TESTING AND SPECIFICATION OF HDPE AND POLYPROPYLENE GEOGRIDS FOR REINFORCED SOIL STRUCTURES

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INTRODUCTION

Reinforced soil structures provide an economical and versatile option for building retaining walls, steepened slopes and bridge abutments. Their use is increasing, and the number of soil reinforcement products available in the market place is also increasing. Designers and project supervisors require satisfactory methods of specifying these products to ensure that the properties of the reinforcing material used are suitable for their purpose, and meet the requirements of the design. Specifications generally consist of a number of physical and mechanical properties, measured by appropriate test procedures.

These reinforcement properties can be divided into two main groups:
- Quality control properties
- Design parameters

This paper outlines the important properties in both categories, and the test methods commonly in use, principally for reinforcement materials manufactured from either high density polyethylene (HDPE) or polypropylene (PP). Special reference is made to conditions and procedures currently used in China.

This paper was presented at the 1st Nationwide Seminar on Geosynthetics Testing Technology, held in Shanghai in June 2001. This seminar included extensive discussion about the current situation in China with regards to testing standards and specification of geosynthetic materials. Following the seminar, this paper has been updated, taking into account some of the information presented at the seminar, as well as the discussions. In particular, reference is made to existing Chinese test standards and an appendix is included with suggestions for making further progress with this important topic in China. ***All additional material added since the original paper was published at the seminar is denoted by italics****.*

QUALITY CONTROL TESTING

Quality control tests are carried out to ensure that a particular reinforcement material has been manufactured correctly. Many manufacturers operate their factories following quality assurance (QA) procedures, such as those given in the ISO 9000 series of standards for quality systems, and measurement of basic physical and mechanical properties should feature in their QA procedures. The table below summarises the main properties measured, indicating test methods where appropriate.

In China a Standard already exists for plastic geogrid materials, GB/T 17689-1999. This standard gives the following required properties:

- Polymer type
- Unit weight
- Tensile strength (short term, including strain at failure, and load at 2% and 5% strain)
- Roll width

Reinforcement property	Test method	Comments
Tensile strength	ISO 10319	Also strain at failure and load at 2% and 5% strains are generally reported
Unit weight		General check on material consistency
Dimensions		General check on material consistency
Polymer type		For long term soil reinforcement applications, HDPE is the preferred polymer. The long term creep performance of PP is inferior.
Carbon black content	BS 2782:Part 4: Method 452B (muffle furnace)	Important that carbon black content should be above 2% for maximum protection from UV light

The tensile test standard required by this specification is the US single rib method, GRI GG1-1987 [Standard Test Method for Geogrid Rib Tensile Strength]. In the table above, the method ISO 10319 is quoted, which is an International Test Standard, and is a wide width method. The main features of these two test methods are summarised below.

Tensile test method	Specimen width	Number of specimens	Rate of loading
GRI GG1	1 rib	10	50 mm/min
ISO 10319	200 mm (minimum)	5	20%/min

The ISO 10319 method has the advantage of testing a wider, more representative specimen, at a fixed rate of strain (see Figure 1 below). The GRI GG1 method tests single ribs only, at a fixed rate of extension. Because different geogrids have different dimensions, this means that the rate of strain will vary from product to product. In tensile testing of polymer materials, rate of strain will affect the measured strength.

The GB/T 17689-1999 document is therefore a partial list of quality control properties only. It does not provide any guidance for a designer to use in designing a reinforced soil structure because:

- There are no design parameters or properties given
- Two geogrids could have identical quality control properties, but completely different design parameters

Figure 1 Tensile test to ISO 10319

DESIGN PARAMETERS

For design of reinforced soil structures various mechanisms must be checked which involve the properties of the reinforcing material. These are summarised on Figure 2. The principal parameters required are:

- Long term design strength of the reinforcement
- Frictional interaction between reinforcement and soil (sliding and pullout)

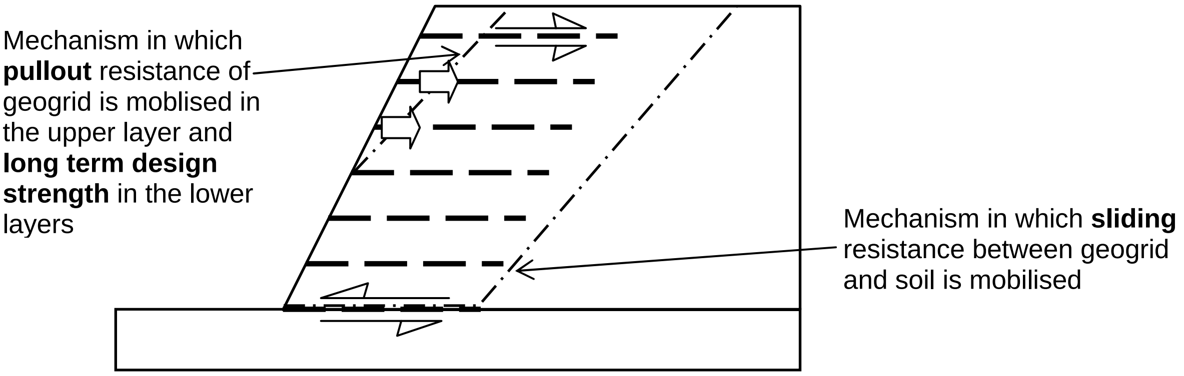


Figure 2 Failure mechanisms in reinforced soil structures

Long term design strength of soil reinforcement material is defined by the expression:

