 ft-lb/ft
RM = 1670231 ft-lb/ft

Case 2
RM = EVd x (MVf + MV1 + MV2) + EHd x MFty
RM = 1.35 x (1780 ft-lb/ft + 783200 ft-lb/ft + 171962 ft-lb/ft) + 1.50 x 475526 ft-lb/ft
RM = 2005161 ft-lb/ft

Case 3
RM = MVf + MV1 + MV2 + MFty
RM = 1780 ft-lb/ft + 783200 ft-lb/ft + 171962 ft-lb/ft + 475526 ft-lb/ft
RM = 1432468 ft-lb/ft

Find the Overturning Moments for each case, OM

Case 1
OM = EHd x MFtx
OM = 1.50 x 598909 ft-lb/ft
OM = 898364.2 ft-lb/ft

Case 2
OM = EHd x MFtx
OM = 1.50 x 598909 ft-lb/ft
OM = 898364.2 ft-lb/ft

Case 3
OM = MFtx
OM = 598909.4 ft-lb/ft

External Stabilty Solution - External Failure Modes cont.

Find the Vertical Force for each case, R

Case 1

R = EVr x (Vf + V1 + V2) + EHd x Fty

R = 1.00 x (3560 plf + 71200 plf + 11997 plf) + 1.50 x 22644 plf

R = 120724 plf

Case 2

R = EVd x (Vf + V1 + V2) + EHd x Fty

R = 1.35 x (3560 plf + 71200 plf + 11997 plf) + 1.50 x 22644 plf

R = 151089 plf

Case 3

R = Vf + V1 + V2 + Fty

R = 3560 plf + 71200 plf + 11997 plf + 22644 plf

R = 109401 plf

Find the Eccentricity for each Case, e, and check Eccentricity is less than B/4 *AASHTO 10.6.3.3*

	(ft)		(ft-lb/ft)		(ft-lb/ft)		(plf)		(ft)		(ft)		(ft)	
Case #	B	/ 2 - (	RM	-	OM	) /	R	=	e		B	/ 4 =	B/4	OK?
Case 1	21.00	/ 2 - (	1670231	-	898364.2	) /	120724	=	4.11	<	21.00	/ 4 =	5.25	OK
Case 2	21.00	/ 2 - (	2005161	-	898364.2	) /	151089	=	3.17	<	21.00	/ 4 =	5.25	OK
Case 3	21.00	/ 2 - (	1432468	-	598909.4	) /	109401	=	2.88	<	21.00	/ 4 =	5.25	OK

Find the Effective Base Length for each Case, B'

	(ft)		(ft)		(ft)
Case #	B	- 2 x	e	=	B'
Case 1	21.00	- 2 x	4.11	=	12.79
Case 2	21.00	- 2 x	3.17	=	14.65
Case 3	21.00	- 2 x	2.88	=	15.24

Determine the Applied Bearing Pressure for each Case, sigmav

	(plf)		(ft)		(psf)
Case #	R	/	B'	=	sigmav
Case 1	120724	/	12.79	=	9441
Case 2	151089	/	14.65	=	10313
Case 3	109401	/	15.24	=	7179

Case 2 yields the Maximum Applied Bearing Pressure

sigmav = 10313 psf

Determine the Ultimate Bearing Capacity, qult (Thru Vesic)

	COHESION			SURCHARGE						SOIL WEIGHT				
qult =	c	x Nc	+	gammaf	x	D	x	Nq	+ 0.5 x (	gammaf	x	B'	x	Ng)
qult =	0 psf	x 30.14	+	120 pcf	x	3.00 ft	x	18.40	+ 0.5 x (	120 pcf	x	14.65 ft	x	22.40)

qult = 26317 psf

qult = 26317 psf

Bearing Capacity Demand Ratio

$$CDRb = RFb \times \frac{qult}{sigmav} = 0.65 \times \frac{26317 \text{ psf}}{10313 \text{ psf}} = 1.66$$

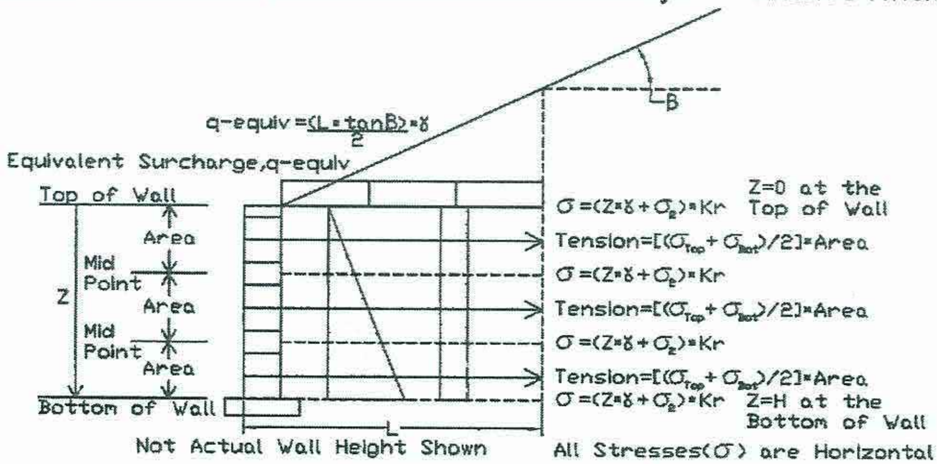
CDRb = 1.66

Internal Stabilty Solution - Summary of Intermediate Tension, Connection, Pullout, and Shear Calculations

Layer	Zn (ft)	Zb (ft)	Zt (ft)	Area (ft-ft)	q-equiv (psf)	sigmaT (psf)	sigmaB (psf)	Tmax (plf)	Reinf. Type	Tult (plf)	Tal (plf)	Ta (plf)	N (plf)	Tc-ult (plf)	Tc (plf)	Tsc (plf)
1	1.00	2.00	0.00	2.00	600	229	321	549	3XT	3500	1585	1427	120	1035	704	NA
2	3.00	4.00	2.00	2.00	600	321	412	733	3XT	3500	1585	1427	360	1275	868	NA
3	5.00	6.00	4.00	2.00	600	412	504	916	3XT	3500	1585	1427	600	1515	1031	NA
4	7.00	8.00	6.00	2.00	600	504	595	1099	3XT	3500	1585	1427	840	1755	1194	NA
5	9.00	10.00	8.00	2.00	600	595	687	1282	3XT	3500	1585	1427	1080	1992	1356	NA
6	11.00	11.67	10.00	1.67	600	687	763	1209	3XT	3500	1585	1427	1320	2109	1435	NA
7	12.33	13.00	11.67	1.33	600	763	824	1058	3XT	3500	1585	1427	1480	2187	1488	NA
8	13.67	14.33	13.00	1.33	600	824	885	1140	3XT	3500	1585	1427	1640	2265	1541	NA
9	15.00	15.67	14.33	1.33	600	885	946	1221	3XT	3500	1585	1427	1800	2343	1595	NA
10	16.33	17.00	15.67	1.33	600	946	1008	1303	3XT	3500	1585	1427	1960	2421	1648	NA
11	17.67	18.33	17.00	1.33	600	1008	1069	1384	3XT	3500	1585	1427	2120	2499	1701	NA
12	19.00	19.67	18.33	1.33	600	1069	1130	1466	7XT	5900	2788	2509	2280	2581	1757	NA
13	20.33	21.00	19.67	1.33	600	1130	1191	1547	7XT	5900	2788	2509	2440	2679	1823	NA
14	21.67	22.33	21.00	1.33	600	1191	1252	1628	7XT	5900	2788	2509	2600	2776	1889	NA
15	23.00	23.67	22.33	1.33	600	1252	1313	1710	7XT	5900	2788	2509	2760	2873	1955	NA
16	24.33	25.00	23.67	1.33	600	1313	1374	1791	7XT	5900	2788	2509	2920	2971	2022	NA
17	25.67	26.33	25.00	1.33	600	1374	1435	1873	7XT	5900	2788	2509	3080	3068	2088	NA
18	27.00	27.67	26.33	1.33	600	1435	1496	1954	7XT	5900	2788	2509	3240	3165	2154	NA
19	28.33	28.67	27.67	1.00	600	1496	1542	1519	7XT	5900	2788	2509	3400	3256	2216	NA
20	29.00	29.67	28.67	1.00	600	1542	1588	1565	7XT	5900	2788	2509	3480	3256	2216	NA

Layer	La (ft)	Le (ft)	MinLe (ft)	OK?	Zp (ft)	N (plf)	F*	Tpo (plf)	CDRpo	N (plf)	Va (plf)	sigmaV (psf)	Area (ft-ft)	Vmax (plf)	CDRsh
1	15.24	4.76	3.00	OK	9.809	5600	0.6	6051	11.01	120	1317	254	1.00	254	5.18
2	14.18	5.82	3.00	OK	11.54	8063	0.6	8713	11.89	360	1450	343	1.00	343	4.22
3	13.12	6.88	3.00	OK	13.28	10969	0.6	11852	12.94	600	1583	435	1.00	435	3.64
4	12.05	7.95	3.00	OK	15.01	14317	0.6	15470	14.08	840	1716	527	1.00	527	3.26
5	10.99	9.01	3.00	OK	16.75	18108	0.6	19567	15.26	1080	1849	618	1.00	618	2.99
6	9.93	10.07	3.00	OK	18.48	22341	0.6	24141	19.98	1320	1982	710	1.00	710	2.79
7	9.22	10.78	3.00	OK	19.64	25410	0.6	27457	25.94	1480	2070	779	0.67	519	3.99
8	8.51	11.49	3.00	OK	20.79	28675	0.6	30985	27.18	1640	2159	840	0.67	560	3.86
9	7.80	12.20	3.00	OK	21.95	32136	0.6	34725	28.43	1800	2248	901	0.67	600	3.74
10	7.09	12.91	3.00	OK	23.1	35795	0.6	38678	29.69	1960	2336	962	0.67	641	3.64
11	6.38	13.62	3.00	OK	24.26	39650	0.6	42844	30.95	2120	2425	1023	0.67	682	3.56
12	5.67	14.33	3.00	OK	25.42	43701	0.6	47222	32.22	2280	2514	1084	0.67	723	3.48
13	4.96	15.04	3.00	OK	26.57	47950	0.6	51813	33.49	2440	2603	1145	0.67	763	3.41
14	4.25	15.75	3.00	OK	27.73	52395	0.6	56616	34.77	2600	2691	1206	0.67	804	3.35
15	3.54	16.46	3.00	OK	28.88	57037	0.6	61632	36.05	2760	2780	1267	0.67	845	3.29
16	2.84	17.16	3.00	OK	30.04	61876	0.6	66861	37.33	2920	2869	1328	0.67	885	3.24
17	2.13	17.87	3.00	OK	31.2	66911	0.6	72302	38.61	3080	2957	1389	0.67	926	3.19
18	1.42	18.58	3.00	OK	32.35	72143	0.6	77955	39.89	3240	3046	1450	0.67	967	3.15
19	0.71	19.29	3.00	OK	33.51	77572	0.6	83821	55.18	3400	3135	1511	0.67	1008	3.11
20	0.35	19.65	3.00	OK	34.09	80360	0.6	86834	55.49	3480	3179	1550	0.33	517	6.15

Internal Stabilty Solution - Calculation of Tension in each Reinforcement Layer *AASHTO 11.10.6.2.1*



Find the Bounds of the Applied Pressure, Zt and Zb

Layer																							
1	Zt	=	Zo =	0	ft																		
	Zb	= (	Zn	+ Zn+1	) /	2 = (	Z 1	+ Z 2	) /	2 = (	1.00	ft +	3.00	ft) /	2 =	2.00	ft						
10	Zt	= (	Zn	+ Zn-1	) /	2 = (	Z 10	+ Z 9	) /	2 = (	16.33	ft +	15.00	ft) /	2 =	15.67	ft						
	Zb	= (	Zn	+ Zn+1	) /	2 = (	Z 10	+ Z 11	) /	2 = (	16.33	ft +	17.67	ft) /	2 =	17.00	ft						
20	Zt	= (	Zn	+ Zn-1	) /	2 = (	Z 20	+ Z 19	) /	2 = (	29.00	ft +	28.33	ft) /	2 =	28.67	ft						
	Zb	=	H =	29.67	ft																		

Find the Area of the Applied Pressure

	(ft)		(ft)		(ft-ft)
Layer	Zb	-	Zt	=	Area
1	2.00	-	0.00	=	2.00
10	17.00	-	15.67	=	1.33
20	29.67	-	28.67	=	1.00

Find the Equivalent Surcharge, q-equiv.

			(ft)					(pcf)
q-equiv. =	0.5	x	L	x tan (	beta	)	x	gammab
q-equiv. =	0.5	x	20.00	x tan (	26.6	)	x	120
q-equiv. =	600	psf						

Find the Applied Pressure at the Bounds, sigmat and sigmab

			(ft)		(pcf)		(psf)					(psf)
Layer	EVd	x (	Zt	x	gammar	+	q-equiv.	)	x	Kr	=	sigmat
1	1.35	x (	0.00	x	120	+	600	)	x	0.283	=	229
10	1.35	x (	15.67	x	120	+	600	)	x	0.283	=	946
20	1.35	x (	28.67	x	120	+	600	)	x	0.283	=	1542

			(ft)		(pcf)		(psf)					(psf)
Layer	EVd	x (	Zb	x	gammar	+	q-equiv.	)	x	Kr	=	sigmab
1	1.35	x (	2.00	x	120	+	600	)	x	0.283	=	321
10	1.35	x (	17.00	x	120	+	600	)	x	0.283	=	1008
20	1.35	x (	29.67	x	120	+	600	)	x	0.283	=	1588

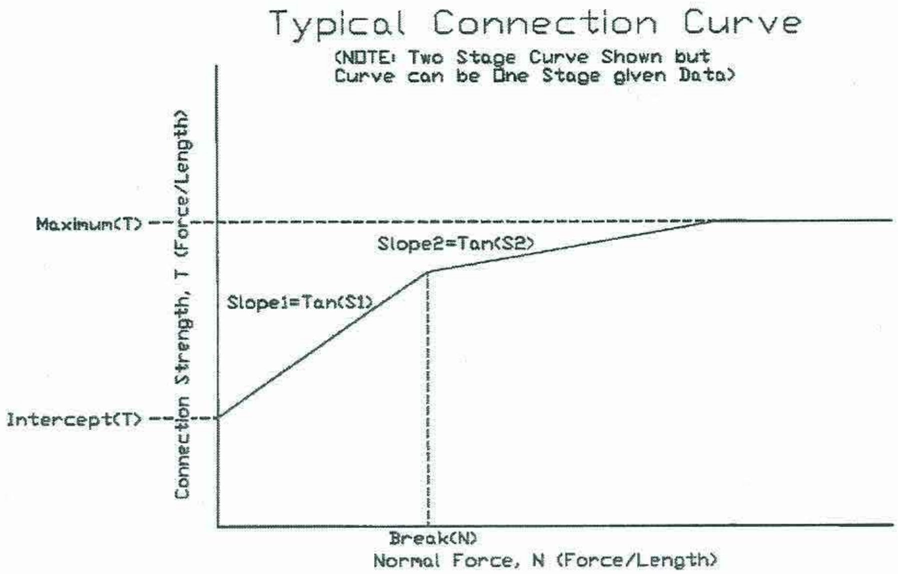
Determine the Tension, Tmax

			(psf)		(psf)					(ft-ft)		(plf)
Layer	[	(	sigmat	+	sigmab	) /	2]	x		Area	=	Tmax
1	[	(	229	+	321	) /	2]	x		2.00	=	549
10	[	(	946	+	1008	) /	2]	x		1.33	=	1303
20	[	(	1542	+	1588	) /	2]	x		1.00	=	1565

Internal Stabilty Solution - Calculation of Tensile Strength and Connection Strength *AASHTO 11.10.6.4.1*

Allowable Tensile Strength, Ta

Layer	Reinf. Type	(plf) Tult	/ (	RFcr	x	RFd	x	RFid	) =	(plf) Tal	RFt	x	(plf) Tal	=	(plf) Ta
1	3XT	3500	/ (	1.60	x	1.15	x	1.20	) =	1585	0.90	x	1585	=	1427
10	3XT	3500	/ (	1.60	x	1.15	x	1.20	) =	1585	0.90	x	1585	=	1427
20	7XT	5900	/ (	1.60	x	1.15	x	1.15	) =	2788	0.90	x	2788	=	2509



Connection Strength, Tc

Find Normal Force, N

Layer	(ft) Wu	x	(ft) Zn	x	(pcf) gammau	=	(plf) N
1	1.00	x	1.00	x	120	=	120
10	1.00	x	16.33	x	120	=	1960
20	1.00	x	29.00	x	120	=	3480

Find the appropriate Connection Strength Equation to use based on the Normal Force, N

If N < Break(N) T = Inter.(T) + N x tan S1 Eq1

If N > Break(N) T = Inter.(T) + Break(N) x tan S1 + (N - Break(N)) x tan S2 if T > Max(T), T = Max(T) Eq2

Layer	Reinf. Type		(plf) N		(plf) Break(N)		Eq#		(plf) N		(plf) Break(N)		Eq#
1	3XT	Tc-ult	120	<	1074	use	Eq1	Tsc	120	<	888	use	Eq1
10	3XT	Tc-ult	1960	>	1074	use	Eq2	Tsc	1960	>	888	use	Eq2
20	7XT	Tc-ult	3480	>	1000	use	Eq2	Tsc	3480	>	1265	use	Eq2

Internal Stabilty Solution - Calculation of Tensile Strength and Connection Strength cont.

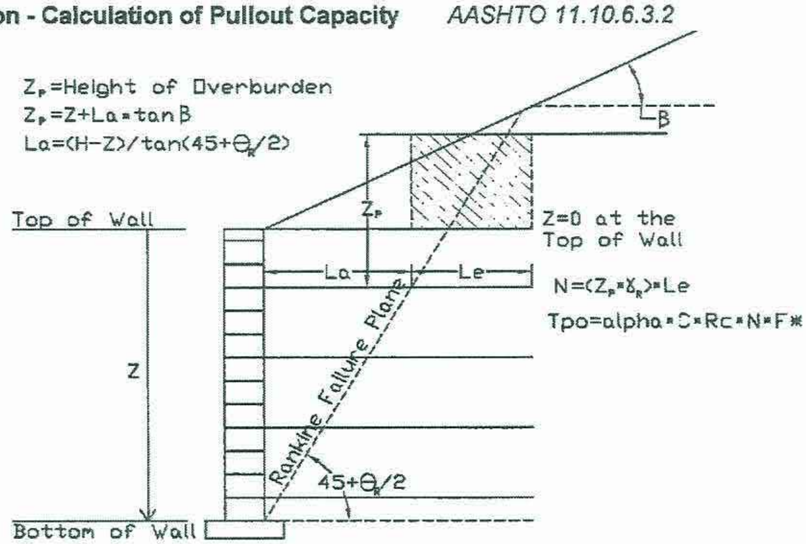
Find the Ultimate Connection Strength, Tc-ult

Layer		(plf)		(plf)					(plf)		(plf)				
1	Tc-ult =	Inter.(T)	+	N	x	tan	S1								
	Tc-ult =	915	+	120.0	x	tan	45								
	Tc-ult =	1035	plf												
		(plf)		(plf)					(plf)		(plf)				
10	Tc-ult =	Inter.(T)	+	Break(N)	x	tan	S1	+ (	N	-	Break(N)	)	x	tan	S2
	Tc-ult =	915	+	1074	x	tan	45	+ (	1960	-	1074	)	x	tan	26
	Tc-ult =	2421	plf	< Max(T) =		2571		plf							
		(plf)		(plf)					(plf)		(plf)				
20	Tc-ult =	Inter.(T)	+	Break(N)	x	tan	S1	+ (	N	-	Break(N)	)	x	tan	S2
	Tc-ult =	764	+	1000	x	tan	46.1	+ (	3480	-	1000	)	x	tan	31.3
	Tc-ult =	3311	plf	> Max(T) =		3256		plf	use Max(T)						

Determine the Peak Connection Strength, Tc *AASHTO C11.10.6.4.4b*

Layer	RFt	x	Tc-ult (plf)	/ (	RFcn-d	x	RFcn-cr	) =	Tc (plf)
1	0.90	x	1035	/ (	1.15	x	1.15	) =	704
10	0.90	x	2421	/ (	1.15	x	1.15	) =	1648
20	0.90	x	3256	/ (	1.15	x	1.15	) =	2216

Internal Stabilty Solution - Calculation of Pullout Capacity *AASHTO 11.10.6.3.2*



Not Actual Wall Height Shown

Find the Embedment Length, Le

Layer	(	(ft) H	-	(ft) Zn	) / tan (	45	+	phir	/ 2) =	(ft) La	(ft) L	-	(ft) La	=	(ft) Le		(ft) MinLe	
1	(	29.67	-	1.00	) / tan (	45	+	34	/ 2) =	15.242	20.00	-	15.242	=	4.76	>	3.00	OK
10	(	29.67	-	16.33	) / tan (	45	+	34	/ 2) =	7.0895	20.00	-	7.0895	=	12.91	>	3.00	OK
20	(	29.67	-	29.00	) / tan (	45	+	34	/ 2) =	0.3545	20.00	-	0.3545	=	19.65	>	3.00	OK

Find the Overburden Height, Zp

Layer	(ft) Zn	+ [(	(ft) La	x tan (	beta	) + (	(ft) h	-	(ft) H	)] / 2 =	(ft) Zp
1	1.00	+ [(	15.24	x tan (	26.6	) + (	39.66	-	29.67	)] / 2 =	9.81
10	16.33	+ [(	7.09	x tan (	26.6	) + (	39.66	-	29.67	)] / 2 =	23.10
20	29.00	+ [(	0.35	x tan (	26.6	) + (	39.66	-	29.67	)] / 2 =	34.09

Find the Normal Force, N

Layer	(	(ft) Zp	-	(ft) Zn	) x	(pcf) gammab	+	(ft) Zn	x	(pcf) gammar	) x	(ft) Le	=	(plf) N
1	(	9.81	-	1.00	) x	120	+	1.00	x	120	) x	4.76	=	5600
10	(	23.10	-	16.33	) x	120	+	16.33	x	120	) x	12.91	=	35795
20	(	34.09	-	29.00	) x	120	+	29.00	x	120	) x	19.65	=	80360

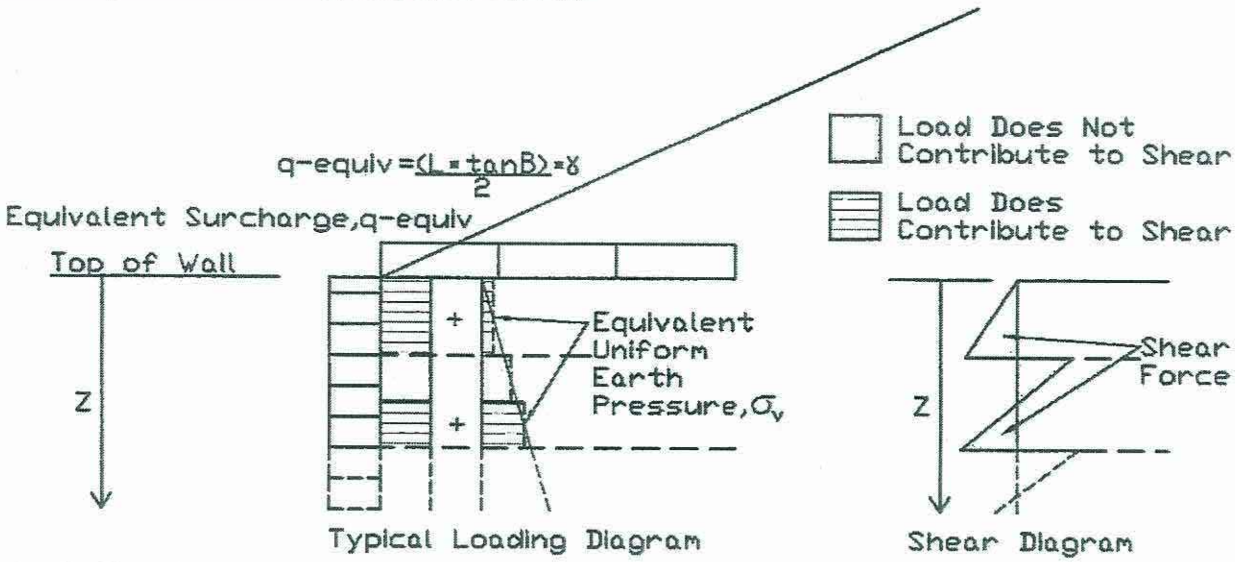
Find the Soil/Reinforcement Friction Factor, F*

Layer	Reinf. Type	Ci	x tan (	phir	) =	F*
1	3XT	0.89	x tan (	34	) =	0.600
10	3XT	0.89	x tan (	34	) =	0.600
20	7XT	0.89	x tan (	34	) =	0.600

Determine the Pullout Capacity, Tpo and the Pullout Capacity Demand Ratio, CDRpo

Layer	alpha	x	C	x	Rc	x	(plf) N	x	F*	x	RFpo =	(plf) Tpo	(plf) Tpo	/	(plf) Tmax	=	CDRpo
1	1.00	x	2.0	x	1.0	x	5600	x	0.6003	x	0.90 =	6051	6051	/	549	=	11.01
10	1.00	x	2.0	x	1.0	x	35795	x	0.6003	x	0.90 =	38678	38678	/	1303	=	29.69
20	1.00	x	2.0	x	1.0	x	80360	x	0.6003	x	0.90 =	86834	86834	/	1565	=	55.49

Internal Stabilty Solution - Calculation of Shear Capacity



Determine the Shear Strength, Va (Note:Use Normal Force from Connection Strength Calculation)

			(plf)					(plf)		(plf)
Layer	EVr	x	N	x	tan	29	+	1250	=	Va
1	1.00	x	120	x	tan	29	+	1250	=	1317
10	1.00	x	1960	x	tan	29	+	1250	=	2336
20	1.00	x	3480	x	tan	29	+	1250	=	3179

Find the Equivalent Earth Pressure that Contributes to Shear, sigmaV

Layer

1 sigmaV = (EVd x q-equiv. (psf) + EHd x 0.5 x (Z 1 (ft) x gammar (pcf))) x Kr
sigmaV = (1.35 x 600 + 1.50 x 0.5 x (1.00 x 120)) x 0.283
sigmaV = 254 psf

10 sigmaV = (EVd x q-equiv. (psf) + EVd x ((Z 9 (ft) + 0.75 x (Z 10 (ft) - Z 9 (ft))) x gammar (pcf))) x Kr
sigmaV = (1.35 x 600 + 1.35 x ((15.00 + 0.75 x (16.33 - 15.00)) x 120)) x 0.283
sigmaV = 962 psf

20 sigmaV = (EVd x q-eqiv. (psf) + EVd x ((Z 19 (ft) + 0.75 x (Z 20 (ft) - Z 19 (ft))) x gammar (pcf))) x Kr
sigmaV = (1.35 x 600 + 1.35 x ((28.33 + 0.75 x (29.00 - 28.33)) x 120)) x 0.283
sigmaV = 1550 psf

Find the Area of Applied Pressure

Layer			(ft)		(ft)				(ft)		(ft)					(ft)		(ft)				(ft-ft)
1	Area	= (	Zn	-	Zn-1	) / 2	= (	Z	1	- Z	0	)			= (	1.00	-	0	)		=	1.00
10	Area	= (	Zn	-	Zn-1	) / 2	= (	Z	10	- Z	9	)	/	2	= (	16.33	-	15.00	)	/ 2	=	0.67
20	Area	= (	Zn	-	Zn-1	) / 2	= (	Z	20	- Z	19	)	/	2	= (	29.00	-	28.33	)	/ 2	=	0.33

Determine the Shear Stress, Vmax and the Shear Capacity Demand Ratio, CDRsh

	(psf)		(ft-ft)		(plf)	(plf)		(plf)		
Layer	sigmaV	x	Area	=	Vmax	Va	/	Vmax	=	CDRsh
1	254	x	1.00	=	254	1317	/	254	=	5.18
10	962	x	0.67	=	641	2336	/	641	=	3.64
20	1550	x	0.33	=	517	3179	/	517	=	6.15

AASHTO 2007-2010 (LRFD)
KeySystem II HITEC Example 2

MSEW(3.0): Update # 13.0

PROJECT IDENTIFICATION

Title:	KeySystem II HITEC Example 2
Project Number:	
Client:	
Designer:	JMF
Station Number:	

Description:

Company's information:

Name: Keystone Retaining Wall Systems
Street: 4444 West 78th Street

Bloomington, MN 55435
Telephone #: 952-897-1040
Fax #:
E-Mail:

Original file path and name: C:\Program Files\ADAMA\MSEW(3.0)\Keysystem II hitec pro.....
..... II hitec prob 2.BEN

Original date and time of creating this file: Mon Apr 12 08:24:41 2010

PROGRAM MODE: ANALYSIS
of a SIMPLE STRUCTURE
using GEOGRID as reinforcing material.

SOIL DATA

REINFORCED SOIL

Unit weight, γ	120.0 lb/ft³
Design value of internal angle of friction, ϕ	34.0 °

RETAINED SOIL

Unit weight, γ	120.0 lb/ft³
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/ft³
Equivalent internal angle of friction, $\phi_{equiv.}$	30.0 °
Equivalent cohesion, $c_{equiv.}$	0.0 lb/ft²

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) = 0.5365 (if batter is less than 10°, Ka is calculated from eq. 16. Otherwise, eq. 17 is utilized)

BEARING CAPACITY

Bearing capacity coefficients (calculated by MSEW): Nc = 30.14 N γ= 22.40

SEISMICITY

Not Applicable

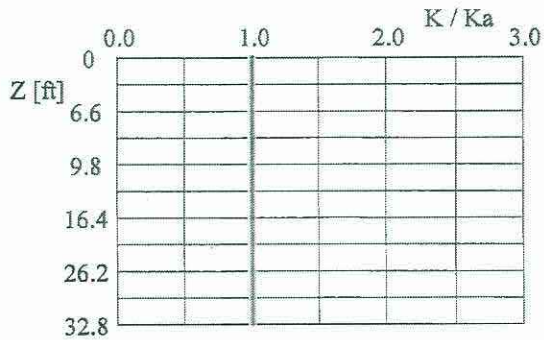
INPUT DATA: Geogrids
(Analysis)

D A T A	Geogrid type #1	Geogrid type #2	Geogrid type #3	Geogrid type #4	Geogrid type #5
Tult [lb/ft]	3500.0	5900.0			
Durability reduction factor, RFd	1.15	1.15			
Installation-damage reduction factor, RFid	1.20	1.15			
Creep reduction factor, RFc	1.60	1.60	N/A	N/A	N/A
CDR for strength	N/A	N/A			
Coverage ratio, Rc	1.000	1.000			
Friction angle along geogrid-soil interface, ρ	30.96	30.96			
Pullout resistance factor, F*	0.89·tanϕ	0.89·tanϕ	N/A	N/A	N/A
Scale-effect correction factor, α	1.0	1.0			

Note: Z for calculating K/Ka and F* is measured from top of the wall at the face (AASHTO).

