The Properties and Performance of Tensar Uniaxial Geogrids

The essential guide to the long-term properties of Tensar Uniaxial Geogrids for use in designing:
- Bridge abutments
- Retaining walls
- Steep embankment slopes
- Slip repairs
This guide is your essential guide to the long-term properties of Tensar uniaxial polymer geogrids for use in reinforced soil structures. Polymers are not simple elastic materials. Their load-strain behaviour is also affected by time and temperature. These effects are product specific and they lead to a unique design strength for each project and set of conditions. There is a simple conceptual formula:

Design strength = \( \frac{\text{Long-term strength}}{\text{factors}} \)

Long term strength may be defined in terms of rupture (ultimate limit state) or limiting strain (serviceability limit state). One of the purposes of this document is to assist engineers to derive the appropriate design strength for their project. The terms in the “conceptual formula” are explained so that the working formula can be created. The major topics of importance are: strength, durability and mechanical interaction with soils. Each topic is discussed, and information presented from actual testing or trials. The important parameters are highlighted. At the end of the guide is a comprehensive list of the design parameters for the Tensar RE uniaxial geogrids.
Tensile strength

All polymer based products are visco-elastic. Their strength and stiffness are affected both by temperature and by rate or duration of loading, as shown on Figure 1. Therefore, it is important that standard methods of tensile testing are used, so that temperature and strain rate are defined. For Tensar uniaxial geogrids, quality control (QC) tensile testing is carried out using the method given in International Standard BS EN ISO 10319:1996. This is a wide width method with specimen width at least 200mm. Strain rate is 20% per minute and test temperature is 20ºC.

The ISO 10319 QC test procedure consists of testing five individual specimens and the lower 95% result is reported. The test equipment is shown on the adjacent picture and a typical result from an ISO 10319 QC test is shown on Figure 2.

These tests are carried out at prescribed intervals according to the certified quality control procedures. The specified QC strength is the 95% lower confidence limit determined in accordance with ISO 2602:1980, based on statistical analysis of all tests carried out.

Figure 1: Effect of temperature and strain rate on tensile strength of polymer geogrid.

Figure 2: Test result for ISO 10319 tensile test on Tensar 80RE.
Long-term creep rupture behaviour

Due to the visco-elastic nature of polymers, it is not possible to use tensile tests to determine load-strain behaviour for long durations of sustained loading. To do this, a different type of test is used, normally referred to as a creep test. A creep laboratory is shown on Figure 3, where a number of creep tests can be seen in progress.

A weight is hung on each specimen, and strain is measured for a standard duration of 10,000 hours. However, many tests are left to run for much longer durations. Each grade of geogrid is subjected to a range of loads. The temperature of each creep laboratory is carefully controlled. Creep tests are run in laboratories at 10°C, 20°C, 30°C, 40°C and 50°C. The testing procedure follows the requirements of BS EN ISO 13431:1999. Figure 4a shows a family of results from creep tests on Tensar 55RE carried out at 10°C.

Creep testing of Tensar RE geogrids started in 1993, and Figure 4b includes four tests which have reached more than 100,000 hours duration. However, this is still much shorter than typical design lifetimes, which can be up to 120 years depending on the application. Mathematical extrapolation of the data on Figures 4a and 4b would result in considerable uncertainty due to the extent of extrapolation required. In order to avoid extrapolation to long durations, a method of interpretation is used which combines tests carried out both at different temperatures (by using time shifting) and on different grades of geogrid (by normalising the rupture load).

Figure 3: Temperature controlled creep test laboratory.

The result of this interpretation is shown on Figure 5, which shows all available rupture data for the Tensar RE geogrids summarised on a single plot. There is sufficient data on this plot to be able to determine a lower bound relationship. This relationship is used to calculate long-term lower bound rupture loads for different temperatures and design lives, without the need to make any direct extrapolation of data.

The high quality, duration and completeness of this data is recognised in BBA Certificate No 99/R109 for Tensar RE geogrids (for design of retaining walls and bridge abutments), where the partial factor for extrapolation of data is 1.0.

Figure 4a: Strain-time plots for Tensar 55RE at 10°C.

Figure 4b: Strain-time plots for Tensar 80RE at 20°C.

