StrataGrid Construction and Overview of Manufacturing

General Product Information:

Products:
StrataGrid 150
StrataGrid 200
StrataGrid 350
StrataGrid 500
StrataGrid 550
StrataGrid 600
StrataGrid 700

The following data applies to all products in this series, unless otherwise mentioned:

> StrataGrid is geogrid reinforcement for soil. These high performance geogrids are constructed of high molecular weight and super-high tenacity polyester fiber utilizing a complex knitting process and polymer coating to provide superior engineering properties. The fibers are precision knitted into a dimensionally stable, uniform network of apertures providing significant tensile reinforcement capacity. The geogrid is engineered to be mechanically and chemically durable, in both the harsh construction installation phase and in aggressive soil environments ($3 \leq pH \leq 9$). A UV stabilized coating provides further benefits.

Description of the StrataGrid Product Line

In creating the geometry and configuration of the StrataGrid product line, Strata Systems, Inc. endeavored to develop a product that is structurally stable, strong, resistant, and unique. The product also needed to have excellent *geogrid-to-soil* interaction properties. In order to fulfill the many demands of reinforcement design protocols and standards, a product line in which the design strengths of the geogrids covered a wide range of applications, was also desirable.

The following sections will give the reader an overview of the StrataGrid product line as well as an insight into the reasoning behind the choice of the several components of the StrataGrid.

Polyester Fibers

The use of super-high tenacity, high molecular weight, and low carboxyl end group (CEG) polyester fiber as the primary material for a geogrid reinforcement element is a sound choice for the following reason:

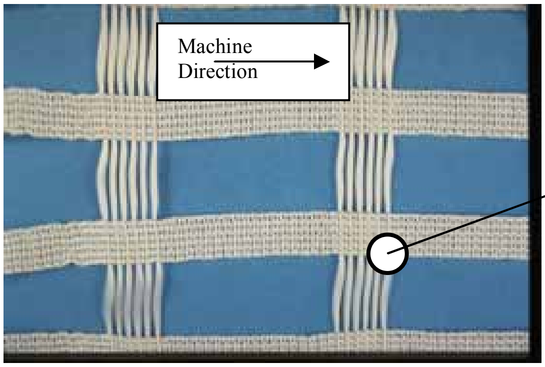
- High Strength
- Low Creep Characteristics
- Durable

- CEG<30 and Molecular Weight > 25,000 g/m as required by U.S. Federal Highway Administration guidelines and AASHTO specifications for geogrid reinforcement
- Excellent Handling Characteristics (i. e., no “memory”)

Example of polyester bundle

Microscopic view of bundle end

Each bundle of polyester fiber is knitted together to make up a strand of StrataGrid. The tie-yarns are used to knit the bundles and they too consist of polyester. Only the machine direction bundles of polyester are knitted along the entire length of the strand. The cross-machine yarns are also made up of the polyester yarns. Unlike the machine direction yarns, the cross machine yarns are knitted only at the junctions between machine and cross machine yarns. This makes for a strong and stable junction.

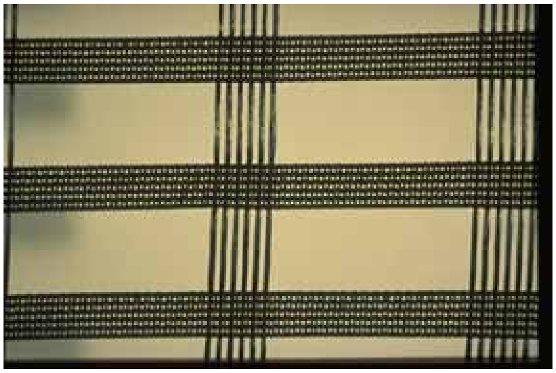


Un-coated (greige) sample

Magnification of tie yarns

Polymer Coating

The primary reason for coating polyester geogrid is to provide structural integrity to the finished product. Uncoated polyester geogrid, knitted or woven, is impractical to handle, to say the least. Coating of the product makes the structure easy to handle for distribution purposes and on-site installation.



Coated sample of StrataGrid

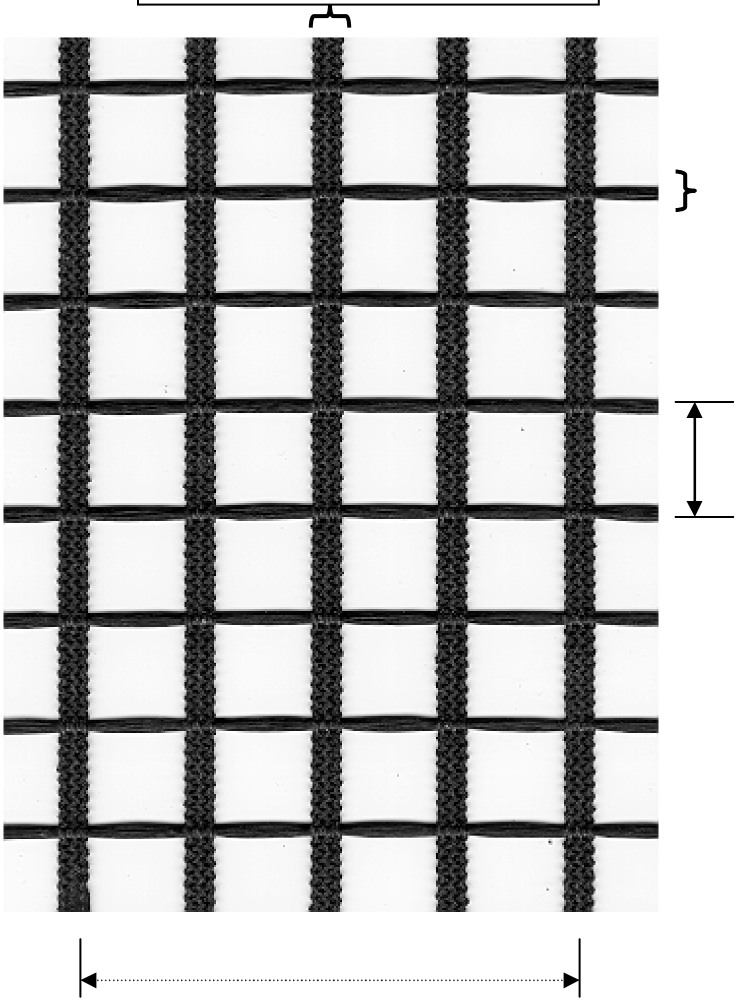
However, to say that coating serves only this purpose is not accurate. The StrataGrid product is coated with a UV stabilized polymer. The coating effectively encapsulates the PET fiber within the polymer. In fact, tiny openings between fiber bundles on the same strand are formed, which “conceptually” add additional frictional interaction between fine-grain soil particles and the geogrid. The coating also protects the PET fiber during installation and compaction of soil, minimizing damage to the geogrid, as well as providing UV protection to the PET fiber.

StrataGrid Construction

The StrataGrid product line consists of seven products: SG150, SG200, SG350, SG500, SG550, SG600 and SG700. Each product is manufactured using identical processes and equipment. The difference in machine direction strength and cross machine direction strength is directly proportional to the number of polyester yarns per bundle, number of bundles per rib, and ribs per foot.

StrataGrid 150, 200 and 350 are, traditionally, lighter-weight products. They are distinguishable by the number of polyester yarn bundles per rib in the machine direction. Each machine direction rib contains three (3) bundles of polyester yarn and the increase in machine direction strength is proportional to the number of yarns per bundle and /or ribs per foot of width of reinforcement. The rib count per foot of width varies from SG150 to 200 to 350. In the cross machine direction, StrataGrid 150, 200 and 350 have one (1) bundle/rib of polyester spaced at varying distances along the machine direction length.