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

where P_{des} = long term allowable design strength
P_c = characteristic long term strength based on 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
f_j = partial factor to allow for connections
LF = load factor (depends on design method used)

The factor f_j is included to take into account the effects of connections. These could be either between the reinforcing material and a wall facing, or to join together two pieces of reinforcing material.

Interaction between geogrid and soil is defined by a simple coefficient of friction given by:

$$\text{friction coefficient} = \alpha \tan\phi'$$

where ϕ' = friction angle of the soil
α = interaction factor

The interaction factor (α) is therefore a reduction factor to take into account sliding between geogrid and soil. Interaction factors are required for two conditions: sliding (α_s) and pullout (α_p).

Various tests are required to establish these design parameters, listed in the table below.

Design feature	**Parameter**	**Testing required**	**Test method**	***Chinese test standard***
P_{des}	P_c	Derived from creep testing	ISO 13431	*GB/T 17637-1998*
	f_m	Depends on QA procedures in manufacturing, long term creep testing database and extrapolation of data		
	f_d	Based on results from full scale site damage trials	BS 8006:1995 Annex D	
	f_e	Resistance to oxidation	ISO 13438	*GB/T 17631-1998*
		Resistance to UV light	UV exposure tests	
		Carbon black content	BS 2782:Part 4: Method 452B	
		Resistance to various chemical and biological conditions	Exposure tests	*GB/T 17632-1998*
Connection	f_j	Connection testing	ISO 10321	
Sliding	α_s	300mm (minimum) shear box adapted to include reinforcement on sliding plane	BS 1377:Part 7	*GB/T 17635-1998*
Pullout	α_p	Pullout testing	GRI GG5	

Of the various tests listed above, one of the most important is the creep test (ISO 13431). This is a relatively simple test in which a piece of reinforcement material of standard dimensions is hung from a frame with a weight attached to the lower edge (see Figure 3). The length of a central gauge section is then measured against time, giving test data in the form of strain versus time. This is carried out in a temperature controlled room, and by carrying out tests at various temperatures, it is possible to predict creep behaviour for very long design lifetimes. Creep testing is required for each grade and type of material in a range of reinforcement materials.

Figure 3 Creep test laboratory

In addition to creep testing, other tests to establish the various partial safety factors given above are also required. Like creep testing, site damage testing to measure f_d is required for each type and grade of reinforcement material in a range of soil types. The majority of the other tests (exposure tests and oxidation resistance) may be carried out on a limited selection from the full range, as the results tend to be dependent mainly on the polymer types used.

Of the two types of interaction testing, sliding interaction is the more important. This is because in designing a reinforced soil structure, the sliding resistance is calculated over the full width of the reinforced soil block (see Figure 2, lower mechanism). Pullout only effects the calculation of anchorage length, and is only critical near the top of a structure.

The table of test methods given above also includes existing test methods given in Chinese National Standards (GB/T series) in the right hand column. These standards are based on existing ISO test standards. In addition to the GB/T series there are standards established by different Ministries in China. The Hydraulics Design Institutes have developed the SLT series of test standards, based mainly on US ASTM test methods.

CASE HISTORY (1) - COMPARING TWO REINFORCING MATERIALS MANUFACTURED FROM DIFFERENT POLYMERS

In order to investigate the possible differences between two reinforcing materials manufactured from different polymers, creep test data is presented below for:

- High density polyethylene (HDPE) uniaxial geogrid manufactured in UK
- Polypropylene (PP) uniaxial geogrid manufactured in China