Figure 5: Normalised rupture load versus time to rupture for all Tensar RE grids shifted to 20°C.
Long-term creep strain behaviour

The long-term deformation behaviour of polymer geogrid is assessed by constructing isochronous load-strain curves. Isochronous data is taken directly from the strain-time curves shown on Figures 4a and 4b by reading off the data from the plotted lines at fixed time values. Figure 6 shows isochronous load-strain curves determined in this way for Tensar 120RE at 20°C, for both 1 month and 120 years duration. For serviceability limit state design to BS8006:1995, isochronous curves are used to find the geogrid load which limits post-construction strain to:

- 1% over the period between 1 month and 120 years for retaining walls,
- 0.5% over the period between 2 months and 120 years for abutments.

Effects of construction activities

Extensive full scale field trials have been carried out to evaluate the effects of construction activities on Tensar uniaxial geogrids. These trials are carried out following the method given in BS8006:1995, using hard angular crushed limestone aggregates. Typical samples of the three gradings used are shown on Figure 7. Maximum particle sizes are 125mm, 37.5mm and 6mm respectively for the coarse, medium and fine gradings (interpolation is used for other particle sizes). Figure 8 shows the arrangement used for the trial.

Figure 7: Coarse, medium and fine crushed limestone used in installation damage trials.

Figure 8: Section of full scale site damage trial carried out to BS8006:1995.
The trial procedure is illustrated in Figure 9. A layer of fill is placed both below and above the geogrid. The upper layer is compacted to three levels of compaction and then carefully excavated so that the geogrid can be recovered. The geogrid is examined to check for damage. Based on this examination, test specimens are selected from the areas which exhibit the greatest damage. Wide width tensile tests are carried out on these specimens, and the results are compared to tests carried out on control samples.

Typical tensile test results for two conditions are shown on Figure 10. The results for Tensar 40RE (the lightest uniaxial grid) and 125mm crushed rock fill (the coarsest fill) represent the most severe conditions tested. The difference in the measured ultimate tensile strength between the control and the site damaged samples is used to calculate partial safety factors \( f_d \) to take into account the effects of installation activities. These factors are used when calculating long term design strength for the ultimate limit state.

Examination of the results shown in Figure 10 indicates that \( f_d \) is quite high for Tensar 40RE, but much less for Tensar 80RE, which is the case in the published \( f_d \) values. This illustrates the importance of testing all grades from a particular family of products. For serviceability conditions, behaviour at low strain is more appropriate. In this case, load at 2% and 5% strain is used to calculate \( f_d \), and the resulting values may be taken as 1.0 for all conditions. This has also been investigated by carrying out creep tests on site damaged uniaxial geogrid. These tests confirm that, under long term loading at likely working loads, the effects of site installation activities are minimal.

Installation trials have been carried out using other fill types, for example: pulverised fuel ash (PFA) and crushed hard igneous rock (diorite). Comparison of the results indicates that the trials carried out using crushed limestone represent the most aggressive conditions likely to be encountered in practice.

Site trials give partial safety factors to take account of installation - \( f_d \)
External exposure

In most applications, geogrid will be buried in soil, so that it will be protected from external environmental conditions. However, at a number of stages during its use, it is likely to be exposed, certainly during handling and installation on site, but also possibly in service. Exposure might be for a relatively long duration, and it is therefore important that the geogrid material is well protected. Some construction specifications and approval certificates provide protection by limiting the allowable duration of exposure, but these requirements are difficult to control and enforce. The most reliable protection is provided by using the optimum content of appropriate additives in the polymer.

Ultra-violet light (UV) can damage unprotected polymers rapidly, by breaking down the molecule chains. Tensar uniaxial geogrids are protected by the inclusion of a minimum of 2% well dispersed carbon black, which gives a high degree of protection by preventing UV light from penetrating beyond a thin layer at the surface.

Figure 12 shows the importance of this 2% minimum. As carbon black content drops below 2%, the life of the polymer drops dramatically. Because very small carbon black percentages will still make a polymer “look” black, it is important that this property is measured using appropriate standards. Laboratory tests have been carried out in which Tensar uniaxial geogrids are exposed to intense UV light in weatherometers.

These tests have shown that, under temperate climates, Tensar uniaxial geogrids will retain 90% of their initial strength for between 20 and 50 years of exposure, depending on their rib thickness. Outdoor exposure trials have recently been completed at Albury, Australia, where UV intensity is very high. These trials were started in 1994, and Figure 12 shows that, after 8 years exposure, there is effectively no change in the tensile strength and stiffness for Tensar 55RE. This excellent resistance to UV degradation means that no special wrapping or covering is required during transportation and storage on site. If grids are exposed during construction, there is no need to specify minimum duration before cover is established.

