INDONESIA 2016
GEOSYNTHETICS CONFERENCE
JAKARTA, 10 MAY 2016

Design Parameters and Specification for Geosynthetic Reinforcement

Michael Dobie CEng FICE FCIHT[1]

[1]Tensar International Limited, mdobie@tensar.co.id

Abstract: The determination of design parameters for geosynthetic reinforcement and their specification present some challenges. The different parties involved have different targets. In the factory, the manufacturer is interested in quality management and consistency of the product, in order to meet established QA limits on tensile strength and dimensions. The designer is interested in the strength and interaction parameters required to prepare the dimensioning and reinforcement layout of the structure, in order to satisfy ultimate and serviceability limit states. The contractor is concerned that he can identify the product delivered to his site, and ensure that it meets the requirements of the contract. The project owner is interested in the post-construction behaviour of the structure, the aesthetics and durability. Long term design strength of geosynthetic reinforcement is normally determined starting from the short term tensile strength, and then taking into account factors for the effects of creep, installation damage and durability. The tests and trials required to determine these factors are extensive and mostly of long duration, so not amenable to checking on a project basis. In general they are carried out in the early stages of developing a product line, and are then taken as applying at any time in the future, but related to the quality control characteristics. So if a product delivered to a site can only be checked in terms of short term tensile strength and dimensions, then how can the long term characteristics be ensured? One approach is to use manufacturer's published data sheets (if they include the required information), but this may be considered as lacking independent verification. It is also possible to apply published default reduction factors, which may be very conservative. An alternative is to establish a fit-for-purpose certificate system, which does not exist in Indonesia, but does elsewhere. An example is the British Board of Agrément system of certificates, which covers a wide range of geosynthetic reinforcement products and facing systems, and is obligatory if such products are to be used in highway projects in the United Kingdom. Such certificates are comprehensive and identify the relevant parameters of interest to all the parties involved. However, if applied for projects in Indonesia, it should be noted that the higher temperatures and humidity in tropical countries would require that some of the reduction factors are re-assessed.

1.0 Introduction

For the design of reinforced soil structures, any design method may be divided into three main components: calculation procedure, material parameters and factors. These are outlined in more detail in Table 1.

Table 1. The main elements of a reinforced soil design method

Element of design method	Details	Comments
Calculation procedure	Method of calculating forces and stresses in order to make a design, covering both external and internal stability, and including an overall stability check. May include serviceability and effect of earthquakes.	For external design, most methods are the same, but for internal design there are significant differences.
Material parameters	- Soil parameters - Reinforcement parameters - Interaction between soil and reinforcement - Connection between reinforcement and facing	Material parameters should be measured using appropriate test methods and assessed as suitable for design.
Factors	- Safety factors - Partial load and material factors - Wall friction angle on back of reinforced soil block - Inclination factors in bearing capacity - Soil strength definition	Factors ensure the margin against failure of the structure, and define some important design parameters.

Some of the papers presented at this conference provide information about different calculation procedures, using both limiting equilibrium methods and numerical analysis methods, and some provide information about target factors of safety or partial factors. The purpose of this paper is to summarise information concerning material properties which relate to the geosynthetic reinforcement, in terms of strength, as well as interaction with the fill and facing. One distinction often made between reinforced soil structures is to describe them as retaining walls or steepened slopes. This distinction is generally based on facing angle:

- Retaining wall: facing steeper than 70° to the horizontal, normally with a concrete or "hard" facing
- Steepened slope: facing less than 70° to the horizontal, normally with a vegetated of "soft" facing

In the progression from right to left in Figure 1, the soil slope with facing angle of 1(vertical):2(horizontal) will have an adequate safety factor due to soil strength alone for a good quality fill. As the facing angle becomes steeper, in order to maintain the required safety factor, the additional resistance required may be provided by geosynthetic reinforcement, such that the resisting forces or moments are provided partly by the soil and partly by the reinforcement. As the facing angle increases, the reinforcement provides a larger and larger proportion of the resistance, and beyond around 70° it will provide the major part. Therefore for retaining walls, with the facing close to vertical, the reinforcement will carry the majority of the force resisting failure. Based on this discussion, it might be considered that reinforcement properties are more important for retaining walls. This might be the case overall, but once designed efficiently, the properties of each individual layer of reinforcement are crucial to maintaining the required factor of safety, independent of the steepness of the facing.

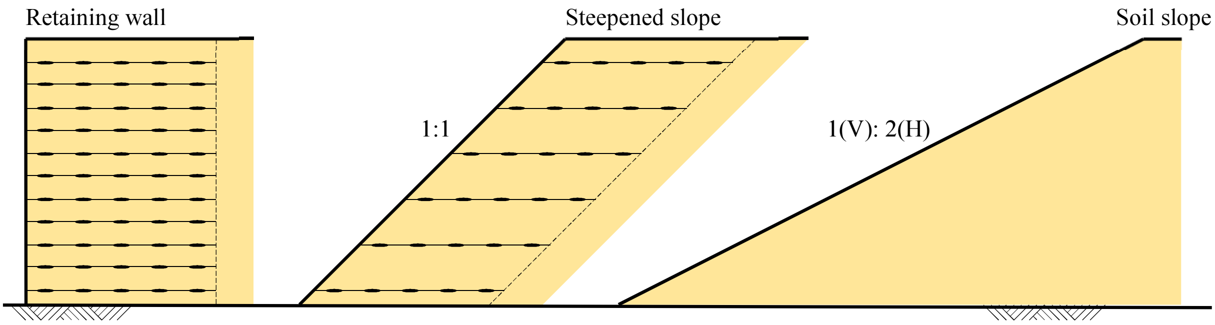

Figure 1: Progression from soil slope (right), to steepened slope (middle) and retaining wall (left)

The purpose of this paper is to outline and discuss the definition of reinforcement properties which affect the design and performance of reinforced soil structures of all types, especially in the context of Indonesia, where facilities to measure these properties are limited. The various parties involved in constructing a reinforced soil retaining wall, the manufacturer, the designer, the contractor and the owner of the structure, have different targets in relation to the properties of geosynthetic reinforcement, which present some challenges. However the main target must be to provide a structure which is fit-for-purpose for its defined design life, and in the prevailing environmental conditions, while at the same time being as cost-effective as possible.

2.0 Properties and parameters relevant to geosynthetic reinforcement

Table 2 summarises properties and features of geosynthetic reinforcement which are generally considered to be of relevance and importance. The second column provides background information and additional details. In the third column an indication is given of which organisations involved in the design and construction of a reinforced soil structure are likely to be concerned about the particular feature. This listing is inevitably subjective to a certain extent, but it does indicate that different parties to a contract are likely to have different interests. One organisation not mentioned is the manufacturing company, so the category "F" is the factory itself, therefore part of the manufacturing company. The manufacturing company should be concerned about all features in Table 2.

