NTPEP Geosynthetic Reinforcement Evaluation Program

by

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Geosynthetic Reinforcement Concepts

• Geosynthetics are used as layers within the soil mass to reinforce the soil
  – The presence of the layers enable the soil to stand more steeply than would be otherwise possible by imparting tensile strength to the soil mass
  – The concept is similar to reinforcing concrete with steel rebar

• Geosynthetic reinforcements can consist of either geotextiles or geogrids, or a combination of the two

• They are made from polymers such as PET, HDPE, or PP (e.g., “plastics”)
  – Consist of long molecular chains entangled with one another or forming crystalline structures
  – Their properties tend to be strongly time and temperature dependent
Examples of Geosynthetic Reinforcement Materials
Typical Reinforcement Applications

- Reinforced Slope
- Geosynthetic wall
- Base Reinforcement
Overview of Geosynthetic Reinforcement Design

- Goal is to make sure that:

\[ T_{\text{max}} < \frac{T_{\text{ult}}}{RF_{ID} \times RF_{CR} \times RF_{D} \times FS} \]

- NTPEP program focus is to obtain these values

- RF_{ID}, RF_{CR}, and RF_{D} reflect actual long-term strength losses, analogous to loss of steel strength due to corrosion
Overview of NTPEP Geosynthetic Reinforcement Program

- Evaluation is based on WSDOT Standard Practice T925
- Two level evaluation process:
  - Product qualification evaluation, performed every 6 yrs
  - Quality assurance evaluation, performed every 3 yrs, to verify product properties are consistent with product qualification evaluation
- Testing conducted by independent NTPEP approved lab (TRI is only lab so far), sampled by independent sampler at supplier’s manufacturing facility or warehouse (typically a state DOT)
- Must be a product that is in production (not experimental products)
- Focus is on the product line
Long-Term Strength Concepts

$T_{ult}$

$T_{ult}/RF_{ID}$

Immediate loss due to installation stresses and abrasion

Long-term loss due to Creep and chemical Degradation (assumes constant load near creep limit applied)

$T_{ult}/(RF_{ID}RF_{CR}RF_{D})$
Current Focus of Durability Evaluation

- **Ultimate limit state design** (i.e., prevent rupture and collapse)
- **Adequate reinforcement strength** must be available throughout lifetime of structure
- **Installation damage** – reinforcement must be capable of resisting installation stresses and abrasion without excessive strength loss
- **Creep** – the reinforcement must not rupture under constant load within the design lifetime
- **Durability** – the reinforcement must have minimal strength losses over the design lifetime due to exposure to chemical environments common in soils (pH, oxygen, etc.)
What is a Product Line?

• “A series of products manufactured using the same polymer in which the polymer for all products in the line comes from the same source, 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.”

• Long-term strength testing is focused on the product line, providing the ability to only test representative products to characterize the line.
Product Qualification Testing

• Product dimensions and general index properties (product weight/unit area, coating weight for PET geogrids, tensile strength, polymer classification, geogrid bend test per WSDOT T926, etc.)
• Full scale installation damage testing
• Long-term creep rupture and low strain creep stiffness testing
• Chemical durability index testing
  – UV resistance
  – Molecular weight and CEG content for PET geosynthetics
  – Oven aging screening tests for polyolefins
Installation Damage Testing

• Focus is to establish the likely magnitude of strength loss that occurs during installation in backfill soil in reinforced soil structures

• General procedure:
  – Place pad of backfill soil, place geosynthetic, and place and compact backfill soil over the top of the geosynthetic
  – Exhume geosynthetic layer, perform tensile tests, compare results to tensile strength before damage
  – Perform for soil gradations (typically a minimum of 3 gradations are used to facilitate interpolation to other gradations) that are similar to what is typically expected for backfill (characterize based on $d_{50}$ size)
  – Testing is conducted on products representative of the product line, using interpolation (based on strength, weight, or coating weight) to establish installation damage strength losses for products in the line not tested
Installation Damage Test:
Field Exposure
Installation Damage Test: Compaction of Soil over Geosynthetic
**Installation Damage Evaluation: Calculation of Strength Retained**

\[ RF_{ID} = \frac{T_{lot}}{T_{dam}} \]

- \( T_{lot} \) is the lot specific tensile strength of the material used in the installation damage tests, but prior to exposing the material to installation.
- \( T_{dam} \) is the tensile strength of the material after exposure to installation (i.e., in a damaged condition).
- In both cases, testing is in accordance with ASTM D4595 or ASTM D6637 (single rib tests on geogrids are not acceptable).
Example Installation Damage Data

Note: $RF_{ID} = 1/P$

$W =$ weight/unit area

d$_{50} =$ sieve size at which 50% of soil passes by weight

$W_3 < W_2 < W_1$

All products are from the same product line.
Example Installation Damage Data, Continued