The properties of HDPE can be affected by oxidation. Tensar uniaxial geogrids are protected by the inclusion of an appropriate content of a proprietary antioxidant. Tests have been carried out on Tensar 40RE to BS EN ISO 13438:2004 to determine its resistance to oxidation. This test requires that the geogrid is subjected to 100°C for a period of 56 days, measuring tensile strength at 6 hours and 56 days. The results show that no significant degradation resulted.
Effects of burial

Biological resistance
The engineering grades of HDPE used to manufacture Tensar uniaxial geogrids have no nutritional value, and are therefore not attacked by micro-organisms. This is confirmed in the UK and many other countries by the approval of such polymers for water supply pipes, where it is critical that they should not support biological growth.

Chemical resistance
Buried geogrid will come into contact with soil and ground water, both of which can contain potentially aggressive substances. HDPE is resistant to a wide range of chemicals, and it is inert to all aqueous solutions of acids, alkalis and salts normally found in soils. In addition, it has no known solvents at ambient temperatures. Because of its stability under a wide range of chemical conditions, HDPE is used in many situations where hazardous or aggressive chemicals are present, for example: liners for hazardous waste sites, gas pipelines and many forms of container for aggressive chemicals. In USA, Tensar uniaxial geogrids have been subjected to a wide range of chemical exposure tests following the protocol in EP9090, and are accepted for use in landfill sites. Due to their high resistance to alkaline conditions, Tensar uniaxial geogrids may be buried in contact with hydrating cement without any danger of degradation. This permits a number of construction techniques to be used where geogrid will come into contact with fresh concrete, such as casting geogrid into concrete panels or shotcreting onto geogrid.

Resistance to environmental stress cracking (ESC)
ESC can occur in polymers when they are subjected to high stress under certain chemical conditions. Surface micro-cracks can develop, which can lead to premature failure. The resistance of Tensar uniaxial geogrids to ESC has been investigated by carrying out special creep tests as shown on Figure 13. A number of creep tests were arranged at different loads, some being exposed to a special chemical which encourages ESC. Control tests were carried out in air. The graph shows that the two series of tests give similar performance, and it can be concluded that Tensar uniaxial geogrids are not affected by ESC.

Figure 13: Test set-up and results for special creep tests to investigate ESC.

A variety of tests and trials give partial factor for environmental conditions - $f_e$
Connecting Tensar Uniaxial Geogrids

Tensar uniaxial geogrids may be easily connected together on site in the direction of loading using a polymer bodkin joint bar. The bodkin joint provides a full strength connection, so that no reduction factor or partial safety factor is required in designs which incorporate the joint. This versatile connector can be used to:

- connect main reinforcement to short starters (as shown in Figure 14)
- use short off-cuts to minimise waste
- form wrap-around connections in slope construction

The unique form and properties of Tensar uniaxial geogrids make them ideal for forming mechanical connections with concrete retaining wall facings. This can be done by casting the geogrid into a concrete panel (as shown on Figure 14), which results in a full strength connection, so that no reduction factor or partial safety factor is required. In addition the excellent chemical durability of HDPE means that Tensar uniaxial geogrids are not adversely affected by the highly alkaline environment created in wet or freshly formed concrete.

Concrete modular block wall facings are now widely used due to their pleasing looks, ease of construction and economy. Tensar’s unique blue polymer connector as shown in Figure 15a, provides a highly efficient method of joining Tensar uniaxial geogrid into the facing.

The advantage of this type of connector is high strength, even for the low normal loads which occur near the top of the wall, or may be generated during an earthquake. The results of full-scale connection testing are shown on Figure 15b. Two sets of data are shown. The results for the mechanical connector (of the type shown in Figure 15a) show that connection strength is independent of normal load, so even very close to the top of the wall, full connection strength is developed. The second set of data is for a frictional connection, where the geogrid is merely “clamped” between the upper and lower faces of two layers of blocks. Pins are also used to link the blocks together, but the connection is mainly frictional in nature, so that at low normal loads very low connection strength is developed.
Mechanical interaction with soil

Stabilising soil masses using reinforced soil techniques requires mechanical interaction between geogrid and soil. Interaction can take the form of sliding or pullout. Examples of failure mechanisms which mobilise these two forms of interaction are shown on Figure 16. Sliding between geogrid and soil is defined by a simple coefficient of friction given by:

\[ \text{friction coefficient} = \sigma \tan \phi' \]

where \( \phi' \) = friction angle of the soil
\( \alpha \) = interaction factor

The interaction factor (\( \alpha \)) is therefore a reduction factor to take into account sliding between geogrid and soil. Different types of interaction testing are required to measure the interaction factors for sliding (\( \alpha_s \)) and pullout (\( \alpha_p \)).