StrataGrid 150, 200, and 350 Construction



MACHINE DIRECTION
For StrataGrid 150, 200, and 350, the bundles of fiber per machine direction rib is the same, (i.e. 3 bundles/rib)

CROSS MACHINE DIRECTION
For StrataGrid 150, 200, and 350, the number of cross machine bundles is the same, (i.e. 1 bundle of varying weight)

CROSS MACHINE DIRECTION
For StrataGrid 150, 200, and 350, the mean distance between the centerline of the bundle varies.

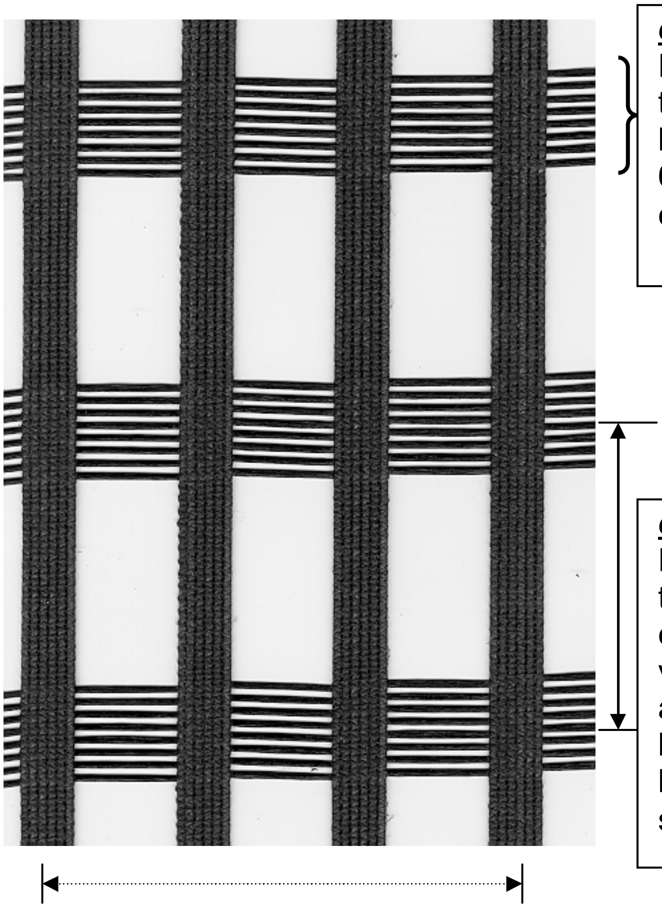
RIB COUNT
The number of ribs per unit width of geogrid.

StrataGrid 500, 550, 600 and 700 are considered heavier-weight products. Each product contains six (6) bundles of polyester yarn per rib and the centerline distance between the ribs is constant. The increase in machine direction strength from StrataGrid 500 to 550 to 600 to 700 is directly proportional to the increase in the number of polyester yarns per bundle. In the cross machine direction, StrataGrid 500 and 550 have two (2) closely spaced bundles of polyester yarn. The centerline distance between bundles of polyester yarn varies between 500 and 550. StrataGrid 600 and 700 have six (6) bundles of closely spaced polyester yarn with equal centerline to centerline distance along the machine direction.

The benefit of having a simple construction configuration is obvious from a manufacturing point of view. It permits rapid fine-tuning of product specifications as well as development of intermediate products. Another less obvious benefit is with testing. Strata has found that, because of the similar structure of the products, testing only one or two products is usually sufficient to describe the properties for all the products. This is especially true for Creep Testing, Installation Damage Testing and Soil-to-Geogrid Interface Testing.

StrataGrid 500, 550, 600 and 700 Construction

MACHINE DIRECTION
For StrataGrid 500, 550, 600 and 700, the bundles of fiber per machine direction rib is the same,
(i.e. 6 bundles/strand)



CROSS MACHINE DIRECTION
For StrataGrid 500 and 550, the number of cross machine bundles is 2. For StrataGrid 600 and 700, the number of cross machine bundles is 6.

CROSS MACHINE DIRECTION
For StrataGrid 500 and 550, the mean distance between centerline of the bundle varies. For StrataGrid 600 and 700, the mean distance between the centerline of the bundles is approximately the same.

Rib COUNT
The number of ribs per unit width of geogrid.

Construction Table

Product	SG150	SG200	SG350	SG500	SG550	SG600	SG700
Bundles/Rib MD	3	3	3	6	6	6	6
Bundles/Rib CMD	1	1	1	2	2	6	6

- Polymers used for fibers, ribs, etc.:
  Polyester is the fiber type for all components, for all products in product line.

- Roll size (length, width, and area):

Property	**Test method**	**Units**	**150**	**200**	**350**	**500**	**550**	**600**	**700**
Roll Size	Width x Length	feet	6 x 150	6 x 300	6 x 300	6 x 300	6 x 300	6 x 300	6 x 300
	Area	sq.yds	100	200	200	200	200	200	200
	Typical Weight (includes packaging)	pounds	45	95	100	125	145	150	175

- Typical lot size:
  Lot sizes are based on master roll quantities manufactured during the knitting process. Lot size testing conforms to ASTM D4354.

- Polymer source(s) used for product:
  Polymer is super-high tenacity PET placed in cross machine and machine direction and knitted to form stable grid structure.

- For PET, minimum production number for average molecular weight and maximum carboxyl end group content:
  Minimum Molecular Weight > 25,000
  Maximum CEG < 30
  These values apply to all products in the product line.

- % of regrind used in product, if any:
  None.

- % of post-consumer recycled material by weight:
  None.

- Typical average weight per unit area for each product:

Property	Test method	Units	150	200	350	500	550	600	700
Typical Average Weight	ASTM D5261	oz/yd^2	5.5	6.5	7.0	9.0	10.5	11.5	13.0

- MARV for ultimate tensile strength:
  Per ASTM D6637 (Method A – Single-Rib), the ultimate strength for each product is:

Property	Test method	Units	150	200	350	500	550	600	700
Machine Direction	**ASTM D6637 (Method A)**	lbs/ft	1,875	3,600	5,000	6,400	8,150	9,100	11,800

- UV resistance at 500 hours in accordance with ASTM D4355:
  At least 70% strength retained for all products in the product line.

- The following is a sample report forming part of the manufacturing quality control program. All testing is carried out by a GAI Accredited Laboratory. Strata Systems uses the services of Glen Raven, Inc. (GAI-LAP 68-10) for QC testing.

ULTIMATE TENSILE PROPERTIES – ASTM D 6637 (Method A)

Style: 200 Machine Direction (LOT# 0014064200) Ribs/ft: 13.7

Sample Identification	Test Number	Specimen (Ribs/ft)	Maximum Load (lbs)	Maximum Load (lbs/ft)	Elongation @ Break (%)	Load @ 2% (lb/ft)	Load @ 5% (lb/ft)	Load @ 10% (lb/ft)	Modulus @ 2% (lbs/ft)	Modulus @ 5% (lb/ft)
Lot# 0014064200, Roll # 004190214	1	13.7	275.4	3773	16.5	481	743	1910	24050	14860
	2	13.7	270.6	3707	15.9	524	770	2029	26200	15400
	3	13.7	276.2	3784	16.2	535	774	2129	26750	15480
	4	13.7	271.2	3715	15.7	520	785	2176	26000	15700
	5	13.7	271.7	3722	16.0	504	770	2017	25200	15400
	6	13.7	275.1	3769	15.9	554	797	2167	27700	15940

Machine Direction	N	6	6	6	6	6	6	6	6
	Average	273.4	3745	16.0	520	773	2071	25983	15463
	StDev	2.5	33.7	0.3	25.2	18.4	104.2	1260	362

Transverse Direction

Ribs/ft: 14.4

Sample Identification	Test Number	Specimen (Ribs/ft)	Maximum Load (lbs)	Maximum Load (lbs/ft)	Elongation @ Break (%)	Load @ 2% (lb/ft)	Load @ 5% (lb/ft)	Load @ 10% (lb/ft)	Modulus @ 2% (lbs/ft)	Modulus @ 5% (lb/ft)
Lot# 0014064200, Roll # 004190214	1	14.4	115.3	1660	28.6	199	287	437	12100	6920
	2	14.4	113.1	1629	28.0	226	301	459	11850	6720
	3	14.4	115.0	1656	26.6	238	313	469	13250	7660