Variation of Lateral Earth Pressure Coefficient With Depth

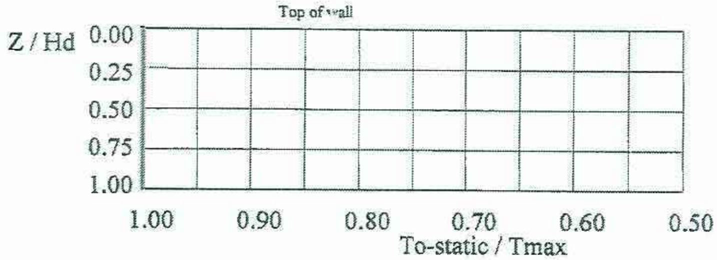
Z	K / Ka
0 ft	1.00
3.3 ft	1.00
6.6 ft	1.00
9.8 ft	1.00
13.1 ft	1.00
16.4 ft	1.00
19.7 ft	1.00



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 1.00/0.67 ft. Horizontal distance to Center of Gravity of block is 0.50 ft.
Average unit weight of block is $\gamma_f = 120.00$ 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



Geogrid Type #1		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
σ [1]	CRult [2]	σ	CRult	σ	CRult	σ	CRult	σ	CRult
0.0	0.26	0.0	0.13	N/A		N/A		N/A	
1000.0	0.55	1000.0	0.33						
2270.0	0.73	3425.0	0.59						
		6000.0	0.59						

Geogrid Type #1 [3]		Geogrid Type #2		Geogrid Type #3		Geogrid Type #4		Geogrid Type #5	
σ	CRcr	σ	CRcr	σ	CRcr	σ	CRcr	σ	CRcr
0.0	0.23	0.0	0.11	N/A		N/A		N/A	
1000.0	0.48	1000.0	0.27						
2270.0	0.64	3425.0	0.48						
		6000.0	0.48						

(1) σ = Confining stress in between stacked blocks [lb/ft ^{2}]
(2) CRult = Tc-ult / Tult
(3) CRcr = Tcre / Tult

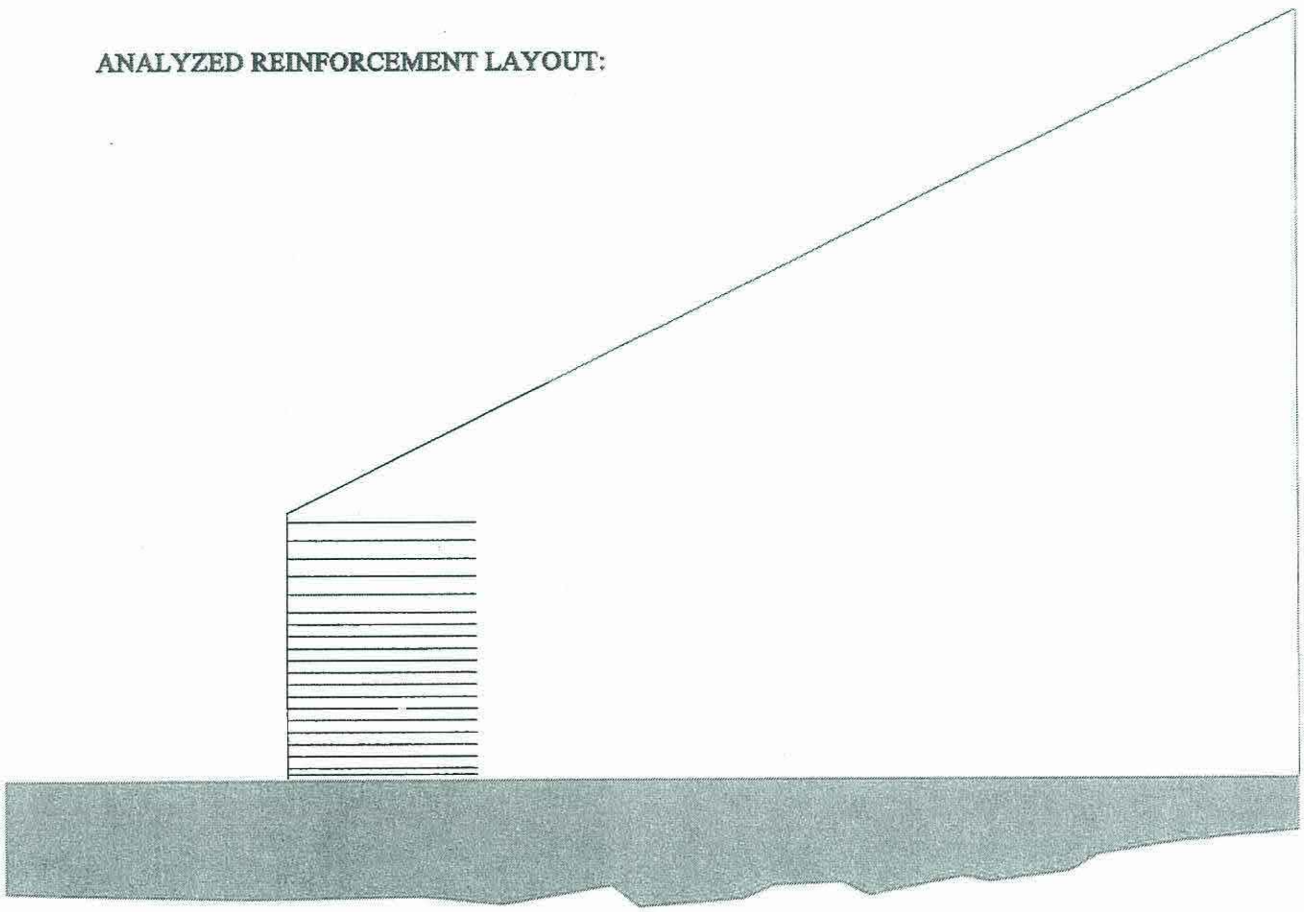
D A T A (for connection only)	Type #1	Type #2	Type #3	Type #4	Type #5
Product Name	Miragrid ..	Miragrid ..	N/A	N/A	N/A
Connection strength reduction factor, RFd	1.15	1.15	N/A	N/A	N/A
Creep reduction factor, RFc	N/A	N/A	N/A	N/A	N/A

INPUT DATA: Geometry and Surcharge loads (of a SIMPLE STRUCTURE)

Design height, Hd	29.67	[ft]	{ Embedded depth is E = 0.00 ft, and height above top of finished bottom grade is H = 29.67 ft }
Batter, ω	0.0	[deg]	
Backslope, β	26.6	[deg]	
Backslope rise	200.0	[ft]	Broken back equivalent angle, I = 26.56° (see Fig. 25 in DEMO 82)

UNIFORM SURCHARGE
Uniformly distributed dead load is 0.0 [lb/ft ²]

ANALYZED REINFORCEMENT LAYOUT:



SCALE:

0 2 4 6 8 10[ft]

AASHTO 2007-2010 (LRFD) Input Data

INTERNAL STABILITY

Load factor for vertical earth pressure, EV, from Table 3.4.1-2:	$\gamma_{p\text{-}EV}$	1.35	
Load factor for earthquake loads, EQ, from Table 3.4.1-1:	$\gamma_{p\text{-}EQ}$	1.00	
Load factor for live load surchrge, LS, from Figure C11.5.5-3(b): (Same as in External Stability).	$\gamma_{p\text{-}LS}$	1.75	
Load factor for dead load surchrge, ES: (Same as in External Stability).	$\gamma_{p\text{-}ES}$	1.75	
Resistance factor for reinforcement tension from Table 11.5.6-1:	ϕ	Static	Combined static/seismic
Geogrid:		0.90	1.20
Resistance factor for reinforcement tension in connectors from Table 11.5.6-1:	ϕ	Static	Combined static/seismic
Geogrid:		0.90	1.20
Resistance factor for reinforcement pullout from Table 11.5.6-1:	ϕ	0.90	1.20

EXTERNAL STABILITY

Load factor for vertical earth pressure, EV, from Table 3.4.1-2 and Figure C11.5.5-2:

		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, from Table 3.4.1-2 and Figure C11.5.5-2:	$\gamma_{p\text{-}EH}$	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, from Table 3.4.1-1 (multiplies P_{AE} and P_{IR}):	$\gamma_{p\text{-}EQ}$	1.00

Resistance factor for shear resistance along common interfaces from Table 10.5.5.2.2-1:

		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 from Table 10.5.5.2.2-1:

	Static	Combined Static/Seismic
ϕ_b	0.65	0.65

ANALYSIS: CALCULATED FACTORS (Static conditions)

Bearing capacity, CDR = 1.18, factor bearing load = 10647 lb/ft^2.

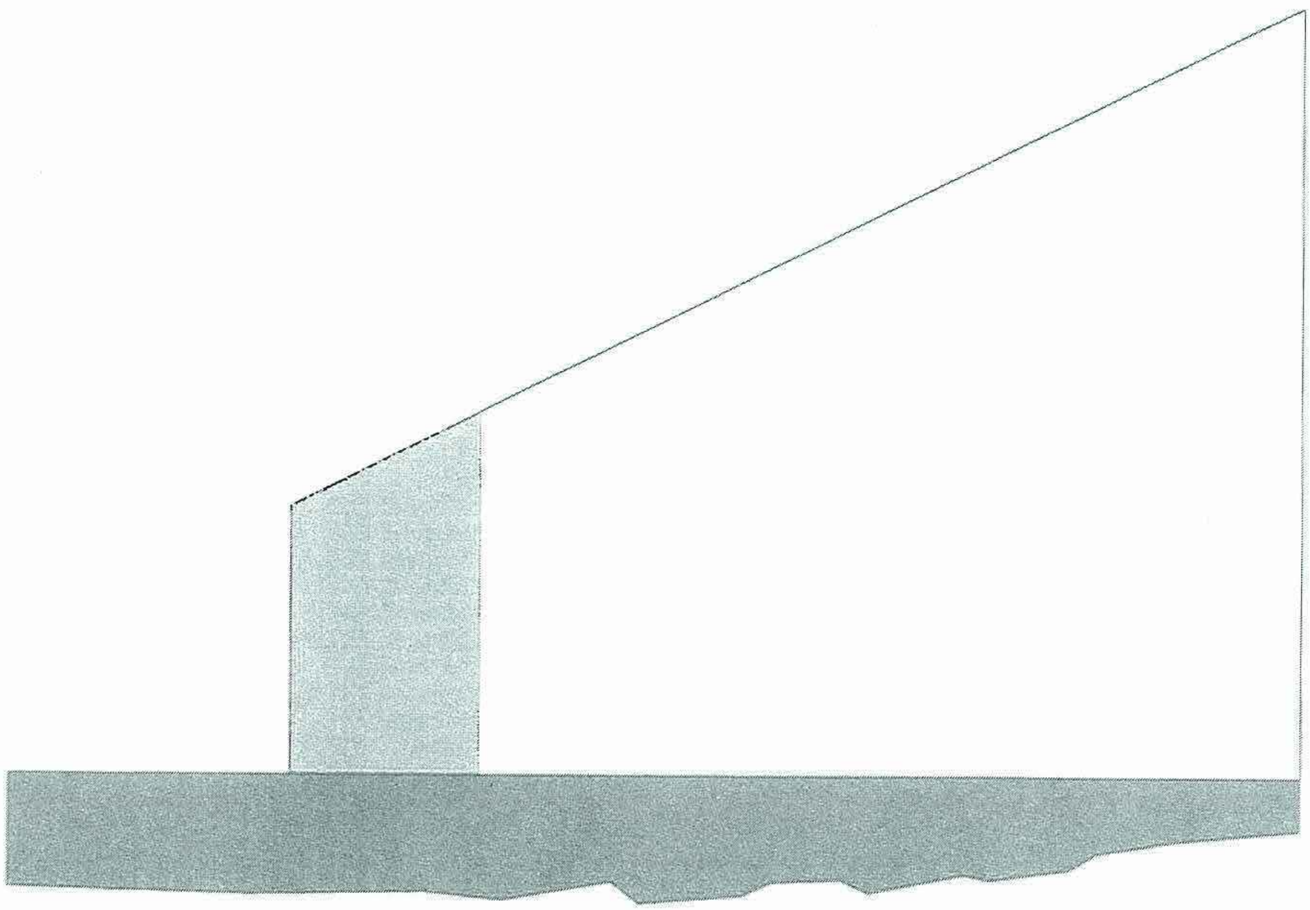
Foundation Interface: Direct sliding, CDR = 1.018, Eccentricity, e/L = 0.2020, CDR-overturning = 1.82

GEOGRID				CONNECTION						
#	Elevation [ft]	Length [ft]	Type #	CDR [connection strength]	CDR [geogrid strength]	Geogrid strength CDR	Pullout resistance CDR	Direct sliding CDR	Eccentricity e/L	Product name
1	0.67	21.00	2	1.41	1.59	1.595	58.359	1.068	0.1933	Miragrid 7XT
2	1.33	21.00	2	1.44	1.64	1.642	58.097	1.079	0.1849	Miragrid 7XT
3	2.67	21.00	2	1.09	1.27	1.275	42.012	1.103	0.1681	Miragrid 7XT
4	4.00	21.00	2	1.11	1.33	1.335	40.907	1.127	0.1517	Miragrid 7XT
5	5.33	21.00	2	1.12	1.39	1.390	39.500	1.153	0.1358	Miragrid 7XT
6	6.67	21.00	2	1.13	1.46	1.456	38.219	1.181	0.1200	Miragrid 7XT
7	8.00	21.00	2	1.15	1.53	1.534	37.111	1.211	0.1047	Miragrid 7XT
8	9.33	21.00	2	1.17	1.61	1.608	35.706	1.242	0.0898	Miragrid 7XT
9	10.67	21.00	2	1.19	1.70	1.696	34.463	1.275	0.0751	Miragrid 7XT
10	12.00	21.00	1	1.22	1.02	1.024	33.333	1.311	0.0608	Miragrid 3XT
11	13.33	21.00	1	1.25	1.08	1.084	31.985	1.349	0.0468	Miragrid 3XT
12	14.67	21.00	1	1.29	1.16	1.155	30.739	1.390	0.0329	Miragrid 3XT
13	16.00	21.00	1	1.34	1.24	1.242	29.647	1.434	0.0194	Miragrid 3XT
14	17.33	21.00	1	1.38	1.33	1.331	28.345	1.480	0.0060	Miragrid 3XT
15	18.67	21.00	1	1.16	1.16	1.164	21.922	1.531	-0.0075	Miragrid 3XT
16	20.67	21.00	1	1.03	1.10	1.097	16.950	1.612	-0.0278	Miragrid 3XT
17	22.67	21.00	1	1.08	1.28	1.278	15.828	1.700	-0.0490	Miragrid 3XT
18	24.67	21.00	1	1.12	1.53	1.528	14.800	1.794	-0.0724	Miragrid 3XT
19	26.67	21.00	1	1.17	1.90	1.901	13.880	1.885	-0.1005	Miragrid 3XT
20	28.67	21.00	1	1.26	2.52	2.516	13.212	1.955	-0.1392	Miragrid 3XT

BEARING CAPACITY for GIVEN LAYOUT

	STATIC	SEISMIC	UNITS
(Water table does not affect bearing capacity)			
Factored bearing resistance. q-n	12607	N/A	[lb/ft ²]
Factor bearing load, σ_V	10647.1	N/A	[lb/ft ²]
Eccentricity, e	3.29	N/A	[ft]
Eccentricity, e/L	0.156	N/A	
CDR calculated	1.18	N/A	
Base length	21.00	N/A	[ft]

Unfactored applied bearing pressure = (Unfactored R) / [L - 2 * (Unfactored e)] =
Unfactored R = 111217.74 [lb/ft], L = 21.00, Unfactored e = 2.98 [ft], and Sigma = 7398.66 [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 = 1.018

#	Geogrid Elevation [ft]	Geogrid Length [ft]	CDR Static	CDR Seismic	Geogrid Type #	Product name
1	0.67	21.00	1.068	N/A	2	Miragrid 7XT
2	1.33	21.00	1.079	N/A	2	Miragrid 7XT
3	2.67	21.00	1.103	N/A	2	Miragrid 7XT
4	4.00	21.00	1.127	N/A	2	Miragrid 7XT
5	5.33	21.00	1.153	N/A	2	Miragrid 7XT
6	6.67	21.00	1.181	N/A	2	Miragrid 7XT
7	8.00	21.00	1.211	N/A	2	Miragrid 7XT
8	9.33	21.00	1.242	N/A	2	Miragrid 7XT
9	10.67	21.00	1.275	N/A	2	Miragrid 7XT
10	12.00	21.00	1.311	N/A	1	Miragrid 3XT
11	13.33	21.00	1.349	N/A	1	Miragrid 3XT
12	14.67	21.00	1.390	N/A	1	Miragrid 3XT
13	16.00	21.00	1.434	N/A	1	Miragrid 3XT
14	17.33	21.00	1.480	N/A	1	Miragrid 3XT
15	18.67	21.00	1.531	N/A	1	Miragrid 3XT
16	20.67	21.00	1.612	N/A	1	Miragrid 3XT
17	22.67	21.00	1.700	N/A	1	Miragrid 3XT
18	24.67	21.00	1.794	N/A	1	Miragrid 3XT
19	26.67	21.00	1.885	N/A	1	Miragrid 3XT
20	28.67	21.00	1.955	N/A	1	Miragrid 3XT

ECCENTRICITY for GIVEN LAYOUT

At interface with foundation: e/L static = 0.2020; Overturning: CDR-static = 1.82

#	Geogrid Elevation [ft]	Geogrid Length [ft]	e / L Static	e / L Seismic	Geogrid Type #	Product name
1	0.67	21.00	0.1933	N/A	2	Miragrid 7XT
2	1.33	21.00	0.1849	N/A	2	Miragrid 7XT
3	2.67	21.00	0.1681	N/A	2	Miragrid 7XT
4	4.00	21.00	0.1517	N/A	2	Miragrid 7XT
5	5.33	21.00	0.1358	N/A	2	Miragrid 7XT
6	6.67	21.00	0.1200	N/A	2	Miragrid 7XT
7	8.00	21.00	0.1047	N/A	2	Miragrid 7XT
8	9.33	21.00	0.0898	N/A	2	Miragrid 7XT
9	10.67	21.00	0.0751	N/A	2	Miragrid 7XT
10	12.00	21.00	0.0608	N/A	1	Miragrid 3XT
11	13.33	21.00	0.0468	N/A	1	Miragrid 3XT
12	14.67	21.00	0.0329	N/A	1	Miragrid 3XT
13	16.00	21.00	0.0194	N/A	1	Miragrid 3XT
14	17.33	21.00	0.0060	N/A	1	Miragrid 3XT
15	18.67	21.00	-0.0075	N/A	1	Miragrid 3XT
16	20.67	21.00	-0.0278	N/A	1	Miragrid 3XT
17	22.67	21.00	-0.0490	N/A	1	Miragrid 3XT
18	24.67	21.00	-0.0724	N/A	1	Miragrid 3XT
19	26.67	21.00	-0.1005	N/A	1	Miragrid 3XT
20	28.67	21.00	-0.1392	N/A	1	Miragrid 3XT

RESULTS for STRENGTH Live Load included in calculating Tmax

#	Geogrid Elevation [ft]	Tavailable [lb/ft]	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	0.67	2509	1573.73	N/A	N/A	1.595	N/A	N/A	Miragrid 7XT
2	1.33	2509	1527.93	N/A	N/A	1.642	N/A	N/A	Miragrid 7XT
3	2.67	2509	1968.41	N/A	N/A	1.275	N/A	N/A	Miragrid 7XT
4	4.00	2509	1879.87	N/A	N/A	1.335	N/A	N/A	Miragrid 7XT
5	5.33	2509	1805.46	N/A	N/A	1.390	N/A	N/A	Miragrid 7XT
6	6.67	2509	1723.83	N/A	N/A	1.456	N/A	N/A	Miragrid 7XT
7	8.00	2509	1636.21	N/A	N/A	1.534	N/A	N/A	Miragrid 7XT
8	9.33	2509	1560.89	N/A	N/A	1.608	N/A	N/A	Miragrid 7XT
9	10.67	2509	1479.26	N/A	N/A	1.696	N/A	N/A	Miragrid 7XT
10	12.00	1427	1392.56	N/A	N/A	1.024	N/A	N/A	Miragrid 3XT
11	13.33	1427	1316.32	N/A	N/A	1.084	N/A	N/A	Miragrid 3XT
12	14.67	1427	1234.69	N/A	N/A	1.155	N/A	N/A	Miragrid 3XT
13	16.00	1427	1148.90	N/A	N/A	1.242	N/A	N/A	Miragrid 3XT
14	17.33	1427	1071.75	N/A	N/A	1.331	N/A	N/A	Miragrid 3XT
15	18.67	1427	1225.77	N/A	N/A	1.164	N/A	N/A	Miragrid 3XT
16	20.67	1427	1299.90	N/A	N/A	1.097	N/A	N/A	Miragrid 3XT
17	22.67	1427	1116.70	N/A	N/A	1.278	N/A	N/A	Miragrid 3XT
18	24.67	1427	933.50	N/A	N/A	1.528	N/A	N/A	Miragrid 3XT
19	26.67	1427	750.30	N/A	N/A	1.901	N/A	N/A	Miragrid 3XT
20	28.67	1427	567.10	N/A	N/A	2.516	N/A	N/A	Miragrid 3XT

RESULTS for PULLOUT Live Load included in calculating Tmax

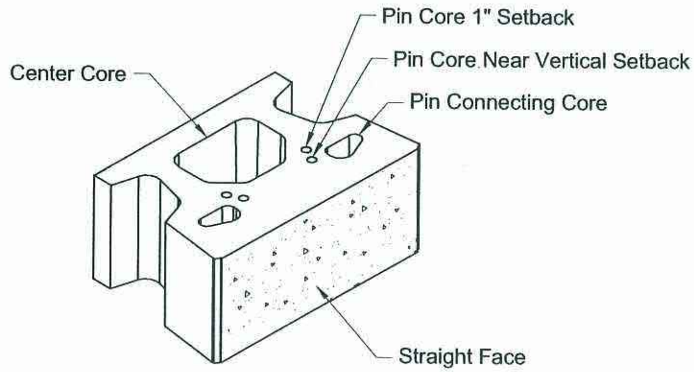
#	Geogrid Elevation [ft]	Coverage Ratio	Tmax [lb/ft]	Tmd [lb/ft]	Le [ft]	La [ft]	Avail.Static Pullout, Pr [lb/ft]	Specified Static CDR	Actual Static CDR	Avail.Seism. Pullout, Pr [lb/ft]	Specified Seismic CDR	Actual Seismic CDR
1	0.67	1.000	1573.7	N/A	20.64	0.36	91841.5	N/A	58.359	N/A	N/A	N/A
2	1.33	1.000	1527.9	N/A	20.29	0.71	88768.1	N/A	58.097	N/A	N/A	N/A
3	2.67	1.000	1968.4	N/A	19.58	1.42	82696.0	N/A	42.012	N/A	N/A	N/A
4	4.00	1.000	1879.9	N/A	18.87	2.13	76900.4	N/A	40.907	N/A	N/A	N/A
5	5.33	1.000	1805.5	N/A	18.17	2.83	71315.3	N/A	39.500	N/A	N/A	N/A
6	6.67	1.000	1723.8	N/A	17.45	3.55	65883.8	N/A	38.219	N/A	N/A	N/A
7	8.00	1.000	1636.2	N/A	16.75	4.25	60722.0	N/A	37.111	N/A	N/A	N/A
8	9.33	1.000	1560.9	N/A	16.04	4.96	55733.7	N/A	35.706	N/A	N/A	N/A
9	10.67	1.000	1479.3	N/A	15.33	5.67	50979.9	N/A	34.463	N/A	N/A	N/A
10	12.00	1.000	1392.6	N/A	14.62	6.38	46418.1	N/A	33.333	N/A	N/A	N/A
11	13.33	1.000	1316.3	N/A	13.91	7.09	42102.2	N/A	31.985	N/A	N/A	N/A
12	14.67	1.000	1234.7	N/A	13.20	7.80	37953.6	N/A	30.739	N/A	N/A	N/A
13	16.00	1.000	1148.9	N/A	12.49	8.51	34061.0	N/A	29.647	N/A	N/A	N/A
14	17.33	1.000	1071.7	N/A	11.79	9.21	30378.9	N/A	28.345	N/A	N/A	N/A
15	18.67	1.000	1225.8	N/A	11.07	9.93	26871.0	N/A	21.922	N/A	N/A	N/A
16	20.67	1.000	1299.9	N/A	10.01	10.99	22033.6	N/A	16.950	N/A	N/A	N/A
17	22.67	1.000	1116.7	N/A	8.95	12.05	17675.7	N/A	15.828	N/A	N/A	N/A
18	24.67	1.000	933.5	N/A	7.88	13.12	13815.8	N/A	14.800	N/A	N/A	N/A
19	26.67	1.000	750.3	N/A	6.82	14.18	10414.4	N/A	13.880	N/A	N/A	N/A
20	28.67	1.000	567.1	N/A	5.76	15.24	7492.4	N/A	13.212	N/A	N/A	N/A

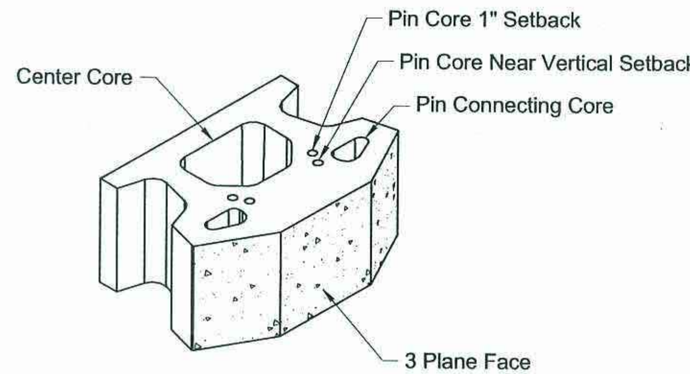
RESULTS for CONNECTION (static conditions)

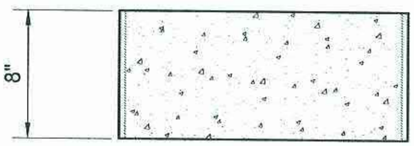
Live Load included in calculating Tmax

#	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	0.67	1574	0.59	0.48	2216	2788	N/A	1.41	N/A	1.59	Miragrid 7XT
2	1.33	1528	0.59	0.48	2207	2788	N/A	1.44	N/A	1.64	Miragrid 7XT
3	2.67	1968	0.57	0.46	2142	2788	N/A	1.09	N/A	1.27	Miragrid 7XT
4	4.00	1880	0.55	0.45	2079	2788	N/A	1.11	N/A	1.33	Miragrid 7XT
5	5.33	1805	0.54	0.44	2015	2788	N/A	1.12	N/A	1.39	Miragrid 7XT
6	6.67	1724	0.52	0.42	1950	2788	N/A	1.13	N/A	1.46	Miragrid 7XT
7	8.00	1636	0.50	0.41	1887	2788	N/A	1.15	N/A	1.53	Miragrid 7XT
8	9.33	1561	0.48	0.39	1823	2788	N/A	1.17	N/A	1.61	Miragrid 7XT
9	10.67	1479	0.47	0.38	1759	2788	N/A	1.19	N/A	1.70	Miragrid 7XT
10	12.00	1393	0.71	0.62	1701	1585	N/A	1.22	N/A	1.02	Miragrid 3XT
11	13.33	1316	0.69	0.60	1646	1585	N/A	1.25	N/A	1.08	Miragrid 3XT
12	14.67	1235	0.66	0.58	1591	1585	N/A	1.29	N/A	1.16	Miragrid 3XT
13	16.00	1149	0.64	0.56	1536	1585	N/A	1.34	N/A	1.24	Miragrid 3XT
14	17.33	1072	0.62	0.54	1481	1585	N/A	1.38	N/A	1.33	Miragrid 3XT
15	18.67	1226	0.60	0.52	1425	1585	N/A	1.16	N/A	1.16	Miragrid 3XT
16	20.67	1300	0.56	0.49	1342	1585	N/A	1.03	N/A	1.10	Miragrid 3XT
17	22.67	1117	0.50	0.44	1205	1585	N/A	1.08	N/A	1.28	Miragrid 3XT
18	24.67	934	0.43	0.38	1041	1585	N/A	1.12	N/A	1.53	Miragrid 3XT
19	26.67	750	0.36	0.32	877	1585	N/A	1.17	N/A	1.90	Miragrid 3XT
20	28.67	567	0.29	0.26	712	1585	N/A	1.26	N/A	2.52	Miragrid 3XT

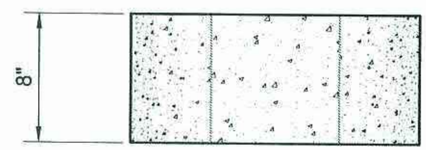
APPENDIX C



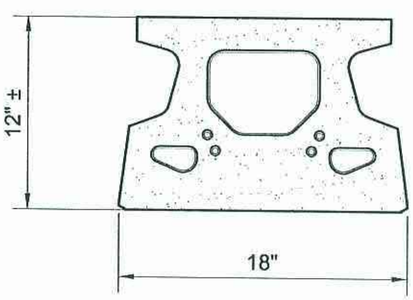




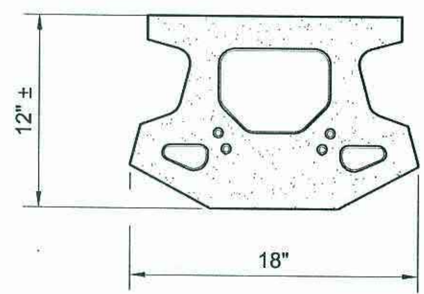
Straight Face Compac II Unit Elevation



3 Plane Compac II Unit Elevation



Straight Face Compac II Unit Plan

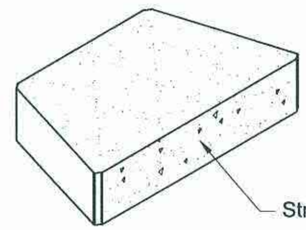


3 Plane Compac II Unit Plan

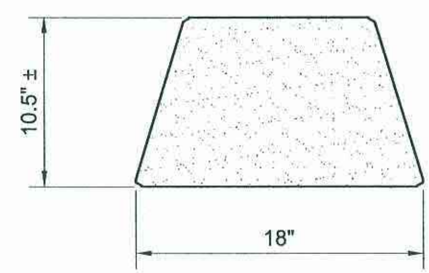
Compac II Unit

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Compac II Unit	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 1



Universal Cap Unit Elevation



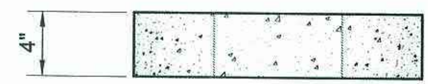
Universal Cap Unit Plan

Universal Cap Unit

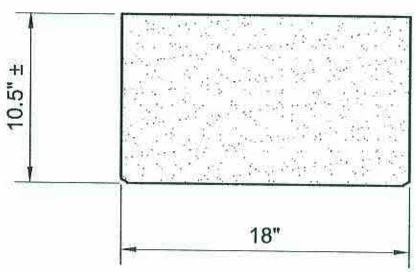
KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title:	4" Universal Cap Unit	Date: 04/2009
Checked By: CDM	Project:	Keystone Retaining Wall System Details	Drawing No: 2
Scale: No Scale			

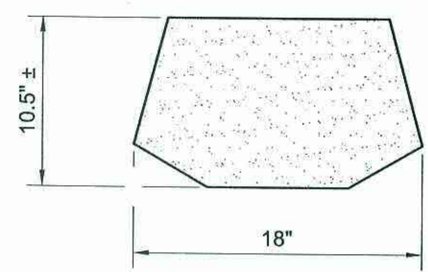
Straight Face Cap Unit Elevation



Tri-Plane Cap Unit Elevation



Straight Face Cap Unit Plan



Tri-Plane Cap Unit Plan

4" Cap Units

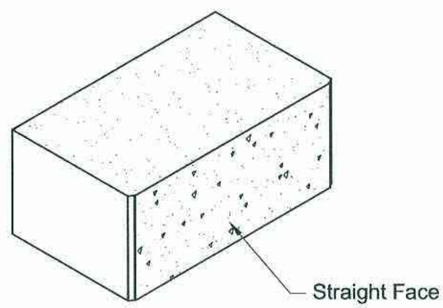
The suitability and/or manner of use of any details contained in this document is the sole responsibility of the user. Final project specific designs shall be prepared by a licensed professional engineer.