The fourth column of Table 2 indicates where specific design parameters are derived, and the fifth column gives test standards and guidance documents. In the discussion and later descriptions given in this paper, the geosynthetic reinforcement properties, parameters and guidance are based on European practice, now governed in many areas of civil engineering by the Eurocodes, which will eventually include reinforced soil. Therefore most of the codes given in Table 2 are either European Standards (EN) or International Standards (ISO). The same list of standards and guidance documents could be made based on US practice, with the main guidance coming from AASHTO R69-2015 "Standard practice for determination of long-term strength of geosynthetic reinforcement". However, despite some minor differences here and there, the overall result of establishing the reinforcement as fit-for-purpose would be the same.

Reference to all standards in the text of this paper is made using the basic standard number (eg. BS 8006), omitting the year and other details. The full details of the current versions of each standard may be found in the references. The main guidance document for geosynthetic reinforcement is EN 13251, entitled "Geotextiles and geotextile-related products – Characteristics required for use in earthworks, foundations and retaining structures". There are similar standards for roads and other trafficked areas, for railways, for drainage systems, for erosion control, for reservoirs and dams, for canals, for tunnels and underground structures, for solid waste disposal and for liquid waste containment.

Table 2. Properties of geosynthetic reinforcement of concern to the various organisations involved

Property	Comments	Concerns	Parameter	Standard
Identification (I)	Labelling of reinforcement rolls	F C		ISO 9864
Dimensions (I)	Thickness and size of apertures	F C		
Quality control	QA procedures	F D C O		ISO 9001
Tensile strength (H) (I)	Short term tensile strength (H) Elongation at maximum load (H) Stiffness at various strain values (S)	F D C	T_{char}	ISO 10319 ISO 10319 ISO 10319
Tensile creep strength (S)	Determined by creep testing Normally based on rupture (S)	D	T_{CR} RF_{CR}	General: ISO/TR 20432 ISO 13431
Junction strength	Measurement of strength between ribs and cross-members	F D		GRI GG2
Installation damage (A) (I)	The effect of compaction of fill over the reinforcement, can be severe for coarser angular fills	D	RF_{ID}	Screen: ISO 10722 Full scale: BS 8006
Durability (H)	Normally of concern are: - Oxidation - Weathering - Hydrolysis in water - Chemical exposure - Microbiological activity	D O	RF_{CH} & RF_{W}	General: ISO/TR 20432 Screen: ISO 13438 Screen: EN 12224 Screen: EN 12447 Screen: EN 14030 Screen: EN 12225
Carbon black content	Protection against weathering	D C O		BS 2782:Part 4:Method 452B
Connection reinforcement to reinforcement (S) (I)	Important where reinforcement is connected in the direction of strength	D		ISO 10321
Connection to facing	Important for all reinforced soil systems, especially modular block walls	D	T_{conn}	ASTM D6638
Interaction with fill (I)	Direct sliding (S) and pull-out interaction between reinforcement and fill	D	f_{ds} & f_b	ISO 12957-1 EN 13738
Post-construction deformation	Serviceability in terms of deformation of the structure during its service life	D O	T_{CS}	General: BS 8006 ISO 13431
Aesthetics	Condition and look of the structure during its service life	O		EN 14475
In relation to BS EN 13251: (H) = regulatory; (A) = relevant to all conditions; (S) = relevant to specific conditions				
Organisation: F = factory day-to-day control; D = designer; C = contractor; O = owner of structure				
(I) indicates that test facilities are available in Indonesia, and such tests can be carried out to required standards. "Screen" indicates that the test is a screening test.				

It is perhaps important to outline the typical development process and life of a family of geosynthetic reinforcement products. The manufacturing organisation would develop the products by selecting a polymer and manufacturing process, which would determine the basic physical properties such as dimensions and unit weight. In the early stages of this development, programmes of testing would be set up to determine the associated engineering properties required for design. Many of these tests are expensive and/or of long duration, especially the creep and durability tests. A family of different grades would be established to provide a range of strengths suitable for typical reinforced soil structures, each with its own specification.

Once established, the family of geosynthetic reinforcement products would go into service, with design parameters based on the initial test programmes. There might be a concern that the products change with time, and may no longer be representative of the initial products manufactured during the development process. Therefore it is important that the factory maintains QA procedures to ensure that this does not happen. For example EN 13251 requires that tensile strength is measured once per week or once per batch. However there is also a requirement that the durability tests are repeated every five years, the same for creep tests. These tests are vital to ensure that the design parameters established during development are being maintained.

Regarding the contents of the third column of Table 2, the interests of the various organisations may be summarised as follows:

- In the factory, the manufacturer is interested in quality management and consistency of the product, in order to meet established QA limits on tensile strength and dimensions.
- The designer is interested in the strength and interaction parameters required to prepare the dimensioning and reinforcement layout of the structure, in order to satisfy ultimate and serviceability limit states, and commonly in Indonesia the earthquake design case.
- The contractor is concerned that he can identify the product delivered to his site, and ensure that it meets the requirements of the contract.
- The project owner is interested in the post-construction behaviour of the structure, the aesthetics and durability.

3.0 Design parameters for geosynthetic reinforcement

3.1 *The designer's requirements*

In order to establish design parameters for geosynthetic reinforcement, the following design conditions should be known:

- Design life (generally 50, 60, 75, 100 or 120 years depending on the purpose of the structure)
- In-soil design temperature (typically 30°C in tropical countries)
- Fill grading and type

Figure 2 shows a typical reinforced soil structure indicating two possible failure mechanisms: a two-part wedge cutting through three reinforcement layers and a second two part wedge sliding over the reinforcement. In the first case resistance may be provided by pull-out from the buried end of the reinforcement (based on f_b), or tensile rupture (based on T_{CR}), or resistance at the connection with the facing (based on T_{Dconn}). In the second case resistance is provided by sliding over the reinforcement (based on f_{ds}).

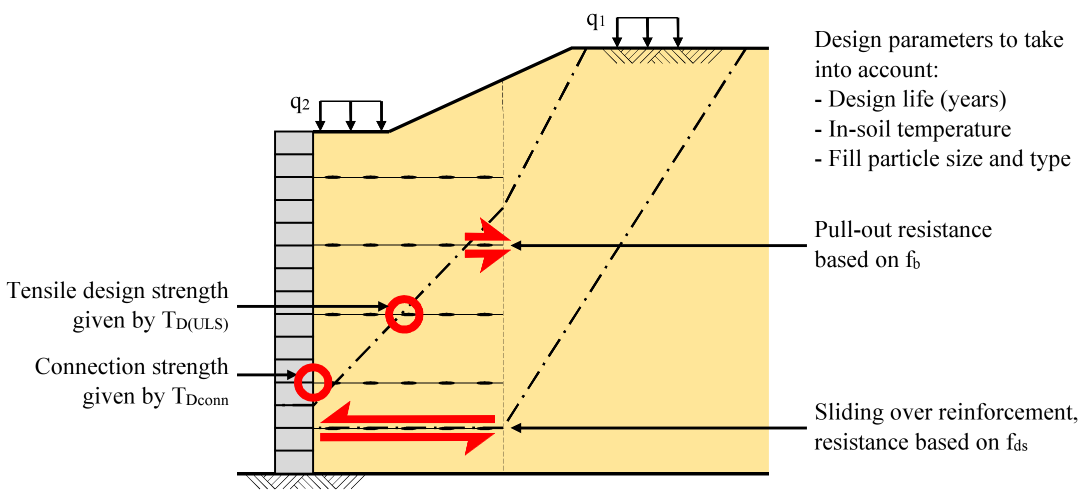

Figure 2: Parameters for geosynthetic reinforcement and interaction to be defined for design

