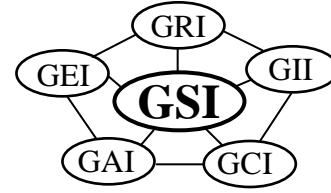


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GRI Standard Practice GG4(b)*

Standard Practice for

"Determination of the Long-Term Design Strength of Flexible Geogrids"

This specification was developed by the Geosynthetic Research Institute (GRI) with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1. Scope

- 1.1 This standard practice is to be used to determine the long-term design strength of flexible geogrids for use in the reinforcement of such structures as embankments, slopes, retaining walls, improved bearing capacity, and other permanent geotechnical and transportation engineering systems. By "flexible" the Standard Practice is meant to be applicable to those geogrids exhibiting less than 1000 g-cm flexural rigidity in the ASTM D1388 stiffness test.
- 1.2 The method is based on the concept of identifying and quantifying reduction factors for those phenomena which can impact the long-term performance of flexible geogrid reinforced systems and are not taken into account in traditional laboratory testing procedures.
- 1.3 The reduction factors to be considered are for installation damage, creep deformation, long term degradation, and joints (seams and connections).

*This GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This practice will be reviewed at least every 2-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

Note 1: Previous versions of this practice included a reduction factor for biological degradation. Since this has not been a factor for the polymers used in geogrid manufacturing it has been removed in this revision.

- 1.4 These reduction factors values can be obtained by direct experimentation and measurement, or by using default values which are given for the various applications which use geogrids.

2. Reference Documents

2.1 ASTM Standards

| | |
|-------|---|
| D123 | Terminology Relating to Textiles |
| D1388 | Test Methods for Stiffness of Fabrics |
| D4354 | Practice for Sampling Geotextiles |
| D4439 | Terminology for Geotextiles |
| D4595 | Tensile Properties of Geotextiles by the Wide Width Strip Method |
| D5262 | Tension Creep Testing of Geosynthetics |
| D5322 | Practice for Laboratory Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids |
| D5818 | Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics |
| D6213 | Practice for Tests to Evaluate the Chemical Resistance of Geogrids to Liquids |
| D6637 | Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi Rib Tensile Method |
| D6992 | Test Method for Accelerated Tensile Creep and Creep Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method |
| D7737 | Test Method for Individual Geogrid Junction Strength |

3. Terminology

- 3.1 General - Many of the terms used in this standard are relatively new and undefined by standards groups such as ASTM, ISO, etc. Therefore a section devoted to definitions follows.

3.2 Definitions

3.2.1 Geogrids - A synthetic planar structure formed by a regular network of tensile strength elements with apertures of sufficiently large size to allow for interlocking with the surrounding soil so as to perform the primary function of reinforcement.

3.2.2 Flexible Geogrids - Those geogrids exhibiting a stiffness, or flexural rigidity, of less than 1000 g-cm as tested via ASTM D1388. These geogrids are generally made by a textile weaving process and generally involve polyester, polyvinyl alcohol or fiberglass yarns.

3.2.3 Apertures - The open spaces formed between the interconnected network of longitudinal and transverse ribs of a geogrid.

3.2.4 Strike-Through - The ability of the soil backfill to be continuous through the apertures of the geogrid allowing for bearing capacity against the transverse ribs.

3.2.5 Longitudinal Ribs - The continuous elements of a geogrid which are in the machine direction as manufactured, or in the major principal stress direction as placed in the field.

3.2.6 Transverse Ribs - The continuous elements of a geogrid which are in the cross machine direction as manufactured, or in the minor principal stress direction as placed in the field.

3.2.7 Junctions (or Nodes) - The interconnections between the longitudinal and transverse ribs of a geogrid which hold the grid structure together providing dimensional stability and load transfer mechanisms.

3.2.8 Joints (or Connections) - The connections made between separate geogrid rolls or between geogrids and wall panels or other parts of the structural system.

3.2.9 Design Strength (T_{design}) - The design, or required, strength of a geogrid needed for successful functioning of the system. It is often arrived at by an appropriate geotechnical design model.