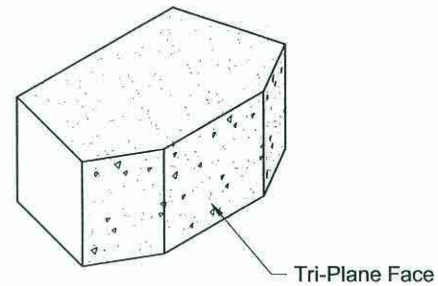
KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY

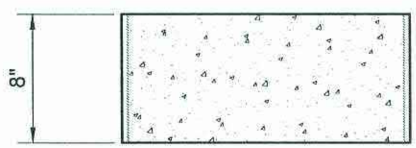
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM
Checked By: CDM
Scale: No Scale

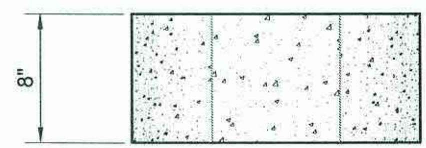
Title: 4" Cap Units
Project: Keystone Retaining Wall System Details
Date: 04/2009
Drawing No: 3



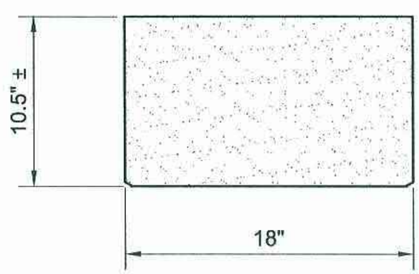




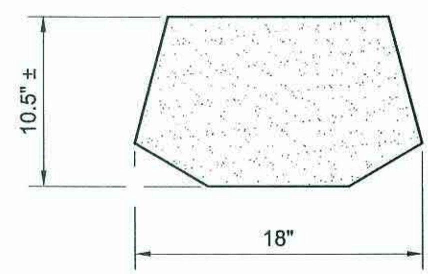
Straight Face Cap Unit Elevation



Tri-Plane Cap Unit Elevation



Straight Face Cap Unit Plan



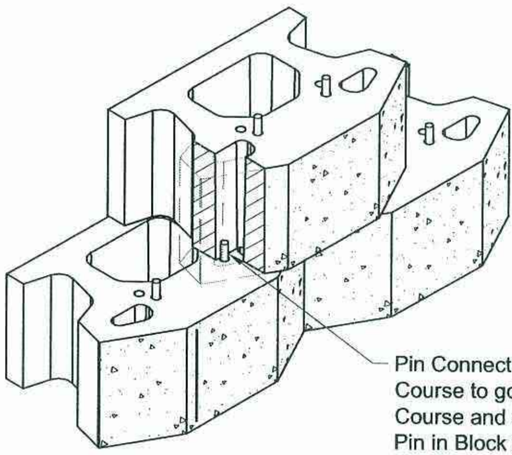
Tri-Plane Cap Unit Plan

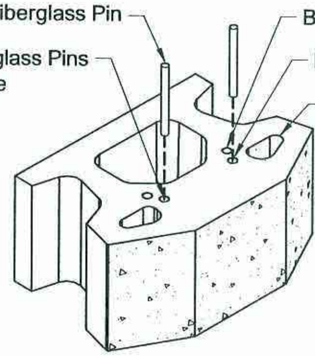
8" Cap Units

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

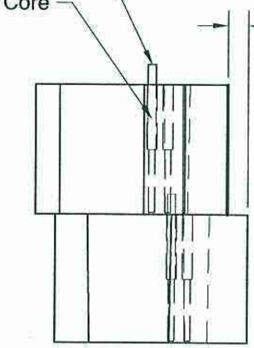
Designed By: RKM	Title: 8" Cap Units		Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details		Drawing No: 4
Scale: No Scale			

Note:
Place two keystone fiberglass pins in each unit.

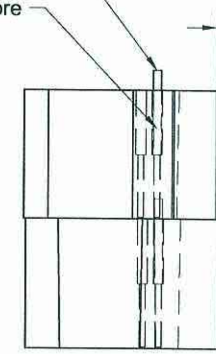




Compac II Block to Block Pin Connections Isometrics



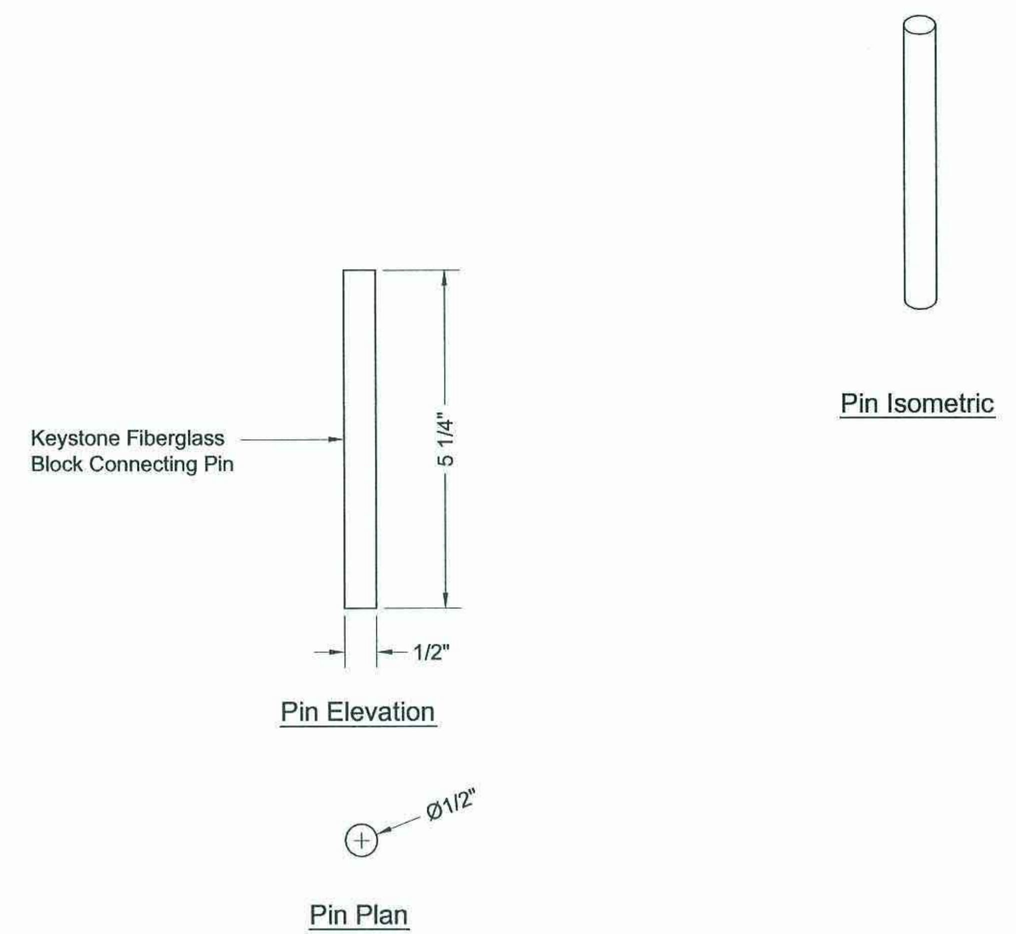
Pin Connection - 1 Inch Setback Section



Pin Connection - Near Vertical Setback Section

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

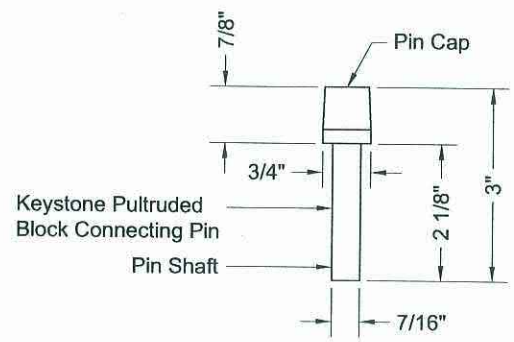
Designed By: RKM	Title: Compac II Unit - Block to Block Pin Connections	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 5



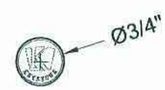
Pin Details

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

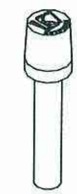
Designed By: RKM	Title: Straight Pin Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 6



Pin Elevation



Pin Plan

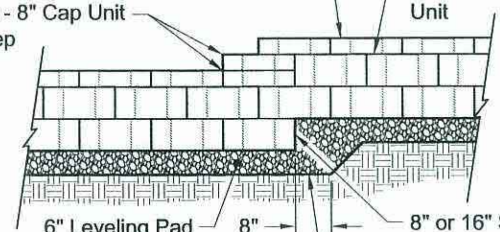


Pin Isometric

Pin Details

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

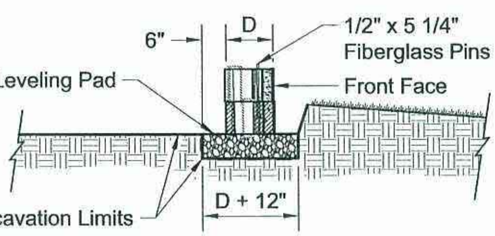
Designed By: RKM	Title: Shoulder Pin Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 7



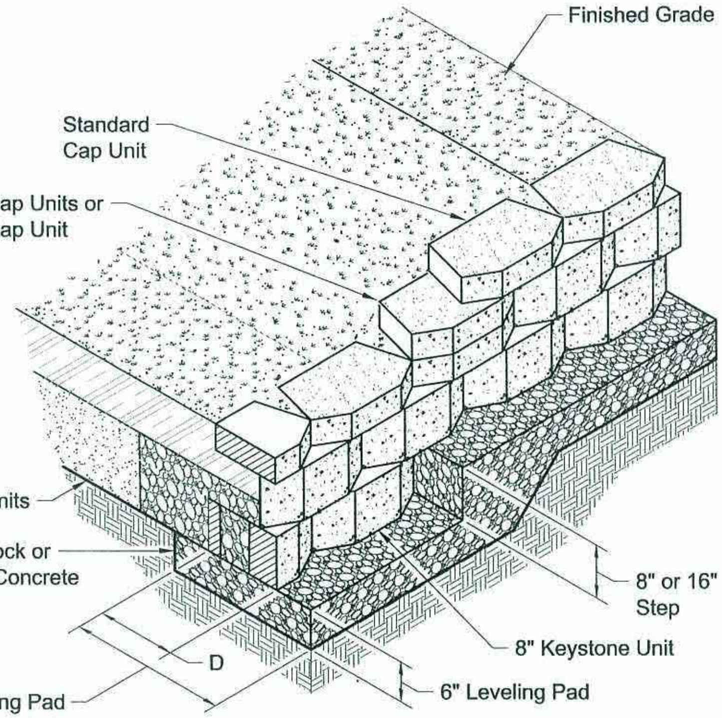
Elevation

Base Leveling Pad Notes:

1. Construct leveling pad with crushed stone or 2500 psi ± unreinforced concrete.
2. The leveling pad foundation is to be approved by the site geotechnical engineer prior to leveling pad placement.



Section

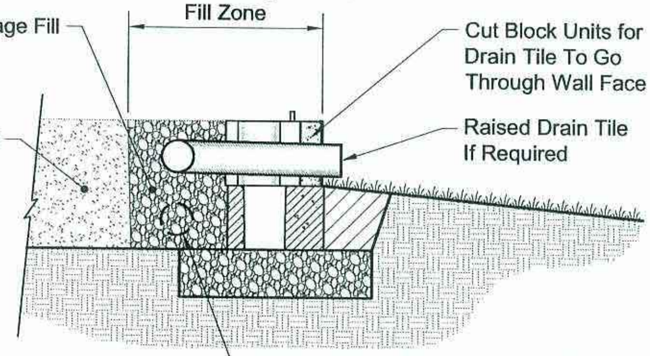


Compac II Unit / Wall Step Isometric Section View

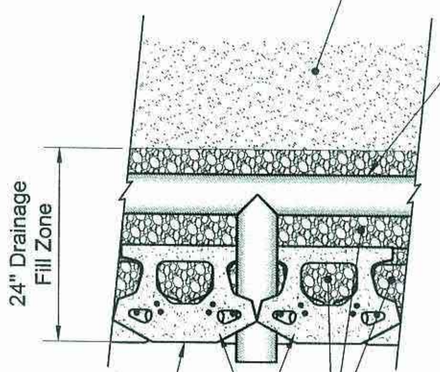
Leveling Pad and Wall Step Detail

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Leveling Pad Details	Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details	Drawing No: 8
Scale: No Scale		



Raised Drain / Unit Drainage Fill Section

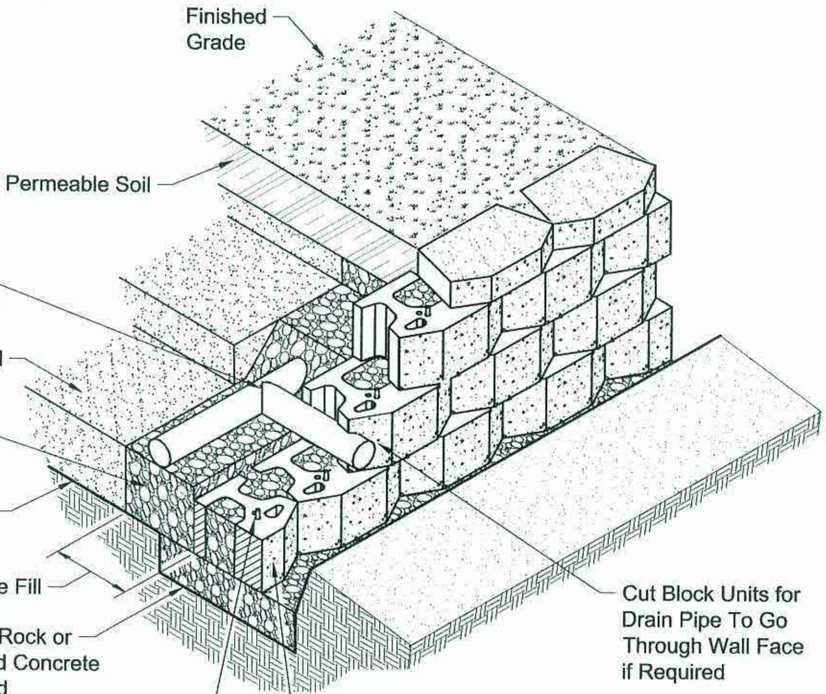


Raised Drain / Unit Drainage Fill Plan

Raised drain tile locations may only be used when:

1. Grading at base does not allow gravity outlet of tile.
2. There is no storm sewer system to outlet tile directly into.

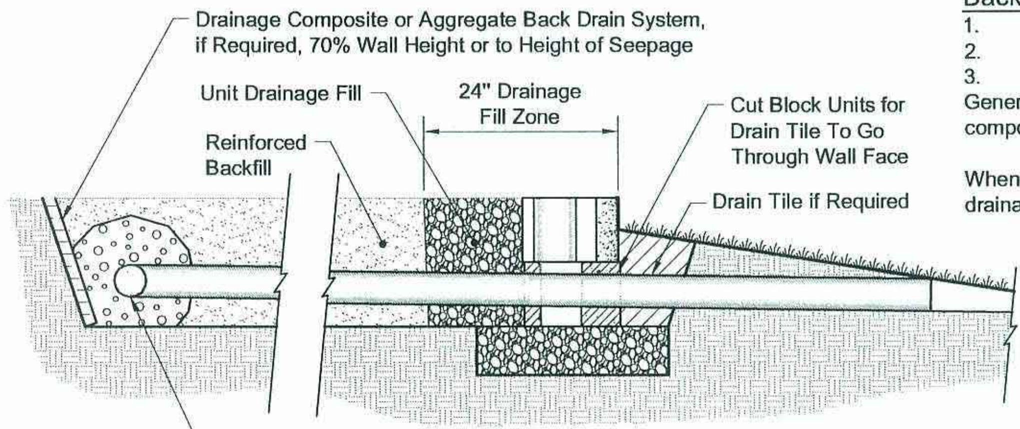
Drainage tile is not required directly behind the wall units for conventional wall construction where retained soils are not a source of groundwater such as fill wall construction or cut walls into relatively dry banks. When required, the size, location, and type of specific drainage materials should be completed as directed by the onsite geotechnical engineer.



Compac II Unit / Raised Wall Drain Isometric Cut Section View

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Wall Drain Behind Wall Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 9



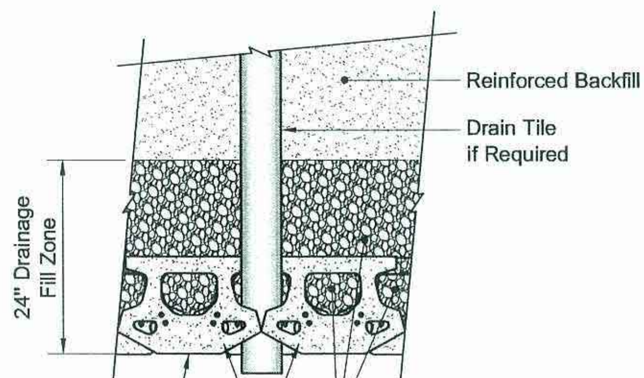
Back Drain / Unit Drainage Fill Section

Back drainage tile should be included when:

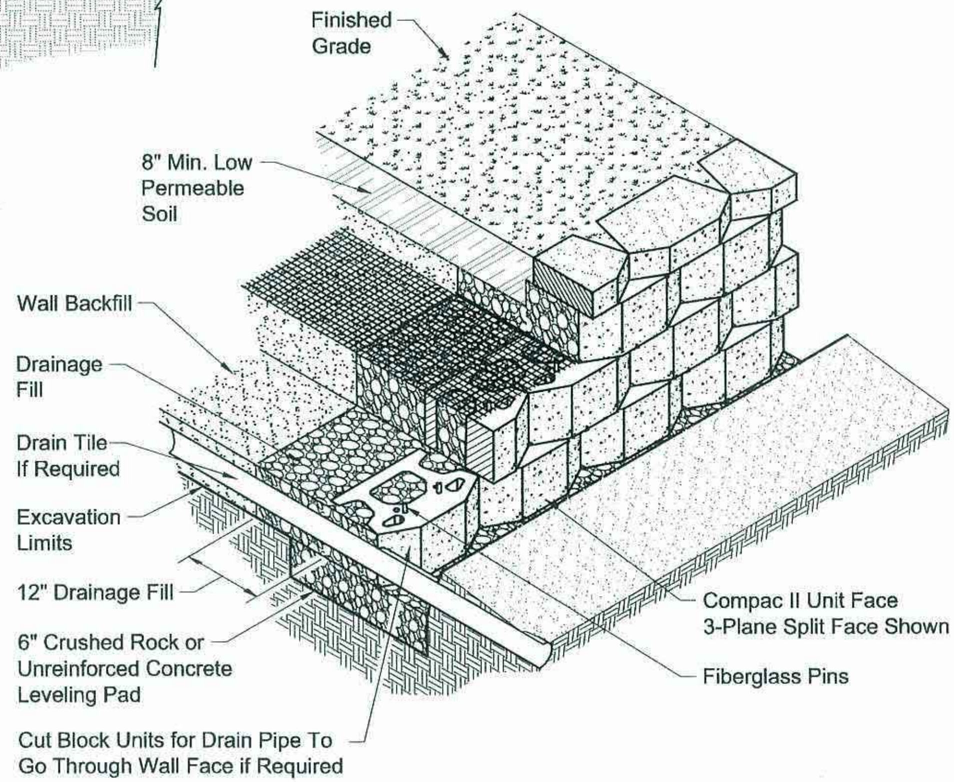
1. Groundwater or seepage is present in retained soils
2. Springs or seasonal seepage potential is noted in geotechnical report
3. Reinforced soil of lower permeability than retained soils

Generally, additional drainage material such as aggregate drains & fabrics and/or drainage composite nets are used in conjunction with rear drainage tile as directed.

When above conditions are not present or groundwater conditions are not a factor, the rear drainage tile may be omitted or alternately located behind units at the base of the drainage fill.



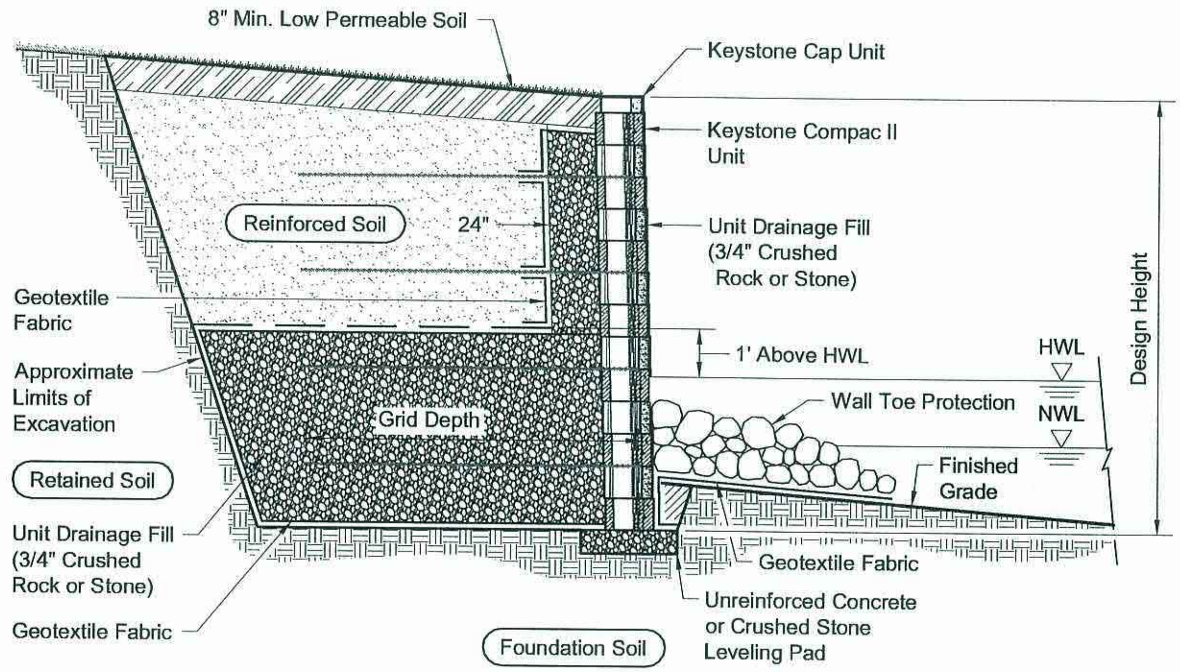
Back Drain / Unit Drainage Fill Plan



Compac II Unit / Back Wall Drain Isometric Cut Section View

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Wall Drain in Back Fill Zone Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 10

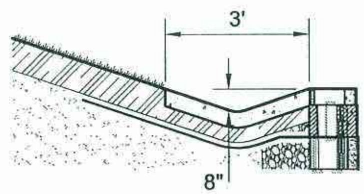


Typical Reinforced Water Wall Section

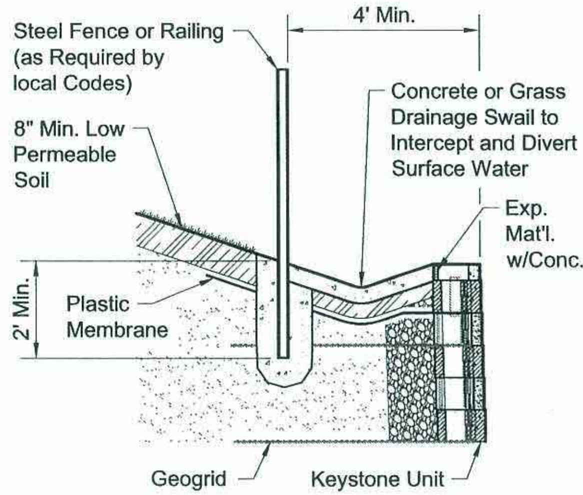
Compac II Unit - Near Vertical Setback

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title:	Reinforced Water Wall Details	Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project:	Keystone Retaining Wall System Details	Drawing No: 11



Swale Dimension Detail

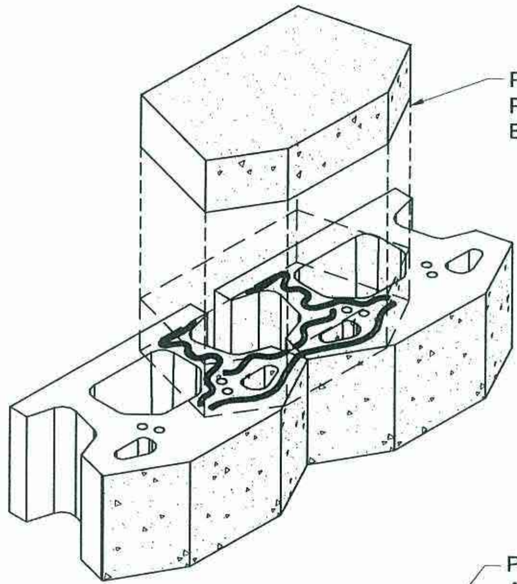


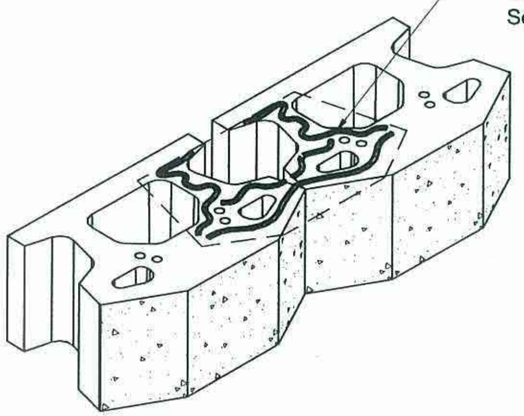
Drainage Swale Detail

Compac II Unit - Near Vertical Setback Shown

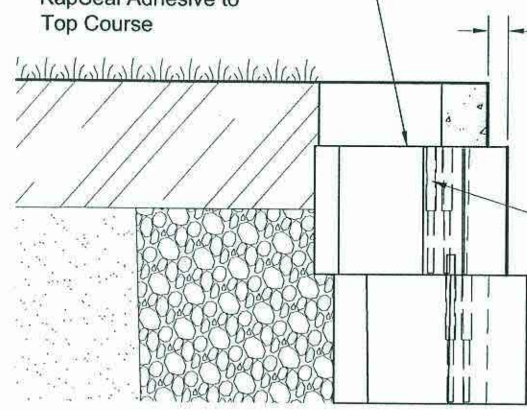
KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Swale Details		Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details		Drawing No: 12
Scale: No Scale			

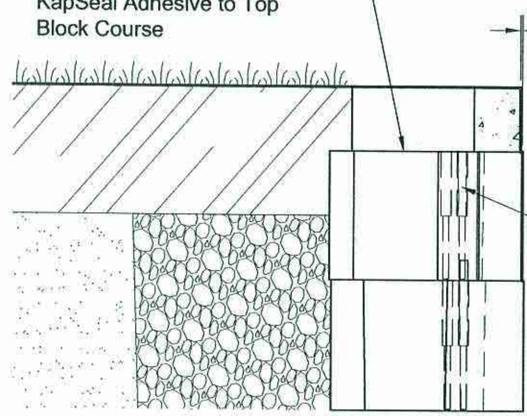




Cap Unit - Cap to Block
Connection Isometrics



Cap Setback - 1 Inch Setback Section

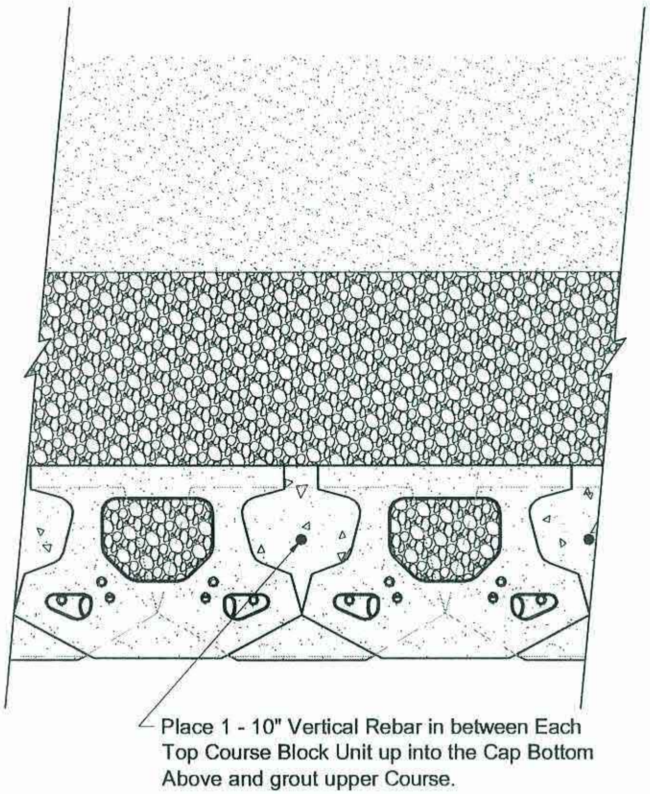


Cap Setback - Near Vertical Setback Section

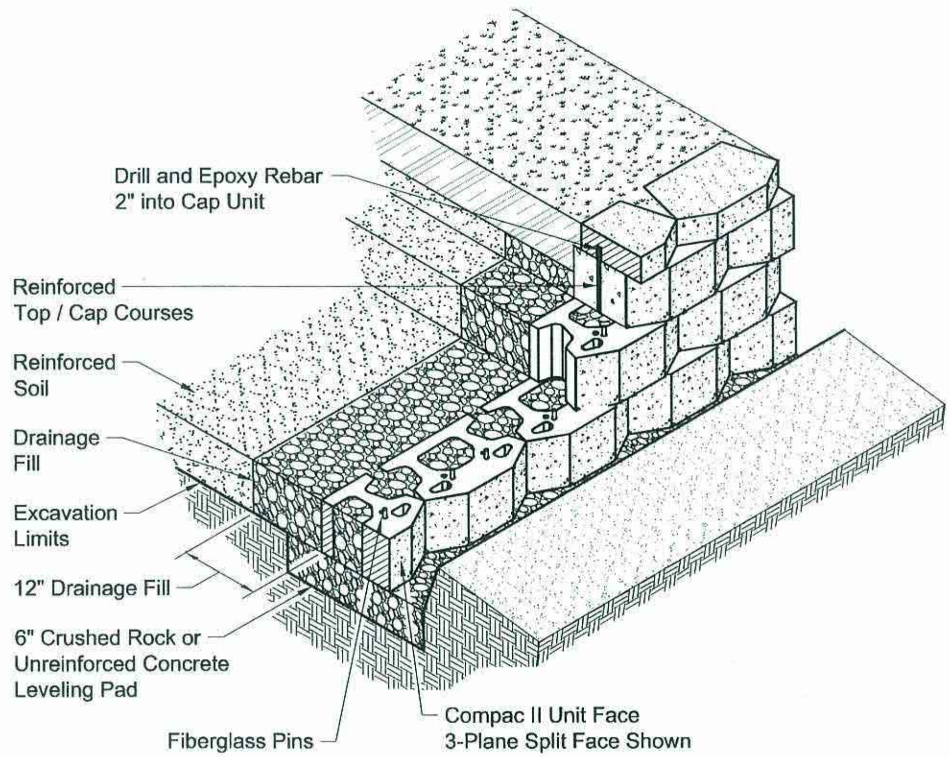
The suitability and/or manner of use of any details contained in this document is the sole responsibility of the user. Final project specific designs shall be prepared by a licensed professional engineer.

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title:	Cap Unit - Cap to Block Connections With Wall Setbacks Details	Date:	04/2009
Checked By: CDM	Project:	Keystone Retaining Wall System Details	Drawing No:	13
Scale: No Scale				



Top Course Grouting Plan

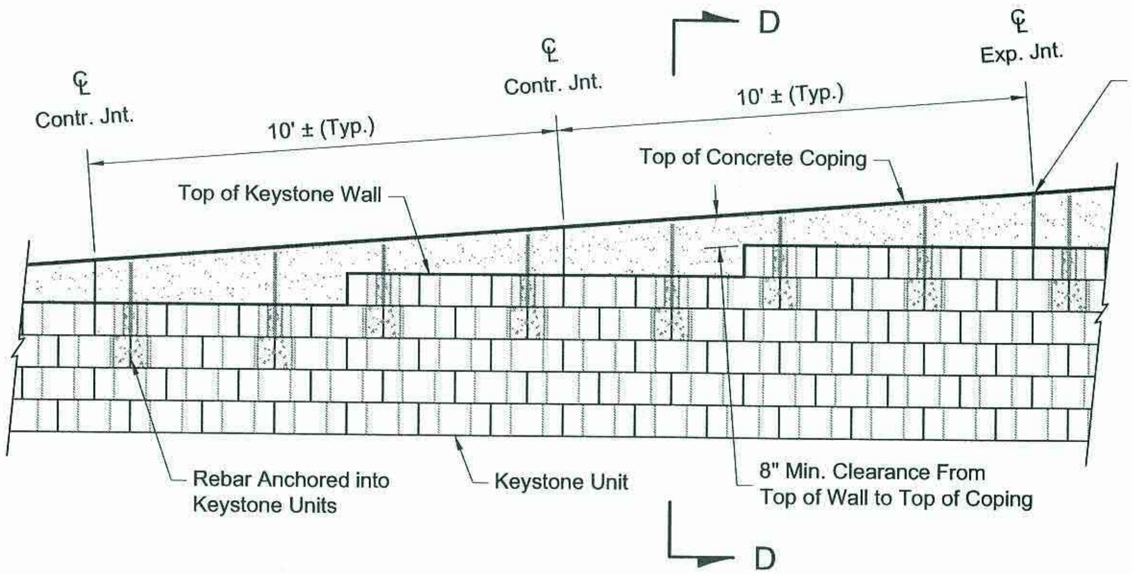


Top Course Grouting Isometric Cut Section View

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY

4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

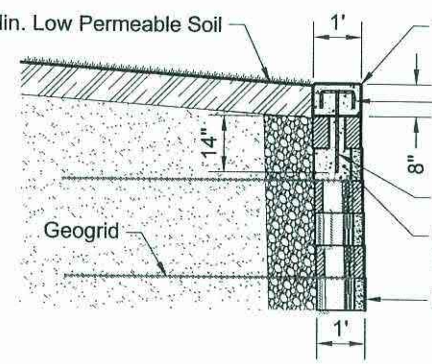
Designed By: RKM	Title: Top of Wall Cap Reinforcement Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 14



Partial C.I.P Top Concrete Coping Elevation

Note:
1. Maintain 2" minimum cover on all rebar.