The expression used to define the design strength of the reinforcement for the ultimate limit state (ULS), denoted as $T_{D(ULS)}$ according to BS 8006 and ISO/TR 20432, is:

$$T_{D(ULS)} = \frac{T_{CR}}{RF_{ID} \times RF_W \times RF_{CH} \times f_s \times f_n} = \frac{T_{char}}{RF_{CR} \times RF_{ID} \times RF_W \times RF_{CH} \times f_s \times f_n} \qquad \text{Equation 1}$$

Where:

$T_{D(ULS)}$ = design strength for ultimate limit state
T_{CR} = creep rupture strength
T_{char} = characteristic tensile strength
RF_{CR} = creep reduction factor
RF_W = reduction factor for weathering
RF_{CH} = reduction factor for chemical & environmental
f_s = factor for extrapolation of data
f_n = partial material factor for consequence of failure

Variants on this expression may be found in US practice, Australian practice and elsewhere, but the target is essentially the same, namely that the characteristic tensile strength is reduced by factors to take into account creep, installation damage and durability. In the expression above, the factor f_s is included to take into account uncertainty due to extrapolation of data, as well as using the Arrhenius technique to derive durability reduction factors. The factor f_n is defined as a "consequence of failure" partial material factor by BS 8006, so is not related directly to the reinforcement properties.

3.2 *Modes of degradation*

ISO/TR 20432 defines three modes of degradation of geosynthetic reinforcement as depicted on Figure 3. These are:

- Mode 1: immediate reduction in strength, insignificant further reduction with time, installation damage is an example and it is appropriate to reduce the tensile strength by a representative time-independent factor;
- Mode 2: gradual, though not necessarily constant, reduction in strength, in which case the tensile strength will be reduced by a time-dependent factor;
- Mode 3: no (significant) reduction in strength for a long period, then after a certain period, onset of rapid degradation, in which case it is not appropriate to apply a reduction factor to tensile strength but rather to reduce service lifetime.

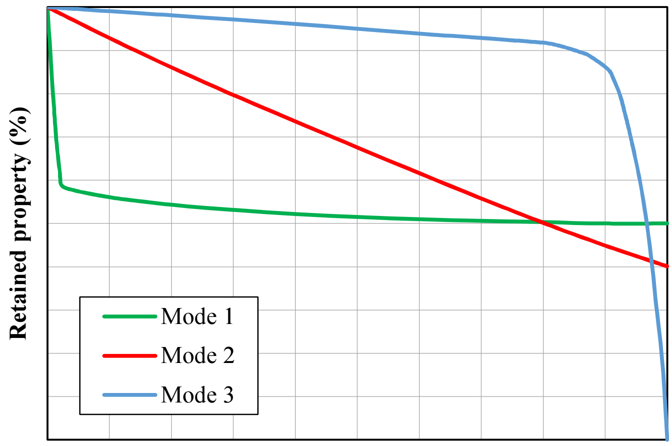

Figure 3: Modes of degradation (after ISO/TR 20432)

The following sub-sections discuss creep, weathering and chemical degradation, relating each to the modes of degradation defined above. Reference will be made to three polymers commonly used to manufacture geosynthetic reinforcement: polyethylene terephthalate or polyester (PET), high density polyethylene (HDPE) and polypropylene (PP). HDPE and PP are collectively referred to as polyolefins. Other polymers are used to manufacture geosynthetic reinforcement such as polyvinyl alcohol (PVA) and polyamide (PA). These polymers are discussed in EN 13251 and ISO/TR 20432, but are used less commonly and are not mentioned further in this section.

3.3 *Creep (T_{CR}, T_{CS}, RF_{CR})*

Creep, or maintained load, testing is a relatively simple test procedure carried out to ISO 13431, consisting of hanging a fixed load on a test specimen (see Figure 4), and then measuring the increase in strain with time, up until the point when the specimen ruptures. Although described as "simple", details such as maintaining constant temperature and good clamping techniques are vital to obtaining consistent and representative test results.

Figure 4: Creep test laboratory

A detailed description of creep testing and its interpretation is beyond the scope of this paper, but some aspects of the resulting data are often misunderstood, and are discussed below. ISO/TR 20432 defines the concepts of creep rupture and residual strength. This is best described by looking at Figure 5, which shows data from 86 creep test specimens where the creep test was terminated before rupture had occurred. In each such case, after dismantling the test, the specimen tensile strength was measured, and both strength and strain at failure were compared to the same data measured before the creep tests were carried out (which had been measured on specimens directly in line with the creep test specimens when the test was set up). Some of these creep tests had reached over five years duration with strains as high as 30%, and yet the short term tensile strength has remained essentially the same, although the stretching has resulted in the specimens becoming slightly stiffer. These measured observations confirm the statement in ISO/TR 20432, namely that creep is a Mode 3 behaviour. The retained strength data for 20°C has been added to Figure 6, but plotted against the duration of loading reached in each creep test.