Transverse Direction	N	3	3	3	3	3	3	3	3
	Average	114.5	1648	27.7	221	300	455	11050	6007
	StDev	1.2	17.2	1.0	19.8	13.3	16.2	999	260

MASS/UNIT AREA DATA

Style: SG200

	Sample Number	Mass/Unit Area (oz./sq.yd)		
Roll Designation Lot# 0014064200, Roll # 004190214	1	6.59		
	2	6.56		
	3	6.79		
	4	6.79		
	5	6.51	N	9
	6	6.56	Average	6.67
	7	6.85	StDev	0.13
	8	6.79		
	9	6.62		

MULTI-RIB TENSILE (D 6637 – Method B) STRENGTH (LBS/FT)	
TEST NUMBER	Lot# 0014064200, Roll # 004190214 Ribs per Specimen: 13.7
1	3695
2	3722
3	3613
Avg	3677
StDev	57

Direct Shear Testing With StrataGrid Products

Introduction

Geosynthetic reinforcement layers may create preferred planes of sliding within the reinforced zone of a segmental retaining wall structure. The movement of a portion of the reinforced soil mass across a stationary layer of geosynthetic reinforcement is modeled as a direct shear failure mode in internal calculations.

The standard by which the coefficient of direct shear is determined is outlined in detail in ASTM D 5321-92 "*Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method*" or, formerly, GRI "GS-6: *Interface Friction Determination by Direct Shear Testing*."

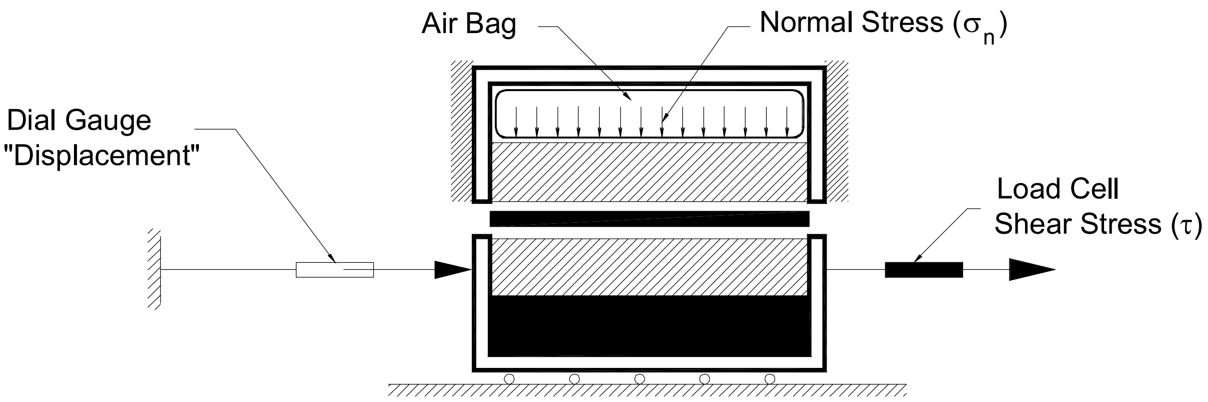


Figure 1: Schematic of Direct Shear testing apparatus.

The coefficient of friction between StrataGrid reinforcement and soil is determined by placing the geogrid and soil in a direct shear box. A constant normal compressive force is applied to the specimen, and a shear force is applied to the direct shear box so that one section of the box moves in relation to the other section. The shear force is recorded as a function of the horizontal displacement of the moving section of the shear box (Figure 2). Peak shear stresses are recorded and plotted against a minimum of three applied normal compressive stresses (Figure 3). Test data are generally represented by a best fit straight line whose slope is the coefficient of friction between the two materials where shearing occurred.

Additional data/results are evaluated by comparison of the direct shear strength of the soil only. This ratio is defined as the *Coefficient of Direct Sliding* (C_{ds}).

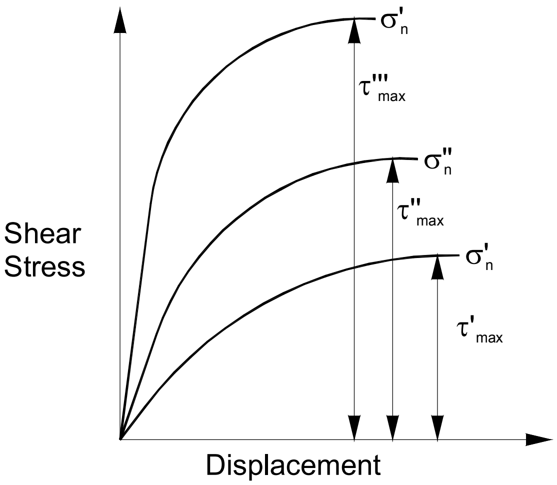


Figure 2: Shear Stress vs. Shear Deformation Response Curves at Different Normal

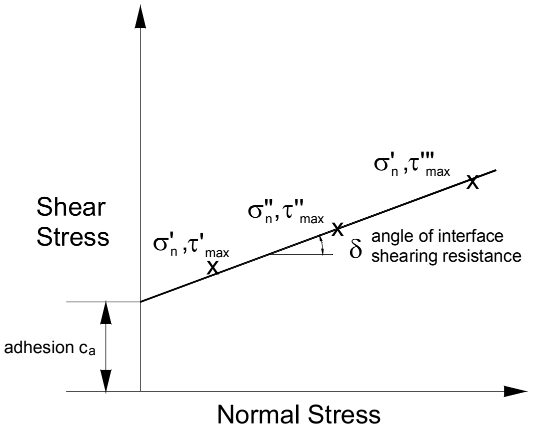


Figure 3: Mohr-Coulomb Stress Space Showing Failure Points and Failure Envelope with Shear Strength Parameters Friction Angle and Adhesion

Experimental Program

Initial testing for StrataGrid products was conducted by the Center for Geosynthetics Research and Development Department of Civil Engineering – Carlton University, July 1991. Testing was conducted using a large direct shear box consisting of the following main components: (a) direct shear box – 40 inch (1000 mm) long by 40 inch (1000 mm) wide by 37 inch (940 mm) high; (b) shear force application with a maximum capacity of 24.5 kips (100 kN); and (c) surcharge load applications of 480, 585 and 731 psf (23, 28 and 35 kPa).

STS Consultants, Ltd. performed additional testing on project specific soils (glacial till) in the fall 1997 using the ASTM D5321, which utilizes a 12” x 12” shear box.

In 2007, a direct shear test program was initiated at TRI/Environmental, Inc. in Austin, Texas to evaluate the interface properties of StrataGrid SG200, SG500, and SG700 placed in manufactured, sub-angular, uniform sand. Testing was conducted in accordance with ASTM D5321 and ISO 12957-1:2005(E). The basis for selecting a uniform sand backfill was to provide basic consistency with the initial testing performed by Carlton University in July 1991 and requirements set under ISO 12957. Test results for products tested at TRI fall within the expected range for StrataGrid placed in uniform granular material and are consistent with recommended design values for the coefficient of direct sliding, $C_{ds.}$

Test Preparation

Two soil types were used for testing by Carlton University: (1) Course sand – commonly known as concrete sand had a maximum dry density of 122.2 pcf (19.2 kN/m^3) and an optimum moisture content of 11 %. The shear strength of the unreinforced course sand was 46 degrees. (2) Crushed Stone Aggregate –had a maximum dry density of 140 pcf (22 kN/m^3) and an optimum moisture content of 6.8 %. The shear strength of the unreinforced crushed stone was 49 degrees. StrataGrid 200 was used in each test. The embedded width of the grid was 38.5 inches (975 mm) while the length varied according to the orientation of the grid in the direct shear box. The soil used for the 1997 testing by STS Consultants, Ltd. was glacial till, described as sand w/little silt, clay & gravel, and had a maximum dry density of 125.5 pcf (19.7 kN/m^3) and an optimum moisture content of 11 %. The shear strength of the unreinforced soil was 30 degrees. StrataGrid 300 was used in for this test series.