Note: $RF_{ID} = 1/P$
Creep Testing

• One of two approaches may be used:
  – Conventional creep testing
  – Combination of Stepped Isothermal Method (SIM) and conventional creep testing

• Focus of testing is to:
  – Establish rupture limit for a given design life, and
  – To establish low strain creep stiffness values

• Testing is conducted on products representative of the product line, using interpolation (usually using $T_{ult}$) to establish creep limits for products in the line not tested

• AASHTO incorporates Elias, et al., 2001 (Report No. FHWA-NHI-00-043) by reference
  – Focus is stress rupture testing and evaluation
  – WSDOT Standard Practice T925 is virtually identical (T. Allen wrote both), but in addition contains guidance for creep strain data evaluation

• Creep rupture testing and evaluation
  – Test in accordance with ASTM D5262
    • Minimum of 12 to 18 rupture points to establish envelope
    • Must have a few data points to 10,000 hrs duration, and a minimum duration of 5 to 10 hrs
    • Rupture points must be evenly distributed among log cycles of time
  – Extrapolation procedures
    • Extrapolate using temperature, or
    • Extrapolate statistically up to two log cycles of time for PET, or up to one log cycle of time for HDPE/PP, without temperature acceleration
Stress Rupture Extrapolation Using Temperature – “Conventional” Approach

Temperature: $T_1 < T_2 < T_3$

Note: Log load level works best for HDPE and PP, and arithmetic load level works best for PET.
Stress Rupture Extrapolation Using Temperature – “Conventional” Approach

Temperature: \( T_1 < T_2 < T_3 \)

Note: Log load level works best for HDPE and PP, and arithmetic load level works best for PET. Entire envelope at a given temperature is shifted by a single shift factor (assumes shift factor is not load level dependent).
Stress Rupture Extrapolation Using Temperature – Stepped Isothermal Method

- The difference between “conventional” approach (ASTM D5262) and Stepped Isothermal Method (SIM – ASTM D6992)
  - Conventional – individual specimens are subjected only to a single temperature – shift factors are then used to relate the creep rupture times obtained at different temperatures
  - SIM – a single specimen is subjected to stepped increases in temperature
    - The creep strain response at each temperature is matched together using time shift factors to produce a single smooth creep curve at the initial temperature, but extrapolated in time
    - The rupture that occurs at the highest temperature tested in effect is already extrapolated in time, even though the test was done in a matter of days
- For SIM, time shift factors are not affected by specimen to specimen variability, and different time shift factors can be used for different load levels
- SIM tends to be less conservative than conventional method
Creep Testing - SIM

Environmental Chamber

Close-up of Specimen
Single specimen subjected to stepped temperatures. A different shift factor is used for each temperature step. Same specimen after time shifting.
Creep Rupture Envelope Using SIM

Conventional creep rupture points at reference temperature

SIM rupture points, shifted to reference temperature

Load Level, $P (%)$

Time to Rupture, $t$ (hrs)
Use of SIM Data

• Use SIM data as supplementary to “conventional” data obtained at the design temperature
  – Obtain a minimum of 6 “conventional” stress rupture points evenly distributed among the log cycles of time
  – Two of the data points must be at more than 2,000 hours (unshifted)
  – In effect, the SIM data is used to extrapolate the conventional stress rupture data

• If the SIM stress rupture envelope is outside of the 95% lower bound confidence limit based on the “conventional” unshifted creep data extended up to 50,000 hrs duration, the SIM data should not be used without more extensive investigation
How is $RF_{CR}$ Calculated?

- Calculate $RF_{CR}$ using the following equation:

\[
RF_{CR} = \frac{T_{lot}}{T_l} = \frac{T_{lot}}{\left( \frac{P_{cl}}{1.2^{(x-1)}} \right)}
\]

- $T_{lot}$ = average lot specific tensile strength of material used in creep testing
- $T_{ult}$ = MARV of tensile strength
- $T_l$ = factored creep limited tensile strength at design life
- $P_{cl}$ = creep limited strength measured directly from extrapolated creep data
- $x$ = number of log cycles of time of extrapolation beyond time shifted data
  = $\log t_d - \log t_{\text{max}}$
- If $x < 1$, set $x-1 = 0$
Creep Stiffness Testing

• Focus is stiffness at 2% strain level at 1,000 hrs
• Determined using combination of short-term ramp and hold (1,000 second) tests and 1,000 hr low strain creep tests
• Provides data needed to design using K-Stiffness Method for MSE walls as well as to address serviceability for reinforced soil structures
Chemical Durability Testing