3.2.10 Ultimate Geogrid Strength (T_{ult}) - The ultimate or maximum geogrid strength, T_{ult} , as determined by a short-term strength test in accordance with an accepted ASTM D6637.

3.2.11 Allowable Geogrid Strength (T_{allow}) - The long-term, allowable strength, T_{allow} , to be used in design taking into account all of the phenomena which could influence the geogrid during its service lifetime.

3.2.12 Factor-of-Safety - A numeric comparison of the geogrid's allowable tensile strength to the design or required tensile strength. The minimum acceptable value reflects the accuracy in defining load conditions, uncertainties in design methods, definition of soil strength and other design parameters.

3.2.13 Reduction Factors - A set of numeric values each of which is focused on a particular phenomenon which may adversely impact the geogrid's performance.

3.2.14 Atmosphere for Testing Geogrids - Ambient air conditions maintained at a temperature of $21 \pm 2^{\circ}\text{C}$ ($70 \pm 4^{\circ}\text{F}$) and a relative humidity of $65 \pm 5\%$.

4. Summary

- 4.1 This standard practice is meant to adjust a laboratory generated short term ultimate geogrid tensile strength value to a site-specific allowable long-term tensile strength value by using reduction factors for selected phenomena. It is then to be used with a factor-of-safety for the site-specific situation under consideration.
- 4.2 The focus of the standard is toward flexible geogrids with a flexural rigidity of less than 1000 g-cm.
- 4.3 Specific procedures for quantifying each of the reduction factors are provided. If these procedures are not followed default values are provided.

5. Significance and Use

- 5.1 Rather than use an unusually high overall factor-of-safety for geogrid reinforced structures (in comparison to those factors-of-safety used in a conventional design involving soil, concrete or steel), this standard of practice uses reduction factors for those particular phenomena which may diminish the performance of the as-received geogrid material.
- 5.2 The reduction factors to be discussed are those of installation damage, creep deformation, chemical degradation, and joints (seams and connections). The result of compensating for these phenomena is an allowable geogrid strength which can be used directly in design.

Note 2: Some applications such as walls and slopes require holes for guard posts, lights, signage, etc. to penetrate through the geogrid reinforcement. If this is the case, an additional reduction factor should be included, e.g., “RF_{Holes}”. Its value has been shown to be a linear reduction of its diameter to the width of the geogrid product: See Reference 11.3.

- 5.3 Procedures are given as to how one obtains each of the above reduction factors for the various phenomenon to be discussed, e.g., installation damage, creep, chemical degradation and joint strength.
- 5.4 As an option to conducting the above procedures, default values are given for each of the different phenomena depending on the particular geogrid reinforcement application.
- 5.5 The standard practice is site specific, application specific, and geogrid product specific, the latter being for flexible geogrids of flexural rigidity of less than 1000 g-cm.
- 5.6 This standard practice is not meant to be a test method, but does require various test protocols to obtain the necessary values for the different reduction factors.

6. Reduction Factor Concept

- 6.1 Required Strength ($T_{reqd.}$) - The required (or design) strength of a geogrid is that numeric value needed for successful functioning of the geogrid under consideration. For geogrid applications it is often calculated by a geotechnical engineer using an applicable design model, adapted for the geogrid's inclusion. It might also be defined in a formal specification or recommended by an owner. The units of $T_{reqd.}$ are in kN/m or lb/ft.
- 6.2 Ultimate Strength (T_{ult}) - The ultimate strength of a geogrid is obtained by one of the following tests. Note that some of them are short term tests which are often used for quality control, while others are long term tests used as performance indicators.
- 6.2.1 ASTM 6637 - This test is a single or multiple rib tensile strength test measuring the short term strength of the longitudinal ribs (or transverse ribs) resulting in a value in units of kN or lbs. By calculation using the number of repeating ribs it is extended to units of kN/m or lb/ft.
- 6.2.2 ASTM D5262 - This test is a sustained load (or creep) test for geosynthetics. It is of the wide width variety in that multiple ribs are evaluated simultaneously. The test is conducted for a minimum time of 10,000 hours. It has been traditionally used to obtain a RF_{CR} -value.
- 6.2.3 ASTM D6992 - This is also an accelerated sustained load (creep) test using stepped temperature increments under the concept of time-temperature-superposition. It greatly shortens the time to arrive at a long term strength value. It is presently generally used to obtain a RF_{CR} -value.
- 6.3 Allowable Strength (T_{allow}) - The allowable long-term strength of a flexible geogrid is to be used in a traditional factor-of-safety formulation and compared directly to the required, or design strength. Note that the allowable strength must always be greater than or equal to the required, or design.