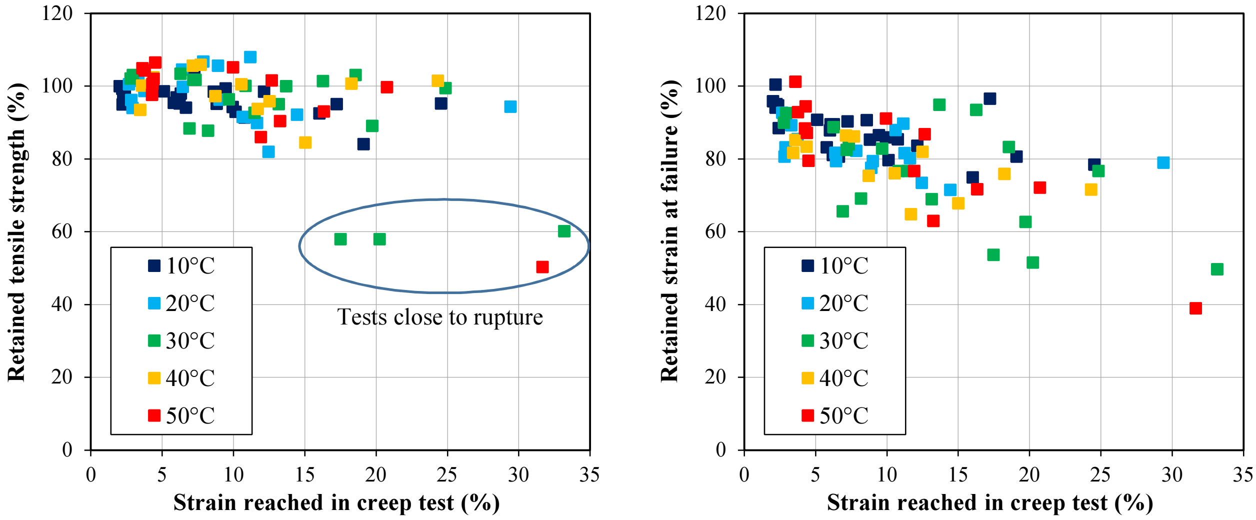

Figure 5: Retained tensile strength (left) and strain at failure (right) for specimens from creep tests terminated before rupture had occurred

One of the main aims of creep testing is to establish the creep rupture regression, consisting of applied load plotted against time to rupture as shown on Figure 6. This regression line is then used to predict the long term design strength, chosen as 120 years on Figure 6. The applied load is given as a percentage of the tensile strength, in this case measured using the ISO 10319 procedure, with a rate of extension of 20% per minute. One feature of Figure 6 which is not so commonly done is that the time axis has been plotted all the way back to 0.0000001 years (3 seconds). The loads applied in these creep tests were normalised to the tensile strength measured using the ISO 10319 procedure, tests completed in about 30 seconds or 0.000001 years. It is then assumed that the creep rupture line reaches 100% load at 30 seconds, as shown. Some additional tensile testing was also carried out at a much higher rate of extension, near the limit of the tensile testing machine, reaching about 200% per minute, such that failure occurred in about 3 seconds, and at about 120% of the ISO

10319 standard strength value. Residual strength based on this high speed testing would be represented by the blue line. Likewise tensile testing following normal US practice to ASTM D6637 (10% per minute, so generally reaching failure in about 1 minute) would appear as the lower green line, at about 95% of the ISO 10913 value.

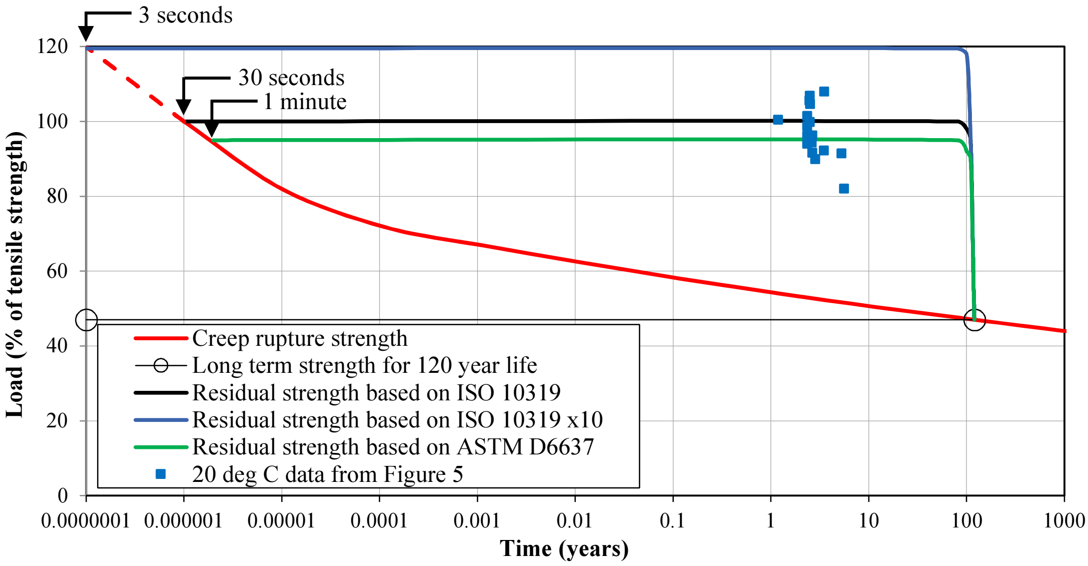

Figure 6: Creep rupture relationship for HDPE geogrid showing residual strength

One important point from the discussion above is that tensile strength is arbitrary, and depends mainly on the rate of elongation used during the test, so there is not a single or unique "tensile strength" for a given geosynthetic reinforcement. However the rupture regression is unique, in terms of absolute load, for the test temperature used. ISO/TR 20432 makes reference to using residual strength in the case of very short term increase in loading such as caused by impact or earthquakes. These loads are likely to last for far less than 30 seconds, so it is probably conservative to use the ISO 10319 strength for this design situation, although this is a common design procedure. In fact this is one of the benefits of geosynthetic polymer reinforcement; that it does have spare capacity to resist short term rapid increases of loading due to vehicle impact or earthquake shaking.

On reviewing the discussion above and Figure 6, it might be asked: why don't we design using short term strength if it remains available until the end of the design life? Of course the answer is that this is Mode 3 behaviour, and it is necessary to limit load to ensure that rupture takes place at or after 120 years, as required by the design conditions. If you applied a load equivalent to the full tensile strength, then the reinforcement would rupture after 30 seconds.

As regards the performance of other polymers under creep loading, PET generally has a slightly higher creep rupture strength at 120 years compared to the relationship shown on Figure 6, typically around 60 to 65% at 120 years. However PP typically does not behave so well, and the 120 year rupture strength could be 20% of tensile strength or less. Creep behaviour is also affected by increasing temperature, with the 120 year creep rupture load becoming lower as temperature increases. This is the case for all polymers, although PET is generally affected to a lesser extent by increasing temperature compared to the polyolefins.

3.4 *Weathering (RF_W)*

Weathering is principally exposure to UV (ultraviolet) light, combined with the effects of elevated temperature and water spray. Globally Indonesia is in one of the highest categories for UV radiation, with the west part of the archipelago being rated at 140 kilo-Langley per annum. Only desert areas such as the Sahara and central Australia are higher, reaching 200 to 220 kilo-Langley per annum. The potential effect of this high UV radiation, combined with high temperature and a humid climate made be seen on Figure 7, which shows a geosynthetic reinforced steep slope, where the facing consists of the woven PP geotextile. No additional facing cover has been provided, so that the geosynthetic material has been fully exposed to sunlight and high temperature. Holes are appearing along the top edge of the wrap-around facing, where the angle of incidence to the sun is most severe. Clearly this material has very poor resistance to weathering.