Figure 16: Failure mechanisms mobilising interaction between geogrid and soil.
Sliding interaction factors

The sliding interaction factor may be determined by carrying out shear box tests using a large (300mm) specially modified shear box in which grid is clamped to the bottom half of the box.

In this way the top half of the box slides over the geogrid, thereby creating sliding between geogrid and soil. The test set-up is shown on Figure 17. Control tests are carried out in the same way, but without geogrid present on the sliding plane. Comparison of the two tests gives the required interaction factor ($\alpha_s = \tan^{-1}(\tan\phi_{grid+soil}/\tan\phi_{soil\ only})$).

Results from interaction tests using Tensar 40RE are shown on Figure 18, for fine and coarse soils. Based on these and similar tests, typical values of sliding interaction coefficient ($\alpha_s$) for Tensar uniaxial geogrids are:

- 0.9 to 1.0 for crushed rocks and gravel
- 0.85 to 0.95 for sands
- 0.8 to 0.85 for pulverised fuel ash (PFA)
- 0.6 to 0.7 for clays

Figure 17a: Cross section of shear box test to measure $\alpha_s$.

Figure 17b: Set up for shear box test on Tensar 80RE.

Figure 18: Results from sliding interaction tests on Tensar 40RE.
Pullout interaction factors

Pullout interaction factors are determined using pullout tests. A typical test arrangement is shown in Figure 19. A length of geogrid is buried in a large box, and a load is applied to the top surface of the fill to represent the required overburden pressure. The geogrid extends through a slot in the side of the box, where it is connected to jacks, which apply load in tension. The results of pullout tests on Tensar uniaxial geogrids are shown on Figure 20. This shows pullout load versus the number of ribs (i.e., length) of geogrid buried in the box. For just 1.2m of overburden, only 5 ribs (less than 1m) are required to generate maximum pullout resistance.

For greater lengths, failure occurs by rupture of the geogrid outside the box. This very efficient interaction is created by the open structure and integral full strength junctions of Tensar uniaxial geogrids. Load is carried mainly by bearing on the thick transverse bars, and transferred through the junctions to the longitudinal ribs at very small deformations. This is shown in the special “X-ray” test, where the light areas represent zones of compression in front of the thick transverse bars of the geogrid. Pullout tests have shown that $\alpha_p \approx \alpha_s$ may be used in the absence of specific test data for Tensar geogrids.

Pullout tests give pullout interaction factor $- \alpha_p$
Independent certification

Tensar geogrids have been given accreditation by a number of independent government and other certifying agencies around the world. No other soil reinforcement material has such a wide range of certification.

- **The British Board of Agrément has awarded certificates both for retaining walls and abutments, and for steep slopes.**

- **Network Rail, the UK authority responsible for the maintenance of the national rail track network, has certified Product Acceptance for Tensar SR and RE uniaxial geogrids for use in reinforced soil railway structures (certificate numbers PA05/175 & PA05/177).**

- **The British Board of Agrément has also awarded certificate No 00/122 (second issue) for the Tensar TWI wall system for reinforced soil retaining walls and bridge abutments.**

- **In Hong Kong, the Geotechnical Engineering Office has awarded Certificate RF 5/03 for the use of Tensar RE geogrids in reinforced fill structures.**

- **Allgemeine bauaufsichtliche Zulassung Z-20.1-102 of the Deutsche Institut für Bautechnik (DIBT), Berlin for reinforced soil with the Tensar geogrids SR55, SR80, SR110.**

- **The Roads & Traffic Authority in Sydney, Australia, has certified both Tensar SR and RE geogrids under Specification RS7 for use in Reinforced Soil Walls.**
Manufacturing process

Tensar uniaxial geogrids are manufactured from carefully selected grades of high density polyethylene (HDPE). HDPE is used in many engineering applications where a long service life and excellent durability are required, often under adverse conditions, for example: landfill and hazardous waste lining, water supply pipes and protective sheathing for stay cables.