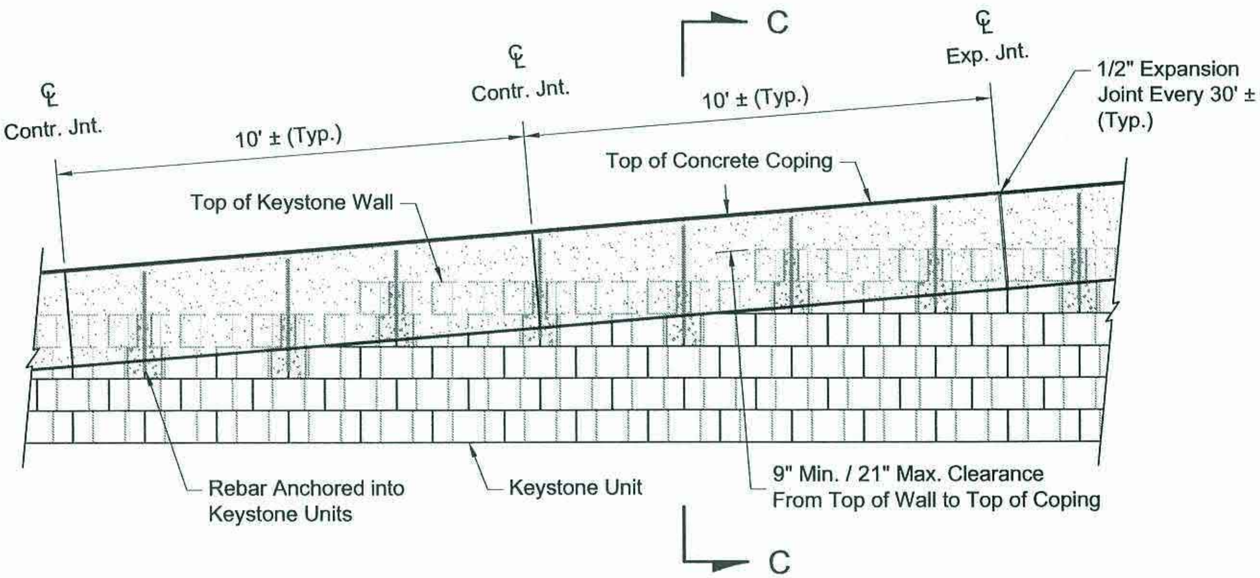
2. Full expansion joints shall be placed every 3rd joint and at all wall radius and bend points.



Section D - D
C.I.P. Top Concrete Coping

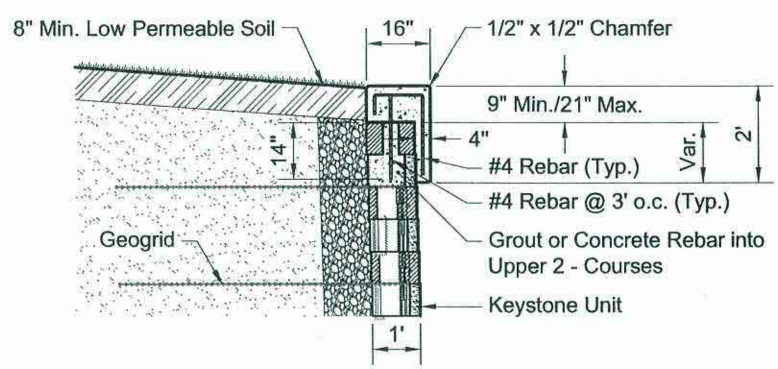
KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Cast in Place Top Coping Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 15



Partial C.I.P Top - Overhanging Concrete Coping Elevation

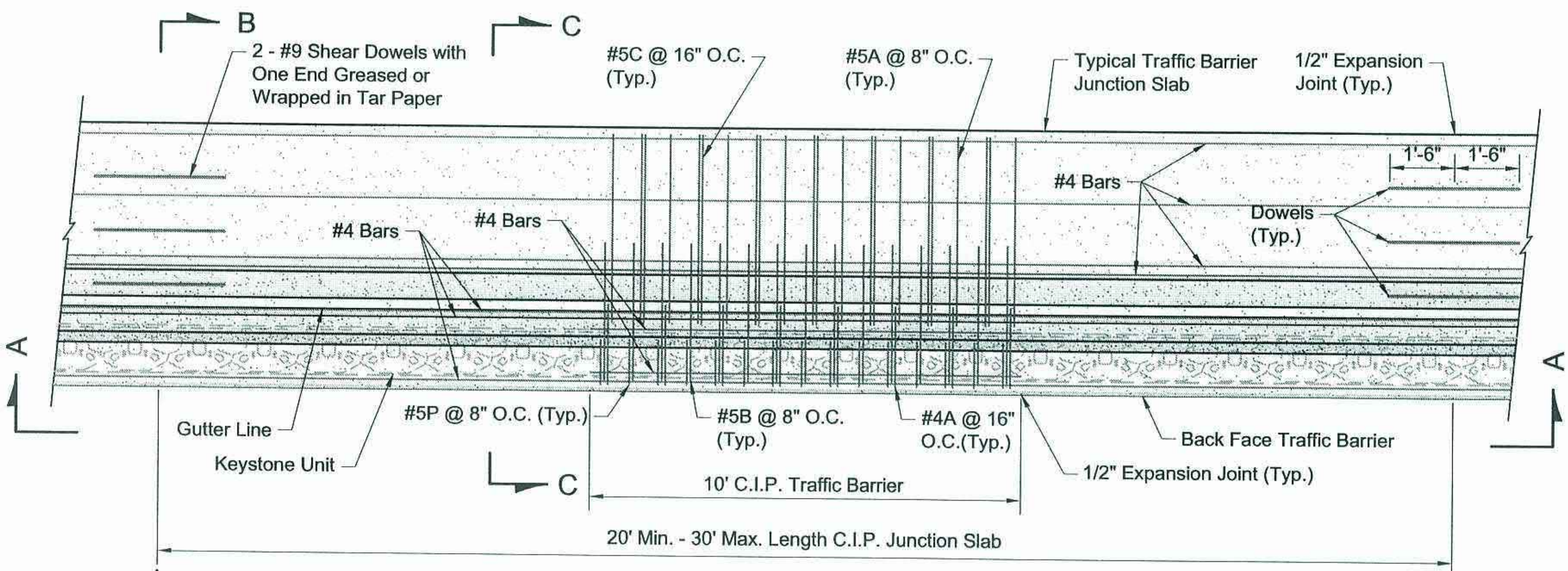
Note:
1. Maintain 2" minimum cover on all rebar.
2. Full expansion joints shall be placed every 3rd joint and at all wall radius and bend points.
3. Insure that all top of wall steps are completely covered by overhang of concrete coping (3" min.).



Section C - C
C.I.P. Top - Overhanging Concrete Coping

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

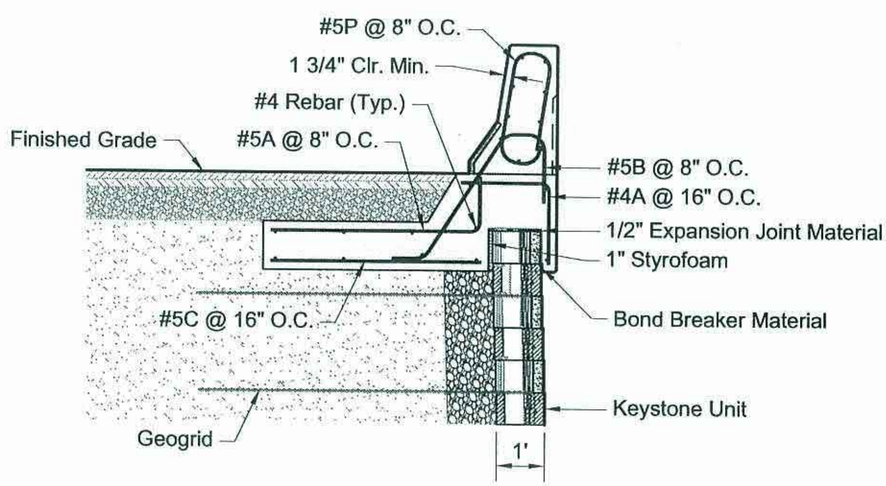
Designed By: RKM	Title: Cast in Place Top - Overhanging Coping Details	Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details	Drawing No: 16
Scale: No Scale		



Partial C.I.P. Traffic Barrier Plan

Note:

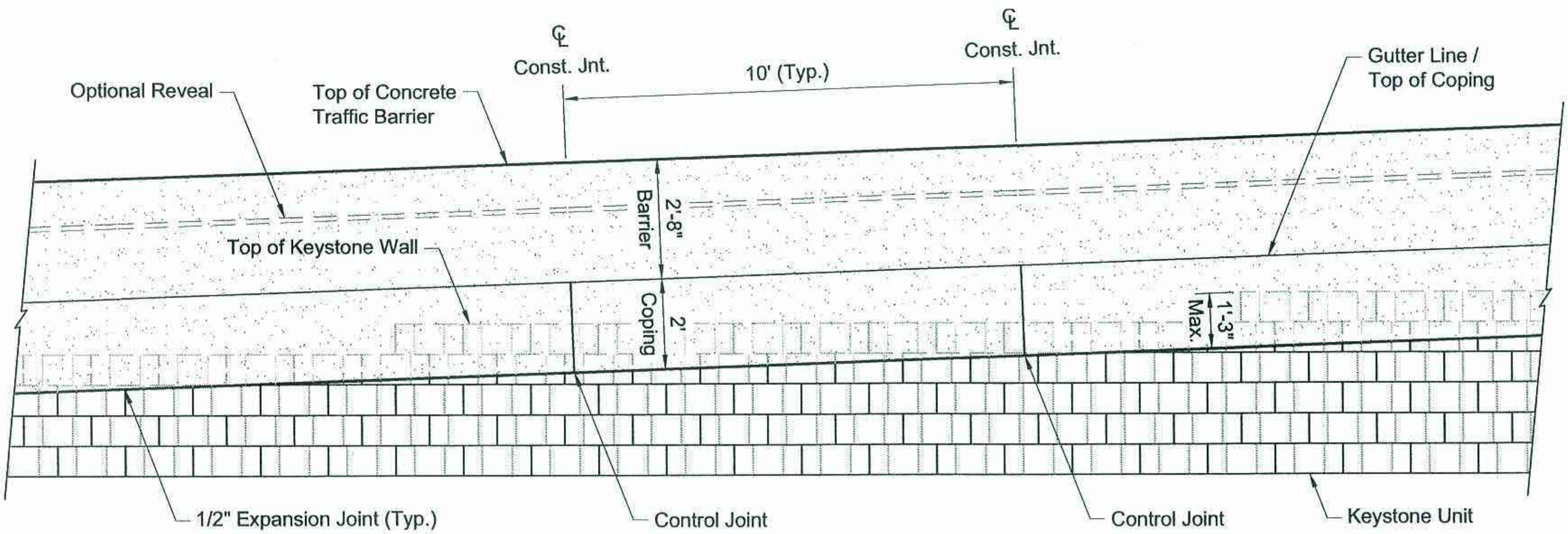
1. All longitudinal bars are #4 as shown
2. Concrete cover 2" (Typ.)



Section C - C C.I.P. Traffic Barrier Reinforcement

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

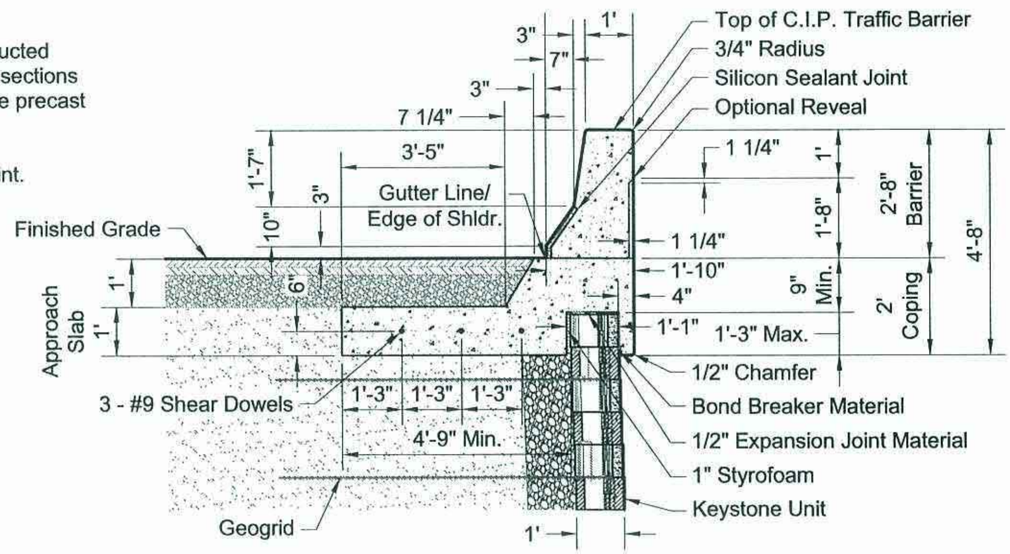
Designed By: RKM	Title: Cast in Place Traffic Barrier Reinforcement Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 17



Partial C.I.P. Traffic Barrier Elevation A - A

Note:

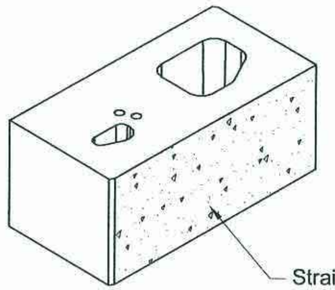
1. If short C.I.P. barrier sections are to be constructed adjacent to precast barrier sections, then this sections dimensions shall be adjusted to conform to the precast dimensions.
2. Elevations shown are at the labeled gutter point.

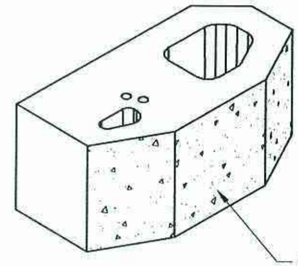


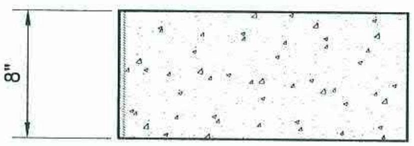
Section B - B C.I.P. Traffic Barrier Layout

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

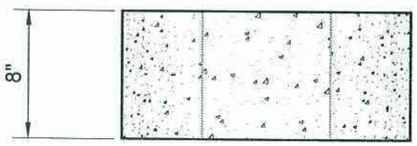
Designed By: RKM	Title: Cast in Place Traffic Barrier Details		Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details		Drawing No: 18
Scale: No Scale			



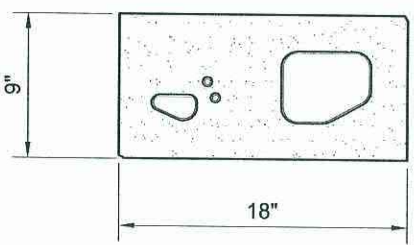




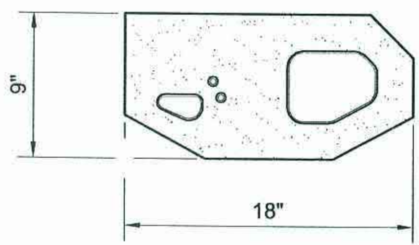
Straight Face Corner Unit Elevation



5 Plane Corner Unit Elevation



Straight Face Corner Unit Plan



5 Plane Corner Unit Plan

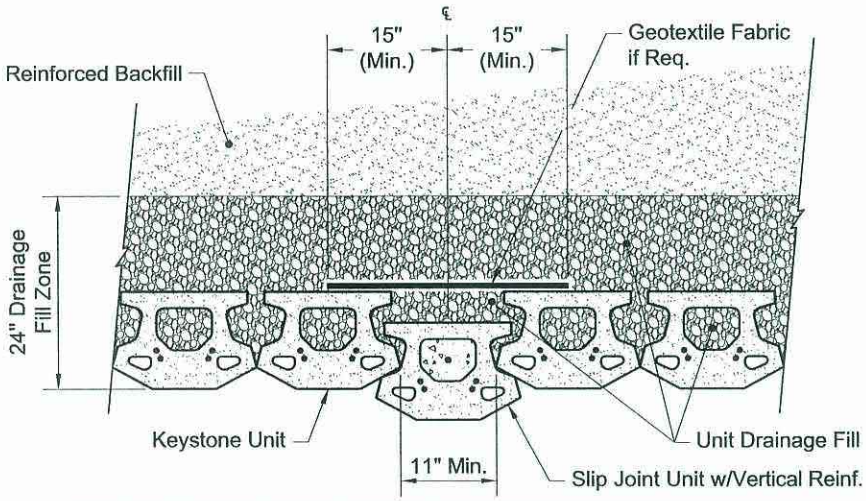
Compac II Corner Units

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

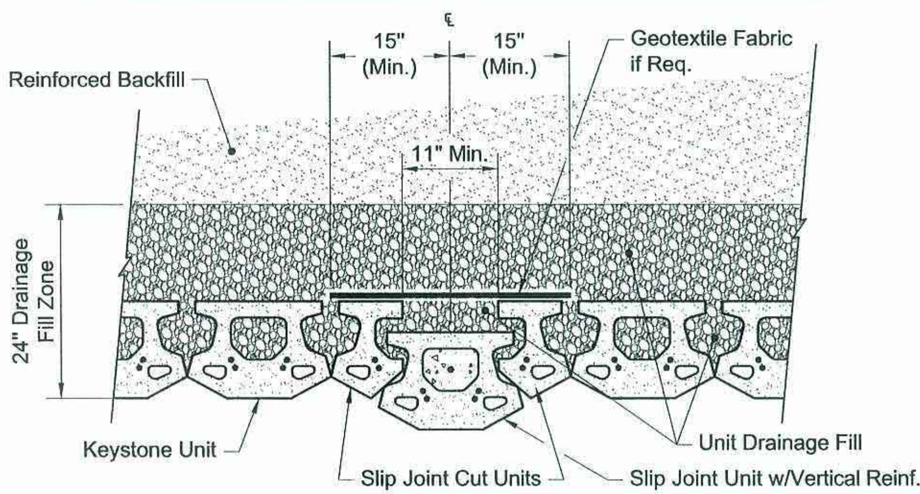
Designed By: RKM	Title: Compac II Corner Units	Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details	Drawing No: 19
Scale: No Scale		

Note:
Attach geotextile to walls with construction adhesive.

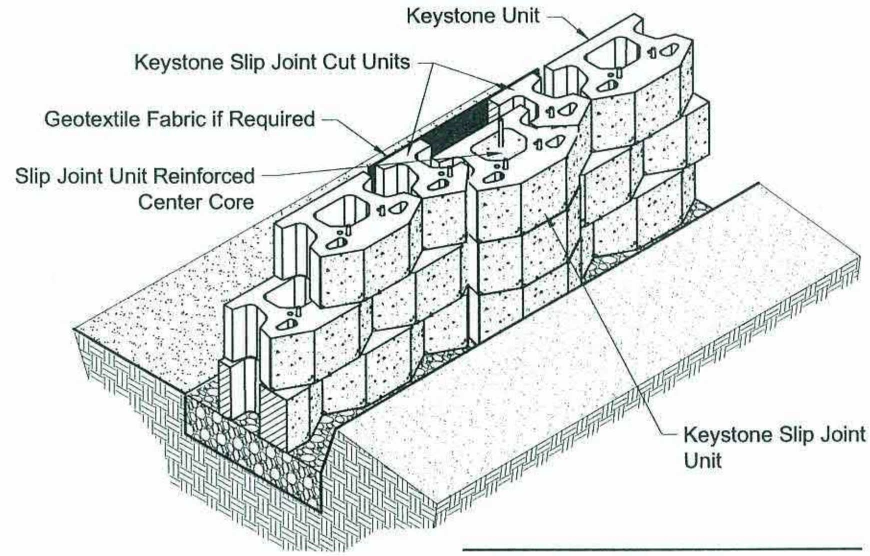
Slip joint units are to be grouted together with vertical #4 Rebar.



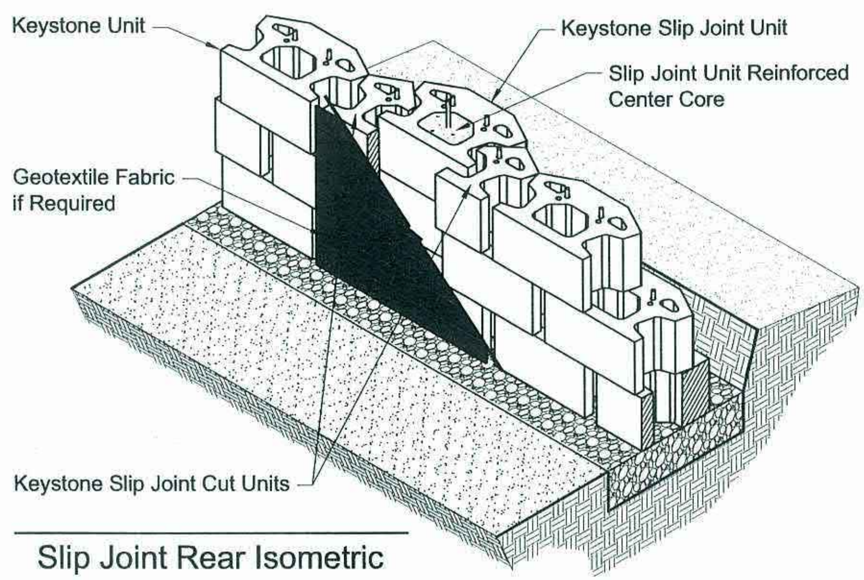
Typical Second and / or Even Numbered Courses



Typical Base and / or Odd Numbered Courses



Slip Joint Front Isometric

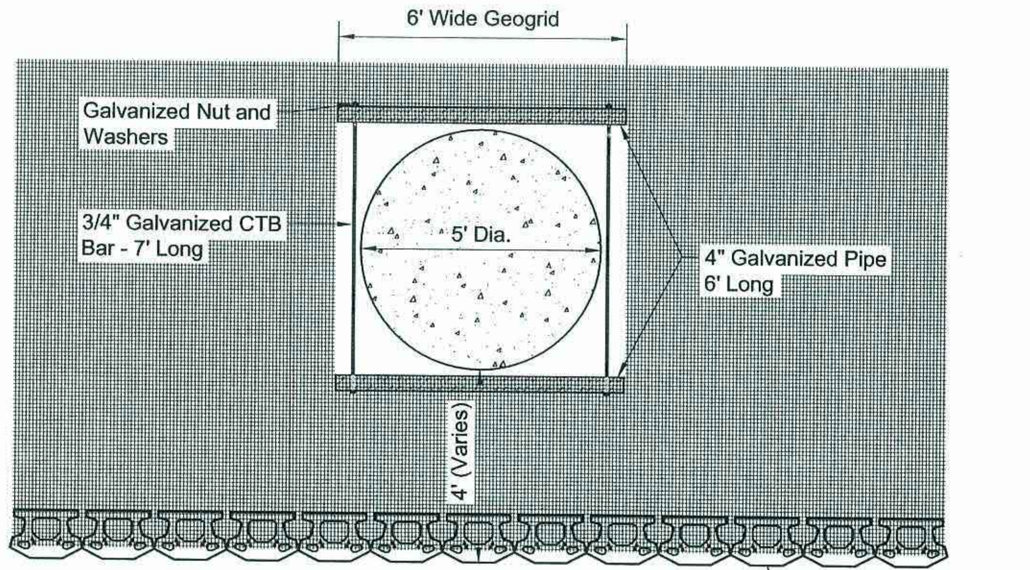


Slip Joint Rear Isometric

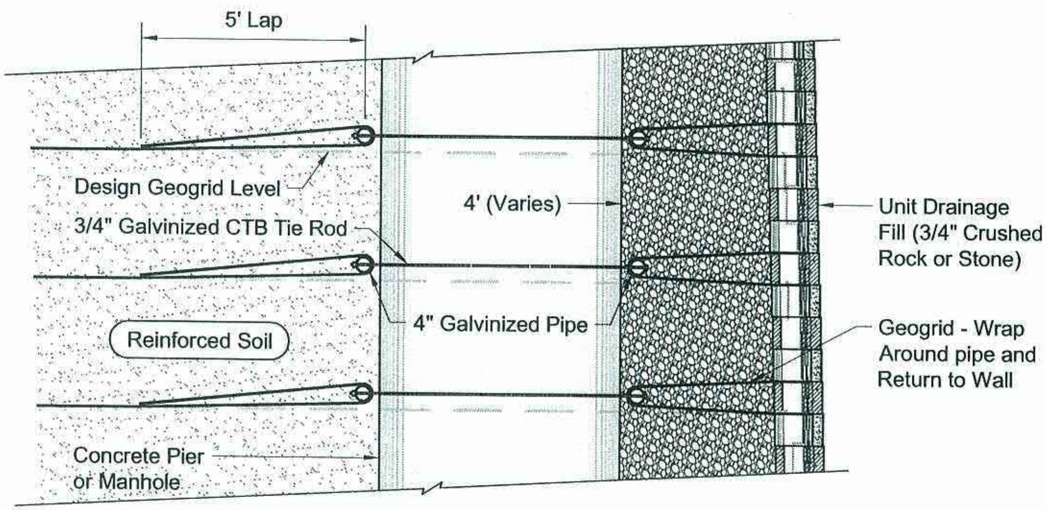
The suitability and/or manner of use of any details contained in this document is the sole responsibility of the user. Final project specific designs shall be prepared by a licensed professional engineer.

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Wall Slip Joint Details	Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details	Drawing No: 20
Scale: No Scale		



Wall Plan at Pier / Manhole



Wall Section at Pier / Manhole

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Obstruction Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 21

Notes:

Keystone Compac II units shown.

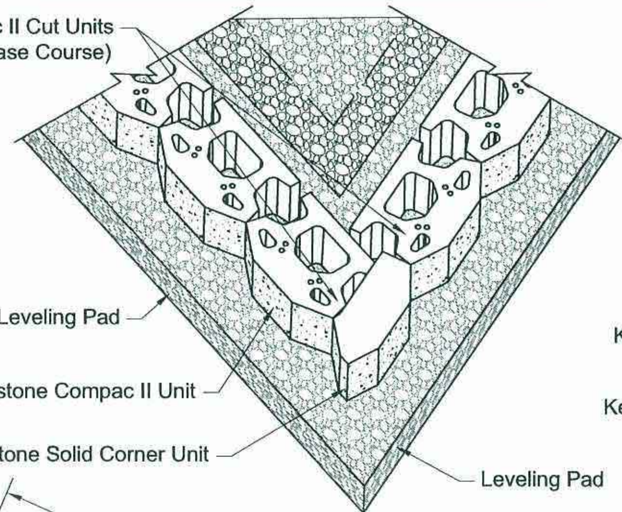
Full corner piece units to be used for each odd or even course vertically up the wall corner.

Due to corner perpendicular wall setback per course to maintain running bond course alignment cut the next unit back from each corner unit labeled "Compac II Cut Unit" at the adjoining edge of unit to the corner unit in both directions for proper wall joint alignment.

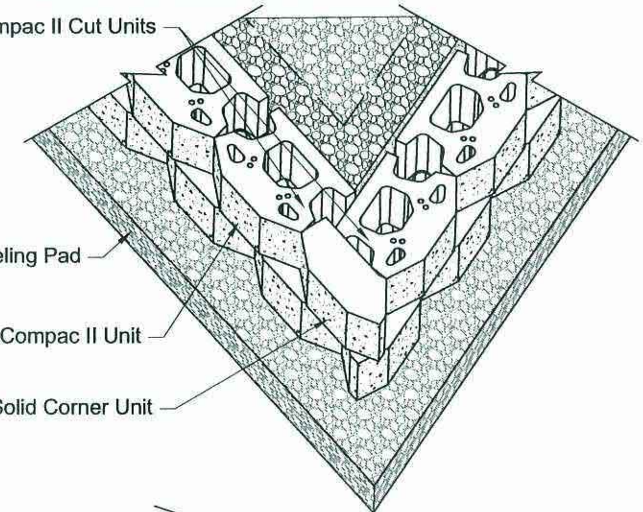
Additional crushed rock or stone drainage fill at outside wall corners to extend back from wall face each way at wall height / 2 (H / 2.).

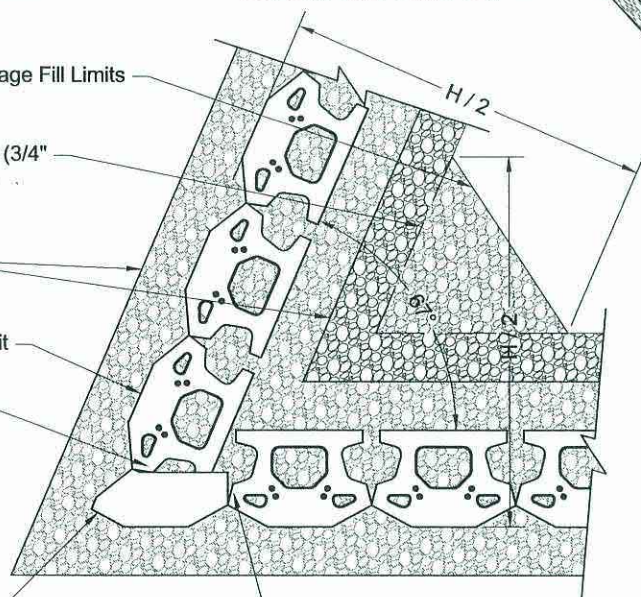
Geogrid reinforcement design as per engineer.

Odd Numbered Courses Iso View

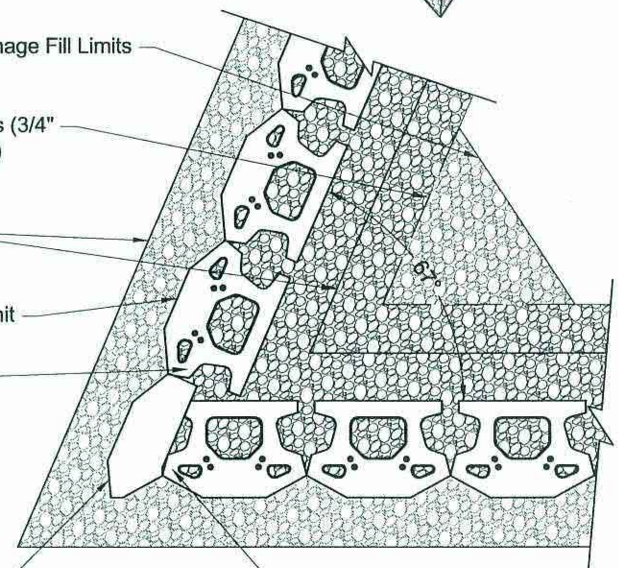


Even Numbered Courses Iso View





Typical Base and / or Odd Numbered Courses

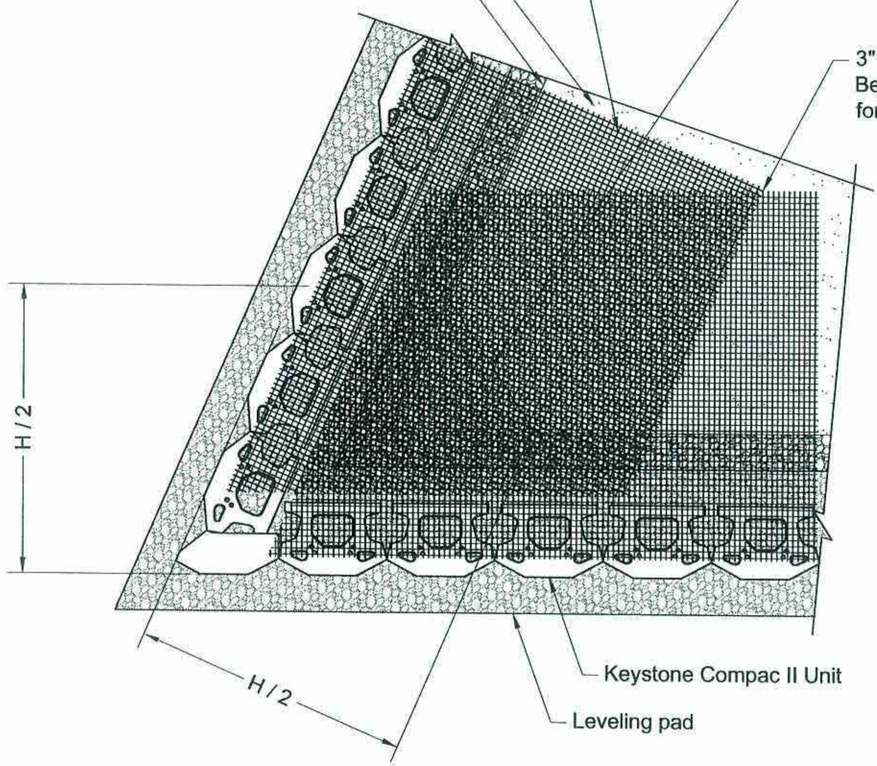


Typical Second and / or Even Numbered Courses

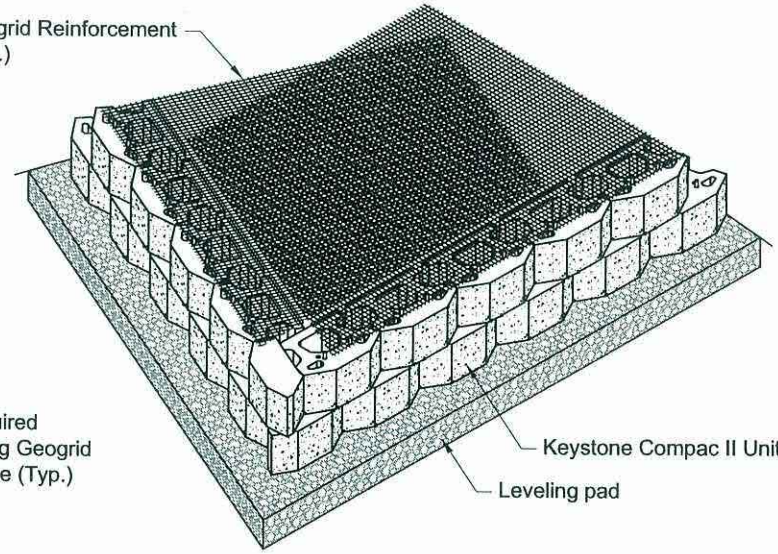
KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Compac II Unit Outside Acute Corner Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 22

Note:
Keystone Compac II units shown.