Prior to conducting individual shear tests, the shear box was cleaned and geogrid samples were cut to fit into the shear box. Moist granular soil was deposited and compacted into the shear box in six layers. Each layer was 6 inches (150 mm) high. A dead load surcharge (using stacked concrete blocks) was applied to the system and soils were allowed to consolidate for several hours before the shear force was applied.

Tests were terminated when the horizontal displacement in the shear box reached 3 inches (76 mm). This displacement was found to be sufficient in all tests to mobilize both peak and residual strength behavior of the unreinforced and reinforced soil.

Results

The shear strength ratio of the soil to the soil/geogrid combination is commonly referred to as the coefficient of direct sliding, C_{ds}. Table No. 1 shows direct shear test data on various StrataGrid Products.

Typical values for the coefficient of direct sliding based on various soil types are listed below. Strata Systems notes that in no case shall the coefficient of direct sliding be greater than 1.0.

Typical Values for C_{ds} for Various Soil Types

Soil Description	USCS	Cds
Gravel, Sand Gravel Mix	GW & SW	0.9 - 1.0
Gravel and Sand, Silty Sand	GP, SP & SM	0.8 - 0.9
Silt, Sandy Silt	SC	0.7 - 0.8
Clay, Silty Clay	CL & ML	0.6 – 0.7

Complete shear test reports including direct shear test equipment, photographs, test results, and data plots are available from Strata Systems, Inc. by calling (800) 680-7750 or (770) 888-6688. Strata Systems recommends site/project specific direct shear testing (as well as any performance testing) when time permits.

Table No. 1 Summary of Direct Shear Tests with StrataGrid

DATE	PRODUCT	TEST LOCATION	SOIL DESCRIPTION	SOIL FRICTION	INTERFACE FRICTION	C_{DS}
1991	SG300	Carlton University	Sand	46°	45°	1.0
	(5033)	(Canada)	Crushed Stone	49°	49°	1.0
1997	SG300	STS Consultants (Illinois)	Glacial Till (sand, with silt and clay)	30°	25.1°	0.8
2008	SG200	TRI	Sub-angular		31.5°	0.8
	SG500	(Austin, TX)	Uniform Sand	37.5°	34.6°	0.9
	SG700				36.1°	0.95

Pullout Testing with StrataGrid Products

Introduction

Geosynthetic reinforcement layers may create preferred planes of sliding within the reinforced zone of a segmental retaining wall or reinforced soil slope structure. The coefficient of interaction for pullout is used to relate the pullout resistance of the geosynthetic reinforcement to the available soil shear strength. The standard by which the coefficient interaction for pullout is determined is outline in detail in Test Standard Geosynthetic Research Institute GRI "GG-5: *Geogrid Pullout*", and ASTM D6706, *Standard Test Method for Measuring Geosynthetic Pullout Resistance in Soil*.

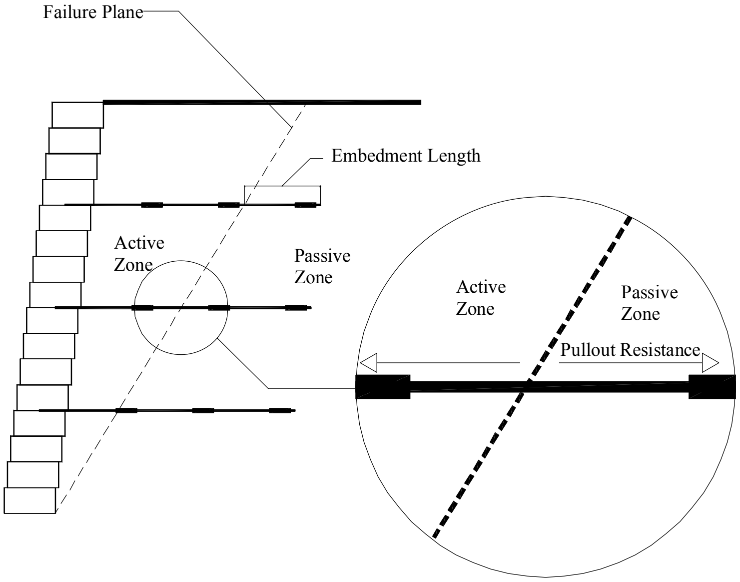


Figure No. 1: Significance of Pullout Testing

The test is carried out by placing the geogrid between two soil layers (Figure No. 2). A normal stress (or surcharge) is applied to the upper soil layer. A clamp is connected to the geogrid and a horizontal pullout force applied. The force required to pull the geogrid from the soil is recorded. The pullout resistance is calculated by dividing the maximum pullout load by the test specimen width. The coefficient of interaction for pullout is determined by reducing data from pullout resistance versus deformation response curves at various normal stresses.

Pullout resistance is a function of soil type, plasticity, density, moisture content and the mechanical properties of the geogrid reinforcement. The pullout resistance is mobilized through two basic soil-reinforcement interaction mechanisms: 1) interface friction and 2) passive soil resistance developed against the transverse elements of open structure geogrid. Approximately 80% of the StrataGrid pullout resistance is mobilized through interface friction.

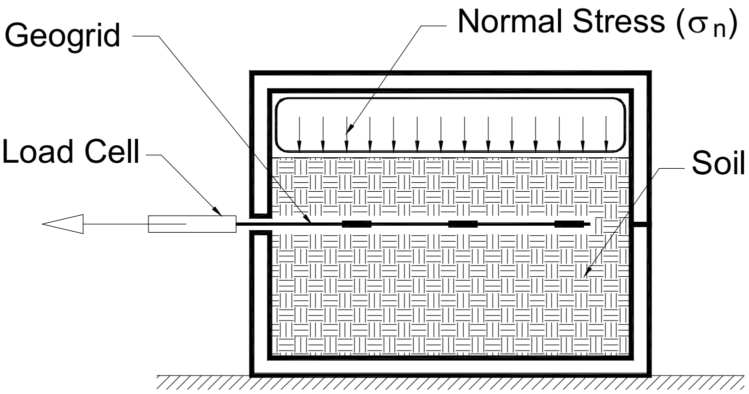


Figure No. 2: Sketch of Testing Apparatus

Testing Program

The Civil Engineering Department at Louisiana State University (LSU), August 1992, conducted a testing program for Strata Systems geogrid products. All tests were performed using fine, uniform Baton Rouge sand at densities averaging between 106 and 107 pcf. Rate of pullout ranged between 0.15 to 0.18 in./min (3.8 to 4.5 mm/min). The shear strength of the fine, uniform Baton Rouge sand varied between 32 and 37 degrees. StrataGrid test specimen width and length were one foot and three feet, respectively.

Prior to conducting individual shear tests, the shear box was cleaned and geogrid samples were cut to fit into the pullout box. The minimum pullout box size is 30 inches (75 mm) wide by 24 inches (60 mm) high by 48 inches (120 mm) long. Moist granular soil was deposited and compacted into the shear box. Three confining pressures, 7, 14, and 21 psi were used. Figure No. 3 shows typical pullout testing curves for various normal loads.

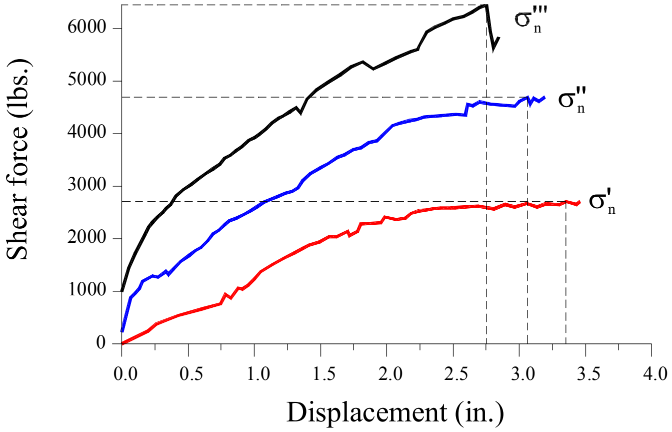


Figure No. 3: Typical Shear Force vs Displacement curves for pullout tests at various loads.