- **General approach**
  - Index tests that provide indication of long-term durability
    - Only applicable for nonaggressive environments (pH of 4.5 to 9, organic content is 1% or less, effective design temperature for site < 30°C)
  - Long-term performance tests

- **Specific index test requirements**
  - UV (ASTM D4355), thermo-oxidation (oven aging screening test per ENV ISO 13438:1999), and hydrolysis resistance (molecular weight per GRI:GG8 and CEG content per GRI:GG7)
  - If requirements are met, can use default $RF_D$ of 1.3 (cooler climates) to 1.5 (warmer climates)

- **If index test requirements are not met, must conduct long-term performance tests**
  - Oven aging or high oxygen pressure testing (PP, HDPE)
  - Elevated temperature immersion tests for hydrolysis (PET)
  - Rarely done due to time and expense required
### AASHTO Chemical Durability Index
#### Test Requirements

<table>
<thead>
<tr>
<th>Polymer Type</th>
<th>Property</th>
<th>Test Method</th>
<th>Criteria to Allow Use of Default $RF_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP and HDPE</td>
<td>UV oxidation resistance</td>
<td>ASTM D4355</td>
<td>Min. 70% strength retained after 500 hrs in weatherometer</td>
</tr>
<tr>
<td>PET</td>
<td>Hydrolysis resistance</td>
<td>Inherent viscosity (ASTM D4603 and GRI-GG8)</td>
<td>Min. number average molecular weight (MW) of 25,000</td>
</tr>
<tr>
<td>PET</td>
<td>Hydrolysis resistance</td>
<td>GRI-GG7</td>
<td>Max. carboxyl end group content (CEG) of 30</td>
</tr>
<tr>
<td>All</td>
<td>% Post-consumer recycled material</td>
<td>Certification of materials used</td>
<td>Maximum of 0%</td>
</tr>
</tbody>
</table>
Inherent Viscosity Determination

Correlations can are used to estimate MW from the inherent viscosity for a given solvent and temperature.

Note that the viscosity measurement performed here is similar to what is done for asphalt testing, but due to the lower viscosity of the PET solution, the tube diameter must be smaller to keep the rate of flow from being too fast.
Determination of CEG

CEG testing is simply an acid-base titration. CEG’s form an acid, and NaOH is added to neutralize the solution, as measured by a pH meter.
Product Quality Assurance (QA) Testing

- Similar to product qualification testing, except:
  - Fewer products in the product line are tested
  - Testing is shorter term (typically 2,000 hrs or less)

- All index tests are still conducted as part of QA testing program (tensile strength, UV resistance, CEG and MW for PET geosynthetics, oven aging screening test for polyolefins)

- Focus is whether or not difference between QA and product qualification testing results is statistically significant based on predefined criteria
QA Acceptance Criteria

• QA test results must meet QA statistical insignificance criteria to maintain presence on NTPEP geosynthetic reinforcement evaluation report or to avoid need to immediately conduct product qualification testing

• Criteria are as follows:
  – Mean of QA tensile strength test results must be greater than MARV assigned to product
  – For installation damage, and the strength retained in the oven aging screening test, the difference between the mean of the QA and product qualification test results must not be greater than what is defined as statistically insignificant based on a one-sided student-t distribution at a level of significance of 0.05
  – For creep, QA tests performed at a load level that results in rupture at approximately 500 hrs and at 100,000 hrs after time shifting to the reference temperature must have a rupture time that is greater than the lower 95% prediction limit based on the student’s-t distribution
Illustration of Creep Rupture QA Criteria

Load or Load level, \( P \) vs Rupture Time (after time shifting), \( t \) (hrs)

Regression line for product qualification data
95% prediction limit for product qualification data
- from qualification testing
\( P_{500} \)
\( P_{100000} \)

\( x \) – from QA testing

Rupture Time (after time shifting), \( t \) (hrs)
Use of Standard Practice T925 at WSDOT

- It was born out of the need to provide a level playing field for geosynthetic reinforcement products.
- It has allowed us to design geosynthetic reinforced structures generically and allow open competition.
- WSDOT uses it as the basis for adding reinforcement products to our Qualified Products List (QPL).
- It has been in use since 1997.
- WSDOT has reviewed and approved 63 reinforcement products from 8 suppliers.
- It is affecting product submission and approval worldwide, and now forms the basis of a proposed ISO standard.
Application of NTPEP Geosynthetic Reinforcement Results to WSDOT Program