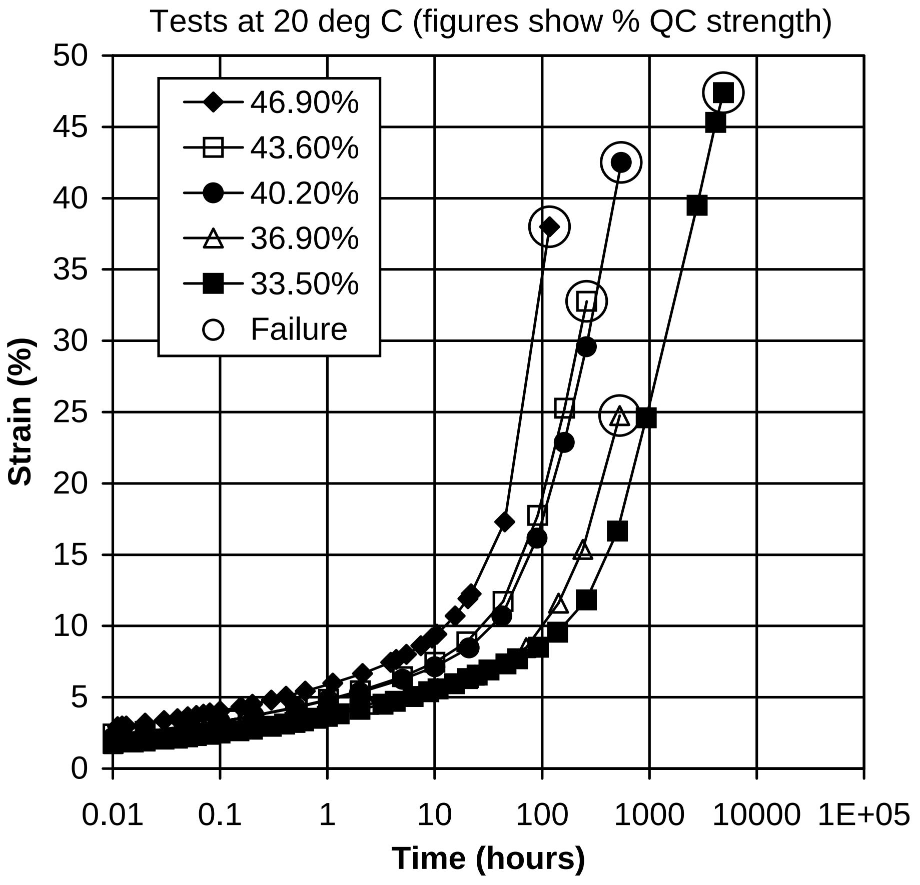


Figure 4a Creep test results on PP geogrid

Figure 4a shows the results of creep tests at 20°C on the PP geogrid. Further tests were carried out at 40°C, to help provide an indication of the longer term behaviour using the principles of time-temperature superposition. In the data presented here the applied loads have been normalised to the short term tensile strength (ISO 10319), referred to as the quality control (QC) strength. It can be seen that at a load as low as 33.5% of QC strength, strain reaches 10% after just 150 hours for the PP geogrids. All the tests reached failure, with the longest time to failure being slightly less than 5000 hours.