All polymers can degrade when exposed to UV light. Protection may be provided by additives (normally by adding carbon black to the polymer in the case of polyolefins) or by applying a UV stabilised coating or by limiting the time of exposure. Exposure can occur during transport, storage, installation and service, depending on the method of construction being used. EN 12224 provides a procedure for carrying out an accelerated weathering index test, and ISO/TR 20432 gives recommended maximum exposure times based on the results. For example if retained strength is > 80%, then a maximum exposure time of 1 month may be acceptable provided that a suitable value of RF_W has been assessed from the results of the testing.

Figure 7: Damage to a woven PP geotextile due to excessive exposure to UV (sunlight) in Indonesia

One method which can be used to assess resistance to weathering and the adequacy of protection additives is to carry out full-scale outdoor exposure tests. Figure 8 shows part of the results from such a trial carried out in Australia, where UV radiation is relatively high. In this trial specimens of various types of geosynthetic reinforcement were set up on a frame facing north, fully exposed to the prevailing weather conditions. Specimens were recovered from time-to-time, and the graphs in Figure 8 show the tensile behaviour of both HDPE and PP reinforcement after 10 years of continual exposure, compared to tests on control specimens. This simple approach demonstrates very clearly the excellent UV resistance of geosynthetic reinforcement when adequately protected with appropriate additives.

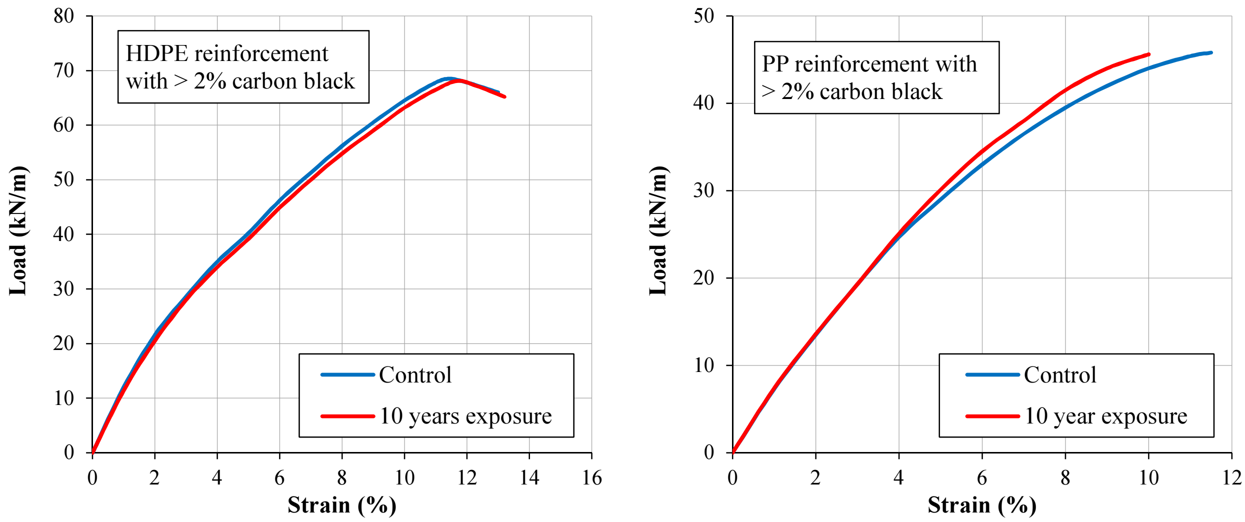

Figure 8: Results of long term exposure tests carried out in Australia

3.5 *Installation damage (RF_{ID})*

Many reinforced soil structures built in Indonesia make use of relatively fine fills, in which case damage due to contact with the fill particles during compaction is likely to be minor. However in the case that coarser fills are used, especially when consisting of angular or crushed rock particles, damage can be more severe and should be investigated. Installation damage is a Mode 1 type of deterioration because almost all the loss of strength is caused during the filling and compaction process. BS 8006 Annex D includes a method of assessing the magnitude of installation damage using a full-scale field test procedure, in which specimens of geosynthetic reinforcement are buried under layers of fill of controlled grading and thickness, followed by compaction. The specimens are carefully retrieved after compaction, and their tensile strengths measured following the ISO 10319 procedure and then compared to control specimens.

ISO/TR 20432 gives further information and details concerning the installation damage test procedure, and warns that the laboratory test method given in ISO 10722 is intended as an index test for comparative purposes and should not be used for the derivation of reduction factors (RF_{ID}) for geosynthetic soil reinforcement. Generally values of RF_{ID} are taken from tables of published values for any particular geosynthetic reinforcement product, however there may be occasions for large projects, or projects with unusually aggressive fills, where project-specific installation damage trials are justified. Apart from the procedure itself, the main test method required is ISO 10319, which is available in Indonesia.

3.6 *Degradation due to exposure to chemicals (RF_{CH})*

The main concerns with exposure of geosynthetic reinforcement to chemicals are: oxidation of polyolefins (HDPE and PP) and hydrolysis of PET. Both are major topics, and many references may be found in the literature. ISO/TR 20432 treats both issues in detail. A few comments are provided below.

Oxidation of polyolefins: oxidation of polyolefins results in breakdown of the polymer chains leading to reduced molecular weight and subsequent loss of strength. This can also lead to embrittlement, surface cracking and loss of colour. Protection against oxidation is normally provided by anti-oxidant stabilisers, specially developed for the purpose, which can extend lifetime dramatically by 100's or 1000's of times. These anti-oxidants must provide protection both during manufacture and during the service life of the geosynthetic reinforcement. The mechanism of this protection is such that the anti-oxidant is gradually consumed by oxidation during service until it is effectively exhausted, at which stage retained strength can reduce rapidly. In order to establish service life, it is necessary to carry out tests under extreme conditions or environments to accelerate the effects of oxidation, such that an extrapolation may be made using the Arrhenius approach to establish lifetime under ambient conditions. An example of such tests is shown in Figure 9, carried out on an HDPE reinforcement product, in this case in pure oxygen and under high pressure. These results emphasise two important points: firstly that the nature of deterioration through oxidation is Mode 3, and secondly that increasing temperature increases the rate of consumption of the anti-oxidant, therefore leading to more rapid deterioration.