Additional pullout testing was carried out at the Asian Institute of Technology (AIT). StrataGrid 300 was placed between layers of Bangkok clay. The clay was comprised of 35% silt particles (0.06 – 0.002mm) and 48.8% clay particles (<0.002mm). The average values of plastic limit and liquid limit for the soil were 27% and 62% respectively. The shear strength of the clay was measured from large direct shear tests, and the clay exhibited a friction angle and cohesion of 22.8 degrees and 1.55 tsm, respectively. The residual shear strength of the clay over the range of applied normal stress is estimated at a soil friction angle of 30 degrees.

A pullout testing program was initiated with Geosyntec Consultants to investigate pullout behavior of StrataGrid 300 and 500 in different granular environments. Testing at SGI Testing Services, LLC investigated SG500 and SG700 in silty sand soils as single embedment length and embedment length directly overlapping a second layer of geogrid.

Pullout testing has been independently performed at the University of South Wales and Louisiana State University investigating SG700 in a uniformly-graded sand and SG500 in silty clay, respectively.

Results

The coefficient of soil/geogrid interaction C_i is calculated as follows:

$$C_i := \frac{P}{2 \cdot L \cdot W \cdot \left(\sigma_n \cdot \tan(\phi) \right)}$$

Where

C_i = coefficient of interaction
P = pullout force (kN or lb)
L = length of the tested specimen (m or ft)
W = width of the tested specimen (m or ft)
ϕ = soil friction angle
σ_n = total normal stress (kPa or psi)

Typical values for the coefficient of interaction for pullout, C_i, based on various soil types are listed below. Strata Systems notes that in no case shall C_i, be greater than 1.0.

Soil Description	USCS	C_i
Gravel, Sand Gravel Mix	GW & SW	0.9 - 1.0
Sand, Silty Sand	SP, GP & SM	0.8 - 0.9
Silt, Sandy Silt	SC	0.7 - 0.8
Clay, Silty Clay	CL & ML	0.6 – 0.7

Table No. 1 shows pullout test data on various StrataGrid Products. Complete pullout test reports including pullout test equipment, photographs, test results and graphs are available from Strata Systems, Inc. by calling (800) 680-7750 or (770) 888-6688.

Strata Systems recommends site/project specific pullout testing (as well as with any performance testing) when time permits.

Table No. 1 Summary of Pullout Tests with StrataGrid

DATE	PRODUCT	TEST LOCATION	SOIL DESCRIPTION	APPARENT SOIL FRICTION	C_I
1992	SG200 (3022)	Louisiana State University (LSU)	Uniform Fine Sand	32° – 37°	0.98
	SG600 (10027)				1.34
	SG700 (15027)				1.13
1996	SG300	AIT (Bangkok)	Clay	30.0°	0.71
1998	SG500	Geosyntec Consultants	Concrete Sand	35° – 37°	0.97
	SG300		Concrete Sand	36° – 39°	0.91
	SG500		Silty Sand	34° – 42°	1.01
	SG300		Silty Sand	37° – 50°	0.97
2005	SG500	SGI Testing	Silty Sand	33° – 35°	0.89
2006	SG700	SGI Testing	Silty Sand	32° - 35°	0.82
1997	SG700	University of New South Wales	Uniformly Graded Sand	34°	0.94
2003	SG500	Louisiana State University	Silty Clay	24°	0.88
2007	SG200 SG600	SGI Testing	Poorly-Graded Gravel, 3-inch Minus	49°	0.8
2007	SG200 SG600	SGI Testing	Uniform Gravel 1-inch to 3-inch	47°	0.84

Installation Damage Data Requirements (RF$_{ID}$)

The available design strength of geosynthetic reinforcement is a function of many factors. The ability of the reinforcement to maintain design strength may be affected by the damage to the physical properties as a result of field installation practices. Installation damage is evaluated by comparing the physical properties, typically ultimate tensile strength in accordance with ASTM D4595 or D6637 (Method B), of field exhumed samples exposed to conventional installation practices to the material properties of control samples. The standard by which the effects of installation damage are evaluated is ASTM D5818, *Standard of Practice for Obtaining Samples of Geosynthetics from a Test Section for Assessment of Installation Damage*. The practice standardizes the procedures for obtaining samples of geosynthetic from a full-scale test section for use in assessing damaged induced only by the installation techniques.

In 2010, installation damage testing for StrataGrid product was conducted with four (4) soil types:

Soil 1: Coarse Gravel (GP) – D_{max} = 50mm, D_{50} = 20mm
Soil 2: Uniform Gravel (GP) – D_{max} = 25mm, D_{50} = 6mm
Soil 3: Silty Sand (SM) – D_{max} = 25mm, D_{50} = 1mm
Soil 4: Silty Sand (SM) – Dmax = 37.5mm, D50 = 0.15mm

In 2011, installation damage testing for StrataGrid product was conducted with three (3) soil types:

Soil 1: Coarse Gravel (GP) – D_{max} = 50mm, D_{50} = 20mm
Soil 2: Uniform Gravel (GP) – D_{max} = 25mm, D_{50} = 6mm
Soil 3: Silty Sand (SM) – D_{max} = 25mm, D_{50} = 1mm

Testing Program

Test Program – TRI/Environmental, Inc. – November 2010

- Installation damage testing was conducted as non-site specific study using Soils 1, 2 and 3.
- Testing was performed in accordance with ASTM D5818 as modified in WSDOT T925. Test program conforms to the requirements of the National Transportation Product Evaluation Program (NTPEP) for Geogrid Reinforcement.
- StrataGrid Products tested: SG200.
- Soil was compacted to >90% of modified Proctor per ASTM D1557.

Test Program – SGI Testing Services, LLC – November 2010

- Installation damage testing was conducted as non-site specific study using Soil 4.
- Testing was performed in accordance with ASTM D5818.
- StrataGrid Products tested: SG200 and SG550.
- Soil was compacted to >95% of standard Proctor per ASTM D698.

Test Program – TRI/Environmental, Inc. – October 2011

- Installation damage testing was conducted as non-site specific study using Soils 1, 2 and 3.
- Testing was performed in accordance with ASTM D5818 as modified in WSDOT T925. Test program conforms to the requirements of the National Transportation Product Evaluation Program (NTPEP) for Geogrid Reinforcement.
- StrataGrid Products tested: SG150 and SG500.
- Soil was compacted to >90% of modified Proctor per ASTM D1557.

A summary of Average Reduction Factors for Installation Damage Testing are provided as follows:

Geogrid	**Soil 1** D_{50} **= 20mm (GP)**	**Soil 2** D_{50} **= 6mm (GP)**	**Soil 3** D_{50} **= 1mm (SM)**	**Soil 4** D_{50} **= 0.15mm (SM)**
SG150	1.68	1.23	1.31	
SG200	1.35 (Avg.)	1.10 (Avg.)	1.12 (Avg.)	1.09 (Avg.)
SG500	1.29	1.05	1.06	
SG550	-	-	-	1.08 (Avg.)

In each test series, running direction of the compaction operations was carried out perpendicular to the machine direction of the StrataGrid, which is representative of typical installation practices. Soil was placed in lifts not less than 8 inches.

Geosynthetic samples, both control and exhumed, were tested in accordance with ASTM D6637-Method B to assess the effect of installation damage.

Based on data reduction performed by Strata, a relationship between the recommended Reduction Factor for Installation Damage (RF_{ID}) and D_{50} particle size has been defined (See Figure No. 1– Average RF_{ID} versus D_{50} Particle Size for each Soil Type).