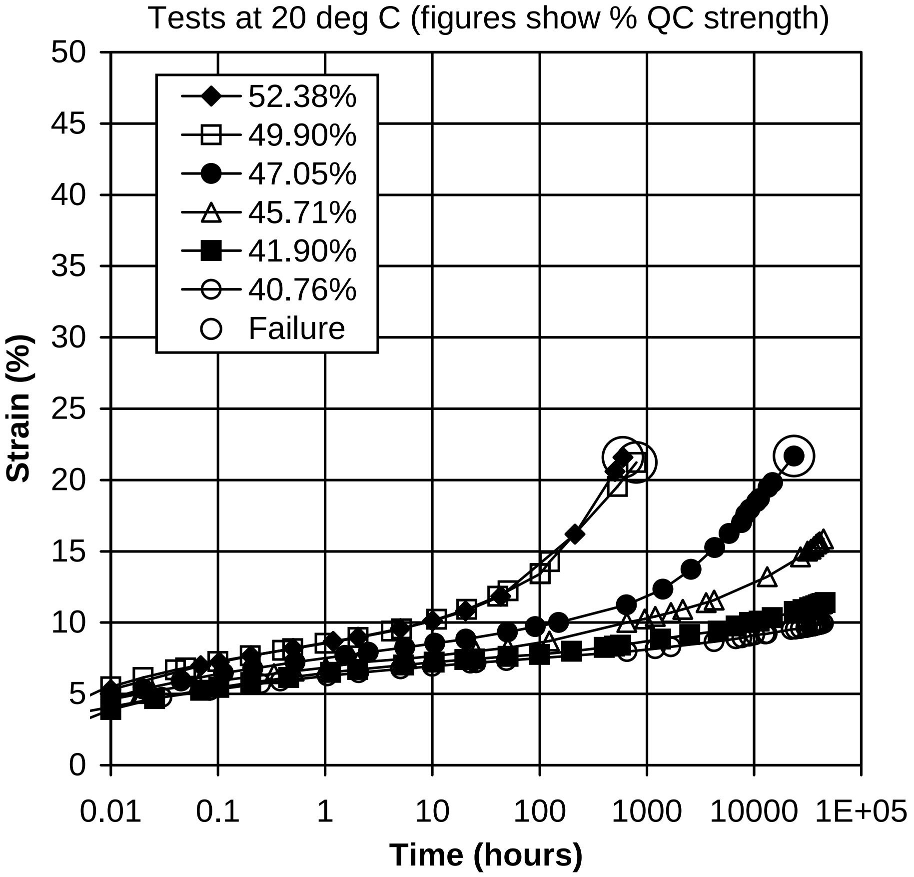
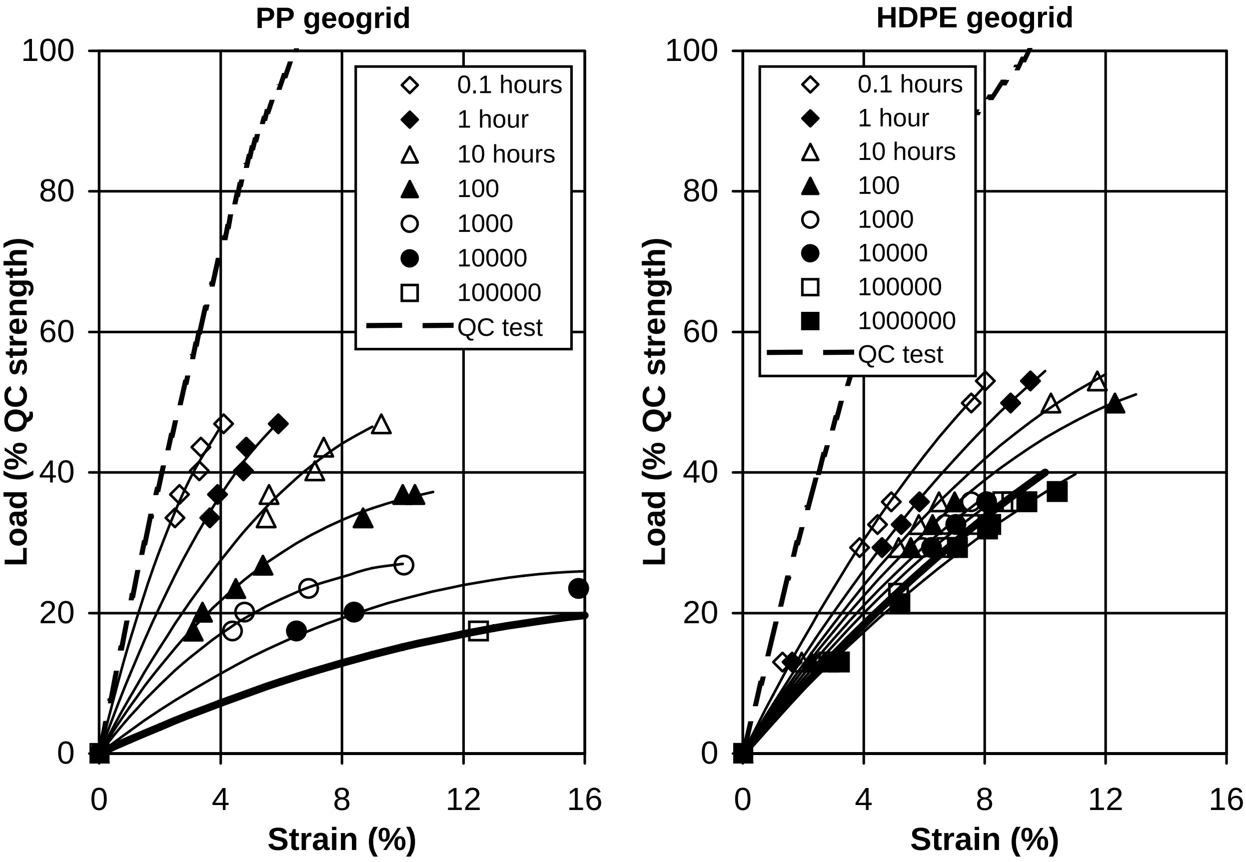


Figure 4b Creep test results on HDPE geogrid

Figure 4b shows a series of creep tests on the HDPE geogrid. There are a number of important differences compared to the PP geogrid performance:

- 10% strain was reached in 150 hours for the test at 47.05% of the QC strength (compared to 33.5% for the PP geogrid)
- Only three of the tests have failed, at much lower strain than the PP geogrids
- The remaining three tests are ongoing with duration now exceeding 45,000 hours (5 years), at relatively high loads

The strain-time data from the creep tests can be interpreted to provide isochronous load-strain curves. These are shown on Figure 5 for both the PP and the HDPE uniaxial geogrids tested, and consist of a series of load-strain curves for different durations of loading. The scales of the two graphs above are the same, so that they provide a direct visual comparison, which shows dramatic differences between the two types of geogrid. The greatest duration that can be interpreted from the data available for the PP geogrids is 100,000 hours, whereas the HDPE geogrid data includes durations up to 10^6 hours. By comparing the 100,000 hour lines (about 11 years - shown by a thicker line), it can be seen that at 10% strain, the PP geogrid only carries 15% of its QC strength, whereas the HDPE geogrid carries about 40% (more than 2.5 times that of the PP grid).