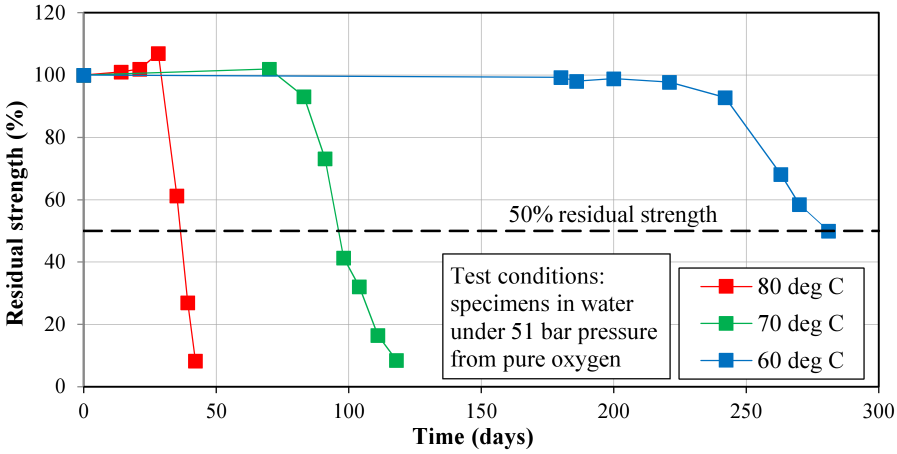

Figure 9: Accelerated oxidation tests on HDPE reinforcement using autoclave

Hydrolysis of PET: hydrolysis of PET is essentially a reversal of the manufacturing process, where free water is absorbed and the PET fibres revert to their original constituents. It is well known that hydrolysis is more severe in elevated temperatures and under extreme pH, especially alkaline conditions. Two important features of PET which help to ensure better performance in terms hydrolysis are the carboxyl end group content (CEG) which should be less than 30 meq/g (ASTM D7409) and average molecular weight (M_n) which should be greater than 25,000 g/mol (according to ASTM D4603). For PET used as reinforcement these limits are normally required in specifications, and are quoted both in EN 13251 and ISO/TR 20432. They are not included in Table 2, because they are specific to PET. It is also common to limit the range of pH to 4 to 9, although environments outside this range may be considered provided that lifetime assessment has been carried out to establish RF_{CH}.

Hydrolysis is a Mode 2 deterioration, taking place gradually with time. In this case RF_{CH} is amenable to assessment by using accelerated testing techniques. To give some indication of the sensitivity to temperature, Figure 10 summarises data from three sources showing RF_{CH} versus temperature, including the required pH limits. In the case of the ISO/TR 20432 values, they are for use in saturated soils, so lower values may be appropriate is the soil is not saturated.

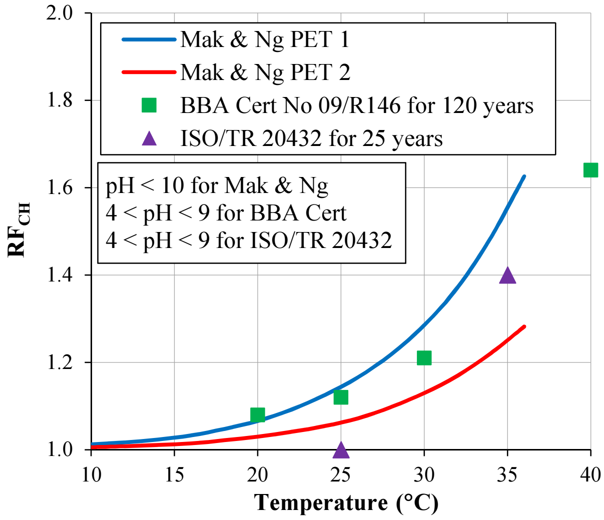

Figure 10: RF_{CH} accounting for hydrolysis of PET versus temperature from various sources

The important result from this summary is that for lower temperatures in neutral conditions, the effect of hydrolysis is minor, provided that the polymer used meets the CEG and M_n limits. However as temperature increases (and pH becomes more extreme) the effect becomes more severe. In particular as temperature rises past 30°C, the effect of hydrolysis is becoming significant, even for neutral conditions, and this is clearly relevant to the environmental conditions of Indonesia.

3.7 *Interaction factors (f_{ds} & f_b)*

Interaction factors are required to calculate the pull-out resistance of geosynthetic reinforcement (f_b), as well as sliding over reinforcement (f_{ds}) as depicted on Figure 2. Sliding interaction has a far bigger influence on design, because it affects the entire length of the reinforcement, whereas pull-out only affects a short part of the reinforcement at its buried end, and only has any significant influence for the top one or two layers in a reinforced soil structure due to the low overburden pressure. Sliding interaction may be investigated using an adapted large shear box (see Figure 11), and such facilities are available in Indonesia. For routine design, values are often assumed based on soil type and published information, however in some situations, testing might be carried out on a project-basis.

One important point to be taken into account is that reinforced soil design is carried out using drained analysis, based on effective stress. Therefore any interaction testing to determine f_{ds} must also be carried out using a drained test procedure. This is easy for granular fills, but poses a problem for finer fills. It is common in Indonesia to use clay fill for reinforced soil structures, in particular residual soil derived from volcanic deposits known locally as “tanah merah” (red soil). If tanah merah is tested in the large shear box, and the test is carried out fully drained, then due to the long drainage paths, the duration of the test could be very long, requiring saturation, consolidation and shearing at a very slow rate. If the shearing as carried out too quickly, then the test cannot be considered as drained, and the derived f_{ds} will not be relevant to the effective stress. The author is aware of many published studies of interaction testing involving fine fills, but in most cases the test condition is undrained, so that the resulting interaction factors are not relevant to reinforced soil design.

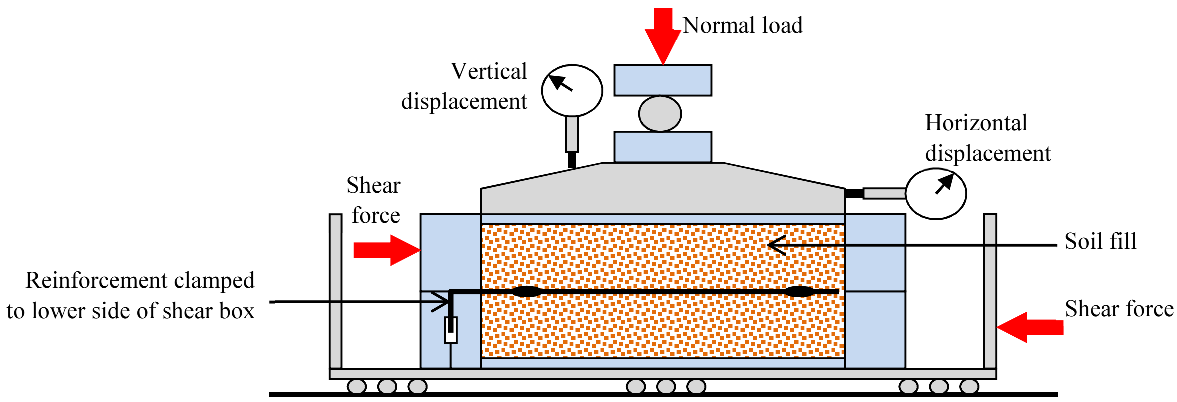

Figure 11: Typical arrangement for setting up shear box to measure sliding interaction factor

4.0 Sources and magnitude of design parameters for geosynthetic reinforcement

In general all of the design parameters listed in the fourth column of Table 2 are rarely measured or checked on a project-by-project basis. Furthermore, of all the test procedures required to measure or verify these parameters, facilities in Indonesia are only available to measure installation damage and interaction factors. To the author's knowledge, adequate facilities to measure creep behaviour and carry out the various long term durability (exposure) tests are not available in Indonesia. In this situation, the designer must obtain this information from alternative sources. This section briefly discusses three possible sources for obtaining design parameters: manufacturers' specification sheets, published default values and independently published fitness-for-purpose certificates.