$$T_{allow} \leq T_{ult} \quad (1)$$

Furthermore, both T_{allow} and $T_{reqd.}$ are less than T_{ult} since they are used to determine the global factor-of-safety value.

$$FS = T_{allow}/T_{reqd.} \quad (2)$$

where

- FS = factor-of-safety for unanticipated loading, construction and material uncertainties and other unknowns (typically a value from 1.25 to 1.5)
- T_{ult} = ultimate strength (kN/m or lb/ft)

T_{allow} = allowable strength (kN/m or lb/ft)
 T_{ult} = required (or design) strength (kN/m or lb/ft)

6.4 Reduction factors - A mechanism by which an ultimate strength of a particular geogrid can be adapted to an allowable strength using values tuned to site specific conditions is afforded by using reduction factors. For example, using geogrids in reinforcement applications the following should be used.

$$T_{\text{allow}} = T_{\text{ult}} \left[\frac{1}{\text{RF}_{\text{ID}} \times \text{RF}_{\text{CR}} \times \text{RF}_{\text{CD}} \times \text{RF}_{\text{JNT}}} \right] \quad (3)$$

where

RF_{ID} = reduction factor for installation damage
 RF_{CR} = reduction factor for creep deformation
 RF_{CD} = reduction factor for chemical degradation
 RF_{JNT} = reduction factor for joints (seams and connections)

Note 3: Temperature, per se, is not included as a reduction factor. If site-specific temperatures are of concern the various tests should be suitably accommodated with the mutual agreement of the parties involved.

7. Default Values for Reduction Factors

In the absence of test information and documentation as to the site specific values for the above listed values of reduction factors in Equation 3, the following default values should be used.

Table 1 - Default Values for Flexible Geogrids for Various Reduction Factors
(Terms are Defined in Equation 3)

| Application | RF_{ID} | RF_{CR} | RF_{CD} | RF_{JNT} |
|------------------|-------------------------|-------------------------|-------------------------|--------------------------|
| embankments | 1.4 | 3.0 | 1.4 | 2.0 |
| slopes | 1.4 | 3.0 | 1.4 | 2.0 |
| retaining walls | 1.4 | 3.0 | 1.4 | 2.0 |
| bearing capacity | 1.5 | 3.0 | 1.6 | 2.0 |

It should be mentioned that the values given in Table 1 are considered to be upper-bound values. Since the impact of multiplying these numbers together for a particular application is very significant in decreasing the ultimate strength, it is usually worthwhile to consider the specific procedures for evaluating the individual reduction factors. They follow in the order presented in Equation 3.

8. Procedures for Evaluating Individual Reduction Factor Values

8.1 Installation Damage, RF_{ID} - Installation damage of a specific type of geogrid is determined by installing a field test strip on the actual site's subgrade, or on a closely simulated version thereof. The geogrid is positioned in place, tensioned as per the intended final installation, and then backfilled using the site specific backfill material, lift height, placement equipment and compaction equipment. If these details are not known at the time of the test, worst case conditions should be assumed. The minimum size of the geogrid test strip is to be 9 m^2 (100 ft^2). If possible, the full roll width should be used. Upon completion of the backfilling the geogrid should be carefully exhumed so as not to create damage. The exhuming should be done immediately, i.e., it is a survivability test and not a long-term aging type of test.