(Load is given as % of QC strength)

Figure 5 Isochronous load-strain curves for both the PP and HDPE geogrids

The graphs on Figure 5 also show typical QC test results, which are similar for both geogrids, with the PP geogrid having slightly lower strain at failure.

Ultimate long term design strength of a polymer geogrid under long term loading (P_c) may be defined as the load resulting in 10% strain (more recently ultimate load has been defined by a number of authorities as the load which causes rupture). The isochronous load strain curves in Figure 5 may be used to find the load which results in 10% strain for a variety of durations of loading. This data can be replotted as load to reach 10% strain versus time. This is shown for both the PP and HDPE geogrids on Figure 6. Comparison between the two curves shows a very major difference in performance of these two types of reinforcement. Generally for reinforced soil structures, design lifetime is in the order of 60 to 120 years. An optimistic extrapolation of the PP geogrid data indicates a 120 year (slightly more than 10^6 hours) ultimate long term strength of about 12% of QC strength.

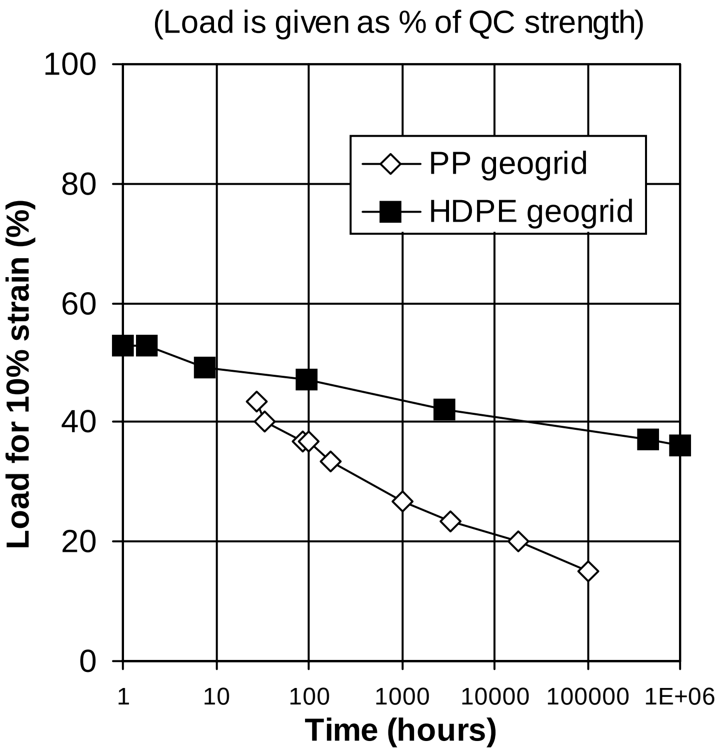


Figure 6 Load resulting in 10% strain versus time

Based on the creep testing, and other tests carried out on these two geogrids, the following summary can be made:

Property	**HDPE geogrid**	**PP geogrid***	**GB/T 17689-1999 requirements**
Unit weight (kg/m^2)	0.29	0.8 (approx)	0.55 ± 0.05
Carbon black (%)	> 2.0	0.35	Not required
QC strength (kN/m)	52.5	> 50	>50
Long term strength (kN/m)	20.7	6.0	Not required