Typical Outside Acute Corner Geogrid Plan



Typical Outside Acute Corner Geogrid Isometric

Installation Notes:

Additional crushed rock or stone drainage fill at outside wall curves to extend back from wall face each way at wall height / 2 (H / 2).

Drainage zone and backfill materials should be placed compacted and up to the geogrid elevation and Keystone unit pins should be in place prior to geogrid installation.

Measure, cut and orient the geogrid, as per the engineers design and the geogrid manufacturers specifications on correct strength direction.

Place the geogrid over the Keystone unit pins and tension the geogrid by pulling it back away from the wall. Place a stake through the geogrid at the back to tension the geogrid in place.

Proceed with placement of additional Keystone units then drainage zone and backfill material. Starting at the wall and moving back away from the wall place the drainage zone and backfill materials over the geogrid to hold the geogrid in place under tension. After the backfilling process the tension stakes may be removed for reuse.

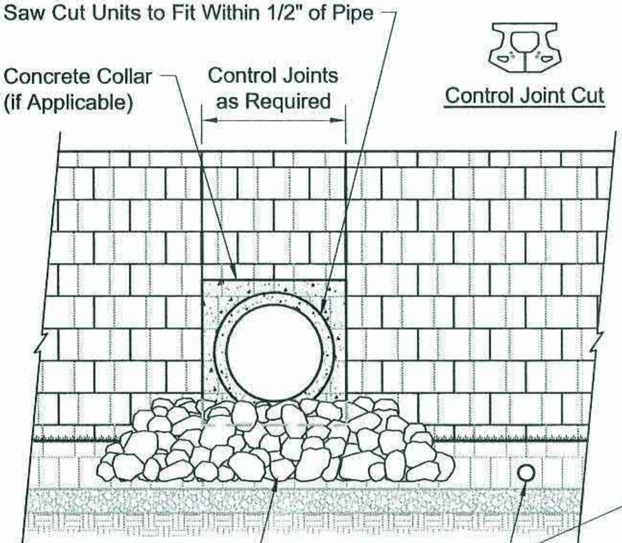
Compact the backfill materials up to the next wall elevation where a geogrid is to be place.

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

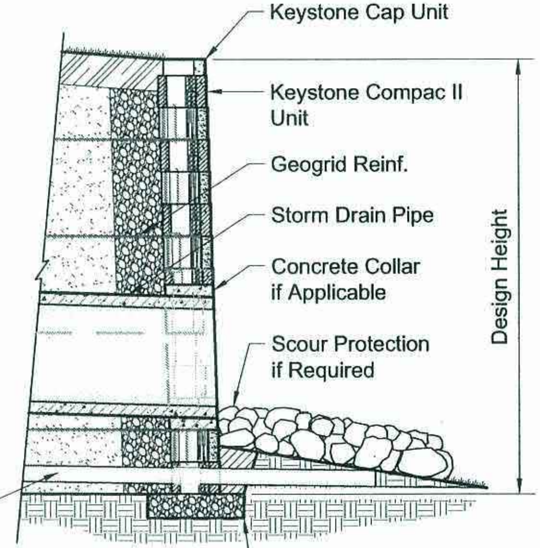
Designed By: RKM	Title: Geogrid Installation on Outside Acute Corner Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 23

Note:

1. For pipes larger than 24", a concrete collar may be cast around pipe for ease of construction and appearance.
2. Provide splash block or concrete gutter for drainage tile wall outlet, scour protection if required.



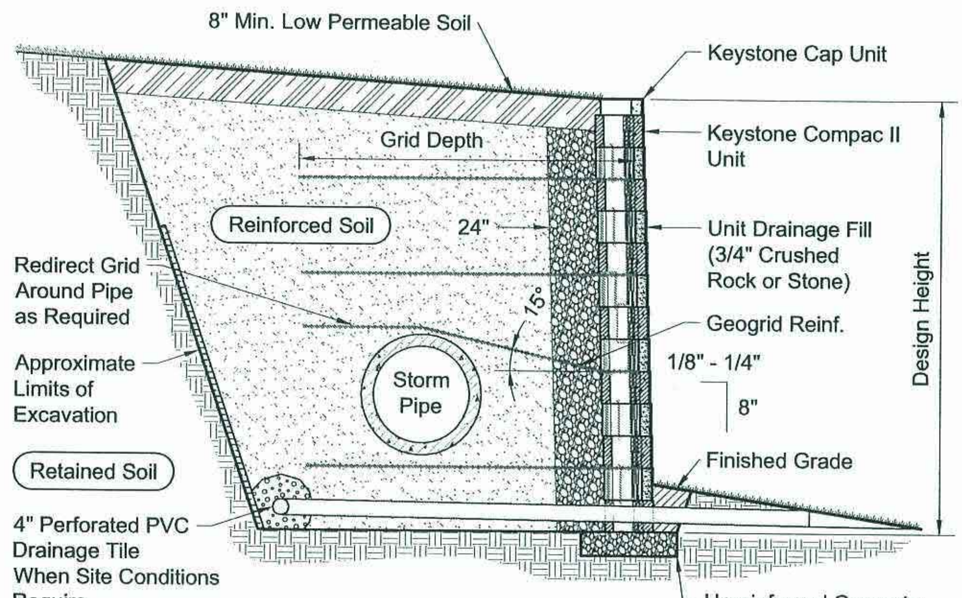
Typical Pipe Outlet Elevation Detail



Typical Pipe Outlet Section Detail

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Typical Pipe Outlet Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 24



Note:
When site conditions require, wrap drainage tile in 3/4" aggregate and filter fabric with drainage composite or aggregate back drain system, as directed by geotechnical engineer.

Wall Section with Pipe in Reinforced Zone

Compac II Unit - Near Vertical Setback

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Horizontal Obstruction Wall Details		Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details		Drawing No: 25
Scale: No Scale			

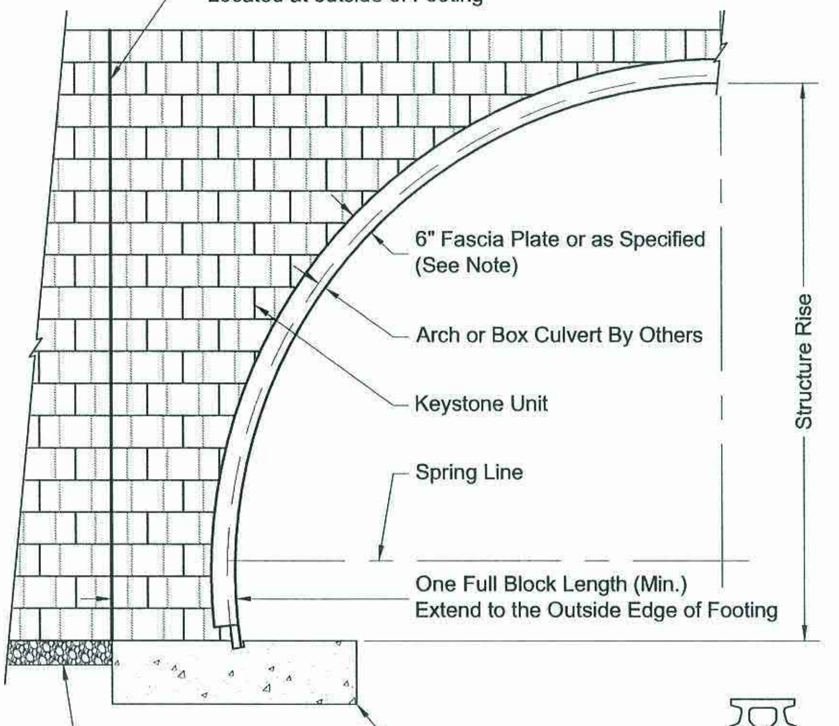
Note:

Keystone Compac II units shown.

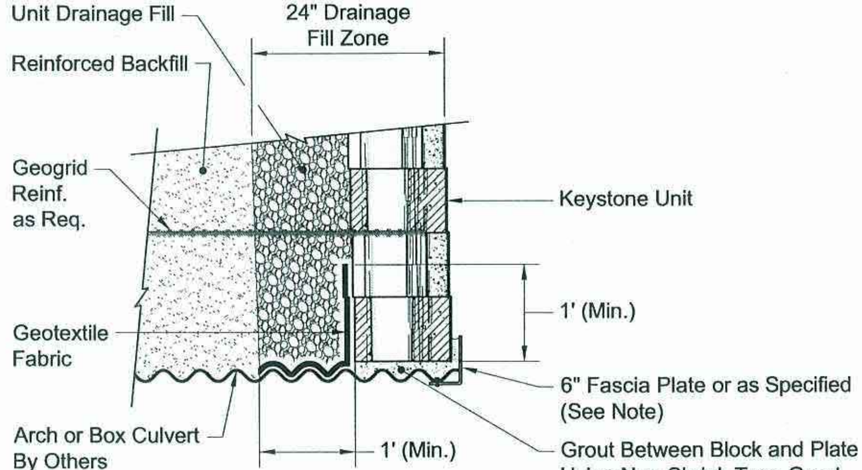
Total width of headwall face must be in full or half width unit increments.

Fascia Plate Shown is 6"x4"x5/16"
Hot Rolled Steel Angle
(Galzinized Finish)
or as Specified

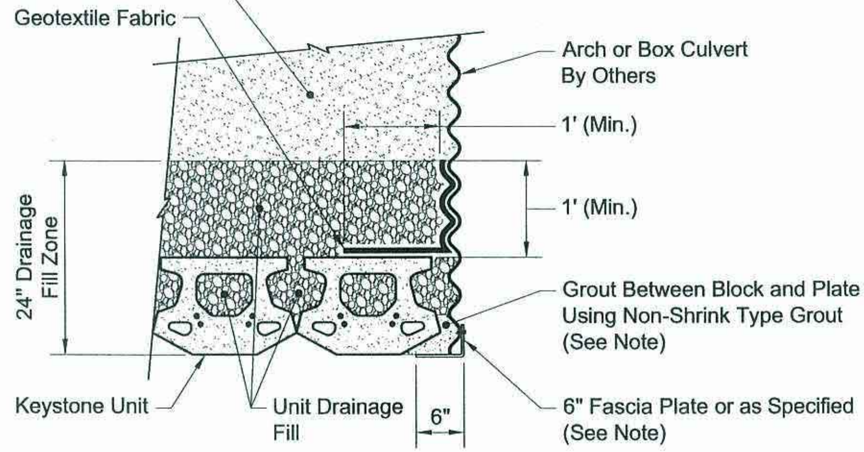
Grout Between Block and Plate Using Non-Shrink Type Grout Conforming to ASTM C1107. Trim Blocks to Leave No Gap with Plate Larger Than 3/4"



Typical Compac II Unit Wall Headwall Detail



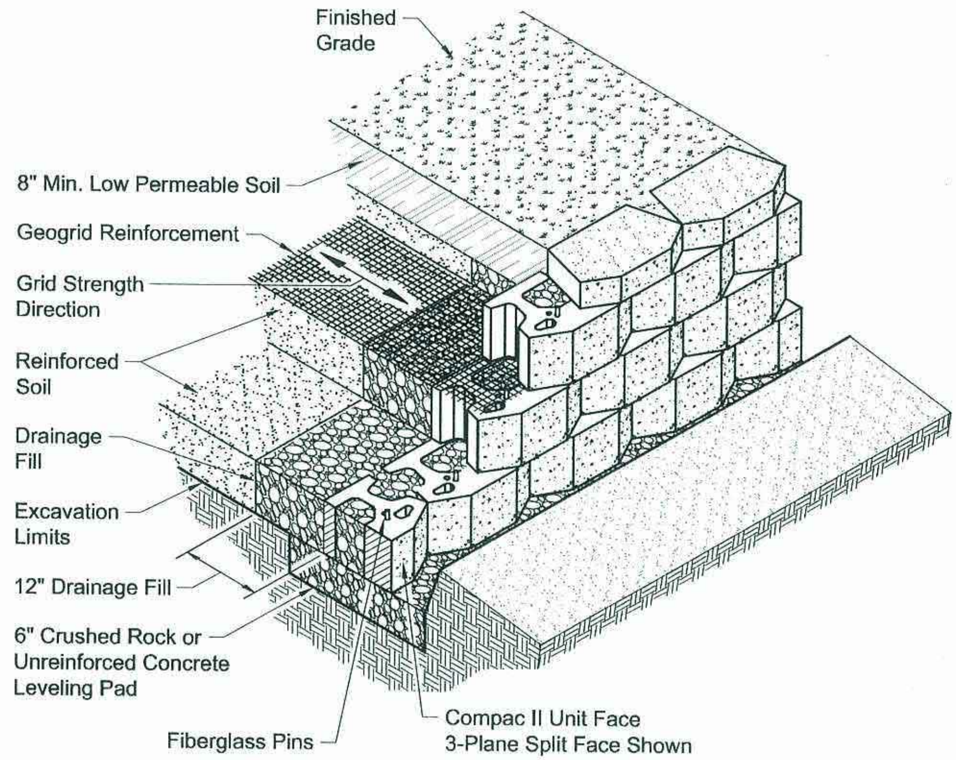
Wall Horizontal Connection Joint Plan



Wall Vertical Connection Joint Plan

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

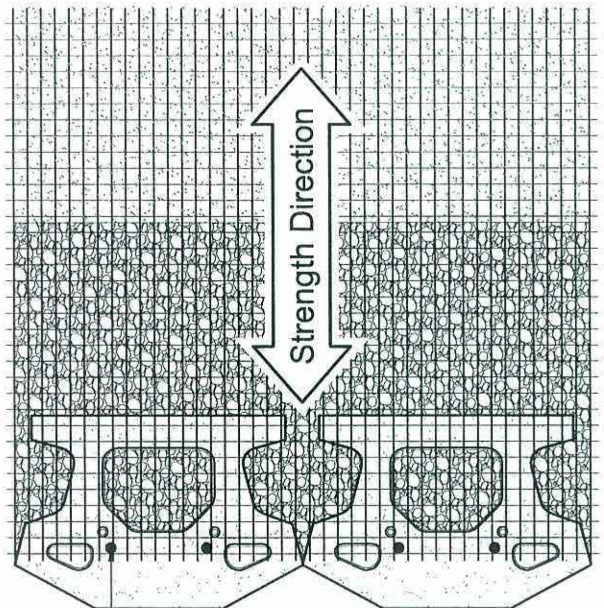
Designed By: RKM	Title: Typical Arch or Box Culvert Details		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 26



Compac II Unit / Wall System Isometric Cut Section View

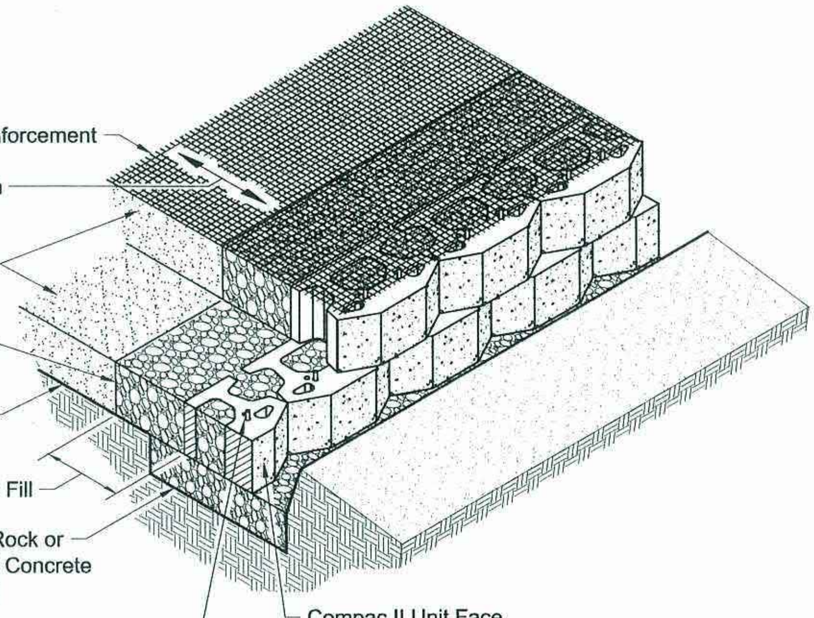
KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Wall System Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 27



Geogrid is to be Placed on Level Backfill and Extended Over the Fiberglass Pins. Place Next Unit. Pull Grid Taught and Backfill. Stake as Required.

Grid & Pin Connection Plan

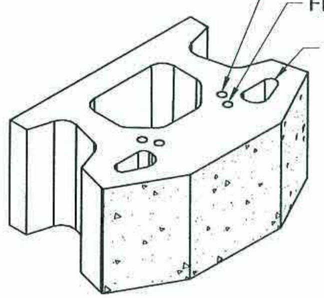


Compac II Unit / Wall Grid Isometric Cut Section View

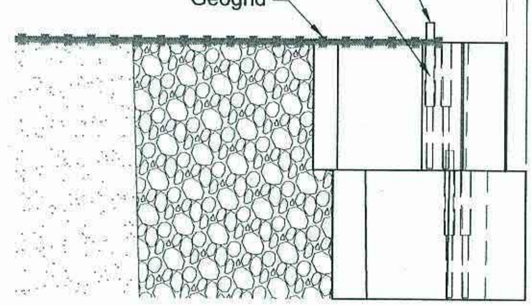
KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Geogrid Installation Details
Checked By: CDM	Project: Keystone Retaining Wall System Details
Scale: No Scale	Date: 04/2009
	Drawing No: 28

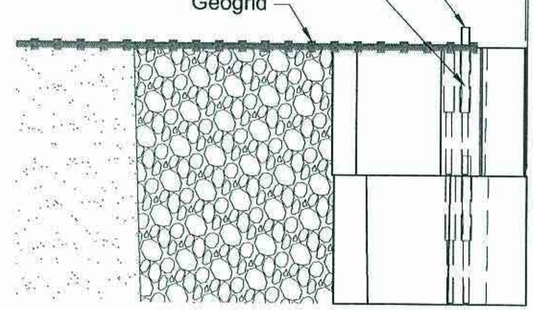
Note:
Geogrid is to be placed on level backfill and extended over the fiberglass pins. Place next unit. Pull grid taught and backfill. Stake as required.



Compac II Unit Isometric



Grid & Pin Connection - 1 Inch Setback Section

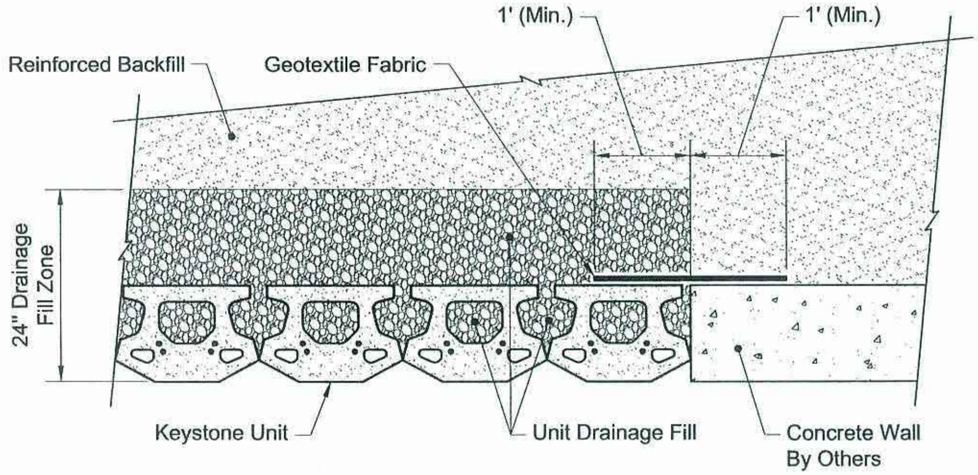


Grid & Pin Connection - Near Vertical Setback Section

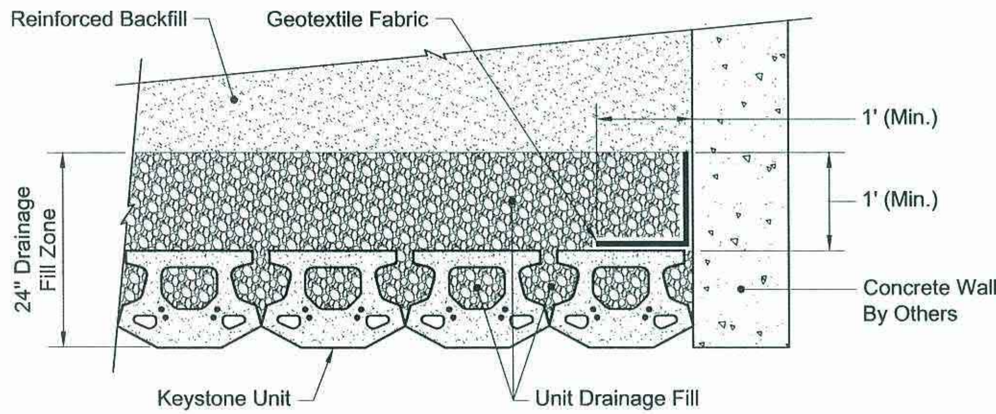
KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Geogrid Installation		Date: 04/2009
Checked By: CDM			
Scale: No Scale	Project: Keystone Retaining Wall System Details		Drawing No: 29

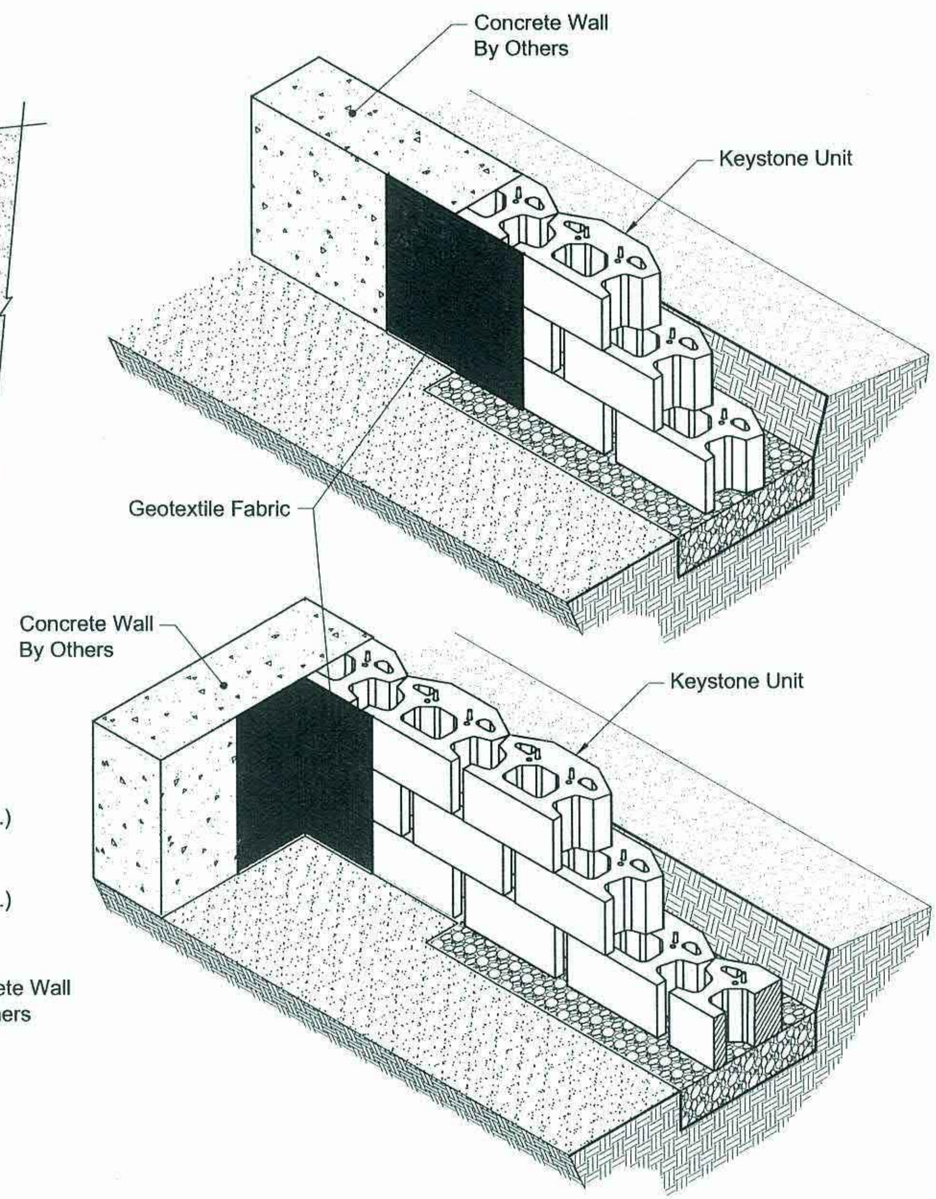
Note:
Attach geotextile to walls with construction adhesive.



Wall Perpendicular Connection Plan



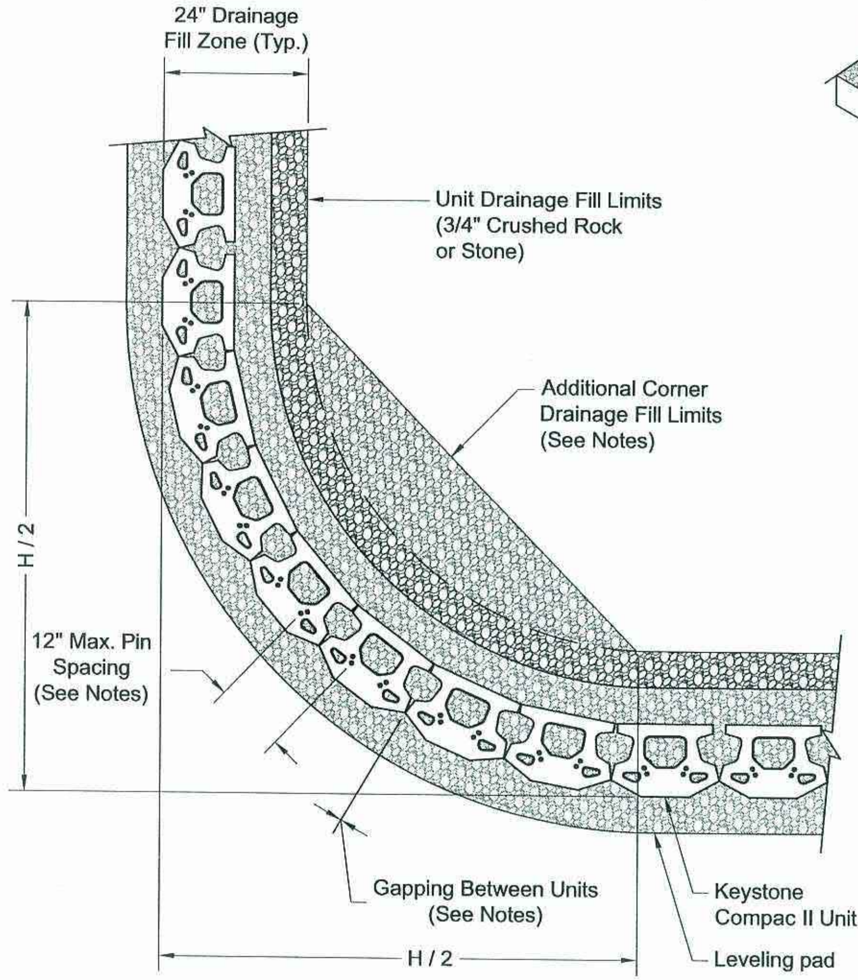
Wall Perpendicular Connection Plan



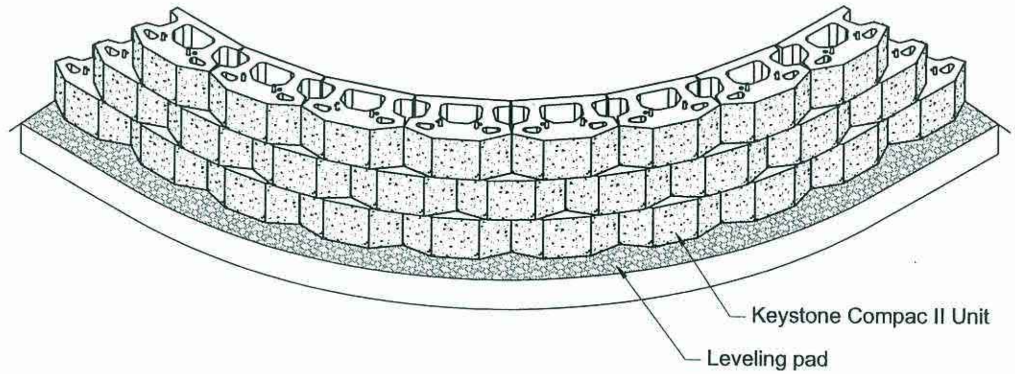
KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY

4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Wall Connection Details		Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details		Drawing No: 30
Scale: No Scale			



Typical Outside Curve Plan



Typical Outside Curve Isometric

Notes:

Keystone Compac II units shown.

Place base course units with a small gap between adjacent units. This gap will close with the placement of each additional course of Keystone units as the units batter, move or setback toward the point of radius. The rate of closure is controlled by the severity of the batter (i.e. a 1in setback will gap more quickly than a near vertical setback) .For best visual appearance, a maximum 1/2" to 3/4" gap is recommended. The distance between the pin holes on adjacent first course units should not exceed 12" on center.

Depending on wall height, radius and setback selection some binding between units may occur. If this prohibits proper placement of additional units, try one of the following:

- Trim unit corners using a masonry cold chisel or concrete power saw.
- Push units back and realign. If gaps exceed acceptable limits, re-drill new pin holes as needed using a 5/8"masonry bit and realign units to close gaps.