Note 4: Past exhuming of geogrids has shown the removal of backfill to be an important consideration in that a significant amount of hand excavation is necessary. If the backfill layer is 30 cm (12 in.) or more, some of it can be removed by a front end loader or backhoe but the lower 15 cm (6 in.) should be removed by hand. Never use a bulldozer or road grader since the scraping action will likely damage the geogrid.

The exhumed geogrid is now tested for its residual strength using single or multiple ribs per ASTM D6637 and compared to test values of the comparable geogrid material which was not installed. The non-installed geogrid should be taken from the same roll as was the installed and exhumed geogrid.

The resulting reduction factor is formulated in a traditional matter, i.e.

$$RF_{ID} = T_{\text{orig.}}/T_{\text{exh.}} \quad (4)$$

where

RF_{ID} = reduction factor for installation damage
 $T_{\text{orig.}}$ = original strength as per D6637
 $T_{\text{exh.}}$ = exhumed strength as per D6637

A minimum number of thirty single rib tests in the machine direction for unidirectional geogrids, and twenty single rib tests in both the machine and cross machine directions for bidirectional geogrids, is necessary. The average value of these tests is to be used in the above formulation for the value of reduction factor for installation damage. The same type of test must be used for both original and exhumed samples, e.g., if multiple rib tests are being used for the original strength they must also be used to evaluate the exhumed strength.

Note 5: The above protocol for determining the installation damage of geogrids can alternatively use the ASTM D5818 Standard Practice. The procedures are approximately equivalent to one another.

8.2 Sustained Load Creep, RF_{CR} - The long-term deformation of geogrids under constant tensile stress can be avoided by using a suitable reduction factor. Called a creep reduction factor, FS_{CR} , it is obtained by hanging a dead weight on a suitably supported geogrid test specimen and monitoring its deformation versus time. The recommended test procedure for geogrids is contained in ASTM D5262 entitled, "Tension Creep Testing of Geosynthetics". Typical creep response curves are shown in Figure 1 for 10,000 hour duration tests. These are the minimum test times using this method.

This data can be extrapolated out one order of magnitude, to approximately 10 years, as a standard polymeric rule of thumb (ASCE Manual of Practice No. 66). RF_{CR} for calculating the T_{allow} for design lives in excess of 10 years may be determined as outlined in 8.2.2 or 8.2.3.

8.2.1 RF_{CR} for 10 Year Design Life - The reduction factor for creep is determined from the 10,000 hour curves as being the load at which the creep curve becomes asymptotic to a constant strain line, of 10 percent or less. This value of strength is then compared to the short term strength of the geogrid in D6637 evaluation as follows:

$$RF_{CR} = T_{ST}/T_{LT}$$

where

- RF_{CR} = reduction factor against creep
- T_{LT} = 10 year design life strength of the geogrid in sustained D6637 or ASTM D5262 testing at which curve becomes asymptotic to a constant strain line (see "limit" on following curves)
- T_{ST} = short term strength of the geogrid in D6637 testing whichever is comparable to the long term creep test, i.e., wide width or single rib test