* testing carried out on lower grade: weight and strength values extrapolated

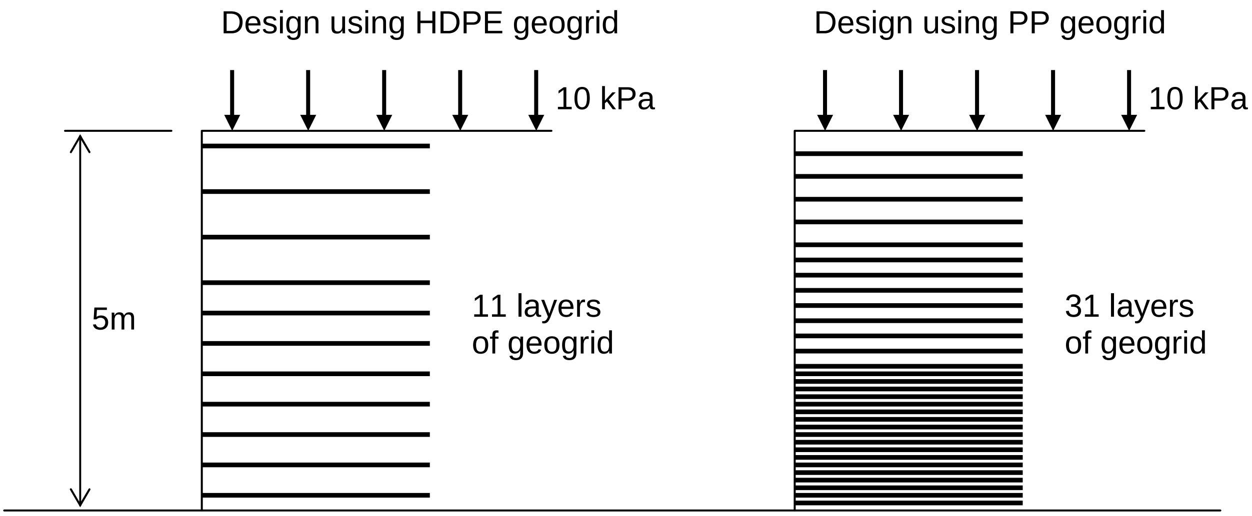


Figure 7 Design of 5m high retaining wall comparing HDPE and PP geogrids

In order to examine the effect on design of a reinforced soil structure, a 5m high retaining wall has been designed using a sand backfill with a 10 kPa surcharge. Designs have been carried out using both the HDPE and the PP geogrids with QC strength of 50 kN/m (properties taken from the table above). The resulting geogrid layouts are shown on Figure 7. It can be seen that the PP geogrid design has 31 layers of geogrid, almost three times as many as the HDPE geogrid design. This has occurred because the long term design strength of the HDPE geogrid is more than 3 times higher than the PP geogrid.

For a designer using Chinese standard GB/T 17689-1999 as a guideline, it might be thought that both HDPE and PP geogrids with QC strengths of 50 kN/m could be considered equivalent, and therefore give similar designs. The example given above, based on actual test data, shows that this is far from the case, and that substitution of a PP geogrid into a design based on the properties of an HDPE geogrid would result in an unsafe condition.

CASE HISTORY (2) - COMPARING TWO REINFORCING MATERIALS MANUFACTURED FROM HDPE

In order to investigate the possible differences between two reinforcing materials both manufactured from HDPE, creep test data is presented below for:

- HDPE uniaxial geogrid developed in UK in the mid 1980's (Geogrid A)
- HDPE uniaxial geogrid manufactured in China in 2001 (Geogrid B)

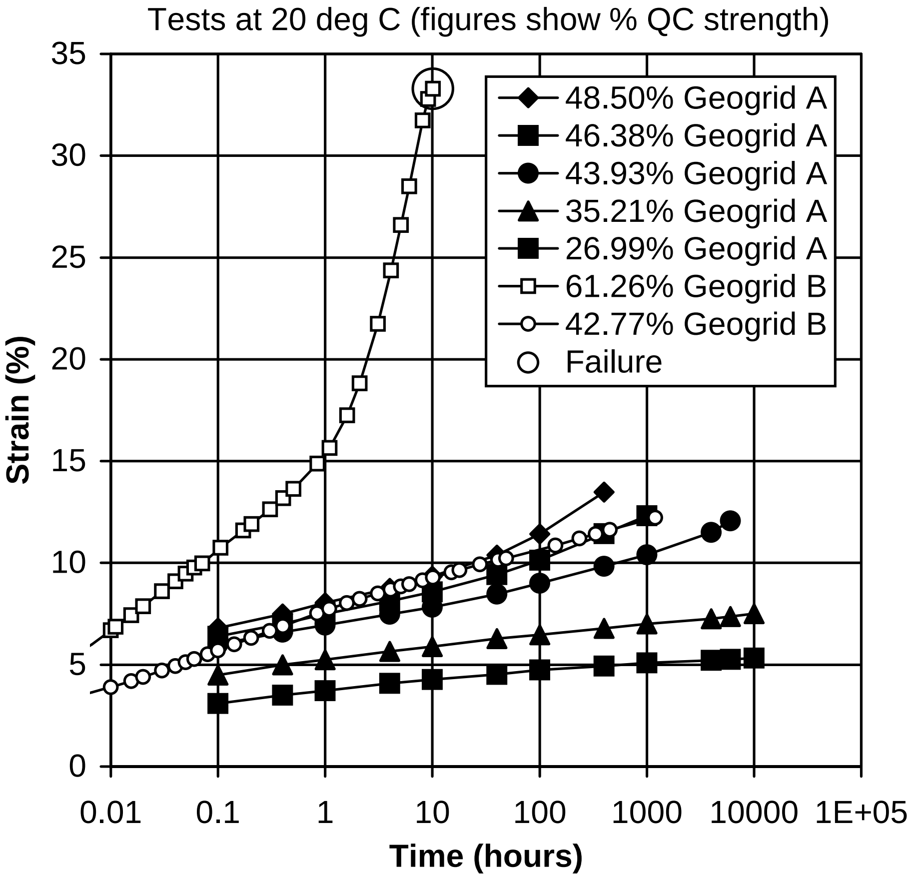


Figure 8 Creep test results for Geogrids A and B

Figure 8 shows the results of creep tests carried out on these two geogrids. The testing on Geogrid A has been used to derive a long term strength (P_c) of 29.4 kN/m at 20°C and 120 years. For Geogrid B, creep testing has only been started recently, so durations are still very short. However it can be seen on Figure 8 that the strain-time behaviour for Geogrid A at *46.38%* QC strength is very close to that for Geogrid B at 42.77% QC strength. By comparing the actual loads used for these two tests, the long term design strength for Geogrid B (P_c) can be estimated as *26.4* kN/m.

