

Determination of Long-Term Strength for Geosynthetic Reinforcement

AASHTO Designation: PP 66-13



INTRODUCTION

Through this protocol, the long-term strength and stiffness of geosynthetic reinforcements can be determined. This protocol contains test and evaluation procedures to determine reduction factors for installation damage, creep, and chemical/biological durability, as well as the method to combine these factors to determine the long-term strength. The long-term strength and stiffness values determined from this protocol can be used as input values for geosynthetic structure designs conducted in accordance with *AASHTO LRFD Bridge Design Specifications* and related Federal Highway Administration (FHWA) design guidelines. The long-term strength and stiffness values determined from this protocol can also be compared to the required design strength and stiffness values provided in the contract for the geosynthetic structure(s) in question to determine whether the selected product meets the contract requirements. This protocol can be used for product qualification or acceptance (e.g., for inclusion in a Qualified Products List), or for quality assurance (QA) to facilitate periodic review of products for which the long-term strength has been previously determined using this standard practice.

1. SCOPE

- 1.1. This protocol has been developed to address polypropylene (PP), polyethylene (PE or HDPE), and polyester (PET) geosynthetics (i.e., geotextiles and geogrids). For other geosynthetic polymers [(e.g., polyamide (PA) or polyvinyl alcohol (PVA)], the installation damage and creep protocols provided herein are directly applicable. While the chemical and biological durability procedures and criteria provided herein may also be applicable to other polymers (for example, hydrolysis testing as described in Annex C is likely applicable to PA and PVA geosynthetics), additional investigation will be required to establish a detailed protocol and acceptance criteria for these other polymers. These other polymers may be considered for evaluation using this protocol once modifications to the chemical/biological durability aspects of this protocol have been developed and are agreed upon by the approval authority.
- 1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not propose to address all safety problems associated with its usage. It is the duty and responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*
- 1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards and Specifications:*

- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- *AASHTO LRFD Bridge Design Specifications*
- *Standard Specifications for Highway Bridges*, 17th Edition

2.2. *ASTM Standards:*

- D 1248, Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable
- D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D 2837, Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
- D 3045, Standard Practice for Heat Aging of Plastics Without Load
- D 3083-89, Standard Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining (Withdrawn 1998)
- D 3418, Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry
- D 3895, Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry
- D 4101, Standard Specification for Polypropylene Injection and Extrusion Materials
- D 4355, Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus
- D 4595, Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method
- D 4603, Standard Test Method for Determining Inherent Viscosity of Poly (Ethylene Terephthalate) (PET) by Glass Capillary Viscometer
- D 5261, Standard Test Method for Measuring Mass per Unit Area of Geotextiles
- D 5262, Standard Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics
- D 5322, Standard Practice for Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids
- D 5818, Standard Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics
- D 5885, Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry
- D 6637, Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method
- D 6992, Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method
- D 7409, Standard Test Method for Carboxyl End Group Content of Polyethylene Terephthalate (PET) Yarns

- 2.3. *Other Standards:*
- ENV ISO 13438:2004, Geotextiles and geotextile-related products—screening test method for determining the resistance to oxidation
 - GRI-GG8, Determination of the Number Average Molecular Weight of PET Yarns Based on a Relative Viscosity Value
 - ISO 10319:1993, Geotextiles—Wide-Width Tensile Test
 - ISO/DIS 10722:2007, Procedure for simulating damage during installation. Part 1: Installation in granular materials
 - ISO/FDIS 9080:2003, Plastic piping and ducting systems—Determination of long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation

3. TERMINOLOGY

- 3.1. *apertures*—the open spaces formed between the interconnected network of longitudinal and transverse ribs of a geogrid.
- 3.2. *d₅₀*—the grain size at 50 percent passing by weight for the backfill.
- 3.3. *effective design temperature*—the temperature that is halfway between the average yearly air temperature and the normal daily air temperature for the warmest month at the geosynthetic structure site.
- 3.4. *HDPE*—high-density polyethylene.
- 3.5. *hydrolysis*—the reaction of water molecules with the polymer material, resulting in polymer chain scission, reduced molecular weight, and strength loss.
- 3.6. *in-isolation testing*—geosynthetic testing in which the specimen is surrounded by air or a fluid (not soil).
- 3.7. *installation damage*—damage to the geosynthetic, such as cuts, holes (geotextiles only), abrasion, fraying, etc., created during installation of the geosynthetic in the backfill soil.
- 3.8. *load level*—for creep or creep-rupture testing, the load applied to the test specimen divided by T_{lot} , the short-term ultimate strength of the lot or roll of material used to form the creep testing.
- 3.9. *MARV*—the minimum average roll value for the geosynthetic, defined as two standard deviations below the mean for the product (i.e., 97.5 percent of all test results will meet or exceed the MARV). For practical purposes, from the user's viewpoint, the average for a sample taken from any roll in the lot shipped to the job site should meet or exceed the MARV.
- 3.10. *minimum value*—the lowest sample value from documented manufacturing quality control test results for a defined population from one test method associated with one specific property.
- 3.11. *MSE*—mechanically stabilized earth.
- 3.12. *nonaggressive environment*—for geosynthetic walls and slopes, soils that have a *d₅₀* of 4.75 mm or less, a maximum particle size of 31.5 mm or less, a pH of 4.5 to 9, and an effective design temperature of 30°C (85°F) or less.
- 3.13. *oxidation*—the reaction of oxygen with the polymer material, initiated by heat, UV radiation, and possibly other agents, resulting in chain scission and strength loss.