Uniaxial geogrids are made by extruding a sheet of HDPE to very precise tolerances, punching an accurate pattern of holes, then stretching the sheet under controlled temperature in the longitudinal direction. This process creates a geogrid with long narrow apertures, called a uniaxial grid because it has been stretched in one direction only. The polymer’s long chain molecules are oriented in the direction of stretching resulting in a dramatic increase in both strength and stiffness.

This orientation passes through both the narrower ribs and the thicker transverse bars, and is unique to the patented Tensar manufacturing process.

Figure 21a: The Tensar manufacturing process for uniaxial geogrids.
Figure 21b: A detailed view of the uniaxial geogrid after stretching.

Tensar geogrids are manufactured in accordance with Quality and Environmental Management Systems which comply with the requirements of BS EN ISO 9001:2000 and BS EN ISO 14001:1996 respectively.
Calculation of long-term design strength

Long-term design strength of Tensar uniaxial geogrids ($P_{\text{des}}$) is given in the form:

$$P_{\text{des}} = \frac{P_c}{f_m f_d f_e LF}$$

where:
- $P_{\text{des}}$ = long-term design strength
- $P_c$ = long-term rupture strength from creep testing
- $f_m$ = partial factor for manufacturing, database and extrapolation
- $f_d$ = partial factor for site installation
- $f_e$ = partial factor for environmental effects
- $LF$ = load factor

The derivation of $P_c$, $f_m$, $f_d$, and $f_e$ is discussed in this brochure and values are given in the table below. $LF$ is a load factor, or overall safety factor, and depends on the design method used. Guidance and typical values of $LF$ are given in various design guidelines and codes.

Example: calculate $P_{\text{des}}$ for Tensar 80RE for the following conditions:
- 10ºC
- 120 years design life
- ultimate limit state
- 37.5mm maximum fill size
- $p_{\text{H}} = 1.1$
- $LF = 1.0$ (Design method HA 68/94)

Referring to the data in the table below:
- $P_c = 39.0$ kN/m
- $f_m = 1.05$
- $f_d = 1.07$
- $f_e = 1.00$

$$P_{\text{des}} = \frac{P_c}{f_m f_d f_e LF} = \frac{39.0}{1.05 \times 1.07 \times 1.00 \times 1.00} = 34.7$$ kN/m

Tensar RE Geogrid specifications

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<th>Property</th>
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Amendment issued February 2006 to include increased strength parameters.

(1) HDPE denotes high density polyethylene
(2) Carbon black inhibits attack by UV light. Determined in accordance with BS 2782:Part 4. Method 452B:1993. Any section of grid fully exposed to sunlight can be expected to retain 90% of its quality control strength for periods of approximately 40 years in temperature climates and 20 years in tropical climates.
(3) Determined in accordance with GN Test Method GG2-87, and expressed as a % of the quality control strength.
(4) Determined as a lower bound using standard extrapolation techniques to creep rupture data obtained following the test procedure in BS EN ISO 13431:1999 and with test durations up to and in excess of 100,000 hours, for 120 year design life. Creep rupture strengths for other design lives and other design temperatures may be obtained from Tensar International Limited.
(5) Determined from creep tests carried out following the test procedure in BS EN ISO 13431:1999 as the load resulting in 1% strain between 1 month and 120 years after the start of loading.
(6) f_m = 1.0 based on the QA procedures, database, use of lower bound values and extrapolation procedures applied by Tensar International. f_m = 1.05 is given in BBA Certificates No 99/R109 and No 99/R113 for Tensar RE geogrids
(7) Derived as worst values from site damage trials carried out following the method given in BS 8006:1995, values as given in BBA Certificate No 99/R109 for Tensar RE geogrids
(8) Values as given in BBA Certificate No 99/R113 for Tensar RE geogrids
Contact Tensar International or your local distributor to receive further literature covering Tensar products and applications. Also available on request are product specifications, installation guides and specification notes.

The complete range of Tensar literature consists of:

- **Tensar Geosynthetics in Civil Engineering** A guide to the products and their applications
- **Ground Stabilisation** Reinforcing unbound layers in roads and trafficked areas
- **Tensar Structural Solutions** Bridge abutments, retaining walls, steep slopes
- **Foundations over Piles** Constructing over weak ground without settlement
- **Basal Reinforcement** Constructing embankments over weak ground
- **Railways** Mechanical Stabilisation of Track Ballast and Sub-ballast
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- **Erosion** Controlling erosion on soil and rock slopes

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