Based on this creep testing, and other tests carried out on these two geogrids, the following summary can be made:

Property	**Geogrid A**	**Geogrid B**	**GB/T 17689-1999 requirements**
Unit weight (kg/m^2)	0.7	1.35	0.7 ± 0.05
Carbon black (%)	> 2.0	0.75	Not required
QC strength (kN/m)	81.5	79.5 *	>80
Long term strength (kN/m)	29.4	*26.4* [#]	Not required

* testing carried out to GRI GG1 as per GB/T 17689-1999 requirements. Geogrid A was tested to ISO 10319. Due to differences in rate of loading, QC strength of the two geogrids measured using the same test method would be almost identical.

[#] *adjusted since initial publication taking into account latest test data (see Figure 8)*

Based on these results, it can be seen that Geogrid B is almost twice as heavy as Geogrid A, yet its design strength is about *10%* less. This difference is not as dramatic as the previous case history comparing HDPE and PP geogrids, but it is still significant. These results demonstrate that, for geogrids of similar polymer and QC strength, fundamental design parameters such as long term design strength can vary significantly.

DISCUSSION CONCERNING SOIL REINFORCEMENT SPECIFICATION AND DESIGN PARAMETERS

Development and subsequent manufacture of a soil reinforcement material follows a general procedure outlined in Figure 9 below.

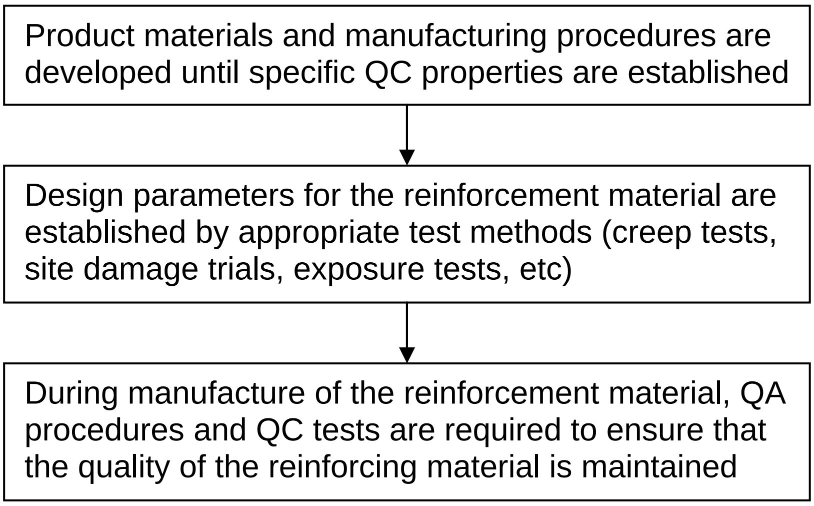


Figure 9 Development and manufacture of a soil reinforcement material

Generally design parameters are established in the early stages of development of a particular reinforcement material, once the basic QC properties are known. Testing to measure design parameters is therefore only carried out once, on samples of known QC properties. During future manufacture, the QC properties are measured and checked for each project or batch of material to ensure that the correct qualities are being achieved.

Chinese standard GB/T 17689-1999 only provides a partial list of QC properties. Although these are important, they must be related to design parameters. As has been shown above, materials of similar QC strength can have completely different long term design strengths. Therefore the Chinese standard does not provide any guidance to a designer on appropriate parameters to use in design.

To help a designer, a national standard or procedure should establish the parameters required for design and the appropriate test methods to be used. At the same time it should stipulate the QC properties required. For any particular product a full set of this data should be established, which can then be published in the form of an approval certificate or specification. Such a system has been in use for more than 10 years in Hong Kong SAR, where the Geotechnical Engineering Office of the Government Civil Engineering Department has established procedures for assessing reinforcement materials and awarding approval certificates. The design parameters given in the certificates are linked to specific design methods, so that the designer is given full guidance to both design parameters and calculation procedures.

CONCLUSIONS

(1) Quality control tests are important as part of the manufacturing quality assurance procedures for soil reinforcement materials, but they do not provide parameters for designing structures.

(2) Chinese standard GB/T 17689-1999 only provides a partial list of QC properties for soil reinforcement materials, and does not give any design parameters.

(3) For long term soil reinforcement applications where design life could be 60 to 120 years, HDPE has far better creep behaviour than polypropylene. This difference in behaviour cannot be established by QC tests such as tensile strength.

(4) Materials of similar quality control properties and the same polymer type can have significantly different design parameters. Therefore quality control properties alone cannot be used as a way of comparing different soil reinforcement materials (manufactured from the same polymer type) to establish “equivalence”.