- 3.14. *PET*—polyester.
- 3.15. *postconsumer recycled material*—polymer products sold to consumers that have been returned by the consumer after use of the products for the purpose of recycling.
- 3.16. *PP*—polypropylene.
- 3.17. *primary and secondary products*—for product line characterization purposes, the primary product is the product in which the full suite of index and performance level tests are conducted to characterize the product line, whereas the secondary products are those used to characterize the consistency of the properties throughout the range of products included in the line (or to facilitate the interpolation of those properties to products in the line not specifically tested) using a limited suite of index and performance level tests.
- 3.18. *product line*—a series of products manufactured using the same polymer (including stabilizers) in which the polymer for all products in the line comes from the same source and/or is purchased or manufactured by the geosynthetic manufacturer using the same property and material specifications for the base polymer plus additives, the manufacturing process is the same for all products in the line, and the only difference is in the product weight/unit area or number of fibers contained in each reinforcement element.
- 3.19. *product qualification testing*—testing used to establish the acceptability of the product or product line by an agency prior to shipment or use of the product in a specific project (e.g., as the basis for adding the product to the agency's qualified or approved products list).
- 3.20. *product quality assurance testing*—testing used to verify that the product or product line has not changed since being tested for product qualification (e.g., as the basis for allowing the product or product line to remain on the agency's qualified or approved products list).
- 3.21. *QPL*—qualified products list.
- 3.22. *RF*—combined reduction factor to account for long-term degradation due to installation damage, creep, and chemical/biological aging.
- 3.23. *RF_{CR}*—strength reduction factor to prevent long-term creep rupture of the reinforcement.
- 3.24. *RF_D*—strength reduction factor to prevent rupture of the reinforcement due to long-term chemical and biological degradation.
- 3.25. *RF_{ID}*—strength reduction factor to account for installation damage to the reinforcement.
- 3.26. *sample*—a portion of material that is taken for testing or for record purposes, from which a group of specimens can be obtained to provide information that can be used for making statistical inferences about the population(s) from which the specimens are drawn.
- 3.27. *specimen*—a specific portion of a material or laboratory sample upon which a test is performed or that is taken for that purpose.
- 3.28. *survivability*—the ability of a geosynthetic to survive a given set of installation conditions with an acceptable level of damage.
- 3.29. *T_{al}*—the long-term tensile strength that will not result in rupture of the reinforcement during the required design life, calculated on a load per unit of reinforcement width basis.

- 3.30. T_{ult} —the ultimate tensile strength of the reinforcement determined from wide width tensile tests.
- 3.31. UV —ultraviolet light.

4. SIGNIFICANCE AND USE

- 4.1. This recommended practice provides a protocol to assess the reduction in tensile strength and stiffness of geosynthetic (i.e., geotextiles and geogrids) reinforcement that occurs due to the installation of the material in or immediately beneath soil backfill and due to time exposure to the ambient environment (e.g., temperature, pH, oxygen, water, or other materials or chemicals in the surrounding environment) during the design life for the structure. This recommended practice is applicable to the assessment of these long-term properties for individual geosynthetic reinforcement products as well as for geosynthetic reinforcement products lines. This reduced strength can be used as a design value in the design of geosynthetic reinforced structures such as walls, reinforced slopes, or embankment base reinforcement, or can be used for material acceptance and QA purposes for the construction of such structures.
- 4.2. Due to the length of time required to obtain the test data required, this recommended practice is generally not practical to be carried out on a suite of products for a specific project. Its primary use is to establish values that can be used at a program level by an agency or the geosynthetic manufacturer, using data developed for a range of site conditions likely to be encountered that can be adapted to the site-specific conditions encountered in specific construction projects as needed.
- 4.3. This practice has not been developed to establish strength and stiffness properties directly applicable to dynamic loading situations, such as in pavement base course reinforcement. The strength and stiffness properties obtained using this practice have been shown to be applicable to seismic loading situations, though the values obtained are likely to be conservative in that case, at least with regard to creep.