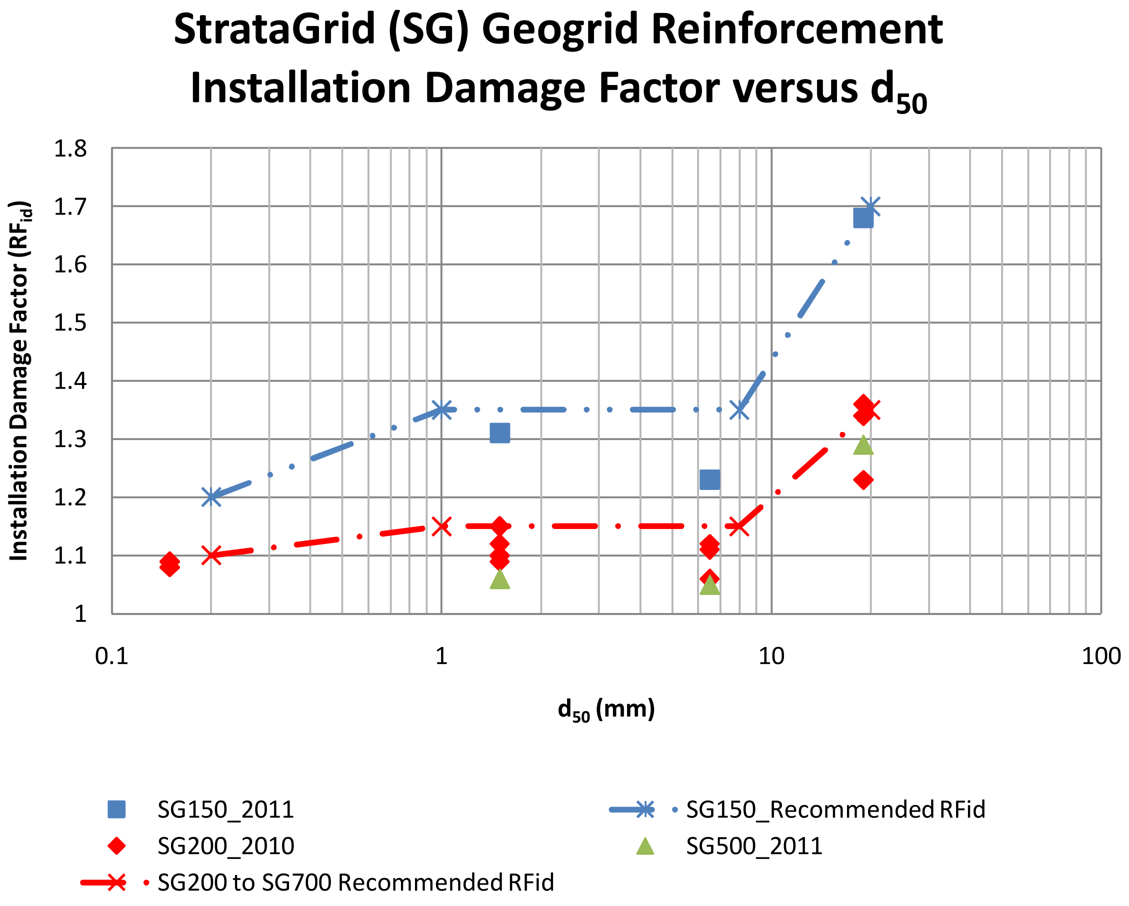


Figure No. 1: RF_{ID} versus D_{50} Particle Size – StrataGrid (SG) Geogrid

A summary of recommended RF_{ID} values for a range of soil gradations is provided as follows:

Soil Gradation	Soil Type USCS	Geogrid Style SG150	Geogrid Style SG200, SG350, SG500, SG550, SG600, SG700
$D_{max} \leq$ 25mm $D_{50} \leq$ 0.2mm	SW, SP, SM, SC	1.20	1.10
$D_{max} \leq$ 25mm $D_{50} \leq$ 8mm	GW, GP, GM, GC, SW, SP, SM, SC	1.35	1.15
$D_{max} \leq$ 50mm $D_{50} \leq$ 20mm	GW, GP, GM, GC	1.70	1.35

Complete installation damage reports are available from Strata Systems, Inc. by calling (800) 680-7750 or (770) 888-6688.

TENSION CREEP TESTING WITH STRATAGRID PRODUCTS

Introduction

The single most important issue concerning the calculation of long term design strength for geosynthetic reinforcement elements is determination of the Reduction Factor for Creep (RFcr). It is well known that polymeric material will continue to strain when subjected to a constant load. This phenomenon is known as creep strain. For designers of geosynthetic-reinforced structures, it is important that the reinforcing element be able to withstand constant loading for a period of time equivalent to the design life of the structure, which can be as long as 75 to 100 years.

Tension Creep Testing

Creep testing for geogrid material is currently evaluated under creep rupture conditions. Creep testing is carried out in accordance with ASTM D5262, *Standard Test Method for Evaluating the Unconfined Creep and Creep Rupture Behavior of Geosynthetics* and ASTM D6992, *Standard Test Method for Accelerated Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method*. In summary, the tension creep behavior of the geosynthetic is measured by applying a sustained load (see Figure No. 1) under controlled temperature conditions, and measuring the total time until the specimen ruptures. In practice, it is generally accepted that creep testing programs utilizing ASTM D6992 Stepped Isothermal Method also include conventional creep rupture data for at least one product tested to 10,000 hours under ASTM D5262.

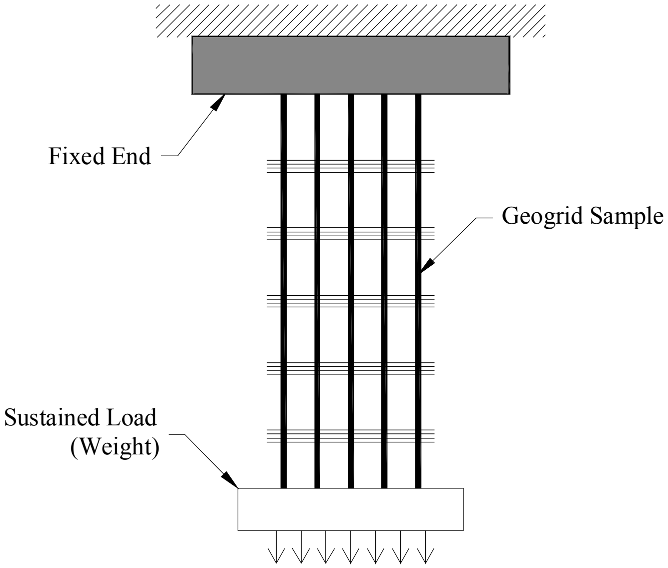


Figure No. 1: Sketch of Testing Apparatus

The standard creep rupture curve is a graph of percent ultimate tensile strength versus log of time, as shown on Figure No. 2. The Creep Reduction Factor, RF_{CR}, which is used to determine the long term design strength, is defined as the inverse of the loading expressed as a percentage of the ultimate strength of the geosynthetic specimen that intersect the required design life time (i.e. 75-years = log $10^{(5.818)}$ or 100-years = log $10^{(6)}$ hours).

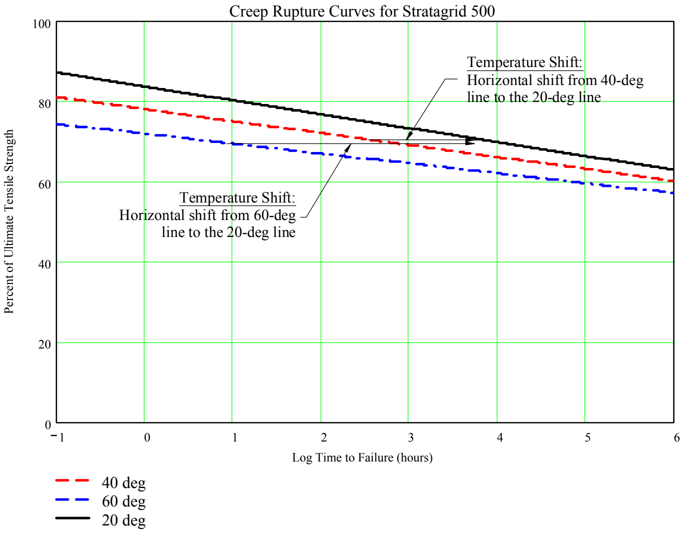


Figure No. 2: Creep Rupture Test Results at various Temperatures

Creep rupture performance data at an elevated temperature permits an additional order of magnitude in extrapolation via time-temperature superposition (TTS) principles. Creep rupture curves from elevated temperature testing can be overlaid upon the creep curves at the desired temperature by ***shifting*** the abscissa time scale. Thus elevated temperature testing can predict creep performance of a polyester geogrid at the desired temperature level in excess of ten years.