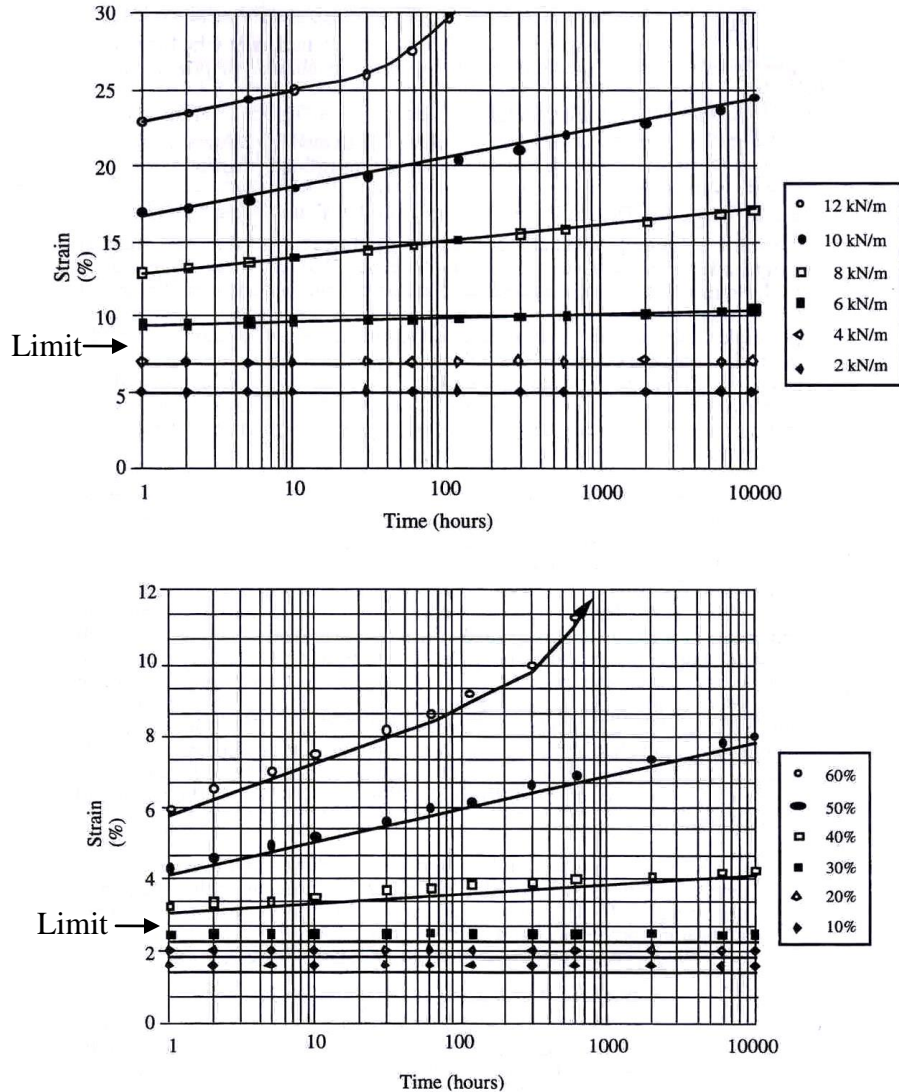


Fig. 1 - Typical Geogrid Curves Taken to 10,000 Hour Duration

8.2.2 RF_{CR} -values for Design Times Greater Than 10 Years - Creep performance data of a polymer product at a desired temperature is limited to one order of magnitude in extrapolation with time (as per ASCE). However, creep performance data at an elevated temperature permits an additional order of magnitude in extrapolation with time via time-temperature superposition principles. Creep curves from elevated temperature testing may be overlaid upon the creep curves at the desired temperature by shifting the abscissa time scale. The magnitude of the shift in time for overlay is the magnitude of the extrapolation of creep data beyond 10 years. Thus elevated temperature testing can predict creep performance of a polymer geogrid at the desired temperature level in excess of 10 years. See the Appendix to ASTM D5262 for the procedure.

8.2.3 The stepped isothermal method (SIM), per ASTM D6992, takes temperature shifting with discrete specimens a step further. SIM increments both temperature and time (appropriately called time-temperature-superposition) on the same test specimen so as to project long term creep in extremely short testing durations. The advantage in addition to greatly shortened testing duration is that there is no test specimen variation between different temperature increments.

- 8.3 Chemical Degradation - The reduction factor for potential chemical degradation of a geogrid is determined by testing before and after immersion in the specific liquid environment under consideration. Resistivity data is a good indication if a problem may arise. Such resistivity charts should be based on immersion tests. The immersion procedure to be used follows the ASTM D5322 Test Methods. Note that the EPA 9090 test method is presently depreciated. In these procedures samples are immersed in a closed container made from stainless steel which is filled with the agreed upon liquid and generally with zero head space. Four (4) geogrid samples measuring approximately 30 by 30 cm (12 by 12 in.) are to be used in each of two identical immersion tanks. One tank is kept at a constant temperature of 23°C, the second tank is kept at 50°C. The selection of the incubation liquid should model site specific conditions as closely as possible and be mutually agreed upon by the parties involved in the testing and acceptance. The precise procedure to be followed is set forth in the referenced standards.