5. EVALUATION OF SOIL ENVIRONMENT AGGRESSIVENESS EFFECTS ON LONG-TERM STRENGTH DETERMINATION

- 5.1. The aggressiveness of the environment with regards to geosynthetic long-term strength determination shall be based on soil gradation and particle characteristics of the backfill soil, chemical properties of the backfill soil and adjacent environment, and site temperature. Soil gradation and particle characteristics primarily affect potential RF_{ID} values, chemical properties affect the potential for high RF_D values, and temperature affects potential for high RF_D and high RF_{CR} values. In general, the more angular the soil, the more uniform its gradation, the greater the maximum particle size, and the more durable the particles, the more aggressive the soil is with regard to potential for installation damage. While installation damage can be evaluated for the anticipated soil gradation and characteristics, it is generally undesirable to use soils and associated installation conditions that result in a RF_{ID} value that is greater than approximately 1.7 due to the likelihood of excessive variability in the results. The decision regarding what gradation characteristics are to be considered too aggressive shall be made by the approval authority.
- 5.2. Regarding chemical properties of the environment surrounding the geosynthetic in the wall or slope, the pH shall be between 4.5 and 9 to be considered nonaggressive. This applies both in the reinforced backfill and at the back of the face of walls or other surficial treatments. See Elias et al. (2009) for a detailed discussion of soil conditions that can contribute to a chemically aggressive environment.
- 5.3. Regarding temperature, the effective design temperature at the wall or slope site shall be less than 30°C (85°F) for the environment to be considered nonaggressive. In all but the most southerly tier

of states in the United States, all geosynthetic structure sites are anticipated to have an effective design temperature that is below 30°C (85°F). Unless otherwise indicated in the contract specifications for a given project, the design temperature used to determine RF and T_{dl} from product specific data shall be assumed to be 20°C (68°F).

- 5.4. The contract specifications for the geosynthetic structure should identify whether the environment is anticipated to be aggressive and the reason for the aggressive environment designation (i.e., backfill gradation, site chemistry, or site temperature). If aggressive conditions are not identified in the contract specifications and the contract specifications provide soil chemical criteria that are consistent with nonaggressive conditions as described herein, the environment should be considered to be nonaggressive to determine the long-term strength. However, the backfill should be tested prior to use to verify that it is nonaggressive.

6. PRODUCT QUALIFICATION TESTING AND EVALUATION

6.1. *Product Qualification Testing Approach:*

- 6.1.1. As a first step, it shall be verified which geosynthetic products should be included as a single product line, unless only a single product is to be evaluated. The focus of the product qualification testing program shall be to characterize the long-term strength and stiffness properties for the entire product line, selecting samples from specific products within the product line to represent the entire product line. If a single product is to be evaluated, the product shall be subjected to the full suite of product qualification tests as described herein.

Note 1—The product line concept provides the ability to conduct performance testing to assess strength reduction factors and stiffness values on selected representative products in the product line. The test results from these representative products are then used to interpolate the reduction factors and stiffness values for the products in the product line not performance tested. This interpolation, or in some cases extrapolation, is performed using a parameter for which a clear relationship with the value of the strength reduction factor or stiffness for the product line exists (e.g., unit weight or tensile strength). Alternatively, a lower bound value could be applied to the rest of the product line based on the test results from the weakest or lightest weight product in the product line, provided the lower bound value can be selected with confidence. The ability to test only representative products from the product line can significantly reduce testing costs. However, it must be recognized that there is some risk associated with the use of this product line concept with regard to the determination of the properties of the intermediate products not specifically tested. The product line concept relies on the ability of the testing/evaluating organization to verify that the polymer source and fibers used to make the products in the line not tested are, in fact, the same as those used in the products that are specifically tested. In addition, for coated geogrids, the consistency of the coating type, process, and thickness/weight across all the products in the product line must also be verified. To reduce this risk to an acceptable level, a manufacturing plant auditing process should be used, and a limited testing program focused on evaluating the consistency among all products in the product line should be conducted on products in the product line not selected and subjected to performance tests as product line representatives. See Section 6.3 for details.