In order to extrapolate to the desired design life of the structure, the rupture lines representing failure at the higher temperature levels are ***shifted*** horizontally to the 20C° line. The creep reduction factor is then defined as the percent of ultimate tensile strength corresponding to the point of intersection of the shifted reference line with the desired design life time line. As an example, the lines in Figure No.2 were shifted and the resulting rupture line is shown on Figure No. 3.

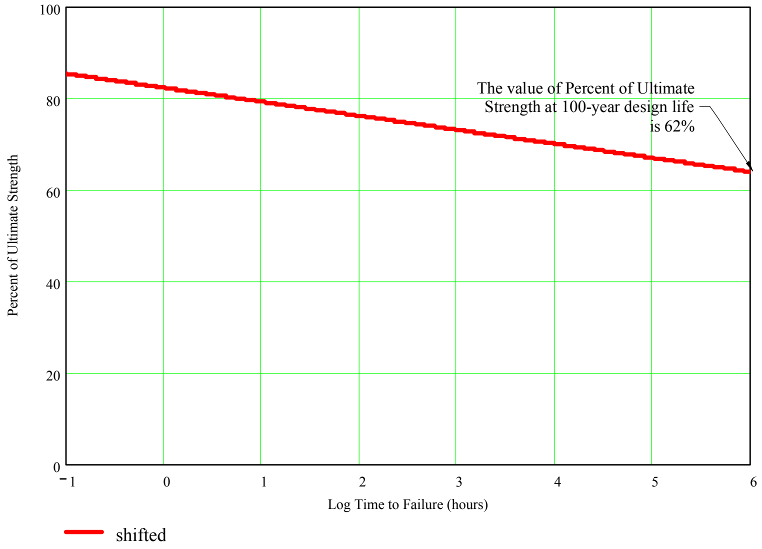


Figure No. 3: Shifted Creep Rupture Curve (@20°C)

Stepped Isothermal Method (SIM)

Recently, the Stepped Isothermal Method has been developed to predict the long term visco-elastic behavior of polymeric materials. SIM is a special case of time-temperature superposition that is convenient for characterizing visco-elastic materials. In summary, it utilizes a single specimen which is loaded continuously through a sequence of timed isothermal exposures at increasing temperature in a stair-stepped fashion. The test is carried out on a single specimen of geosynthetic, thus eliminating the inter-specimen variability. The graph on Figure No. 4 illustrates the concept. Similar to conventional creep rupture, SIM testing is carried out for a given product for several different load conditions (i.e. 60%, 70%, 75% of Tult) and the data collected is plotted as % of Tult versus log time (see Figure No. 5).

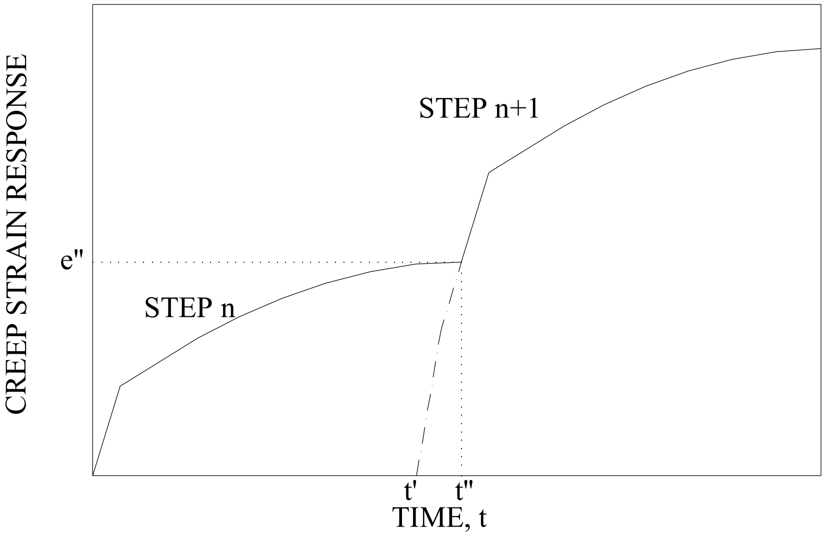


Figure No. 4: Stepped Isothermal Method – Strain Response for Two Temperature Steps

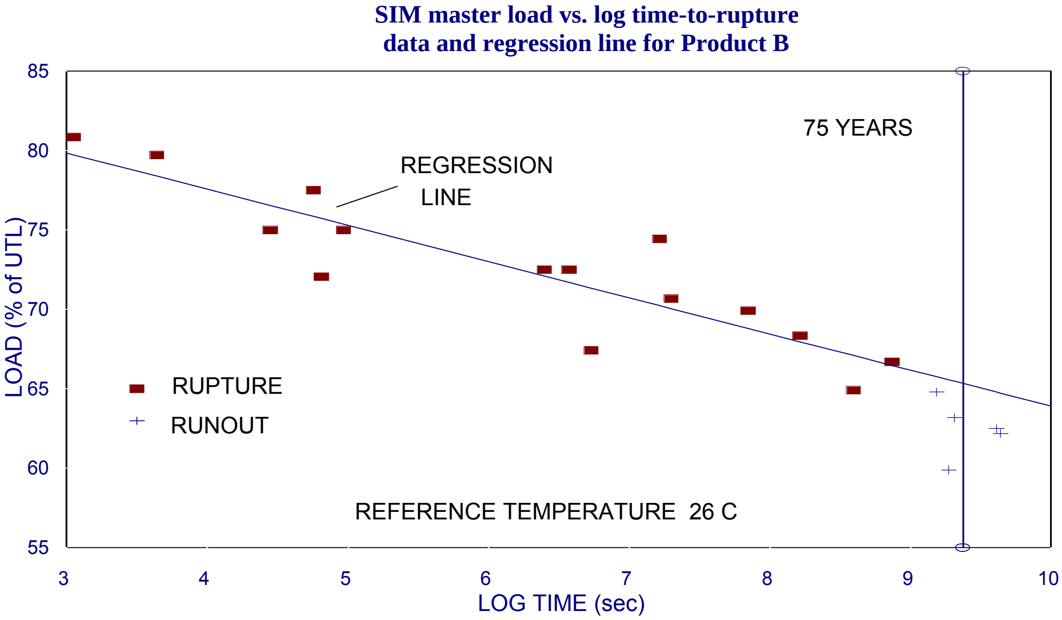


Figure No. 5: SIM load vs. log time-to-rupture data and regression line

A creep rupture testing program was initiated at TRI/Environmental, Inc. in Austin, Texas to define the creep performance of StrataGrid. The program entails both convential creep rutpure and creep rupture using the Stepped Isothermal Method (SIM). The following table summarizes the testing program:

Creep Testing Matrix (%Utlimate Strength)

Test	SG150	SG200	SG350	SG500	SG550	SG600	SG700
ASTM D6992 (SIM)		65, 70, 75, 79			65, 70, 75, 80, 83, 85		65, 70, 75, 80
ASTM D5262 (Conventional)	70	65, 2@70, 72, 75, 77, 84, 85	72	72	72, 73, 76	76	76

A creep rupture testing program was initiated at TRI/Environmental, Inc. in Austin, Texas to define the creep performance of StrataGrid SG150, cross machine direction. The program entials creep rupture using the Stepped Isothermal Method (SIM). The following table summarizes the testing program:

Creep Testing Matrix (%Utlimate Strength)

Test	SG150
ASTM D6992 (SIM)	65, 80

Test results are summarized as follows:

1. SIM and Conventional creep rupture results for StrataGrid indicate a 75-year and 114-year design creep reduction factor of 1.54 and 1.55, respectively (See Figure No. 6).
2. 1000-hour conventional creep testing was conducted using products SG150, SG350, SG500, SG600, and SG700. 1000-hr creep strain curves indicate similar creep behaviour across the product styles. As example, creep strain curves for SG350 is in agreement with the strain behavior of SG200 (see Figure No. 7).
3. Cross machine direction testing of SG150 indicates a 114-year design creep reduction factor less than 1.65.