4.1 *Manufacturers' specification sheets*

Manufacturing organisations will generally publish specification sheets for their geosynthetic reinforcement products, providing all or some of the data listed in Table 2. However the designer or project owner might like to have some independent verification of this data, by way of an audit of the data provided by the manufacturer. The next two sections outline possible approaches to meeting this aim.

4.2 *Published default values*

In cases where either no (reliable) data is available for a particular source of geosynthetic reinforcement, or independent verification is sought to judge the veracity of published data on a specification sheet, one approach is to use published default values. One long established recommendation is given in the AASHTO LRFD Bridge Design Specification (AASHTO, 2012), where in Table 11.10.6.4.3b-1, for permanent applications not having severe consequence should poor performance or failure occur, and polymers meeting basic durability requirements, an overall reduction factor combining creep reduction, installation damage and durability of 7.0 may be used. In terms of the definitions used in this paper based on European practice, this means that $RF_{CR} \times RF_{ID} \times RF_W \times R_{CH} \times f_s = 7.0$. The conditions for this are:

- Soil is considered non-aggressive
- pH in the range 4.5 to 9
- maximum particle size less than 20mm
- design temperature less than 30°C

This lumped factor of 7.0 might appear quite high, however its use is intended where full and appropriate test data is not available. An alternative independent source of default design values for geosynthetic reinforcement is given in Appendix K of the Australian standard for earth-retaining structures, AS 4678. This information is far more detailed than the simple lumped factor of 7.0 described above. Also ranges of values are given, so that some judgement may be made based on the actual design conditions. Furthermore factors are given for the three main reinforcement polymers, PET, HDPE and PP. The values and ranges of these default factors are summarised in Table 3. The nomenclature used in AS 4678 is different compared to European practice, so the various components have been grouped as closely as possible to match RF_{CR}, RF_{ID}, RF_W and RF_{CH}. It should be noted that in AS4678, the factors are defined as reduction factors (subscript "r") and uncertainty factors (subscript "u"), and are therefore quoted with values equal to or less than 1.0. In Table 3, the values have been inverted to appear similar to European practice, as indicated in the second column. It can be seen that the lumped product of the factors, based on mean values of the ranges, varies from 7.8 for PET to 22.9 for PP. Table 3 also gives minimum lumped factors based on the lower value of each range.

Table 3. Summary of default reduction and uncertainty values published in AS 4678

Factor	Factor* in AS 4678	PET	HDPE	PP
RF_{CR}	$1/\Phi_{rc}$ $1/\Phi_{ue}$ (2 log cycles real time)	2.0 1.3	3.3 1.3	5.9 1.3
RF_{ID}	$1/\Phi_{ri}$ (varies 1.7 to 1.1, use mean)	1.4	1.4	1.4
$RF_D =$ $RF_W \times R_{CH} \times f_s$	$1/\Phi_{rt}$ (for loss of thickness, 1.0 to 1.1, use mean) $1/\Phi_{rs}$ (for loss of strength, 1.1 to 2.0, use mean) $1/\Phi_{rst}$ (for temperature, included) $1/\Phi_{ud}$ (degradation uncertainly)	1.05 1.55 1.0 1.25	1.05 1.55 1.0 1.25	1.05 1.55 1.0 1.25
Manufacturing	$1/\Phi_{up}$ (1.05 if based on characteristic strength)	1.05	1.05	1.05
Overall	$= RF_{CR} \times RF_{ID} \times RF_W \times R_{CH} \times f_s$	7.8 (min 4.1)	12.8 (min 6.8)	22.9 (min 12.2)
*It should be noted that in AS 4678 all Φ values are actually defined as reduction factors with values of 1.0 or less				

4.3 *Fitness-for-purpose approval certificates*

The magnitude of design strength derived from the default values outlined above will inevitably be low, however this is intended to be the case when that there is significant uncertainty about the appropriate design parameters for any particular geosynthetic reinforcement. An alternative approach is to use independently published fitness-for-purpose certificates. No such certificate system has been established in Indonesia, so it would be necessary to make use of certificates published by authorities outside Indonesia. One such source is the British Board of Agrément (BBA), which publishes technical approvals for construction for a wide range of construction materials and systems. These certificates include three main applications of geosynthetic reinforcement: retaining walls and load bearing bridge abutments (steeper than 70°), embankment slopes (less steep than 70°) and basal reinforcement. Some certificates are designated as HAPAS Certificates, standing for Highways Authority Product Approval Scheme, and are mandatory in the United Kingdom if such products and systems are to be used for Department of Highways structures. The certificates may be freely downloaded from the BBA website: www.bbacerts.co.uk. Currently there are about 24 published certificates which incorporate geosynthetic reinforcement, including the polymers PET, HDPE, PVA and PA. There are no certificates for PP reinforcement, which does not seem surprising based on the default design parameters given in Table 3. The certificates generally include facings, in several cases modular block systems, in which case information on design connection strength is included.

A typical HAPAS certificate is 11 to 12 pages long, with contents as summarised in Table 4. There is a lot of information covering the needs of all organisations involved in a project as discussed in Section 2: factory control, designer, contractor and owner of the structure. So it very much fulfils the requirements listed in Table 2.

Table 4. Summary of contents of BBA HAPAS certificate for retaining wall and bridge abutment

Section	**Content**	**Details**	**Factors or parameters**
1	Description	Label colours, dimensions, unit weight, tensile test data	T_{char}
2	Manufacture	Polymer, process, QA system	
3	Delivery	Label examples, storage & handing recommendations	
4	General	General information about design	
5	Practicability	Requirements for installers	
6	Design	Methodology, definition & purpose of partial factors, interaction factors, facing information	f_{ds} f_b
7	Properties	Creep rupture, serviceability, partial factors	T_{CR}, RF_{CR}, T_{CS}, RF_{ID}, T_{conn}
8	Environmental	Weathering, chemical	RF_W, RF_{CH}
9	Extrapolation	In relation to creep and chemical durability data	f_s
10	Maintenance		
11	Durability	General statement on adequacy for design life	
12, 13, 14	Construction	Outline of installation method and important details	
15	Investigations	Summary of data investigated	
	References	Reference code and standards	

One important warning if BBA Certificates are to be applied to projects in Indonesia is that the in-soil design temperature used to establish the various reduction factors in the certificates is either 10°C or 20°C. As emphasised in Section 3.0, the various processes which cause deterioration or reduction in design life (for example: creep, hydrolysis and oxidation) tend to be accelerated by elevated temperature, so this would need special consideration and possible re-assessment in applying design values from BBA Certificates to projects in Indonesia. Certificates are also published by the Geotechnical Engineering Office of the Hong Kong Government, which are for higher design temperature. However they are less comprehensive, providing less information than BBA Certificates, with no design parameters for connection to facings nor serviceability parameters.