6.2. *Sampling:*

- 6.2.1. All materials or products, or both, to be tested will be furnished by the manufacturer/supplier at no cost to the review/approval authority. Samples will be selected for testing by agency or owner personnel or designated parties.
- 6.2.2. Sampling shall be conducted in accordance with the requirements in the specific AASHTO, ASTM, GRI, or ISO test standard for the specific tests conducted as part of this standard practice. For products selected as representative of the product line, an entire roll should be taken, but no

less than the sum of the sample sizes required for all tests to be conducted on each product. For the remaining products in the product line, a sample with the dimensions of the product roll width by 20 ft should be taken. As a minimum, the following shall be obtained:

- A geosynthetic product sample of sufficient size to accommodate all of the specified testing;
- Information showing the manufacturer's name and description of product (style, brand name, etc.);
- Product roll and lot number; and
- A sample of the polymer component(s) used to manufacture the product or product line in sufficient quantity to conduct the specified polymer tests. Typically, a minimum 500-gm sample of the component material(s) will be sufficient.

6.2.3. All samples for the specified product qualification testing shall be from the same roll of material for each product tested. Regarding the polymer components, they should be obtained from the production line used to produce the geosynthetic products being evaluated.

6.2.4. A sampling report should be developed and, as a minimum, should include the following information:

- Date of sampling;
- A brief description of the manufacturing facility/production line;
- The facility location;
- Any prearrangements made with the manufacturer to sample, especially considering any advance warning of the sampling event provided to the manufacturer;
- The information for each sample required in Section 6.2.2;
- Where the sample was taken within the facility; and
- How the sample was prepared for shipping and supervised by the sampler.

6.3. *Evaluation of Product Lines:*

6.3.1. *Assessment to Define Product Line*—Data must be obtained for each product to facilitate the determination of which products should be considered as included in the product line. The assessment of whether or not all products identified as a product line by the geosynthetic manufacturer qualify as such should be based, as a minimum, on the following information for each product in the product line:

- Geosynthetic type, structure, and weaving process used to construct yarns or ribs;
- For geogrids, spacing and dimensions of geogrid elements, including photographs or small samples for visual examination. The receiving laboratory should verify these dimensions upon receipt of the sample(s) using hand measurement techniques. This is especially critical for strength determination based on a single or limited number of ribs in the specimens tested.
- Polymer(s) used for fibers, ribs, etc.;
- Polymer(s) used for coating, if present;
- Polymer source(s) used for product;
- For HDPE and PP, primary resin ASTM type, class, grade, category (for HDPE use ASTM D 1248, and for PP use ASTM D 4101), and any other material and property specifications used to purchase the raw materials or as manufacturing targets;
- For PET, minimum production number average molecular weight (ASTM D 4603 and GRI-GG8) and maximum carboxyl end group content (ASTM D 7409), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided, and any other material and property specifications used to purchase the raw materials or as manufacturing targets;
- Percent of postconsumer recycled material, by weight;

- Minimum weight per unit area for product (ASTM D 5261); and
- minimum average roll value (MARV) for ultimate wide width tensile strength (ASTM D 4595 or ASTM D 6637), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.

6.3.2. Once an initial assessment of the product line has been made based on the product description and index property data described above, performance and additional index property testing for installation damage, creep, and durability shall be conducted for the products identified as a product line. The full suite of performance tests for installation damage, creep, and durability shall be obtained for at least one product in the product line to qualify the product line. This product shall be designated as the “primary product” for product line characterization purposes. For certain tests, such as UV resistance and oven aging, it is permissible to test only the lightest weight product in the product line, provided it is obvious that doing so will be a conservative characterization of the entire product line for those specific properties. Additional product specific test results for installation damage, creep, and durability as described herein shall be obtained for a minimum of two other products in the product line (designated as “secondary products”) to verify consistency of the other products in the line with the primary product and the ability to interpolate installation damage, creep, and durability behavior to estimate strength reduction factors for the entire product line. For larger product lines (i.e., greater than 10 products in the line), a minimum of one secondary product per each additional 5 products in the product line shall be tested to characterize the creep behavior of the product line. In addition, a limited manufacturing plant audit shall be conducted at the time the samples for testing are obtained. See Sections 6.3.2.1 through 6.3.2.4 and Note 1 for additional guidance on the assessment of each product in the product line.

6.3.2.1. Product-specific installation damage data obtained in accordance with Annex A should be obtained for each product in the line. However, it is permissible to obtain installation damage data for only some of the products in the product line if interpolation of the installation damage reduction factor between products is feasible, or if an upper bound value of RF_{ID} can be determined for the entire product line. Testing and interpretation requirements to determine RF_{ID} for each product in the product line provided in Annex A, Section A1.1.6.4 shall be followed. For the products in the product line not tested in accordance with Annex A as primary or secondary products for product line characterization, a limited testing program should be conducted that allows direct comparison to the installation damage test results obtained for the products (primary and secondary per Section 6.3.2) used to characterize the product line. One of the following two options should be used to accomplish this:

1. Conduct bench-scale installation damage tests (ISO 10722-1) on all products in the product line; or
2. Conduct a full-scale field installation damage test per Annex A and ASTM D 5818, but using only the soil with a d_{50} size that is equal to or larger than a d_{50} size of 4.75 mm, or other d_{50} size as determined by the approval authority, and the aggregate shall have a maximum LA Abrasion (T 96) percent loss of 35 percent.