Note 6: The selection of the liquid to be used for immersion is a critical decision and must be well planned and agreed upon by all parties concerned. If it is an aggressive and/or hazardous liquid, proper laboratory procedures and cautions must be followed. The standard operating procedures used for geomembrane evaluation must be followed.

At time periods of 30, 60, 90, and 120 days one sample from each tank is removed, blotted dry of liquid and cut for test specimens to be used in ASTM D6213. As many replicate test specimens as possible from each sample should be obtained for statistical averaging.

Note 7: This is a geogrid specific decision since the geometric patterns of different geogrids vary widely. Discussion among the parties involved should agree upon the specimen cutting pattern before incubation of the samples begins.

For uniaxial applications, the longitudinal ribs are to be tested, for biaxial applications, both the longitudinal and the transverse ribs are to be tested. The results of the average values of the incubated test specimens are to be compared to nonincubated test specimens (in the same type of test) and plotted as per Figure 2.

If the data appears well behaved in that no erratic trends are observed and if the 50°C change is greater or equal to the 23°C change and in the same direction (i.e., increasing or decreasing), the reduction factor is obtained as follows.

$$RF_{CD} = \frac{1}{1 - R_{50-120}}$$

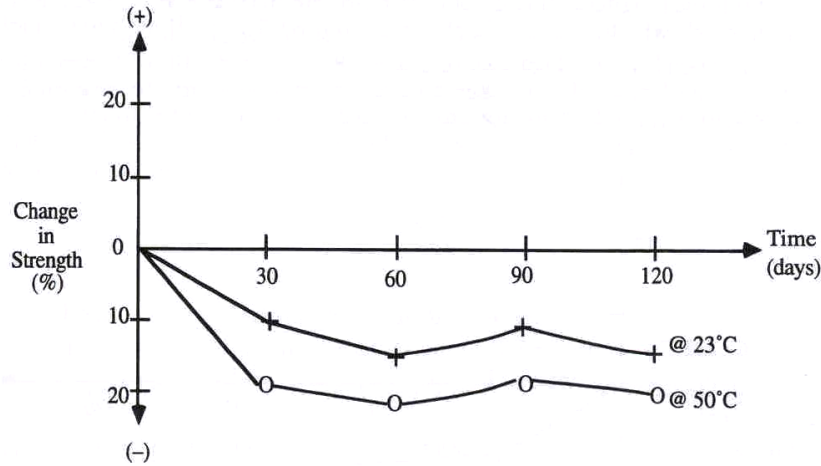


Figure 2. - Example Trend Curves from Chemical Incubation

where

RF_{CD} = reduction factor for chemical degradation
 R_{50-120} = strength reduction ratio of the 50°C incubation test at 120 days exposure (absolute value)

If the data is not well-behaved the entire immersion and subsequent strength tests must be repeated.

Note 8: Previous versions of this standard practice had a separate reduction factor for “biological degradation”. Presently it is the institute’s opinion that degradation from bacteria and fungi is so unlikely as to not warrant this remote form of degradation to geosynthetic polymer products. This is clearly not the case for natural biologic products, e.g., jute, coir, etc.

8.4 Joint Strength - Whenever seams are required to join geogrid panels together or connections are to be made with wall panels or other structural systems, a reduction factor for joint strength must be included. The test procedure to be followed is a sustained ASTM D5262 test. Note that this test is to be conducted for 1,000 hours at a minimum. The comparative tests include one with the joint in the center of the test specimen and the second with no joint included. In both cases, the stress at which a horizontal asymptote is reached is to be used in calculating the value of RF_{JNT} . Its formulation is as follows:

$$RF_{JNT} = \frac{T_{\text{as-received geogrid}}}{T_{\text{joined geogrid}}}$$

Note 9: This section on joint strength has been written around a mechanical joint such as a bodkin, pin or clamp. For those cases where the joint strength is mobilized by overlapping two sheets of geogrid, or a geogrid placed within a structural system (e.g., a block wall), a friction test is necessary. ASTM D5321 should be used in this regard.