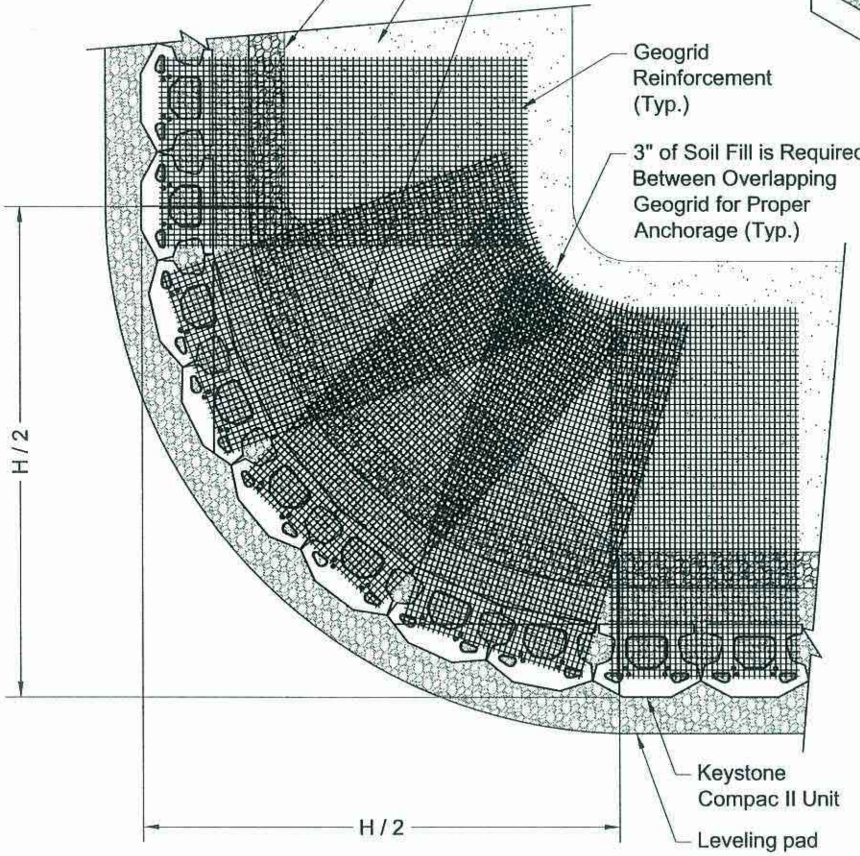
Minimum gapping will be required with a near vertical setback.

Additional crushed rock or stone drainage fill at outside wall curves to extend back from wall face each way at wall height / 2 (H / 2).

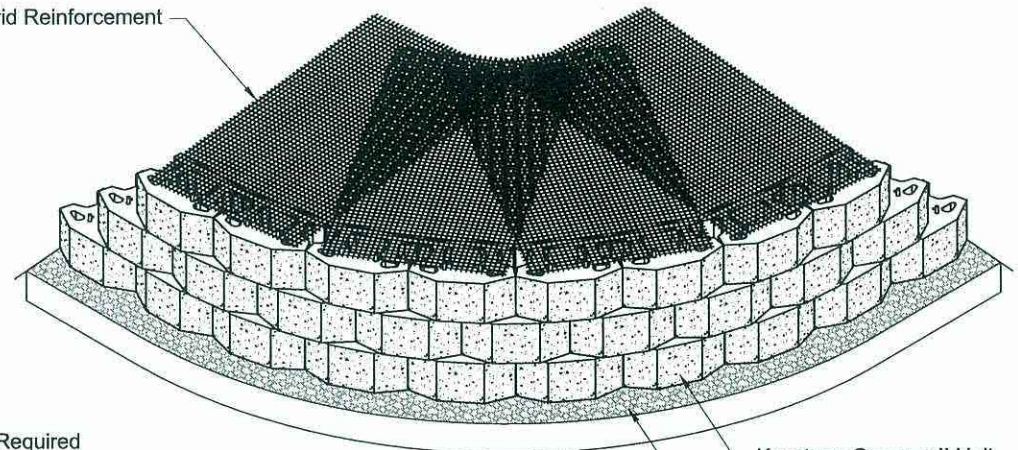
KEYSTONE® RETAINING WALL SYSTEMS — A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Compac II Unit Outside Curve Details		Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details		Drawing No: 31
Scale: No Scale			

Note:
Keystone Compac II units shown.



Typical Outside Curve Geogrid Plan



Typical Outside Curve Geogrid Isometric

Installation Notes:

Additional crushed rock or stone drainage fill at outside wall curves to extend back from wall face each way at wall height / 2 (H / 2).

Drainage zone and backfill materials should be placed compacted and up to the geogrid elevation and Keystone unit pins should be in place prior to geogrid installation.

Measure, cut and orient the geogrid, as per the engineers design and the geogrid manufacturers specifications on correct strength direction.

Place the geogrid over the Keystone unit pins and tension the geogrid by pulling it back away from the wall. Place a stake through the geogrid at the back to tension the geogrid in place.

Proceed with placement of additional Keystone units then drainage zone and backfill material. Starting at the wall and moving back away from the wall place the drainage zone and backfill materials over the geogrid to hold the geogrid in place under tension. After the backfilling process the tension stakes may be removed for reuse.

Compact the backfill materials up to the next wall elevation where a geogrid is to be place.

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Geogrid Installation on Outside Curve Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 32

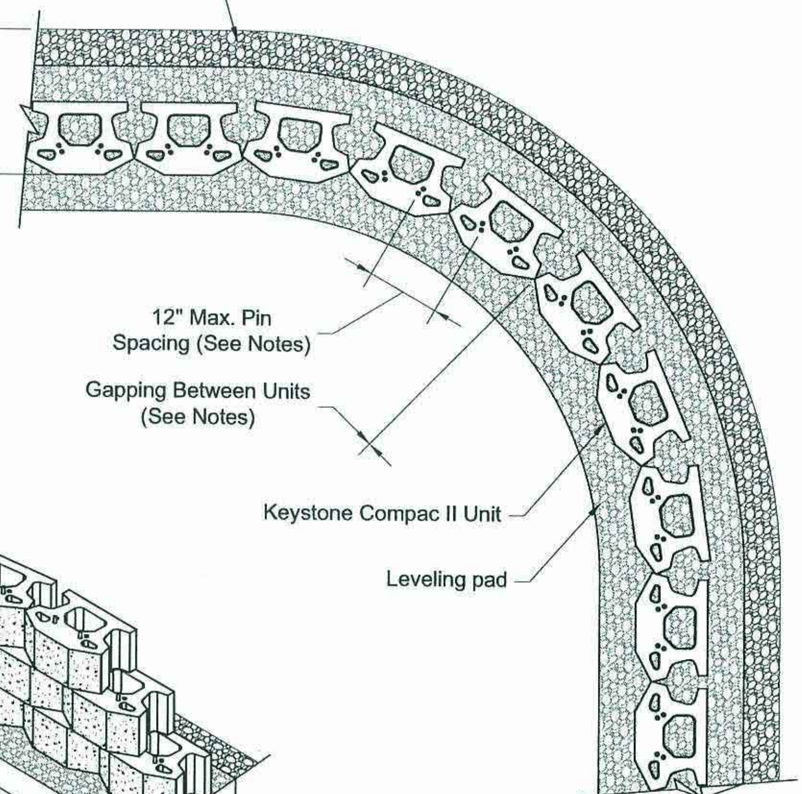
Notes:

Keystone Compac II units shown.

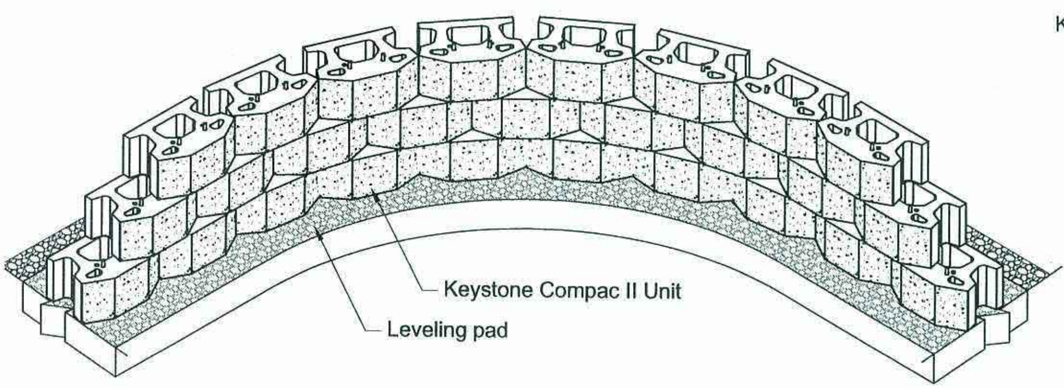
Gapping between the units will occur as the units batter, move or setback away from the point of radius. The rate of gapping is controlled by the severity of the batter (i.e. a 1in setback will gap more quickly than a near vertical setback).

The distance between the pin holes on adjacent first course units should not exceed 12" on center. For best visual appearance, a maximum 1/2" to 3/4" gap is recommended.

Depending on wall height, radius and setback selection some gapping between units may occur. If gaps exceed acceptable limits, re-drill new pin holes as needed using a 5/8"masonry bit and realign units to close gaps.



Typical Inside Curve Plan



Typical Inside Curve Isometric

The suitability and/or manner of use of any details contained in this document is the sole responsibility of the user. Final project specific designs shall be prepared by a licensed professional engineer.

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY

4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Compac II Unit Inside Curve Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 33

Installation Notes:

Drainage zone and backfill materials should be placed compacted and up to the geogrid elevation and Keystone unit pins should be in place prior to geogrid installation.

Measure, cut and orient the geogrid, as per the engineers design and the geogrid manufacturers specifications on correct strength direction.

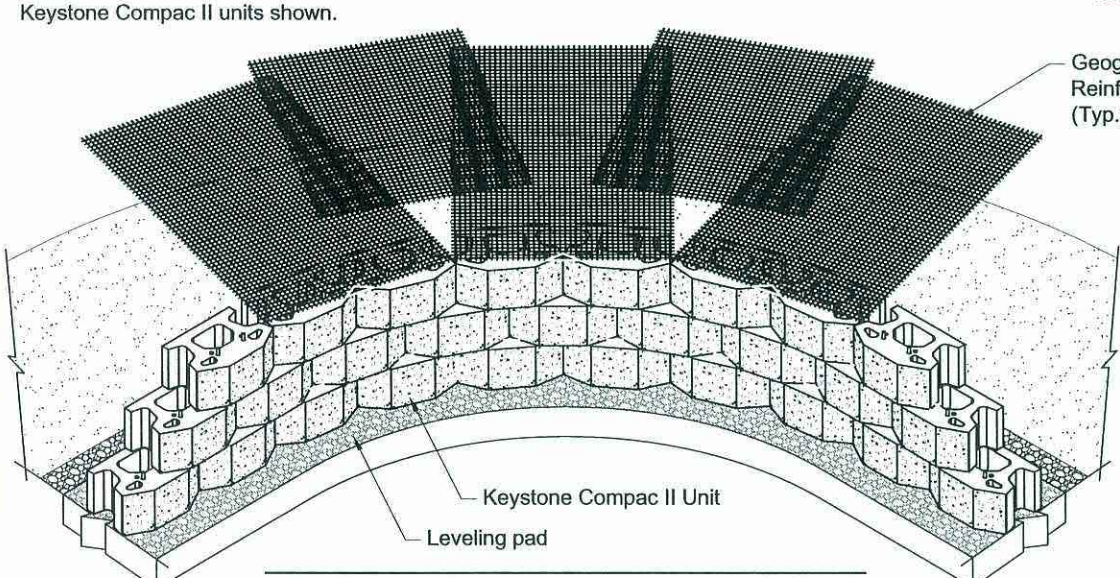
Place the geogrid over the Keystone unit pins and tension the geogrid by pulling it back away from the wall. Place a stake through the geogrid at the back to tension the geogrid in place.

Proceed with placement of additional Keystone units then drainage zone and backfill material. Starting at the wall and moving back away from the wall place the drainage zone and backfill materials over the geogrid to hold the geogrid in place under tension. After the backfilling process the tension stakes may be removed for reuse.

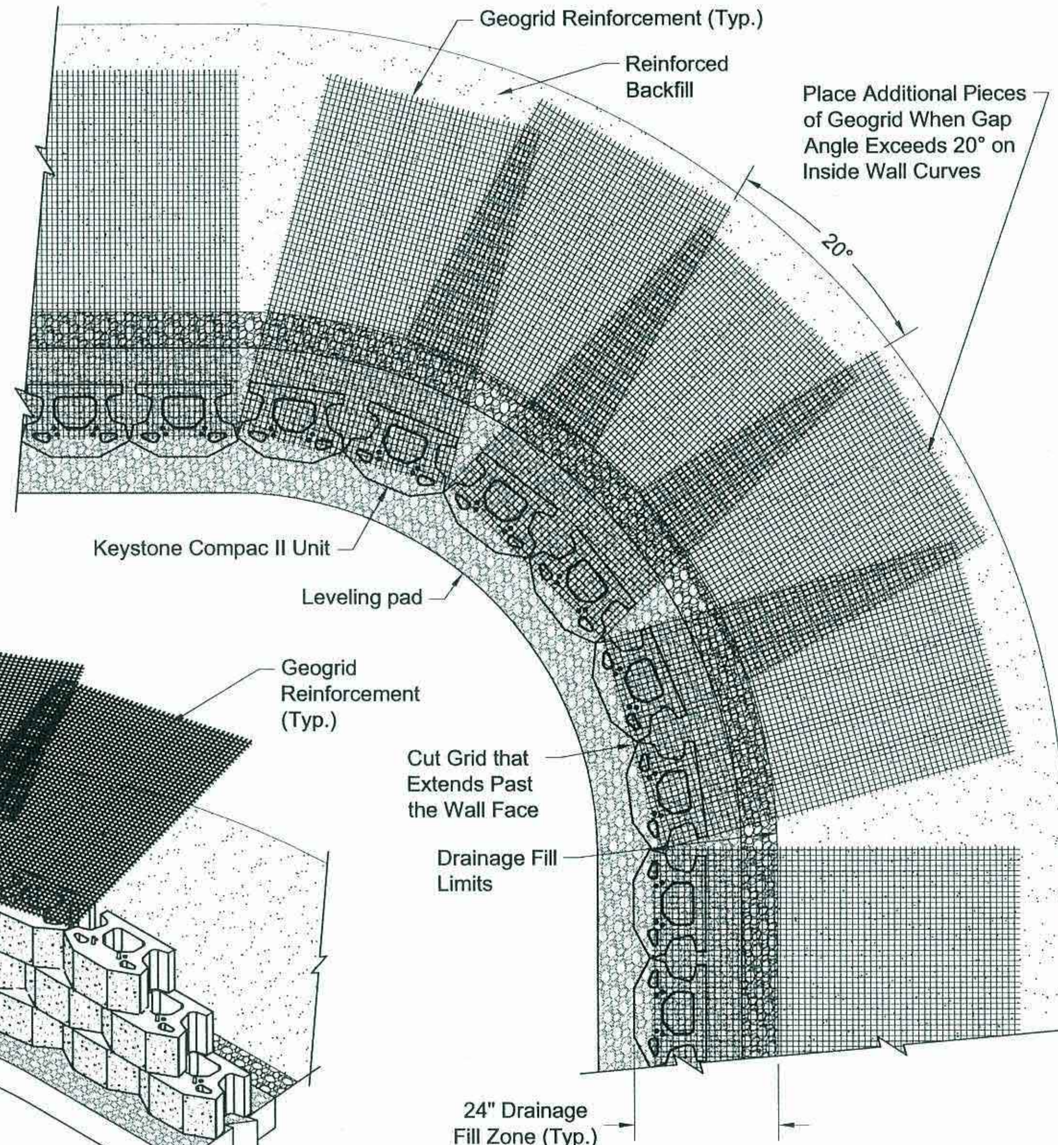
Compact the backfill materials up to the next wall elevation where a geogrid is to be place.

Note:

Keystone Compac II units shown.



Typical Inside Curve Geogrid Isometric



Typical Inside Curve Geogrid Plan

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Geogrid Installation on Inside Curve Details	Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details	Drawing No: 34
Scale: No Scale		

Notes:
Keystone Compac II units shown.

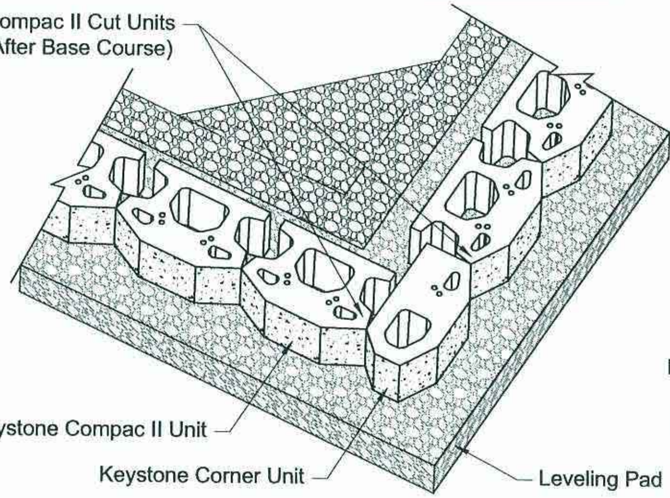
Full corner piece units to be used for each odd or even course vertically up the wall corner.

Due to corner perpendicular wall setback per course to maintain running bond course alignment cut the next unit back from each corner unit labeled "Compac II Cut Unit" at the adjoining edge of unit to the corner unit in both directions for proper wall joint alignment.

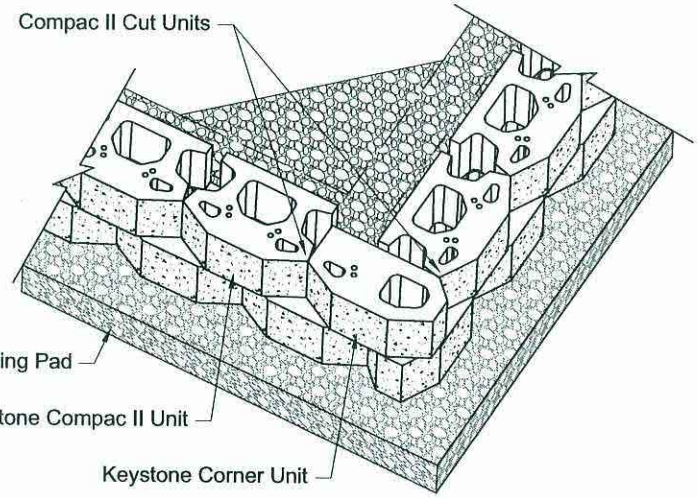
Additional crushed rock or stone drainage fill at outside wall corners to extend back from wall face each way at wall height / 2 (H / 2.).

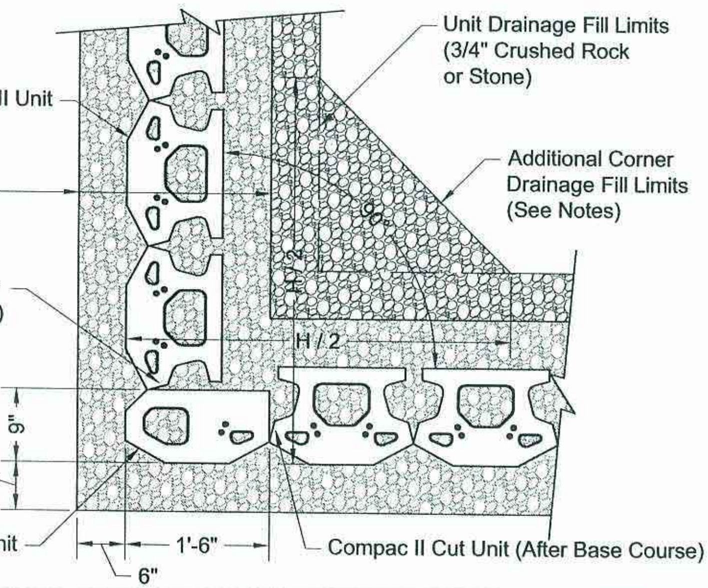
Geogrid reinforcement design as per engineer.

Odd Numbered Courses Iso View

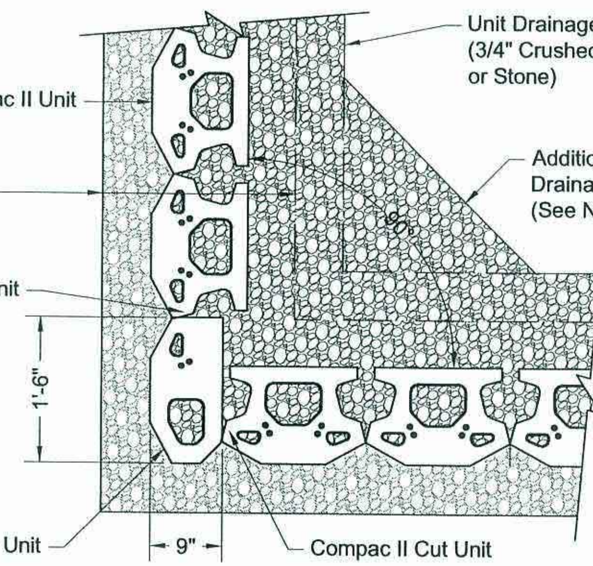


Even Numbered Courses Iso View





Typical Base and / or Odd Numbered Courses



Typical Second and / or Even Numbered Courses

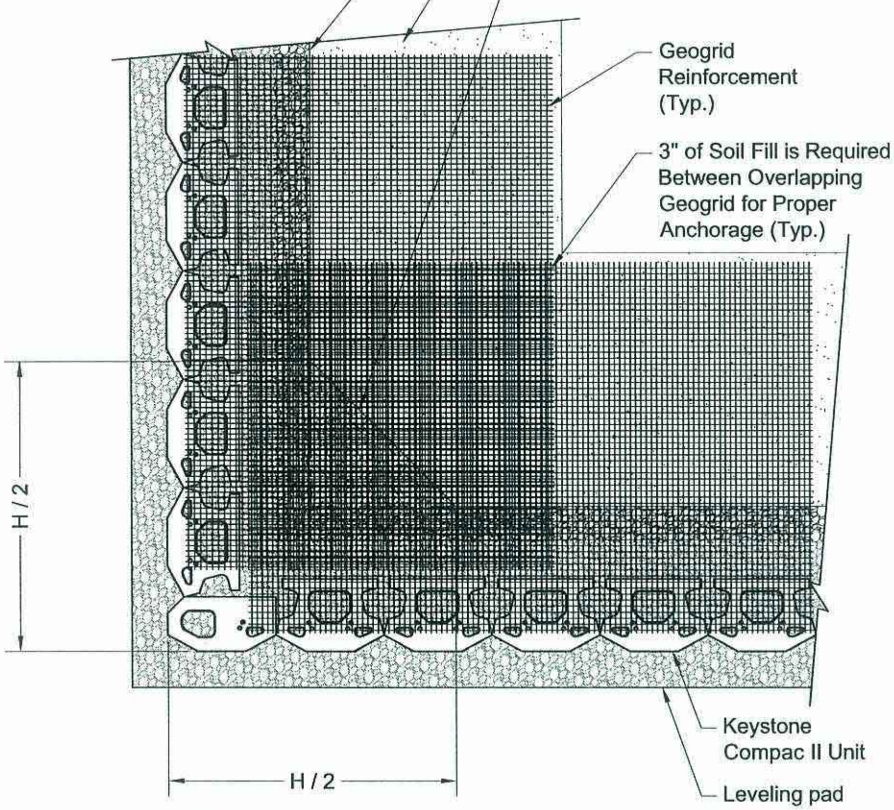
The suitability and/or manner of use of any details contained in this document is the sole responsibility of the user. Final project specific designs shall be prepared by a licensed professional engineer.

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY

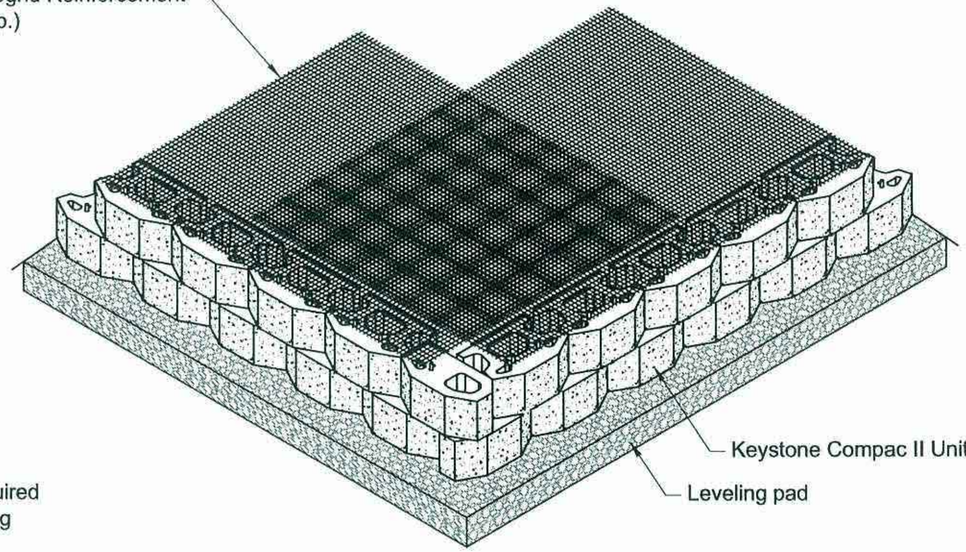
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Compac II Unit Outside Corner Details	Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details	Drawing No: 35
Scale: No Scale		

Note:
Keystone Compac II units shown.



Typical Outside Corner Geogrid Plan



Typical Outside Corner Geogrid Isometric

Installation Notes:

Additional crushed rock or stone drainage fill at outside wall curves to extend back from wall face each way at wall height / 2 (H / 2).

Drainage zone and backfill materials should be placed compacted and up to the geogrid elevation and Keystone unit pins should be in place prior to geogrid installation.

Measure, cut and orient the geogrid, as per the engineers design and the geogrid manufacturers specifications on correct strength direction.

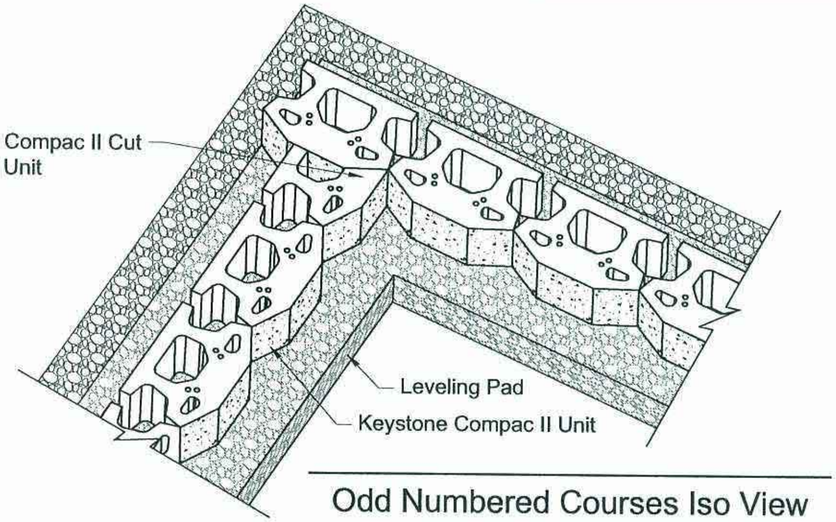
Place the geogrid over the Keystone unit pins and tension the geogrid by pulling it back away from the wall. Place a stake through the geogrid at the back to tension the geogrid in place.

Proceed with placement of additional Keystone units then drainage zone and backfill material. Starting at the wall and moving back away from the wall place the drainage zone and backfill materials over the geogrid to hold the geogrid in place under tension. After the backfilling process the tension stakes may be removed for reuse.

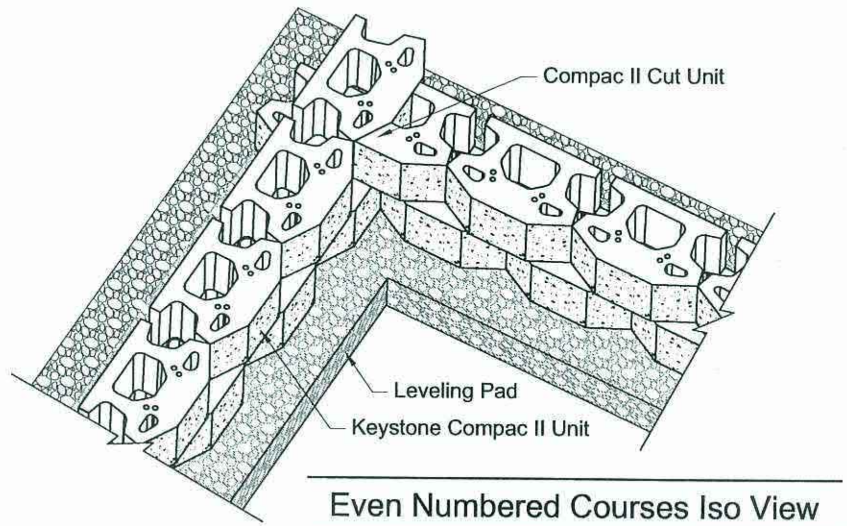
Compact the backfill materials up to the next wall elevation where a geogrid is to be place.

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

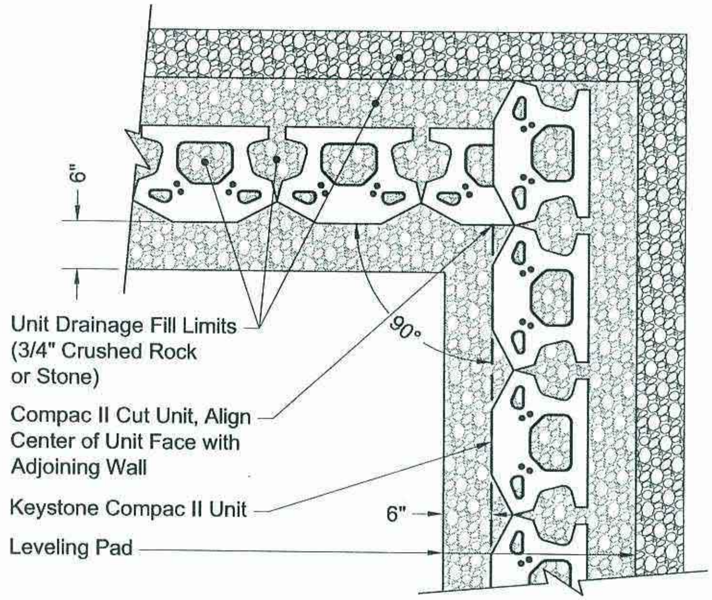
Designed By: RKM	Title: Geogrid Installation on Outside Corner Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 36



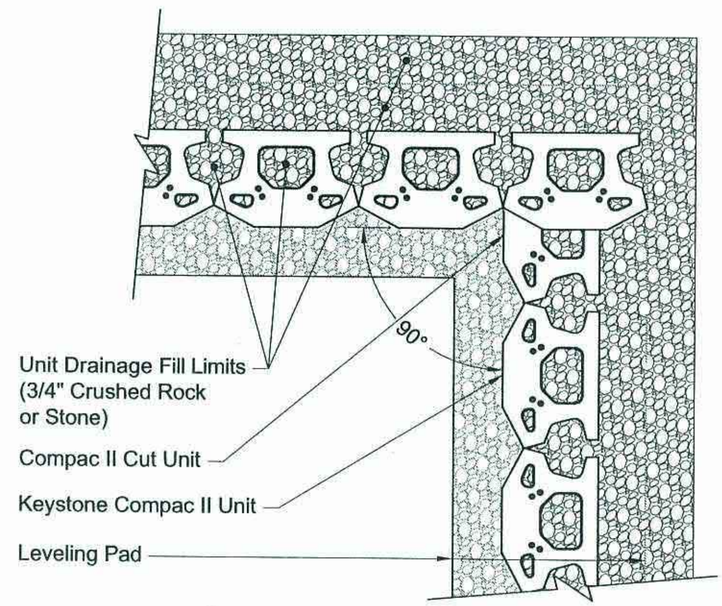
Odd Numbered Courses Iso View



Even Numbered Courses Iso View



Typical Base and / or Odd Numbered Courses



Typical Second and / or Even Numbered Courses

The suitability and/or manner of use of any details contained in this document is the sole responsibility of the user. Final project specific designs shall be prepared by a licensed professional engineer.