This limited testing program should be used to verify that the installation damage test results for products not tested as primary or secondary products per Section 6.3.2 for product line characterization are consistent with the installation damage data for the primary and secondary products. Consistency between the primary and secondary product test results and the limited test results for the remaining products in the product line should be judged as described in Section A1.1.6.4.

The comparison between the primary/secondary product installation damage test results and the test results for the remaining products shall be conducted for the same type of installation damage test (i.e., ISO tests for all products in the product line, or full-scale installation damage tests for one soil for all products in the product line).

6.3.2.2. For extension of the creep data obtained on the product identified as the primary product for the product line to the entire product line as defined herein, a limited creep testing program shall be

conducted on at least two additional products (i.e., secondary products per Section 6.3.2) in the product line. If the results are not consistent with the primary product creep-rupture envelope in accordance with Section B1.7 in Annex B, all products in the product line shall be creep tested, or the product line should be divided into groups of products that are consistent and that meet the definition of a product line.

6.3.2.3. For determination of the durability reduction factor, RF_D , for the product line, the weakest or lightest product in the range of products in the product line should be tested. For molecular weight/viscosity and carboxyl end group testing of polyester geosynthetics, it is acceptable to perform the tests on the yarn sampled at the geosynthetic manufacturing facility provided that it can be demonstrated that the yarn sampled is used to manufacture the geosynthetic products that are included in the product line being evaluated, in accordance with Section 6.3.2.4. If this cannot be verified, then yarn/fibers obtained from each product in the product line shall be tested.

6.3.2.4. The focus of the geosynthetic reinforcement manufacturing plant limited audit is to verify traceability of materials used for each product in the product line, and to verify consistency in the manufacturing process used for all products in the product line. The audit of the geosynthetic reinforcement manufacturing facility, as a minimum, shall include the following:

- Verification that the same base polymer and yarn is used in all products included in the product line;
- Verification of polymer source(s) used and consistency of the polymer property standards for the sources used;
- Verification of the consistency of the manufacturing process used with regard to the base polymeric yarn, filament, or rib, including heating/quenching history, weaving, rib junction construction, etc.; and
- For coated geogrids, verification of the coating material used and its consistency for all products in the line, including thickness and/or weight per unit area, temperature history, and other processing variables.

The audit should be conducted in conjunction with the sampling conducted. A report of the audit findings shall be developed by the auditor and included with the sampling report.

6.4. *Determination of Long-Term Geosynthetic Strength for Initial Product Qualification:*

The long-term geosynthetic strength shall be determined by applying strength reduction factors to the ultimate tensile strength of the geosynthetic, as shown in Equations 1 and 2.

$$T_{al} = \frac{T_{ult}}{RF} \quad (1)$$

where:

$$RF = RF_{ID} \times RF_{CR} \times RF_D \quad (2)$$

where:

T_{al} = the long-term tensile strength that will not result in rupture of the reinforcement during the required design life, calculated on a load per unit of reinforcement width basis;

T_{ult} = the minimum ultimate tensile strength (MARV) of the reinforcement determined in accordance with ASTM D 4595 for geotextiles and ASTM D 6637 for geogrids;

RF = a combined reduction factor to account for potential long-term degradation due to installation damage, creep, and chemical/biological aging;

RF_{ID} = a strength reduction factor to account for installation damage to the reinforcement;

RF_{CR} = a strength reduction factor to prevent long-term creep rupture of the reinforcement; and

RF_D = a strength reduction factor to prevent rupture of the reinforcement due to chemical and biological degradation.

- 6.4.1. The value selected for T_{ult} is the MARV for the product to account for statistical variance in the material strength. For geogrids, a statistically based minimum value may be used in lieu of the MARV. Other sources of uncertainty and variability in the long-term strength include installation damage (Annex A), creep extrapolation (Annex B), and chemical degradation (Annex C). The observed variability in the creep-rupture envelope should be assumed to be 100 percent correlated with the short-term tensile strength, T_{ult} , as the creep strength is typically directly proportional to the short-term tensile strength within a product line (Bathurst et al., 2012) (see Annex B and Note B7 in Annex B if this is not the case). Therefore, the MARV of T_{ult} adequately takes into account that source of variability. For additional discussion of this issue, see Note 2.