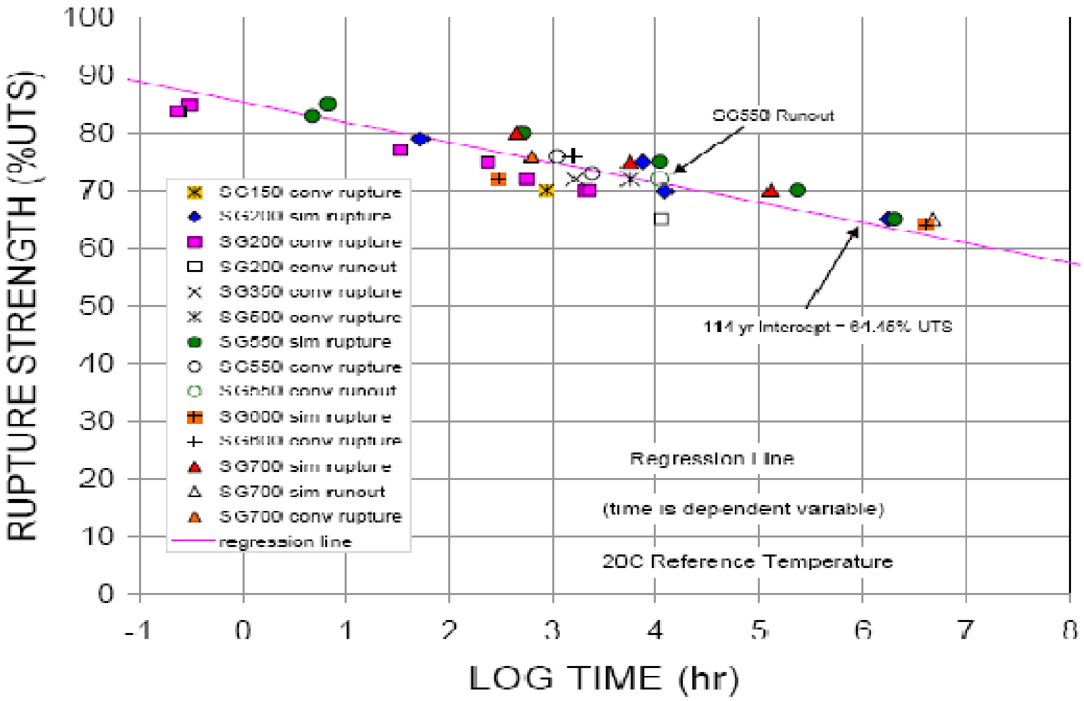


Figure No. 6: Creep Behavior of the StrataGrid Family

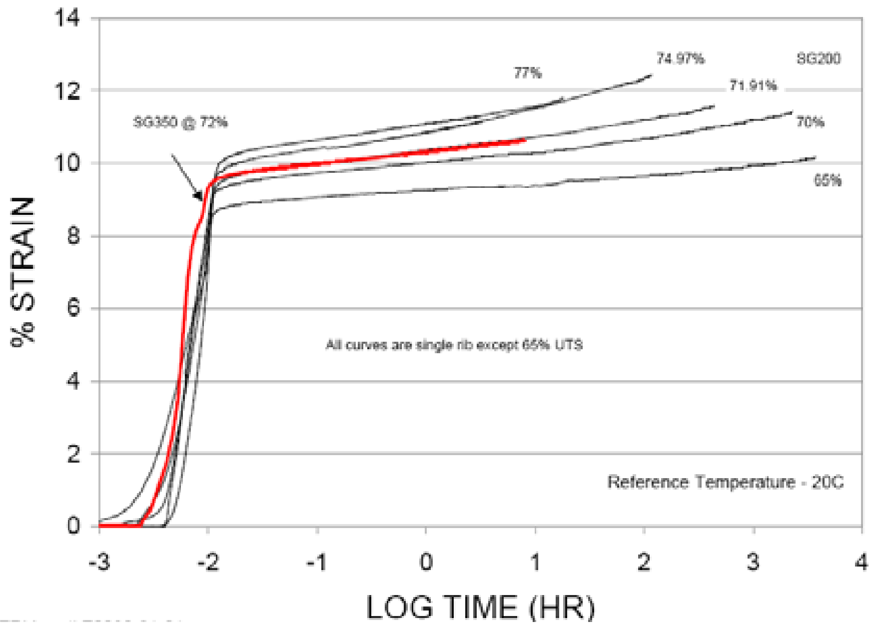


Figure No. 7: SG200 and SG350 Creep Strain Comparison

Based on the availabe Conventional Creep Rupture and SIM Creep Rupture data for StrataGrid products, the recommended design creep reduction factor for SG150 is 1.65 and 1.55 for product styles SG200, SG350, SG500, SG550, SG600, and SG700 (see Table 1 - Reduction Factor for Creep (RFCR) and Creep Reduced Strength for StrataGrid).

Table 1. Reduction Factor for Creep (RF_{CR}) and Creep Reduced Strength for StrataGrid

Type	MARV ASTM D6637 (lbs/ft)	RF_{CR}	Creep Reduced Strength (lbs/ft)
StrataGrid 150	1875	1.65	1136
StrataGrid 200	3600	1.55	2323
StrataGrid 350	5000	1.55	3226
StrataGrid 500	6400	1.55	4129
StrataGrid 550	8150	1.55	5258
StrataGrid 600	9100	1.55	5871
StrataGrid 700	11800	1.55	7613

Copies of test reports are available from Strata Systems, Inc. by calling (800) 680-7750 or (770)888-6688.

Long-Term Durability Data Requirements (RF_D)

A battery of test has been carried out by Strata Systems (and Conwed Plastics) to determine the long-term durability of the StrataGrid product line. The following table is a summary of durability testing conducted on StrataGrid products:

Test	PET Fiber	SG150	SG200	SG500
GRI-GG7	2011			
GRI-GG8	2011			
Chemical ISO 12960		2007		
Biological ISO 12226		2007		
Hydrolysis ISO 12447		2011		
Chemical Exposure Test (Conwed)			1991	
EPA 9090 Test Method				1992
Bacteria/Fungal ASTM G22/G21			1990	
UV ASTM D4355			2011	
UV ISO 12224		2011	2010	

Reports are available upon request from Strata Systems, Inc.

- Polymer characteristics for the lot or roll of material actually tested before long-term exposure in the laboratory, including, for example, molecular weight and carboxyl end group content for PET:
  For all StrataGrid products, the molecular weight is > 25,000, and the carboxyl end group content is < 30.

- Strata recommends an overall reduction factor for durability, including chemical and biological degradation, of 1.10. Durability reduction factors for soil having a pH outside the range of 3 to 9 require evaluation by Strata Systems, Inc.

Copies of durability test reports are available from Strata Systems, Inc. by calling (800) 680-7750 or (770) 888-6688.

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ASTM D4595, "Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method", *Philadelphia, PA, USA*

ASTM D4603, "Standard Test Method for Determining Inherent Viscosity of Poly (Ethylene Terephthalate) (PET) by Glass Capillary Viscometer", *Philadelphia, PA, USA*

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ASTM G21, “Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi”, *Philadelphia, PA, USA*

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