KEYSTONE® RETAINING WALL SYSTEMS A CONTECH COMPANY

4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Compac II Unit Inside Corner Details	Date: 04/2009
Checked By: CDM		
Scale: No Scale	Project: Keystone Retaining Wall System Details	Drawing No: 37

Installation Notes:

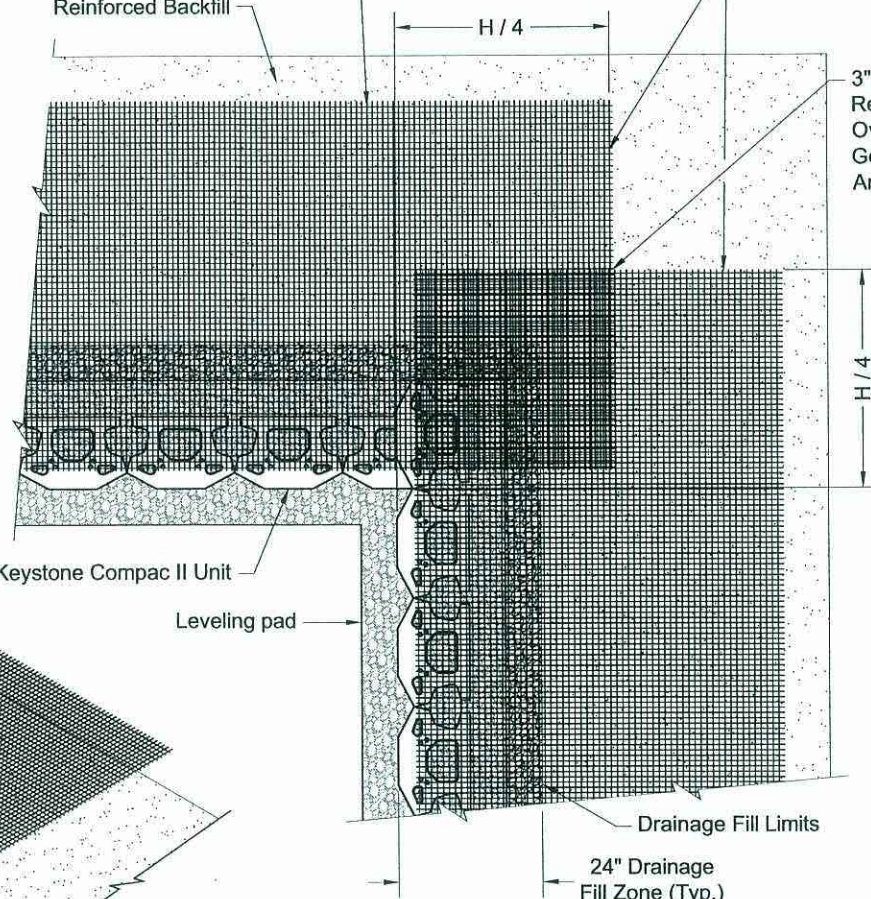
Drainage zone and backfill materials should be placed compacted and up to the geogrid elevation and Keystone unit pins should be in place prior to geogrid installation.

Measure, cut and orient the geogrid, as per the engineers design and the geogrid manufacturers specifications on correct strength direction.

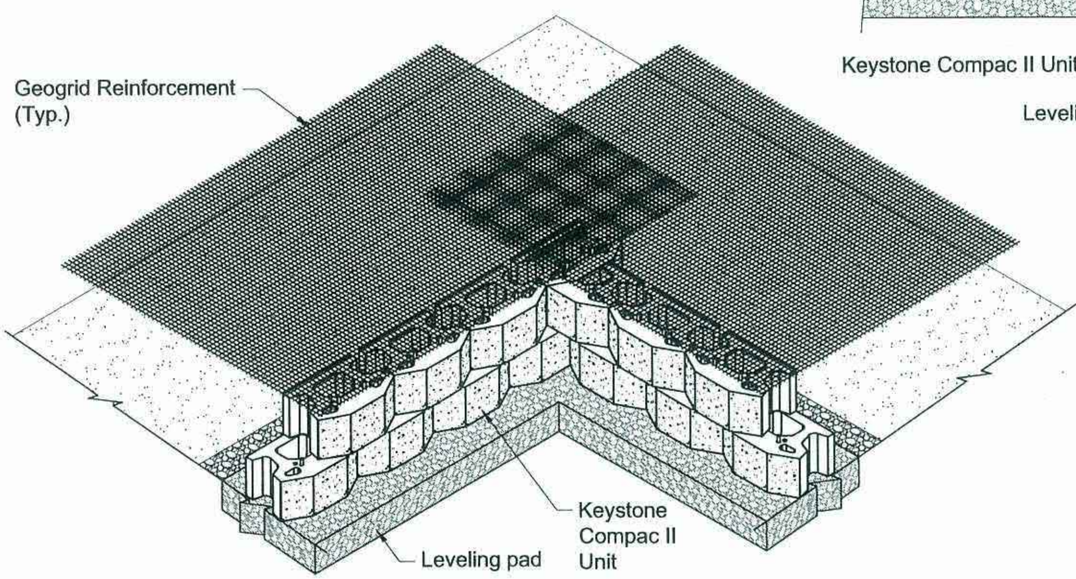
Place the geogrid over the Keystone unit pins and tension the geogrid by pulling it back away from the wall. Place a stake through the geogrid at the back to tension the geogrid in place.

Proceed with placement of additional Keystone units then drainage zone and backfill material. Starting at the wall and moving back away from the wall place the drainage zone and backfill materials over the geogrid to hold the geogrid in place under tension. After the backfilling process the tension stakes may be removed for reuse.

Compact the backfill materials up to the next wall elevation where a geogrid is to be place.



Typical Inside Corner Geogrid Plan



Typical Inside Corner Geogrid Isometric

Note:
Keystone Compac II units shown.

Extend geogrid the wall height / 4 (H / 4) beyond the adjoining wall face at inside wall corners.

KEYSTONE® RETAINING WALL SYSTEMS
A CONTECH COMPANY
4444 W 78th Street
Minneapolis, MN 55435
952-897-1040

Designed By: RKM	Title: Geogrid Installation on Inside Corner Details		Date: 04/2009
Checked By: CDM	Project: Keystone Retaining Wall System Details		Drawing No: 38
Scale: No Scale			

APPENDIX D

Quality Control Plan

Miragrid® and Basxgrid®

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 Ten Cate Nicolon conform to specification.

PERSONNEL

The Quality Control Lab consists of sufficient staff and testing equipment to properly conduct quality testing on Ten Cate Nicolon products. The Quality Manager determines "sufficient staff" based on testing needs. Resource requirements are regularly reviewed during Management Review.

TRAINING

A job description is maintained for each job classification. A training form is maintained for each employee in the QC Lab, detailing training activities. 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

Ten Cate Nicolon 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.

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 the sample is tested as delivered to meet 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

Physical Property	2XT-8XT	10XT-18XT	20XT-24XT	BasXgrid 11 & BasXgrid 12
ASTM D5261 Mass per Unit Area	Greater of every 10,000 yd^2 or 1 per lot	Greater of every 7500 yd^2 or 1 per lot	Greater of every 6500 yd^2 or 1 per lot	Greater of every 4800 yd^2 or 1 per lot
ASTM D6637 Tensile Properties by Single or Multi-Rib	Greater of every 10,000 yd^2 or 1 per lot	Greater of every 7500 yd^2 or 1 per lot	Greater of every 6500 yd^2 or 1 per lot	Greater of every 4800 yd^2 or 1 per lot
GRI GG-2 Junction Strength	Greater of every 10,000 yd^2 or 1 per lot	Greater of every 7500 yd^2 or 1 per lot	Greater of every 6500 yd^2 or 1 per lot	Greater of every 4800 yd^2 or 1 per lot
CEG	1/yr	1/yr	1/yr	1/yr
Molecular Weight	1/yr	1/yr	1/yr	1/yr

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 D-4354 Practice for Sampling of Geosynthetics for Testing
ASTM D-4873 Guide for Identification, Storage, and Handling of Geotextiles

CONTROL OF NONCONFORMING PRODUCT

Ten Cate Nicolon's 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

Ten Cate Nicolon 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 nonconformances to detect and eliminate potential causes of nonconformances

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.

Keystone License Agreement (Partial)

for

Production & Quality Assurance

Standard License agreement, paragraphs that apply to Quality Assurance:

...

11. PRODUCT QUALITY.

(a) Licensee shall manufacture the Product (including the Softsplit Product) in strict accordance with the specifications, directions, processes, technical assistance, and Know-How furnished by Licensor. Licensor may, from time to time, deliver new specifications, directions, processes, technical assistance, and Know-How to Licensee and Licensee shall begin to manufacture the Product in accordance with such new specifications, directions, processes, technical assistance, and Know-How no later than 30 days after receipt thereof, or within such time as Licensor may designate. Current manufacturing specifications, including Product testing procedures and quality controls required of Licensee, are set forth in SCHEDULE D of this Agreement, attached hereto and incorporated herein by reference.

(b) Licensor shall have the right, from time to time, to inspect those production and shipping facilities of Licensee directly related to the manufacture of the Product (including Softsplit Product) in order to monitor the quality of the Product. Licensor, at its sole expense, may from time to time remove Product samples in limited quantities from production and inventory for independent testing to specifications. Licensee agrees to cooperate with Licensor in such testing practices. Should such testing reveal deficiencies in the quality of the Product according to the specifications established by Licensor, Licensee, upon written notice by Licensor, shall promptly make the necessary adjustments in manufacturing methods to bring the Product into conformity to the specifications.

(c) Licensee shall provide to purchasers of the Product such instructions for installation and related documents, in the form provided by Licensor, as necessary to insure the proper installation of the Product.

SCHEDULE C

SPECIFICATIONS

A. REFERENCE STANDARDS

1. ASTM C1372-09 Standard Specification of Segmental Retaining Wall Units.
2. ASTM C140-11 Sampling and Testing Concrete Masonry Units
3. ASTM C1262-10 Standard Test Method for Freeze Thaw Durability.

B. CONCRETE UNITS.

1. Concrete wall units shall meet the requirements of ASTM C1372 and have a minimum required net average compressive strength after 28 days of 3000 psi (net). The concrete units shall have the required freeze/thaw protection with a maximum moisture absorption rate of 8%.

2. Testing shall be in accordance with ASTM C-140-11.

C. QUALITY CONTROL.

1. Compressive and absorption tests shall be conducted a minimum of twice per year by a recognized independent testing laboratory. Copies of test results shall be forwarded to KEYSTONE RETAINING WALL SYSTEMS, LLC upon receipt by Licensee. Licensee shall bear all expenses for testing and reporting.

2. Critical dimensions relative to mold wear shall be measured and reported a minimum of once per calendar quarter. Reports shall be completed by the production manager and forwarded to KEYSTONE RETAINING WALL SYSTEMS, LLC.

KEYSTONE®
RETAINING WALL SYSTEMS
A CONTECH COMPANY

Retaining Excellence™

Quality Control /Quality Assurance Recommended Procedures for KeySystem Projects under to Contract for Highway work

Quality Assurance/Quality Control Procedures

CONCRETE MANUFACTURING

KeyStone concrete units shall be manufactured to the requirements of ASTM C1372, or the specific project specifications for compressive strength and absorption. Testing shall be done in accordance with ASTM C140.

MINIMUM PERFORMANCE REQUIREMENTS:

Weight Classification	Lightweight	Medium Weight	Normal Weight
Density, pcf	<105	105 to 125	>125 pcf
Absorption-pcf	<18	< 15	>13

Table of concrete density & absorption (ref. ASTM C1372, Table 1 modified)

For all KeySystem projects the minimum compressive strength shall be 4000 psi at 28 days with absorption no greater than 5 percent.

MATERIAL REQUIREMENTS:

Raw Materials

Sand - clean, angular, durable conforming to the requirements of ASTM C1372.

Aggregate - clean, angular, , durable conforming to the requirements of ASTM C1372.

Cement - Type I, II or III conforming to the requirements of ASTM C1372.

Additive - efflorescence control as required.

Mix Design

As required to meet strength and durability requirements.

Finish Time

In most production facilities the finish times are approximately 2 seconds per cycle. Adjust finish time as required to achieve density and absorption requirement.

MANUFACTURING TOLERANCE:

Height:

All units shall be manufactured in accordance with the tolerance limits specified in ASTM C1372 except as noted:

* 1/16 inch from the published height.

Length/Width Tolerance:

All units shall be manufactured in accordance with the tolerance limits specified in ASTM C1372:

* 1/8-inch from the published dimension, with the exception of split surfaces shall be within 1/2- inch of published dimensions.

WEAR PART TOLERANCES:

* Side liners: 1/32-inch
* Kidney core: 1/32-inch
* Pin core: 1/64-inch

Tolerances shall be checked and recorded every 10,000 cycles or before the mold box is installed in the machine, whichever is less.

NOTE: Crucial end and face liners that affect the critical dimensions of the final product shall have the tolerances listed above. Other end and face liners may have larger tolerances as long as they do not effect the quality of the final unit.

PRODUCTION CHECKS:

Mold Check

* Check for bridging of mix between mold cores – 30-minute or less
* Check for broken cores or pin inserts – 30-minutes or less

Product Check

* Gage height – 30 minutes or less
* Gage length/width – 30 to 60 minutes
* Test pin hole for depth/alignment – 30 to 60 minutes

Unit Cleaning

Compressed Air- If possible, provide for compressed air right before the brushing process.

Brush- It is recommended that a clean brush be used to provide the final cleaning process to the manufactured units.

Wire- As an option, a taught wire may be placed in front of the brush to cut off any upward projections left over from the molding cycle

Curing

Curing time is based on the amount of time necessary for the unit to achieve adequate strength for handling and splitting purposes while also providing a continuing strength gain potential. Curing of units to be split shall be sufficient to allow the aggregate to split without a large percnetage of pulling. Normal curing is 24 hours.

Splitting

Splitter shall be of sufficient size and capacity to handle the size and compressive strength for the Keystone. Side knives are recommended, but not required.

Cubing

KeyStone units shall be placed on pallets of a design that will handle the weight of the cube. Pallets are normally made of wood and may be of a 3 or 4 stringer design.

PRODUCTION RECORDS

Records of production shall be kept for each day's production or lot, whichever is less. The reports shall contain, as a minimum, the following information:

Date of Manufacture

Mix Design

* cement content as a percent of dry weight of aggregate
* type of cement (Type I or Type III)
* water content
* aggregate – coarse fraction and fine fraction, fineness modulus
* Additives – type (efflorescent control, plasticizer, etc.) and amount per 100-lbs of cement

Finish time

* Specify size of mold box and finish time per cycle
* Actual finish time (seconds)

Height & Width Tolerance check

* Record – "OK," or note measurements if out of tolerance with comment on location and type of tolerance discrepancy.

Mold Box Tolerance

* Record measurements of critical wear pieces to within 0.05mm ($^1/_{64}$in)
* Record approximate number of cycles since major rebuild or installation of new wear parts.

Design Quality Control/Quality Assurance Systems

General

Keystone is responsible for the simple external and internal stability of the wall system. Design control is the responsibility of the Keystone Director of Engineering. The Director maintains a project list, and status that is updated weekly.

Design Planning

The Director of Engineering initially receives projects. He does a preliminary review of the scope of work and then assigns the work to the engineer and draftsmen experienced in similar work. The overall scope of the work is reviewed verbally and special conditions pointed out on the plans or in the specifications.

Any special software or idea sketches are made available to the assigned engineer. The engineer prepares the preliminary drawings and supporting calculations.

Organizational Interfaces

Keystone's engineers are located in adjoining offices and are free to exchange ideas and/or solve design issues in small our large groups.

Keystone's engineers also resolve many questions by direct contact with the owner or his engineer. All communications are documented in the job file. Communication records contain as a minimum:

- Date of correspondence
- Type of correspondence: verbal, facsimile, letter, email, etc.
- Person or persons involved in correspondence, including name, title, job responsibility
- Brief description of topic or specific items discussed.
- Detailed.description of agreed course of action.
- Comments on actions to be taken and follow-up actions required.

Design Input

Design parameters are completed from a checklist, documented and kept in the job file. Design items that are addressed shall include as a minimum:

- Governing codes and regulatory agencies are identified, documented and filed in the job file.

- Geotechnical and other engineering properties of materials are identified and documented in the job file.
- Loading characteristics are identified, documented and filed in the job file.
- Geometries are identified, documented and filed in the job file.

Design Output

Plans are generated containing the information as identified by the project specifications. As a minimum these include input parameters furnished, wall profiles with geogrid layout, geogrid lengths, stationing, finished grade, leveling pad elevations, top of wall elevations, utilities or structures in the reinforced zone, slip joints, wall bearing loads, and any cast-in-place facing attachments. Plans include typical cross sections for each separate condition on the project. Detail sheets detail KeySystem II components. A registered professional engineer seals plans.

Calculations are furnished for every change in reinforcement length and/or basic external loading condition. Calculations include a complete summary of input parameters. Calculations identify acceptance criteria and criteria for proper functioning of the system. A registered professional engineer seals calculations.

Design Reviews

Preliminary plans are reviewed by an engineer other than the designer and verified by initialing on the plans. If plans are changed as a result of the review, they are modified by the designer and resubmitted, reviewed and verified by initialing.

Input and calculations are reviewed by an engineer other than the designer and verified by initialing the cover. If calculations are changed as a result of the review, they are modified by the designer and resubmitted, reviewed and verified.

The Director of Engineering or designated Senior Engineer shall review the final plans prior to delivery to client. The review shall include, as a minimum, design checks for :

- Accuracy
- Conformance to project specifications and local building codes
- Format and completeness
- Technical and contract requirements

The Director of Engineering or designated Senior Engineer shall initial all plans signifying review and date of review. All plans for final design shall be sealed with the applicable Professional Engineers seal for the state where the project is located.

Design Changes (Owner)

If the Owner or Owner's Representative reviews and comments on design drawings or calculations, the design comments shall be reviewed by the design engineer for applicability and technical significance. Design changes shall be reviewed with the Owner or Owner's Representative for understanding prior to incorporating into the design submittals. All communications shall be documented as described above.

Once a set of plans have been issued, all revisions to the plans shall be clearly marked on the drawing and noted in the revision box on each plan sheet. Clouding shall mark revisions. Each marked area shall be referenced to the revision number noted in the revision box of the drawing sheet.

If plans are changed they modified by the designer and again reviewed and verified by initialing.

Revision Notation

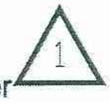
Initial Revision

All revisions to plans shall be marked as follows:

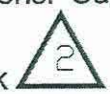
- Deletion: The area where items were deleted from the drawings shall be clouded  and marked with the reference revision number. The revision number shall be enclosed in an open triangle. 
- Insertion: The items added to a drawing shall be clouded and marked with the reference revision number as noted above.
- Revision or change to an existing item on a drawing: The changes shall be made to the specific items on the drawing. The area shall be clouded and marked with the reference revision number.

Multiple Revision

Second or multiple revisions to the same set of plans or calculations shall be noted as follows:

Prior revision marks: all prior revision cloud marks  shall be removed. The revision mark number 

shall be left in place.

New revisions: New revisions shall be noted as deletions, additions, or revisions as detailed above in Initial revisions. Subsequent revisions shall be marked with the appropriate revision mark 

. Revisions shall be noted in the revision text box on each respective drawing page.

Superceded Drawings

Paper/Vellum copies

All drawings revised by subsequent revisions shall be marked "Superceded __/__/__" with the date of issue of the revised drawings. The initials of the responsible engineer shall be placed next the to the Superceded notation. Superceded drawings and calculations shall be filed with the project for a permanent record of project history.

Electronic copies

CADD files or other electronic files of project records shall be saved as separate documents in a revision directory or separate electronic storage media (diskette, CD, tape, etc.). Notation to the revision or superceded document shall be made part of the permanent electronic file.

Records

Keystone maintains permanent records of all projects designed. The records include plans, specifications, correspondence and interoffice communications. One copy of each issue of drawings and calculations shall be kept on file. One copy of superceded drawings and calculations shall be kept on file.

After a set of drawings has been revised, written notification shall be sent to **all** plan holders. New drawings shall be issued. The title sheet shall have a note indicating those sheets that have been revised. Revision sets may be the whole plan set, or the title page and only the revised pages.

KeySystem II Construction Quality Assurance/Quality Control

A. Field Quality Assurance - The Owner shall engage inspection and testing services, including independent laboratories, to provide quality assurance and testing services during construction. As a minimum, quality assurance testing should include foundation soil inspection, inspection for the need for any additional drainage, soil and backfill testing, verification of design parameters, and observation of construction for general compliance with design drawings and specifications. This does not relieve the Contractor from securing the necessary construction quality control testing during construction.

B. Field Quality Control - The Contractor's quality control testing and construction inspection services shall only be performed by independent, qualified and experienced technicians and engineers. The Contractor's quality control testing, as a minimum, shall include:

1) Field density testing

a. Subgrade: one test for every 2500 square feet of subgrade.

b. Reinforced Backfill: one test for every 2500 square feet per lift with a minimum of one test for every other lift.

c. Retained and Foundation Soil: per Section 02200.

2) Laboratory Moisture Density - minimum one test per soil type.

3) Gradation Analysis

a. Unit Fill: one test per 500 CY

b. Backfill: one test per 1000 CY

4) Field Observations

a. Leveling pad installation

- Correct location
- 6 inch minimum thickness or as specified in the construction documents
- Confirm minimum embedment and elevations shown on plans with actual field conditions

b. Unit placement

- Running bond configuration
- Pin placement and alignment

- Check units for level, side to side, front to back

c. Reinforcement placement

- Correct length & strength for location
- Reinforcing placed over steel pins and pulled toward fill

d. Fill placement

- Proper fill material in conformance to design and specification requirements
- Lift thickness control

e. Alignment

- Check alignment visually and by measure every reinforcement lift (approx. 2 feet)
- Adjust alignment as necessary

I. Purpose

This manual provides installation procedures and guidelines for the KeySystem™ II retaining wall system. The system is specifically designed for use in the highway and heavy construction industries.

KeySystem II retaining walls are designed, supplied and technically supported by KeyStone Retaining Wall Systems, Inc. and its worldwide network of licensees. When KeySystem II is specified, a complete retaining wall system is engineered and supplied to meet site specific conditions. Through local licensees, KeyStone furnishes designs, materials and can suggest local experienced installation contractors. KeyStone also provides on-site start up assistance and training for the contractor and agency inspectors. Additional support is available upon request.

II. Responsibilities for Construction Compliance

A) Contractor

The contractor is responsible for providing construction in accordance with the contract documents, plans and specifications. The contractor, at a minimum, is responsible for:

a) verification of line and grade, and other physical features.

b) verification that the latest issue of approved plans and specifications for construction are being used.

c) verification that the correct materials are delivered and in sufficient quantity to complete the work.

B) Engineer or Owner's Representative

The engineer or Owner's designated representative is responsible for the enforcement of the contract documents, plans and specifications.

C) Keystone Technical Representative

KeySystem II technical representatives may assist the contractor in scheduling material deliveries and advising the contractor and inspection staff on recommended construction procedures within the guidelines of this manual, contract documents, plans and specifications. The representatives are available at the start of the wall construction for assistance and training of the contractor and agency inspectors, and thereafter, only as requested and necessary.

III. Materials, Handling, Equipment and Supplies:

A) KeySystem II Supplied Materials and Accessories

1) KeySystem II Units are of two types.

a) The Keystone Compac II unit is:

- 8 inches high
- 18 inches wide

- 12 inches deep

b) The Cap unit is:

- 8 inches or 4 inches high
- 18 inches wide
- 10 -12 inches deep

2) KeyStone Connection Pins - Connection pins are pultruded fiberglass, 1/2 inch diameter x 5 1/4 inches long.

3) Mirafi Miragrid Reinforcement Elements – Miragrid geogrids are packaged in rolls which are 6 feet or 12 feet wide by 200 feet long. Each roll is marked with the Miragrid type and is packaged in plastic sheeting to protect the roll from environmental factors.

B) Handling KeySystem II Materials

1) KeySystem II Units are delivered on pallets to be unloaded and stored by the contractor. The transport unit must have firm ground upon which to travel and the pallets must be placed on a reasonably level and stable base. Pallets can be handled by forklifts or properly rigged double slings. Empty pallets should be stored by the contractor for pickup by the KeyStone supplier.

2) The Connection Pins are delivered with the KeyStone Engineered Units. These pins should be stored in a secure, dry location to avoid loss, theft or damage.

3) The Miragrid geogrid soil reinforcing is packaged in rolls of one hundred square yards. The rolls are labeled with the type of Miragrid and production lot number.

4) Additional information and guidance:

a) It is the contractor's responsibility to verify the quantities and general condition of the materials before accepting delivery. The contractor shall immediately notify the KeySystem II Representative of any shortages or damage to the materials and note the shortages or damage on the delivery ticket.

b) The materials are F.O.B. the job site with a two hour off-loading allowance.

C) Contractor Supplied Materials

The following tools are recommended, but should not be limited to this list. Conditions may require other equipment, tools and material.

1) Tools

a. Four foot and two foot levels
b. Tape measure
c. Transit/Level
d. Dead blow/Sledge hammer
e. Masonry saw
f. Carpenter hammer
g. Masonry chisel
h. String line
i. Shovels
j. Broom
k. Shimming Material
l. Caulk gun

2) Materials
   a. Leveling pad material – Concrete or granular
   b. Leveling pad forming material for concrete
   c. Drainage fill
   d. Reinforced fill
   e. Random fill

3) Equipment:
   a) Forklifts, small cranes, or boom trucks capable of lifting a minimum of 11/2 tons to handle the palletized units.
   b) Small dozer, small front end loader or skid steer equipment to deliver and place drainage fill, reinforced fill, and common fill.
   c) Plate compactors and a smooth drum vibratory roller (54 in) to compact the backfill.
   d) Labor and supervision for wall construction.

IV. Preparatory Work for Wall Construction

A) Preconstruction Checklist.
   1) Preconstruction meeting.
   2) Verify approval of drainage fill and structural backfill material.
   3) Verification of foundation soils and conditions.
   4) Verify lines and grades by survey.
      a) Verify wall location offset stakes to include wall batter

B) Review of site conditions
   1) The construction drawings should be reviewed to confirm:
      a) Leveling pad elevations and location are correct and do not interfere with other site utilities or right-of-way
      b) Reinforcing layout should be reviewed to confirm there is sufficient room for a safe excavation for installation of reinforcing.

C) Wall Excavation

Unclassified excavation shall be in accordance with the specification and in reasonably close conformity to the construction limits shown on the plans. Evaluation and approval of foundation suitability is the responsibility of the engineer. Any foundation soils found to be unsuitable by the engineer shall be removed and replaced according to the specification.

D) Foundation Preparation

The foundation for the structure shall be graded level for a width equal to the length of the KeySystem II units and reinforcing elements, plus one foot, or as shown on the plans. Prior to wall construction, except where constructed on rock, the foundation shall be proof rolled and compacted with a smooth drum vibratory roller.

V. Wall Construction

A) Leveling Pad Installation

1) The leveling pad may consist of well graded ¾" crushed stone or unreinforced concrete.

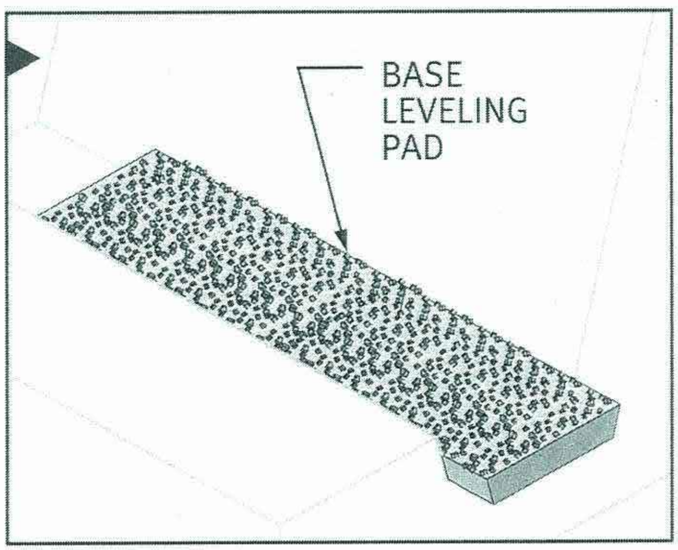
2) The leveling pad is installed starting at the lowest elevation and working up.

3) The leveling pad shall be 6 inches thick and 2 feet wide. Leveling pad steps shall be in increments of 8 inches.

4) The KeySystemII units are 8 inches +/- 1/16 inch. All leveling pad steps must accurately reflect that height increment; therefore, the contractor should verify the unit height before construction of the leveling pad.

5) The leveling pad shall be within 1/8" of plan elevations. Any minor imperfections (e.g. dips, ridges, etc.) can be corrected by grinding, or with a thin layer of sand or mortar.

6) Concrete leveling pads shall be cured a minimum of 24 hours before placement of wall units.



B) First Course of KeySystem II Units

1) Proper placement of the first course of units is critical to the proper installation, alignment and appearance of the wall. Proper alignment may be achieved with the aid of a string line to align the back of the units or the pins placed in the units. Start building from the lowest elevation of the wall.

2) The first course shall be placed in full contact with the leveling pad and checked for proper elevation, alignment and levelness from front to back and side to side. Adjacent units shall also be checked for levelness from unit to unit. Maintain the 12 inch pinhole spacing between units.

FIGURE 1.04

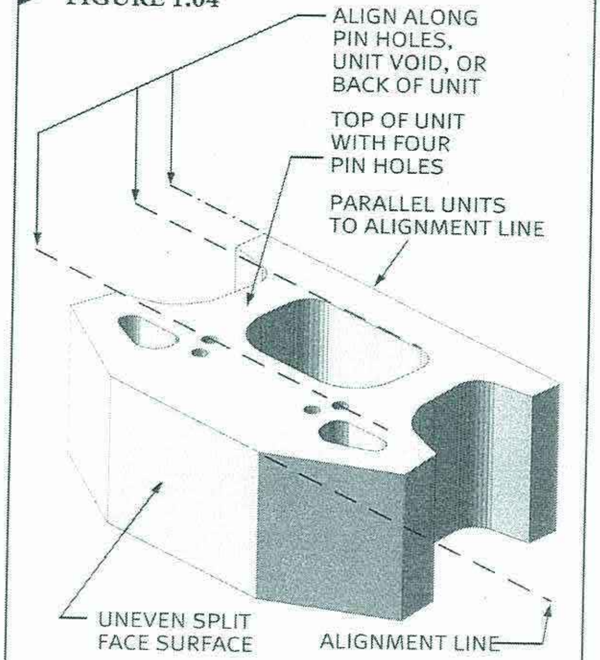
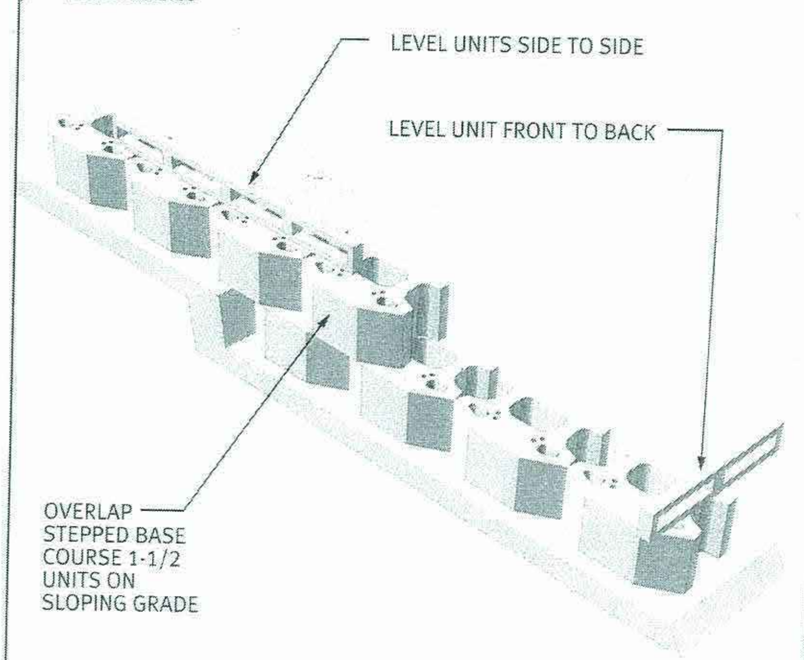
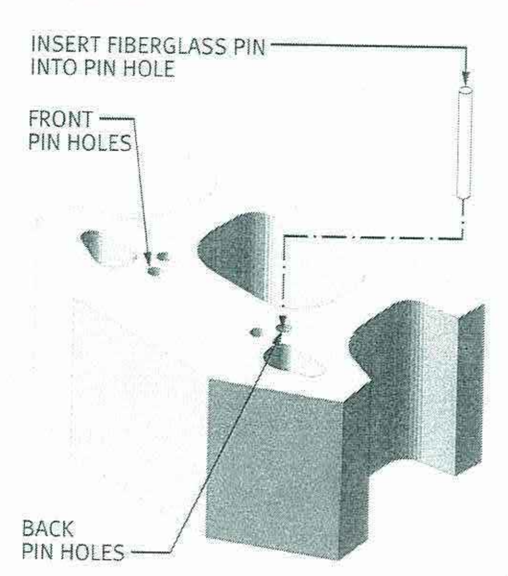


FIGURE 1.05



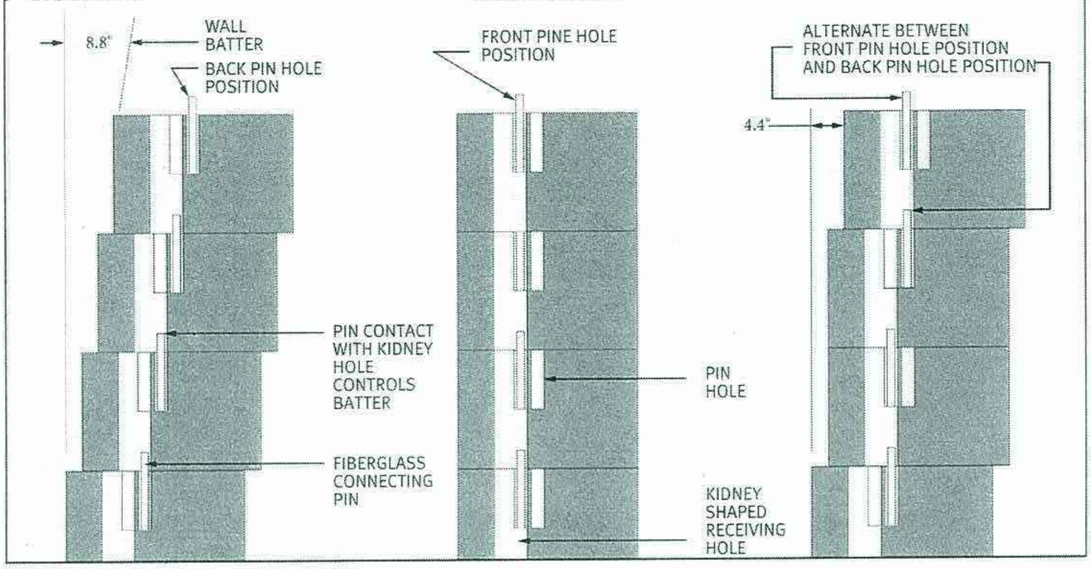
3) Install the alignment pins in the holes in the top of the units.