9. Report

- 9.1 A complete description of the geogrid product tested including the product name, manufacturer and style; longitudinal rib dimensions, repeat pattern and other relevant characteristics; transverse rib dimensions, repeat pattern and other relevant characteristics; junction (node) construction, fabrication including coating type and approximate thickness, and other relevant characteristics; mass per unit area of the product and stiffness as per ASTM D1388.
- 9.2 Details as to determination of RF_{ID} and the resulting average value. This must describe the entire process in a step-by-step procedure. If the value obtained is less than the default value given in Table 1, it should be clearly stated as being such.
- 9.3 Details as to determination of RF_{CR} and the resulting average value. This must describe the entire process in a step-by-step procedure. If the value obtained is less than the default value given in Table 1, it should be clearly stated as being such.
- 9.4 Details as to determination of RF_{CD} and the resulting average value. This must describe the entire process in a step-by-step procedure. If the geogrid changes in color, texture, appearance or other surface feature it must be described. If the value obtained is less than the default value given in Table 1, it should be clearly stated as being such.
- 9.5 Details as to determination of RF_{JNT} and the resulting value. This must describe the entire process in a step-by-step procedure. If the value obtained is less than the default value given in Table 1, it should be clearly stated as such. If no seams or connections are involved, this item is to be omitted.
- 9.6 Details as to determination of the ultimate strength of the geogrid (T_{ult}) which is to be used in Equation 3.
- 9.7 Calculation of the allowable strength of the geogrid (T_{allow}), as per Equation 3, for use in long-term design of geogrids.

10. Example

The use of the method of modifying a short term index-type test value of strength into a site specific long term allowable (or performance) value of strength using reduction factors is illustrated in the following example.

Example: What is the allowable tensile strength of a flexible geogrid to be used in the construction of a permanent embankment if the ultimate short-term strength is 4200 lb/ft and the reduction factors have the following values? (Note that this problem does not require a RF_{JNT} since full rolls will be involved and no facing panels are present)

$$RF_{ID} = 1.25 (< 1.4 \text{ default value})$$

$$RF_{CR} = 2.5 (< 3.0 \text{ default value})$$

$$RF_{CD} = 1.2 (< 1.4 \text{ default value})$$

Solution: Since the measured values were all less than (or equal to) the default values, the measured values are used in the calculations.

$$\begin{aligned} T_{\text{allow}} &= T_{\text{ult}} \left[\frac{1}{RF_{ID} \times RF_{CR} \times RF_{CD}} \right] \\ &= 4000 \left[\frac{1}{1.25 \times 2.5 \times 1.2} \right] \\ &= 4200 \left[\frac{1}{3.75} \right] \\ &= 1120 \text{ lb/ft} \end{aligned}$$

11. References

- 11.1 American Society of Civil Engineers, "Structural Plastics Selection Manual," ASCE Manuals and Reports on Engineering Practice No. 66, prepared by Task Committee on Properties of Selected Plastics Systems of the Structural Plastics Research Council of the Technical Council on Research of ASCE, New York, 1985, pp. 584.
- 11.2 See White Paper #25 (2012) on GSI's website www.geosynthetic-institute.org which in turn is based on Koerner, R. M., Hwu, B.-L. and Wayne, M. H. (1986), "Soft Soil Stabilization Designs Using Geosynthetics," Proc. GRI-1 on Soft Soil Stabilization Using Geosynthetics Conference, GSI, Folsom, PA, pp. 33-51 and Jour. Geotextiles and Geomembranes, Vol. 6 (1987), pp. 33-51.