- An NTPEP evaluation will be required (by mid-2007) for inclusion of geosynthetic reinforcement on the WSDOT QPL (must also be kept current)
- From NTPEP results, WSDOT will obtain the following information and include it in our QPL (Appendix D):
  - $T_{ult}$ (MARV)
  - Long-term design strength, $T_{al} = T_{ult}/RF_{ID}RF_{CR}RF_{D}$
    - $RF_{ID}$ is determined at $d_{50} = 4.75$ mm (corresponds to WSDOT gravel borrow) from strength retained vs. $d_{50}$ plots for each product tested in the line, interpolated to other untested products in the product line using the recommended interpolation procedure (i.e., unit weight, coating weight, etc.)
    - $RF_{CR}$ is determined at 75 yr design life from creep rupture envelope
    - Default value of 1.3 is used for $RF_{D}$ if all index test criteria are met
  - 2% creep stiffness at 1,000 hrs, $J_{2\%}$
Issues Where Some Judgment will Be Needed to Apply NTPEP Results

- For determination of $RF_{\text{ID}}$, interpolation between tested products to untested products within a product line may not be straightforward, especially for PET geogrids – NTPEP may have additional products tested because of this, or an upper bound approach may be taken (see T925).
- WSDOT has historically used $RF_{D}$ of 1.1 instead of 1.3 for HDPE due to well known exceptional durability of that material.
- The 1.3 default value is really aimed at PP geosynthetics, due to smaller thickness of ribs fibers and relatively greater susceptibility to oxidation of PP relative to HDPE.
- Oxidation resistance of PP geosynthetics is difficult to accurately quantify and to detect changes in product antioxidant formulations and polymer structure – current test protocols should be considered approximately representative of potential long term durability for PP.
WSDOT Application of Design Strengths Obtained from NTPEP Testing to Design and Construction Specifications

- Standard Plan geosynthetic walls
  - From line and grade wall plans, contractor identifies wall design height and surcharge conditions
  - Contractor goes to Standard Geosynthetic Wall Plans to get minimum $T_{al}$ (i.e., design strength) needed
  - Contractor goes to QPL to identify products that have $T_{al}$ values greater than or equal to $T_{al}$ required in Standard Plans for the design wall height and surcharge conditions
  - Contractor informs WSDOT project office of choice of product(s)
  - WSDOT inspector obtains samples from roles of geosynthetic shipped to site and submits samples to HQ Materials for testing (primarily tensile strength per ASTM D6637 or ASTM D4595, and geogrid bend test per WSDOT T926)
WSDOT Application of Design Strengths Obtained from NTPEP Testing to Design and Construction Specifications, Cont.

- Preapproved proprietary MSE walls
  - Wall supplier uses published QPL design strengths \( (T_{al}) \) to determine strength and spacing of reinforcement required
  - WSDOT Bridge Office and Geotechnical Division review wall supplier’s shop drawings for walls to be built in construction project for acceptability - see WSDOT Geotechnical Design Manual Chapter 15 and appendices for review criteria and preapproved wall details at http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manu als/2005GDM/GDM.htm
  - WSDOT inspector obtains samples from roles of geosynthetic shipped to site and submits samples to HQ Materials for testing (primarily tensile strength per ASTM D6637 or ASTM D4595, and geogrid bend test per WSDOT T926)
  - For modular block faced walls, connection strength handled separately through wall preapproval process
WSDOT Application of Design Strengths Obtained from NTPEP Testing to Design and Construction Specifications, Cont.

- Project specific geosynthetic reinforced structures (reinforced slopes, and non-Standard Plan geosynthetic walls)
  - Engineer determines design strength required per AASHTO and WSDOT GDM using LRFD approach (i.e., $T_{\text{max}} \gamma / \phi = T_{\text{al}}$) for MSE walls, or using allowable stress design and FS value for reinforced slopes and fills over soft ground
  - $T_{\text{al}}$ as a function of reinforcement spacing and structure/fill height is provided in the Special Provisions as a table – the Contractor can select products from the QPL that meet requirements in table
  - WSDOT inspector obtains samples from roles of geosynthetic shipped to site and submits samples to HQ Materials for testing (primarily tensile strength per ASTM D6637 or ASTM D4595, and geogrid bend test per WSDOT T926)
WSDOT Application of Design Strengths Obtained from NTPEP Testing to Design and Construction Specifications, Cont.

- Application to reinforcement of fills over soft ground
  - Geosynthetic must function temporarily until soft soil gains adequate strength (typically a few months to a few years)
  - $T_{al}$ is determined as $\frac{T_{ult}}{RF_{ID}RF_{CR}}$, where $RF_{CR}$ is determined for a much shorter temporary life (obtain $RF_{CR}$ from NTPEP creep rupture plot at the desired design life)
  - In the reinforced fill application, $RF_D$ is not a significant consideration for such a short design life

- Application to temporary geosynthetic walls
  - $T_{al}$ is determined as above, but for anticipated design life of temporary structure, or alternatively, a default overall strength reduction factor of 2.5 to 4 applied to $T_{ult}$ could be used
Questions? Comments?
Don’t Be Left Out!