FIGURE 1.06



4) The alignment pins shall be placed in the front pin hole, rear pin hole or the combination of alternating front and rear pin holes required to achieve the wall batter as required by the design drawings.

FIGURE 1.07



5) Backfill and compact behind the first course before installing other courses.

B) Unit, Reinforcement and Backfill Placement

1) Subsequent courses of units should be stacked one high, backfilled, and placed so that complete in-filling is achieved.

2) Clean all excess material from the top of the units prior to installing the next course. Install each succeeding course so that the units bridge the two units below it.

FIGURE 1.08

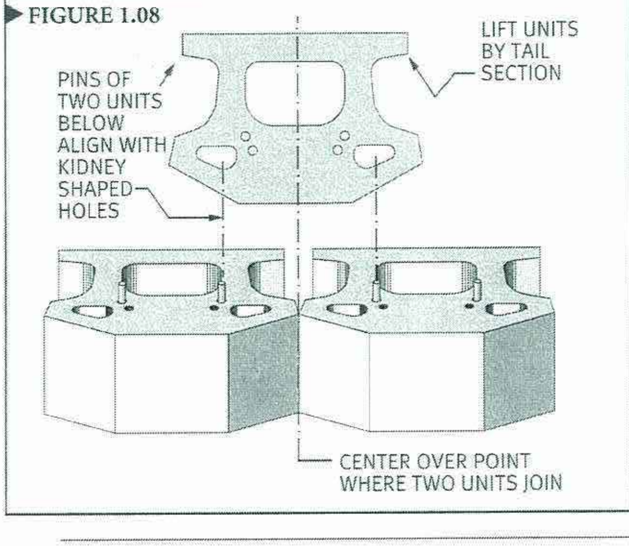
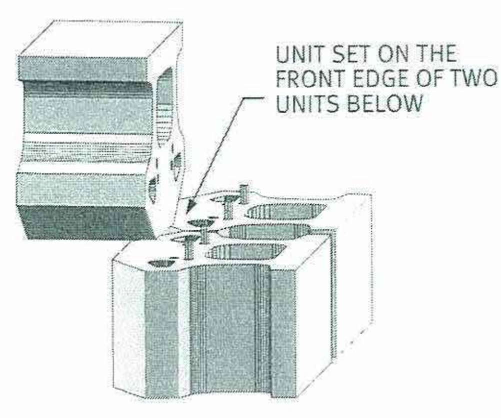


FIGURE 1.09



Place the unit's pin receiving holes so that they cover one pin from each of the two lower units.

Slide the unit forward toward the exposed wall face until restrained by the pins in the previous course. Before backfilling the course, check and correct the alignment of the units.

FIGURE 1.10

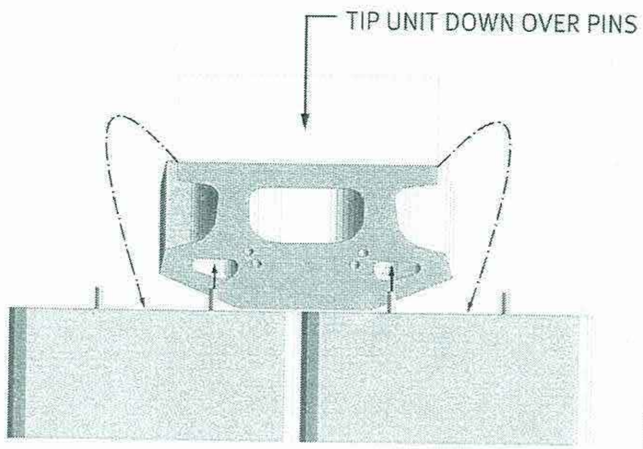
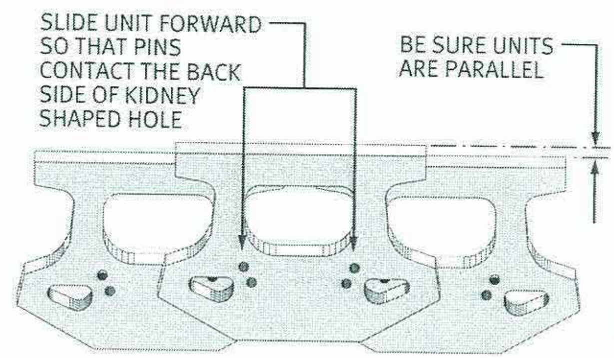


FIGURE 1.11

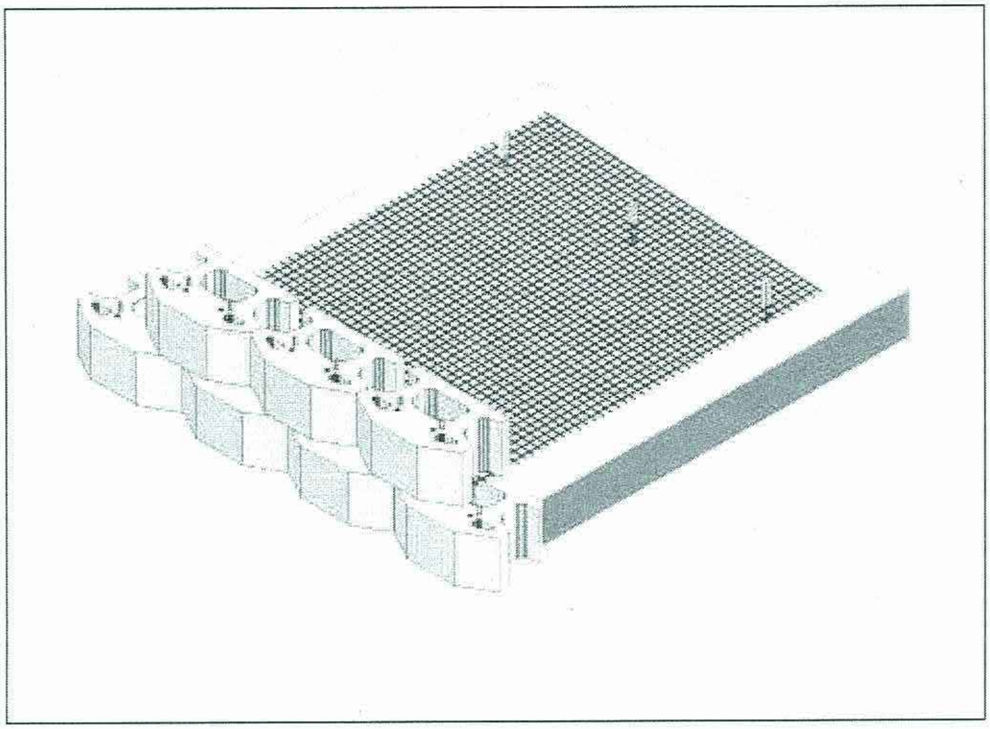


3) Fill all voids in and between the units and for 12 inches behind the units with specified drainage fill. Place the specified reinforced fill behind this course and compact to the specified density.

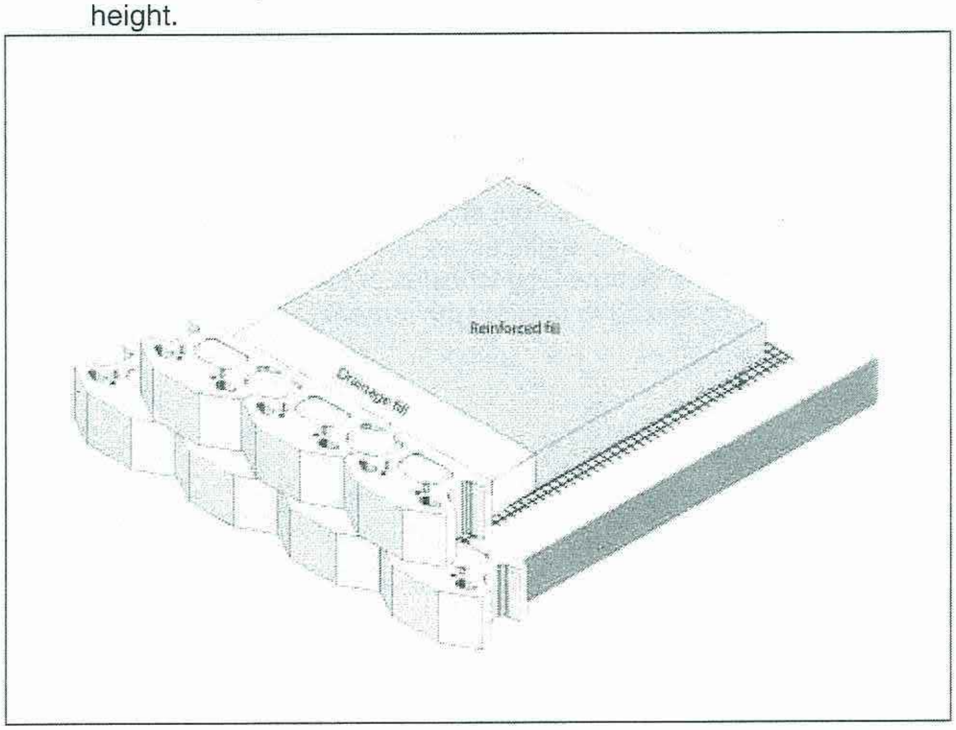
   a) The maximum lift thickness shall not exceed 8 inches. The contractor shall decrease this lift thickness, if necessary, to obtain the specified density.

4) At each reinforcement level, the reinforced fill shall be placed to the level of the connection to plus 2 inches before placing the soil reinforcement.

5) The soil reinforcement shall be placed over the alignment pins. The next course of units is placed as directed above. The geogrid is then pulled taught to remove any wrinkles or folds and anchored with small piles of soil or staked to prevent movement during the backfill placement.



6) The soil reinforcement shall then be covered with 6 inches of reinforced fill for protection. The top of the unit is swept off and the next unit placed and aligned. The drainage and reinforced fill are then placed in 8 inch lifts and compacted. Repeat this procedure to the extent of the wall height.



a.) Structural and drainage fill shall be placed, spread and compacted to avoid any damage or disturbance of the wall materials or misalignment of the facing units or reinforcing elements. As reinforced fill material is placed behind the units, the units are maintained in position by means of the connection pin.

b.) Reinforced fill shall be compacted to 95 percent of the maximum density as determined by AASHTO T-99, Method C or D (with oversized corrections as outlined in Note 7 of that test). For reinforced fills, a method of compaction consisting of at least 3 passes by a heavy roller shall be used.

c.) The moisture content of the reinforced fill material prior to and during compaction shall be uniformly distributed throughout each layer. Reinforced fill materials shall have a placement moisture content from 3 percent less than to the optimum moisture content. Reinforced fill, with a placement moisture content in excess of the optimum moisture content, shall be removed and reworked until the moisture content is uniformly acceptable throughout the entire lift.

7) Reinforcement elements shall be placed perpendicular to the face of the wall. Prior to placement of the reinforcing elements the reinforced fill shall be compacted in accordance with the specifications.

The reinforcement elements can be overlapped in curves with a 3 inch soil separation between layers. The reinforced fill is then placed on top.

8) Alignment and batter should be checked at each coarse. Corrections to alignment shall made as required before proceeding. Wall facing vertical tolerances and horizontal alignment shall not exceed 3/4 inch when measured with a 10 foot straight edge. During construction, the maximum allowable offset in any unit joint shall be 3/8 inch. The overall vertical tolerance of the wall (top to bottom) shall not exceed 1 1/4 inch over 10 feet. If out of tolerance, conservative measures of shimming may be applied.

a) Shimming is accomplished by running a resilient material between the units around the connection pins. This can be a 1/4 inch rope, geogrid strips, strips of fiberglass shingles or other approved materials.

9) Tracked and rubber-tired construction equipment shall not operate directly on the reinforcing elements. Turning shall be minimized to prevent damage and keep the reinforcing elements from pushing the units out of alignment.

a) Only lightweight, hand operated, compaction equipment will be operated within 3 feet of the tails of the units. Compaction shall be achieved by at least 3 passes of a lightweight mechanical tamper, roller or vibratory system.

b) In the 3 foot transitional zone, between the unit, drainage fill and the reinforced fill, effort should be made to compact the fill in lifts.

Reduction in compaction effort in this zone may be required to maintain wall alignment.

10) At the end of each day's operation, the contractor shall slope the backfill away from the wall face to rapidly direct runoff away from the wall. In addition, the contractor shall not allow surface runoff from adjacent areas to enter the wall construction site.

C) Wall Cap and Coping Installation

1) Cap - Position the KeyStone Cap Unit in place. The cap units shall be attached to underlying units by means of a 10 inch dowel bar epoxyed 2 inches into the bottom of the cap unit and extended into the core area of unit(s) below. The dowel bar is grouted into the core. An alternative method is to adhere the cap to underlying units by means of an all-weather adhesive or epoxy intended for concrete to concrete adhesion. The adhesive or epoxy shall have a 10 year warranty.

2) Coping with Traffic Barrier - Install the KeySystem II wall per general installation instructions. Set and secure forming materials along the top course of the KeySystem II wall using standard forming procedures. If the design requires an overhanging coping, form the edge using an L-shaped galvanized steel or plastic forming material. Fasten this material to the KeySystem II wall. Pour and finish the traffic barrier per engineered design. Insert control joints at a maximum of 10 feet on center, along the length of the coping, or as specified by the engineer. These control joints shall align with the vertical joints of the KeySystem II units as they exit the coping.

D) Clean Area and Remove or Dispose of Any:

1) broken or unused units

2) extra connection pins

3) extra reinforcing materials

4) on-site or imported fill materials

Appendix A

Construction and In-service Structure Problems

Causes, Effects and Repairs

Construction Alignment Effects and Causes

Effect

1. Horizontal Alignment
   a. Bulging
   b. Wall Leaning in (Excessive Batter)
   c. Wall Leaning Out
2. Vertical Alignnment
   a. Hump
   b. Dip
3. Units Won't Stack Flat
   a. Leveling Pad
   b. Units
   c. Drainage fill
4. Units Pinch or Gap
   a. Horizontal Spacing

Cause

1.a1. Excessive compaction or compacting in too thick lifts.

1.a2. Compacting too close to the back of the units.

1.a3. Compaction of soil wet of optimum.

1.b1. Unit heights not consistent

1.b2. Inconsistency of front to rear level of the units.

1.b3. Inconsistency in shimming of the units tail.

1.c1. Loading too close to the back of the units. (typically trucks or rubber tired equipment).

1.c2. Excessive compaction too close to the units.

1.c3. Not enough coverage on the geogrid and as the backfill is placed and spread toward the wall causing pushing and movement of the units.

2.a1. Particles in between units

2.a2. Core bar in marks in on the top of the units removed during placement.

2.b1. Footing not level.

2.b2. Utility crossing.

3.a1. Base course not level

3.b1. Top of unit has production imperfections.

3.c1. Top of unit not swept clean.

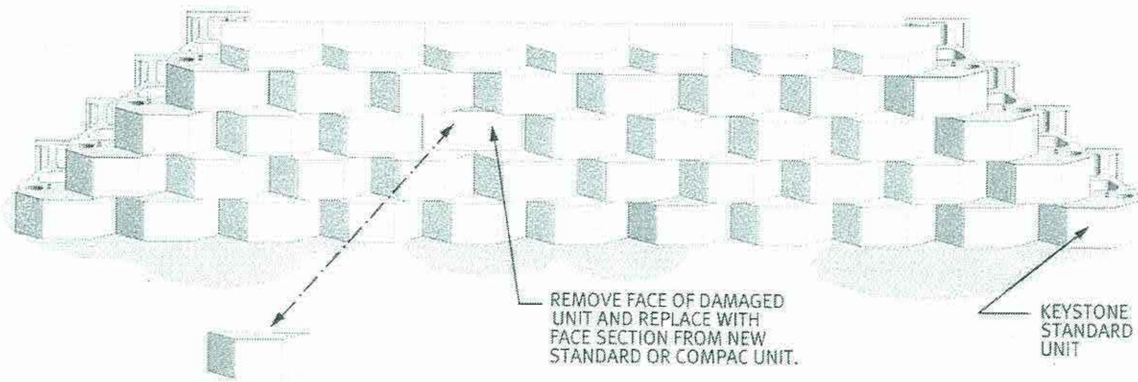
4.a1. Horizontal spacing not 12 inches between pinholes of adjacent units.

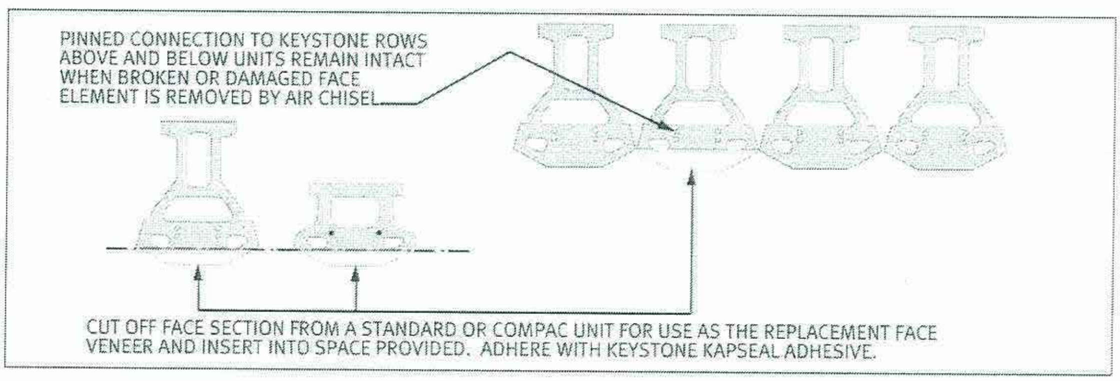
PROBLEM: Damaged or cracked unit in wall.
SOLUTION:
For minor cracks, fill opening with construction epoxy and dust lightly with concrete material of similar color. Use a ground up piece from another Keystone® unit.

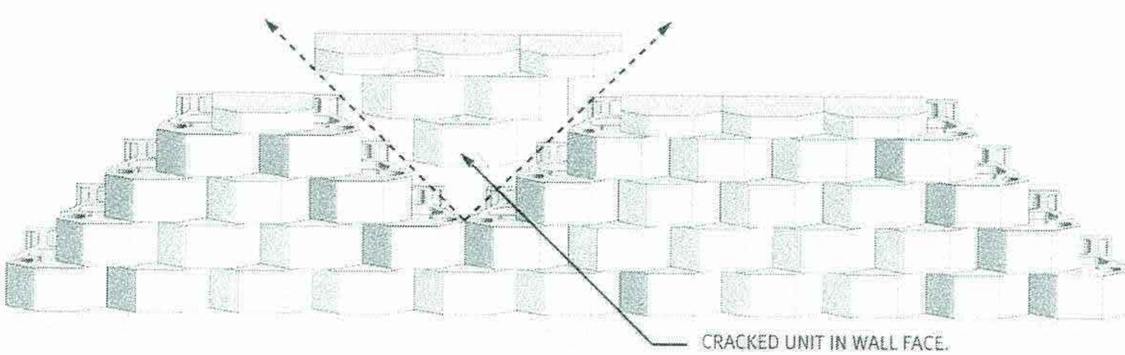
For low height walls, dismantle units down to broken unit(s), replace with new unit(s). Rebuild wall placing corefill and backfill with necessary light compaction until capping of wall as shown in above detail.

For taller walls or where it is not practical to dismantle the wall, follow steps shown in the details below.

Note: Solution allows wall to remain intact. Wall structure with geogrid soil reinforcement is not interrupted.







ISBN 978-078441214-5

9 780784 412145

the collingroup

Glenn C. Vaughan 16 April 2018
Director, Office of Structures
Maryland State Highway Administration
707 North Calvert Street
Baltimore, MD 21202

Reference: Keystone Compac II/Miragrid Retaining Wall System - Maryland Department of Transportation Proprietary Retaining Wall Approval Process

Dear Mr. Vaughan:

In accordance with SHA's policy and procedure memorandum on Proprietary Retaining Walls (dated 8/30/99) Keystone Retaining Wall Systems (Keystone) has contracted with The Collin Group, Ltd. (TCG) (SHA approved professional engineering firm) to review their Compac II/Miragrid Retaining Wall System (KeySytsem II) for compliance with AASHTO interim 2017 specifications and MSHA requirements. The following documents, provided by Keystone, were reviewed as part of our evaluation:

- HITEC Evaluation of the KeySystem II Retaining Wall
- Mirafi XT Geogrid Property Specification Sheet
- Mirafi XT Determination of the Long-Term Properties for Miragrid XT Geogrids
- Mirafi XT 2015 NTPEP Report – Final Product Verification Report for Miragrid XT Geogrid Product Line
- Keystone Compac II – Short-Term Connection Strength – 3XT and 7XT
- Keystone Compac II – Sustained Load Connection Strength – 3XT and 7XT
- Keystone Compac III – Short-Term Connection Strength – 3XT and 7XT
- Keystone Compac III – Sustained Load Connection Strength – 3XT and 7XT

Based on the documents review, the KeySystem II retaining wall system is in my professional engineering opinion in compliance with the current AASHTO LRFD specifications. For all MSHA projects, I recommend that the computer software MSEW developed by ADAMA Engineering, for the Federal Highway Administration, be used for the wall design. The design parameters that should be used for the KeySystem II are provided in the following tables and are consistent with the HITEC Evaluation.

Table 1A - KeySystem II – MSEW Input Parameters Mirafi Geogrid

GEOGRID SOIL REINFORCEMENT						
Data/Geogrid		3XT	5XT	7XT	8XT	10XT
T_{ult} (lb/ft)		3,500	4,700	5,900	7,400	9,500
Durability Reduction factor, RF_D	5<pH<8	1.15[a]	1.15[a]	1.15[a]	1.15[a]	1.15[a]
	4.5≤pH≤5	1.3	1.3	1.3	1.3	1.3
	8≤pH≤9	1.3	1.3	1.3	1.3	1.3
Installation Damage Reduction Factor, RF_{ID}	¾" max aggregate	1.2 to 1.4[b]	1.15 to 1.3[b]	1.15 to 1.3[b]	1.15 to 1.3[b]	1.15 to 1.3[b]
	> ¾" aggregate	c	c	c	c	c
Creep Reduction Factor, RF_{CR}	75 years	1.60	1.60	1.60	1.60	1.60
	100 years	1.65	1.65	1.65	1.65	1.65
Coverage Ratio		100	100	100	100	100
Friction coefficient geogrid-soil interface, ρ	Fine to medium sands[d]	0.8	0.8	0.8	0.8	0.8
	Well-graded sands, sands & gravel[d]	0.9	0.9	0.9	0.9	0.9
Pullout resistance factor, F*	Sands[d]	0.6	0.6	0.6	0.6	0.6
	Gravels[d]	0.67 tanφ	0.67 tanφ	0.67 tanφ	0.67 tanφ	0.67 tanφ
Scale-effect correction factor, α	Sands[d]	1.0	1.0	1.0	1.0	1.0
	Gravels[d]	0.8	0.8	0.8	0.8	0.8

[a] Increase value to 1.3 for cases where the MBW facing is anticipated to be wet for an extended period of time;
[b] The upper end of the range value is recommended in absence of site specific (or representative) tests;
[c] Project-specific (or representative) installation damage testing and RF_{ID} quantification should be performed for MSE fills with a maximum aggregate size greater than ¾";
[d] Predominate material.

Table 1B - - KeySystem II – MSEW Input Parameters Compac II/Miragrid Connection Strength

Facia Geometry and Unit Weight	Depth/height = 1.0 ft/ 0.67 ft				
	Horizontal distance to center of gravity = 0.5 ft				
	Average unit weight of block core filled = 120 pcf				
Connection Strength	CR_{ult}[a]				
Normal stress (lb/ft^2)	3XT	5XT	7XT	8XT	10XT
0	0.26	0.31	-	-	-
500	-	-	-	-	0.21
1000	0.55	-	0.33	0.27	-
1700	-	0.49	-	-	-
2270	0.73	-	-	-	-
3000	-	-	-	-	0.38
3400	-	-	-	0.54	-
3425	-	0.56	0.59	-	-
Connection strength durability reduction factor, RF_d	1.15[b]	1.15[b]	1.15[b]	1.15[b]	1.15[b]
Creep reduction factor, RF_C	1.15	1.21	1.23	1.23	1.27

[a] MSEW program term = $T_{ULT\text{-}conn}/T_{ULT\ geogrid}$;
[b] Increase value to 1.3 for cases where the MBW facing is anticipated to be wet for an extended period of time.

In addition to reviewing the KeySystem II for MSHA acceptance into their approved "Proprietary Retaining Wall Systems", Keystone has requested that TCG review the Compac III block with Miragrid reinforcement. Figure 1 shows both the Compac II and Compac III blocks currently being manufactured under license to Keystone. The major difference between the II and III is the weight of the unit. The Compac II has a nominal weight of 85 lbs. and the Compac III has a nominal weight of 75 lbs. Because of the reduction in weight of the Compac III the surface contact area where the block above one course bears on the block below is reduced. This effects the connection strength between the geogrid and facing. Both short-term and long-term connection testing on the Compac III and Miragrid 3Xt and 7XT were reviewed as part of our evaluation. Table 2 provides the recommended input parameters for the MSEW software when designing for the Compac III in lieu of the Compac II with Mirafi geogrids. The input parameters for the Mirafi geogrids in table 1A are appropriate for use when the Compac III block is used.

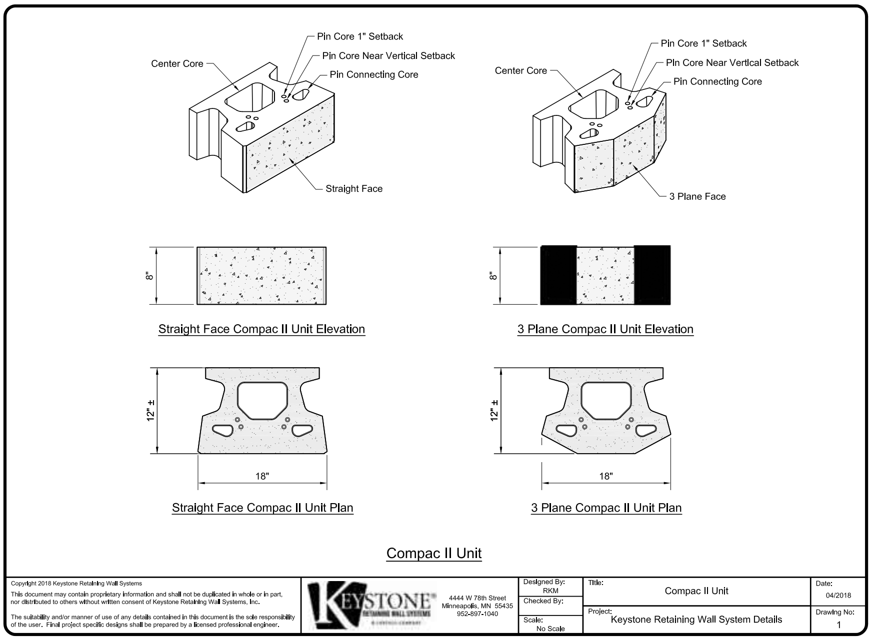


Figure 1A. Compac II Unit Details

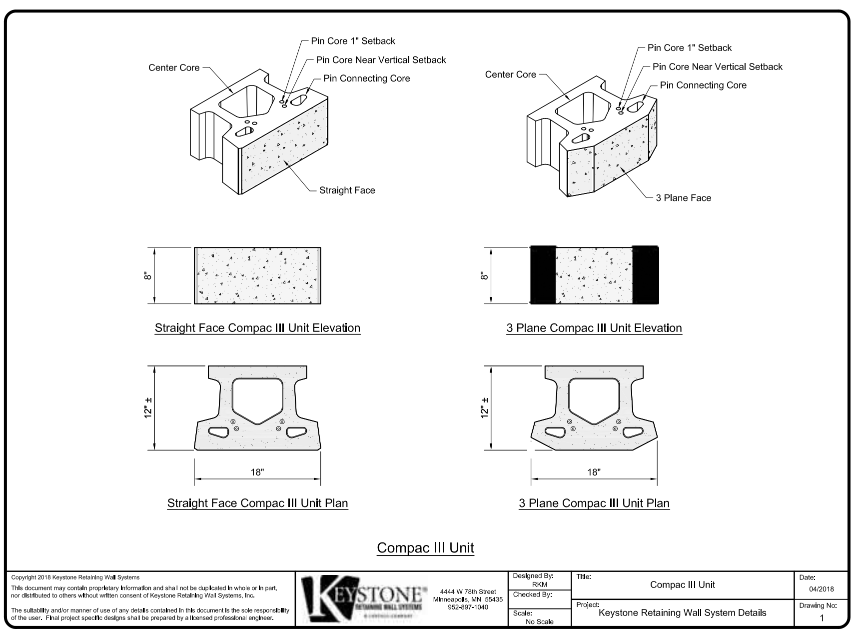


Figure 1B. Compac III Unit Details

Table 2 - KeySystem III – MSEW Input Parameters Compac III/Miragrid Connection Strength

Facia Geometry and Unit Weight	Depth/height = 1.0 ft/ 0.67 ft				
	Horizontal distance to center of gravity = 0.5 ft				
	Average unit weight of block core filled = 120 pcf				
Connection Strength	CR_{ult}[a]				
Normal stress (lb/ft^2)	3XT	5XT	7XT	8XT	10XT
0	0.28	NA	0.16	NA	NA
500	-	NA	-	NA	NA
1100	-	NA	0.37	NA	NA
1300	0.62	NA	-	NA	NA
2252	0.66	NA	-	NA	NA
3380	-	NA	0.55	NA	NA
3500	0.66	NA	0.55	NA	NA
Connection strength durability reduction factor, RF_d	1.15[b]	NA	1.15[b]	NA	NA
Creep reduction factor, RF_C	1.20	NA	1.28	NA	NA

[a] MSEW program term = $T_{ULT-conn}/T_{ULT\ geogrid}$;
[b] Increase value to 1.3 for cases where the MBW facing is anticipated to be wet for an extended period of time.

It is my professional engineering opinion that the substitution of the Compac III unit for the Compac II is in accordance with the current AASHTO LRFD specifications. The connection strength between the Compac III and Miragrid reinforcement is less than with the Compac II and may control the design. TCG only reviewed connection strength testing for the Compac III unit and Miragrid 3XT and 7XT. We therefore recommend that 3XT and 7XT are the only grids allowed for use on MSHA project with the Compac III unit.

If you have any questions concerning the above information, please do not hesitate to contact me.

Sincerely,

James G. Collin, PH.D., P.E.
President

7445 Arlington Road, Bethesda, MD 20814 • O: 301.907.9501 • C: 301.442.7182