(5) In order to provide designers with adequate design data, national standards or procedures should include both QC testing and measurement of design parameters. The two should be linked together, and a procedure established for issuing approval certificates which give a comprehensive list of all relevant data. The relationship between QC properties and design parameters is product specific, so these certificates should be issued for each manufacturer’s products or series of products.

(6) The carbon black content of a variety of HDPE and PP geogrids manufactured in China has been measured well below 1%. At these low levels the materials appear black, but protection from the effects of UV light is minimal. For these materials it will be important to protect them from UV light during transport and handling, and limit the duration of exposure to sunlight during installation and subsequent use.

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APPENDIX A

SUGGESTIONS FOLLOWING DISCUSSION AT SHANGHAI SEMINAR IN JUNE 2001

Following the discussions at the Shanghai Seminar, the CCIGS proposed to set up several committees to look into the testing and specification aspects of various different geosynthetic functions. This Appendix summarises various ideas and suggestions, mainly for the reinforcement function of geosynthetics.

(1) Suitable test procedures exist in Chinese codes to measure most of the required reinforcement design parameters. The National Standards are based on ISO (GB/T series), whereas other institutes use ASTM (Hydraulics Institute SL/T series). It would make sense to standardise following ISO standards as much as possible.

(2) Currently, the QC tensile test is the single rib test, and Chinese laboratories have experience carrying out this test. Wide width testing (ISO 10319) requires more sophisticated clamping techniques, and could be difficult to introduce. It is suggested that the single rib test should be retained, but that the rate of extension should be fixed at 20% per minute (same as ISO 10319). Therefore the procedure would be summarised as follows:

Tensile test method	***Specimen width***	***Number of specimens***	***Rate of loading***
Single rib tensile test	*1 rib*	*10*	*20%/min*

(3) It is necessary that a National Guideline is published which gives the important QC and design parameters which must be stated in product specification sheets or approval certificates.

(4) The National Guideline should include default values of all design parameters, as a guide to designers, in the case that a product does not have a specification sheet or approval certificate. Suitable default values are summarised below for three classes of geogrid: HDPE extruded/strectched, Polypropylene (PP) extruded/stretched and polyester (PET) woven/coated.

Design parameters		***Geogrid type***		
		HDPE	***PP***	***PET***
QC strength T_{ult}		*Measured using the single rib test procedure*		
RF_{CR}		*3.5*	*8.0*	*2.0*
f_m		*1.2*	*1.2*	*1.2*
f_d	*coarse (>75mm)*	*1.4*	*1.4*	*1.6*
	medium (<75mm)	*1.25*	*1.25*	*1.4*
	Fine (sand/silt/clay)	*1.1*	*1.1*	*1.2*
f_e	*aggressive (high/low pH)*	*1.1*	*1.2*	*2.0*
	Neutral	*1.0*	*1.05*	*1.5*
α_s	*coarse (gravels)*	*0.95*	*0.95*	*0.95*
	medium (sand)	*0.8*	*0.8*	*0.8*
	fine (silt/clay)	*0.6*	*0.6*	*0.6*
α_p	*coarse (gravels)*	*0.95*	*0.95*	*0.95*
	medium (sand)	*0.8*	*0.8*	*0.8*
	fine (silt/clay)	*0.6*	*0.6*	*0.6*

With reference to the third section of the paper, this data allows all required design parameters to be calculated using the following expressions:

***Long term design strength** of soil reinforcement material is defined by the expression:*

$$P_{des} = \frac{T_{ult}}{RF_{CR} f_m f_d f_e f_j LF}$$

***Friction coefficient for sliding** = $\alpha_s \tan\phi'$*

***Friction coefficient for pullout** = $\alpha_p \tan\phi'$*

It would not be possible to give default values for f_j as this would depend very much on the form of the geogrid reinforcement.

The Guideline should require that these default values are to be used for design, unless suitable testing has been carried out for a specific product to measure the appropriate values. This will have the effect of encouraging manufacturers to carry out the required testing, as the measured values will generally result in higher design strength than the default values, which are considered to be lower bound.

(5) It is important that design calculations are carried out at an early stage in the process of developing the National Guideline to establish which of the design parameters are the most important (ie. give the largest variation in the final design of a typical structure). This will help the authors of the guideline, manufacturers and test institutes to concentrate on the tests which are most relevant. These are likely to be:

- *Creep testing*
- *Site damage in coarse soils*
- *Durability in alkaline conditions (PET only)*
- *Sliding interaction*

(6) The National Guideline should list the quality control (QC) properties to be published in product specification sheets or approval certificates:

- *Tensile (QC) strength according to the single rib method*
- *Loads at 2% and 5% strain from the QC test*
- *Strain at maximum load in the QC test*
- *Basic dimensions (aperture size, rib and node thickness, rib width)*
- *Unit weight*
- *Roll dimensions and weight*
- *Polymer type*
- *Carbon black content*