Note 2—The product strength variability is not taken into account by using the creep limited strength, T_l , directly or in normalizing T_l by $T_{baseline}$ (see Annex B). T_l only accounts for extrapolation uncertainty. Furthermore, $T_{baseline}$ is specific to the lot of material used for the creep testing. Normalizing by $T_{baseline}$ makes the creep reduction factor RF_{CR} applicable to the rest of the product line, as creep strength is typically directly proportional to the ultimate tensile strength, within a product line. As shown below, it is not correct to normalize the creep strength T_l using T_{ult} , the MARV of the tensile strength for the product, nor is it correct to use T_l directly in the numerator to calculate T_{al} .

$$RF_{CR} = \frac{T_{baseline}}{T_l} \neq \frac{T_{ult}}{T_l} \quad \text{and} \quad T_{al} \neq \frac{T_l}{RF_{ID} \times RF_D}$$

In the former case, the creep strength is not indexed to the actual tensile strength of the material used in the creep testing, and because there is a 50 percent chance that $T_{baseline}$ will be less than or equal to T_{ult} , using T_{ult} in this case would result in an unconservative determination of RF_{CR} . In the latter case, where T_l is used directly as a creep-reduced strength, the product strength variability is not taken into account, because T_l is really a mean creep strength. Hence, RF_{CR} must be determined as shown in Equation B1-5 (see Annex B), and the MARV or minimum value must be used for T_{ult} when determining T_{al} . Note that the use of the MARV for T_{ult} may not fully take into account the additional variability caused by installation damage. For the typical degree of installation damage observed in practice, this additional variability is minor and can be easily handled through the overall safety factor used in design of reinforced structures. For specific procedures regarding how to account for this additional variability, see Bathurst et al. (2011). For durability (RF_D), additional variability does not come into play if a default reduction factor is used. If a more refined durability analysis is performed, additional variability resulting from chemical degradation may need to be considered.

- 6.4.2. The RF_{ID} and RF_{CR} shall be determined from product specific data for all geosynthetic reinforcement products or product lines. The product specific data for these reduction factors shall be interpreted/extrapolated in accordance with Annexes A and B. RF_D shall be determined from long-term product specific data interpreted/extrapolated in accordance with Annex C, or a default value may be used as described below. A default reduction factor for RF_D may be used if the environment is nonaggressive and if the product meets the minimum polymer and physical property requirements provided in Table 1. In this case, a default value for RF_D of 1.3 may be used for PET, HDPE, and PP geosynthetics.

Note 3—The default value for RF_D of 1.3, which can be used for products that meet the minimum property requirements in Table 1, was determined for effective design temperatures that are less than or equal to 20°C (68°F). A higher default value of 1.5 for products that meet the property requirements in Table 1 may be desirable for more temperate climates that still meet the requirements for a nonaggressive environment, especially to address polyolefin oxidative degradation, as the potential for this type of degradation, even for products that meet the property requirements in Table 1, becomes more uncertain at higher temperatures due to the lack of protocols that can accurately identify the amount or effectiveness of end use antioxidants present.

- 6.4.3. If the environment is identified as aggressive due to the chemical regime or due to temperature, or if the geosynthetic product does not meet the requirements in Table 1, default reduction factors should not be used for RF_D . For chemically aggressive or elevated temperature environments, RF_D must be determined based on long-term product specific data for an environment that is as or more aggressive than the project specific environment in question. Aggressive environments need to be addressed in the product submittal only if specifically requested by the contracting agency or the geosynthetic supplier. Once the appropriate reduction factors are established, the long-term geosynthetic strength is determined using Equations 1 and 2, or as determined in Note B7 of Annex B.
- 6.4.4. If a default reduction factor for RF_D is to be used, geosynthetic products likely to have good resistance to installation stresses and to long-term chemical degradation are required to minimize the risk of significant long-term degradation. Polymer materials not meeting the requirements in Table 1 could be used if detailed product specific data, extrapolated to the design life intended for the geosynthetic structure (see Annex C), is provided.
- 6.4.5. Unless otherwise specified by the agency or owner, geosynthetic reinforcement elements in MSE walls and reinforced slopes should be designed to have a durability to ensure a minimum design life of 75 years for permanent structures in accordance with the *AASHTO LRFD Bridge Design Specifications*. This design life requirement should be reflected in the long-term strength test data and analysis.