5.0 Concluding remarks

Soil structures stabilised with polymer reinforcement may be used to construct a wide range of structures, from decorative garden walls to loading bearing bridge abutments and even structures over 50m high. Whatever the project, the designer requires a number of parameters to be able to dimension the structure and create a safe yet economical layout of reinforcement. One of the required design parameters is the long-term design strength, where the "term" or design life may be 100 years or more. Performance data for such long durations of service does not exist for the polymers used to manufacture geosynthetic reinforcement, so that predictions must be made by extrapolating short term test results. All polymers used to manufacture geosynthetic reinforcement will deteriorate with time in the environments where they are used, so that durability is a major concern with regards to such products being fit-for-purpose. Freshly manufactured geosynthetic reinforcement products will all look much the same, but their look does not guarantee their long term durability. It is vital that tests are carried out which accelerate deterioration, so that an assessment may be made of the appropriate design life or appropriate reduction factors to take into account these effects. The science of these predictions is still evolving, but by now, European practice has established procedures to help ensure that the expected design lives are achieved.

European Standard EN 13251 provides guidance on the test requirements and limitations for the use of geotextiles and geotextile-related products in retaining walls, including conditions which affect durability. Annex B covers durability aspects, and amongst other requirements restricts the use of recycled Post-Industrial and Post-Consumer resins to non-reinforcing applications with less than 5 years durability. Importantly Section B.1.1 on service life clarifies that screening tests (see Table 2) only show the ability of a product to serve for a certain time, and do not allow the determination of the all-important reduction factors. These must be determined by carrying out lifetime assessment test programmes, with advice and methods described in ISO/TR 20432.

With regards to the use of geosynthetic reinforcement to stabilise soil structures in Indonesia, it is recommended that an established certificate system is used to provide independent verification of design parameters, such as the BBA Certificate system. This extensive system of certificates provides detailed information, as well as all required design parameters and factors. However it needs to be appreciated that BBA Certificates are published for use in a temperate climate, so that some adjustment is required to take into account the hotter more humid conditions in Indonesia.

References

BBA Certificate No 09/R146. Paraweb straps for reinforced soil retaining walls and bridge abutments. British Board of Agrément (BBA), Watford, United Kingdom.

Mak J. C. H. & Lo S. C. R. (1996). Towards a limit state design specification for reinforced soil walls. Earth Reinforcement: Proceedings of the 3rd International Symposium on Earth Reinforcement, Fukuoka, Kyushu, Japan, 12-14 November, 1996, Volume 2, 415-420.

Referenced standards

AASHTO R69-2015. Standard practice for determination of long-term strength of geosynthetic reinforcement. American Association of State Highway and Transportation Officials, Washington DC, USA.

AASHTO (2015). AASHTO LRFD Bridge Design Specifications - Customary US Units. American Association of State Highway and Transportation Officials, Washington DC, USA.

AS 4678. Earth-retaining structures. AS 4678-2002, Standards Australia, Sydney, Australia.

ASTM D4603. Standard Test Method for Determining Inherent Viscosity of Poly(Ethylene Terephthalate) (PET) by Glass Capillary Viscometer. ASTM D4603-03, ASTM International, Pennsylvania, USA.

ASTM D6637. Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method. ASTM D6637M-15, ASTM International, Pennsylvania, USA.

ASTM D6638. Standard Test Method for Determining Connection Strength Between Geosynthetic Reinforcement and Segmental Concrete Units (Modular Concrete Blocks). ASTM D6638-11, ASTM International, Pennsylvania, USA.

ASTM D7409. Standard Test Method for Carboxyl End Group Content of Polyethylene Terephthalate (PET) Yarns. ASTM D7409-15, ASTM International, Pennsylvania, USA.

BS 2782:Part 4:Method 452B. Methods of testing – Plastics – Part 4 – Chemical properties – Method 453B. Determination of carbon black content of polyolefin compound. BS 2782:Part 4:Method 452B:1993, British Standards Institution, London, United Kingdom.

BS 8006. Code of practice for strengthened/reinforced fills. BS 8006-1:2010, British Standards Institution, London, United Kingdom.

EN 12224. Geotextiles and geotextile-related products – Determination of the resistance to weathering. BS EN 12224:2000, British Standards Institution, London, United Kingdom.

EN 12225. Geotextiles and geotextile-related products – Method for determining the microbiological resistance by a soil burial test. BS EN 12225:2000, British Standards Institution, London, United Kingdom.

EN 12447. Geotextiles and geotextile-related products – Screening test method for determining the resistance to hydrolysis in water. BS EN 12447:2001, British Standards Institution, London, United Kingdom.

EN 13251. Geotextiles and geotextile-related products – Characteristics required for use in earthworks, foundations and retaining structures. BS EN 13251:2014+A1:2015, British Standards Institution, London, United Kingdom.

EN 14030. Geotextiles and geotextile-related products – Screening test method for determining the resistance to acid and alkaline liquids. BS EN 14030:2001, British Standards Institution, London, United Kingdom.

EN 14475. Execution of special geotechnical works – Reinforced fill. BS EN 14475:2006, British Standards Institution, London, United Kingdom.

GRI GG2. Geogrid Junction Strength. GRI-GG2-05, Geosynthetic Institute, Philadelphia, USA

ISO 9001. Quality management systems. Requirements. BS EN ISO 9001:2015, British Standards Institution, London, United Kingdom.

ISO 9864. Geosynthetics – Test method for the determination of mass per unit area of geotextiles and geotextile-related products. BS EN ISO 9864:2005, British Standards Institution, London, United Kingdom.

ISO 10319. Geosynthetics – Wide-width tensile test. BS EN ISO 10319:2015, British Standards Institution, London, United Kingdom.

ISO 10321. Geosynthetics – Tensile test for joints/seams by wide-width strip method. BS EN ISO 10321:2008, British Standards Institution, London, United Kingdom.

ISO 10722. Geosynthetics – Index test procedure for the evaluation of mechanical damage under repeated loading – Damage caused by granular material. BS EN ISO 10772:2007, British Standards Institution, London, United Kingdom.

ISO 12957-1. Geosynthetics – Determination of friction characteristics – Part 1: Direct shear test. BS EN ISO 12957-1:2005, British Standards Institution, London, United Kingdom.

ISO 13431. Geotextiles and geotextile-related products – Determination of tensile creep and creep rupture behaviour. BS EN ISO 13431:1999, British Standards Institution, London, United Kingdom.

ISO 13438. Geotextiles and geotextile-related products – Screening test method for determining the resistance to oxidation. BS EN ISO 13438:2004, British Standards Institution, London, United Kingdom.

ISO/TR 20432. Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement. PD ISO/TR 20432:2007, British Standards Institution, London, United Kingdom.