Table 1—Minimum Requirements for Geosynthetic Products to Allow Use of Default Reduction Factor for Long-Term Degradation

Polymer Type	Property	Test Method	Criteria to Allow Use of Default RF^*
PP and HDPE	UV oxidation resistance	ASTM D 4355	Min. 70% strength retained after 500 h in weatherometer
PET	UV oxidation resistance	ASTM D 4355	Min. 50% strength retained after 500 h in weatherometer if geosynthetic will be buried within 1 week, 70% if left exposed for more than 1 week.
PP and HDPE	Thermo-oxidation resistance	ENV ISO 13438:2004, Method A (PP) or B (HDPE)	Min. 50% strength retained after 28 days (PP) or 56 days (HDPE)
PET	Hydrolysis resistance	Inherent viscosity method (ASTM D 4603 and GRI-GG8), or determine directly using gel permeation chromatography	Min. number average molecular weight of 25,000
PET	Hydrolysis resistance	ASTM D 7409	Max. carboxyl end group content of 30
All Polymers	% postconsumer recycled material by weight	Certification of materials used	maximum of 0%

Note 4—The requirements provided in Table 1 utilize currently available index tests and are consistent with current *AASHTO LRFD Bridge Design Specifications*. These index tests can provide an approximate measure of relative resistance to long-term chemical degradation of geosynthetics. Values selected as minimum criteria to allow use without additional long-term testing are based on values for such properties based on long-term research reported in the literature. These values are considered indicative of good long-term performance or represent a readily available current standard within the industry that signifies that a product has been enhanced for long-term environmental exposure. There is little long-term history or even laboratory data regarding the durability of geosynthetics containing a significant percentage of recycled material. Therefore, their potential long-term performance is unknown, and it is recommended that long-term data be obtained for products with significant recycled material to verify their performance before using them.

- 6.5. *Report—Product Qualification Testing:*
For product qualification, the following information shall be included in the product or product line evaluation report:
- 6.5.1. Basis for Determination of Product Line Members:
- 6.5.1.1. Geosynthetic type, structure, and weaving process used to construct yarns or ribs.
- 6.5.1.2. Spacing and dimensions of geogrid elements, including photographs or small samples for visual examination. The receiving laboratory should verify these dimensions upon receipt of the sample(s) using hand measurement techniques. This is especially critical for strength determination based on a single or limited number of ribs in the specimens tested.
- 6.5.1.3. Whether or not the polymer material and property specifications used by the manufacturer to obtain or manufacture the products was consistent throughout the product line, as described in the audit report for the manufacturer obtained in accordance with this standard practice.
- 6.5.1.4. Polymer(s) used for coating, if present.
- 6.5.1.5. Whether or not the polymer material and property specifications used by the manufacturer to obtain or manufacture the products was consistent throughout the product line, as described in the audit report for the manufacture obtained in accordance with this standard practice.
- 6.5.1.6. For HDPE and PP, primary resin ASTM type, class, grade, category (for HDPE use ASTM D 1248, and for PP use ASTM D 4101).
- 6.5.1.7. For PET, minimum production number average molecular weight (ASTM D 4603 and GRI-GG8) and maximum carboxyl end group content (ASTM D 7409), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.
- 6.5.1.8. Percent of postconsumer recycled material by weight.
- 6.5.1.9. Minimum weight per unit area for product (ASTM D 5261).
- 6.5.1.10. MARV for ultimate wide width tensile strength (ASTM D 4595 or D 6637), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.
- 6.5.2. Installation Damage Data Requirements (RF_{ID}):
Installation damage testing and interpretation shall be conducted in accordance with Annex A. As a minimum, for each product tested, the following information should be obtained:
- 6.5.2.1. Date tests were conducted.
- 6.5.2.2. Name(s), location(s), and telephone number(s) of laboratory(ies) conducting the testing and evaluation.
- 6.5.2.3. Whether installation damage testing was conducted as a site-specific evaluation for an actual construction project or was conducted as a non-site-specific evaluation.
- 6.5.2.4. Description of specific procedures used to conduct the installation damage testing, including installation procedures, sample size, method of specimen selection, sample removal procedures,

etc. Identify any deviations in the installation procedures relative to typical installation practice in full-scale structures, if the testing was not site specific.

- 6.5.2.5. Photographs illustrating procedures used and the conditions at the time of the testing, if available.
- 6.5.2.6. Measured mass/unit area per ASTM D 5261 for the sample tested for installation damage and for the sample used to establish the undamaged strength. Also obtain product manufacturer Quality Control (QC) data on the uncoated product (i.e., greige-good) for the lot used for installation damage testing, if available.
- 6.5.2.7. Tensile test results for the product before exposure to installation conditions (i.e., virgin material, $T_{baseline}$), and whether both virgin and damaged samples were taken from the same roll of material, or just from rolls within the same lot of material.
- 6.5.2.8. Tensile test results for specimens taken from the damaged material after installation.
- 6.5.2.9. Tensile test results for both virgin and damaged specimens should include individual test results for each specimen, typical individual load–strain curves that are representative of the specimens tested, including associated calibration data as necessary to interpret the curves (curves in which strain and load/unit width are already calculated are preferred), the average value for each sample, the coefficient of variation for each sample, and a description of any deviations from the standard tensile test procedures required by Annex A.
- 6.5.2.10. Gradation curves for backfill material located above and below the installation damage geosynthetic samples, including the d_{50} size, maximum particle size, and a description of the angularity of the soil particles per ASTM D 2488, including photographs illustrating the soil particle angularity, if available. Also include LA Abrasion (T 96) test results for the backfill material used.
- 6.5.2.11. Photographs or a description, or both, of the type and extent of damage visually evident in the exhumed samples and specimens.
- 6.5.2.12. The RF_{ID} , and a description of the data interpretation method used to determine RF_{ID} for each sample.
- 6.5.3. *Creep Data Requirements (RFCR and Creep Stiffness J):*
Creep testing and interpretation shall be conducted in accordance with Annex B. As a minimum, for each product tested, the following information should be obtained:
 - 6.5.3.1. Date tests were conducted.
 - 6.5.3.2. Name(s), location(s), and telephone number(s) of laboratory(ies) conducting the testing and evaluation.
 - 6.5.3.3. Photographs illustrating the creep testing equipment and procedures used, as available.
 - 6.5.3.4. Tensile test results for the product before creep testing (i.e., virgin material), and whether both virgin and creep tested samples were taken from the same roll of material or just from rolls within the same lot of material.
 - 6.5.3.5. Tensile test results should include individual test results for each specimen, typical load–strain curves that are representative of the specimens tested, including associated calibration data as necessary to interpret the curves (curves in which strain and load/unit width are already calculated are preferred), the average value for each sample, the coefficient of variation for each sample, and a description of any deviations from the standard tensile test procedures required by Annex B.

- 6.5.3.6. Creep test standard used and any deviations from the procedures required in Annex B.
- 6.5.3.7. Load and time to rupture for each specimen as a minimum; however, strain data as a function of time are desirable if available.
- 6.5.3.8. If elevated temperature testing is conducted, creep data before and after time/load shifting, including shift factors used and a description of how the shift factors were derived, shall be provided.
- 6.5.3.9. Data illustrating the variability of the creep test environment, including temperature and humidity, during the creep test time period, or some assurance that the creep test environment was maintained within the variation of temperature prescribed herein, shall be provided.
- 6.5.3.10. Description of statistical extrapolation procedures used in accordance with Annex B, if statistical extrapolation is performed.
- 6.5.3.11. RF_{CR} , and a description of how RF_{CR} was determined for each product.
- 6.5.3.12. In addition, regardless of which approach is used to determine RF_{CR} , creep strain data at a load level that results in a strain of 2 percent at approximately 1000 h shall be submitted to determine the low strain (i.e., 2 percent) creep stiffness at 1000 h and at the specified design life (typically 75 years).
- 6.5.3.13. For both creep rupture and low strain creep stiffness testing, if single-rib, yarn, or narrow-width specimens are used, 1000-h creep data in accordance with Annex B that demonstrate the single-rib, yarn, or narrow-width test results are consistent with the results from multirib/wide-width testing.
- 6.5.4. Long-Term Durability Data Requirements to Establish Default Value of RF_D :
If a default value for RF_D is to be used, the following information and test results shall be provided in the report:
 - 6.5.4.1. Ultraviolet resistance at 500 h in weatherometer (ASTM D 4355). Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.
 - 6.5.4.2. Oven-aging tests conducted in accordance with ENV ISO 13438:2004, Method A (PP) or B (HDPE), for polyolefin geosynthetics. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.
 - 6.5.4.3. Inherent viscosity/molecular weight (ASTM D 4603 and GRI-GG8) and carboxyl end group (CEG) content (ASTM D 7409) for polyester geosynthetics conducted on the base yarn used for the manufacture of the geosynthetic. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.
- 6.5.5. Long-Term Durability Data Requirements if Default Value for RF_D is Not Used:
If it is desired to submit detailed durability performance test data to justify a lower RF_D , or to allow use in environments classified as chemically aggressive, durability testing and interpretation shall be conducted in accordance with Annex C and, as a minimum, for each product tested, the following information shall be obtained:
 - 6.5.5.1. Date tests were conducted.
 - 6.5.5.2. Name(s), location(s), and telephone number(s) of laboratory(ies) conducting the testing and evaluation.