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DESIGN PARAMETERS FOR SOIL STRUCTURES REINFORCED WITH POLYMER GEOGRIDS

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1.0 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 require suitable design parameters for these products to ensure that designs are not only cost effective, but also safe.

This paper outlines the principal parameters required for design, and relates them to appropriate test methods. The paper follows on from discussions held at the 1st Nationwide Seminar on Geosynthetics Testing Technology in Shanghai in June 2001, and reference is made to a paper published there, Dobie (2001). The Shanghai Seminar was an important event, helping to define ideas and aims for the specification and testing of geosynthetics in China. This paper concludes by proposing elements of a possible National Design Guideline, and reference is made to current developments in Hong Kong.

2.0 DESIGN PARAMETERS

When designing a reinforced soil structure, a designer requires certain parameters, which must be derived from the results of appropriate testing. Chinese Test Standard for Geosynthetics (Plastic Geogrid) GB/T 17689-1999 gives 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.

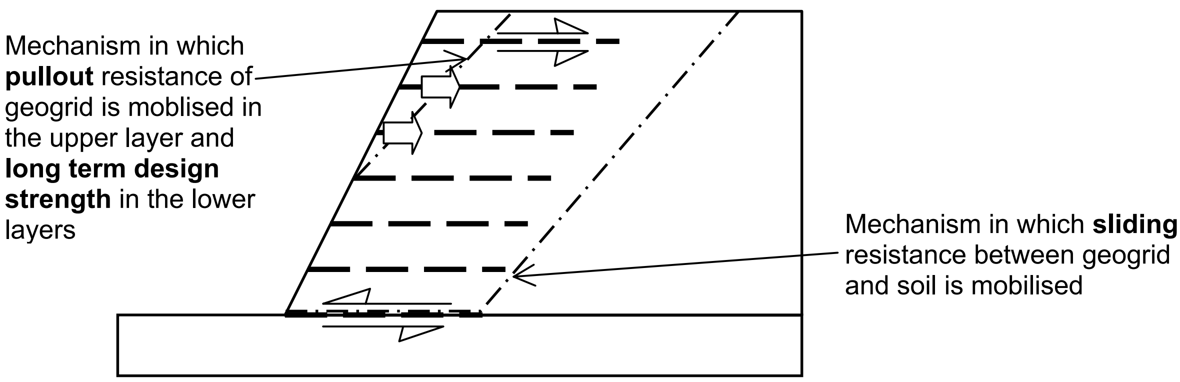

Figure 1 Failure mechanisms in reinforced soil structures

For design of reinforced soil structures various mechanisms must be checked which involve the properties of the reinforcing material. These are summarised on Figure 1. The principal parameters required are:

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

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, and they are listed in Appendix A at the end of the paper. Of the various tests required, 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 2). 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.

Design strength may also be related to quality control (QC) tensile strength by the following expression:

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

where T_{ult} = quality control (QC) tensile strength
RF_{CR} = creep reduction factor

This appears to suggest that creep testing is not required, because P_c is absent. However to find the value of the creep reduction factor RF_{CR}, it is necessary to carry out creep testing, then calculate RF_{CR} from the expression:

$$RF_{CR} = \frac{T_{ult}}{P_c}$$

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.

Figure 2 Creep test laboratory

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 1, lower mechanism). Pullout only effects the calculation of anchorage length, and is only critical near the top of a structure.

3.0 EXAMPLE OF USING DESIGN PARAMETERS FOR HDPE AND PP GEOGRIDS

Chinese Test Standard for Geosynthetics (Plastic Geogrid) GB/T 17689-1999 includes both high density polyethylene (HDPE) and polypropylene (PP) uniaxial geogrids. This type of geogrid is used to construct reinforced soil structures such as retaining walls and bridge abutments, where long term performance is very important. Tests were carried out on samples of geogrid manufactured from both HDPE and PP. Data derived from the creep test results is summarised in Figure 3, which shows the time to reach 10% strain at various different loads (10% strain is sometimes used as criterion to determine the long term design strength of polymer geogrids).

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 (this is the same as RF_{CR} = 8.3).

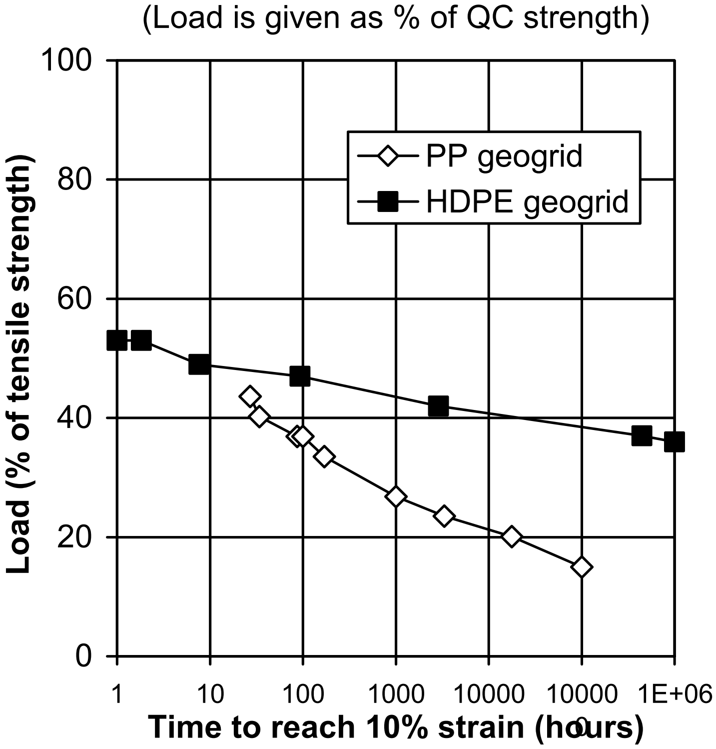

Figure 3 Load resulting in 10% strain versus time

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/m²)	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

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 4. 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.

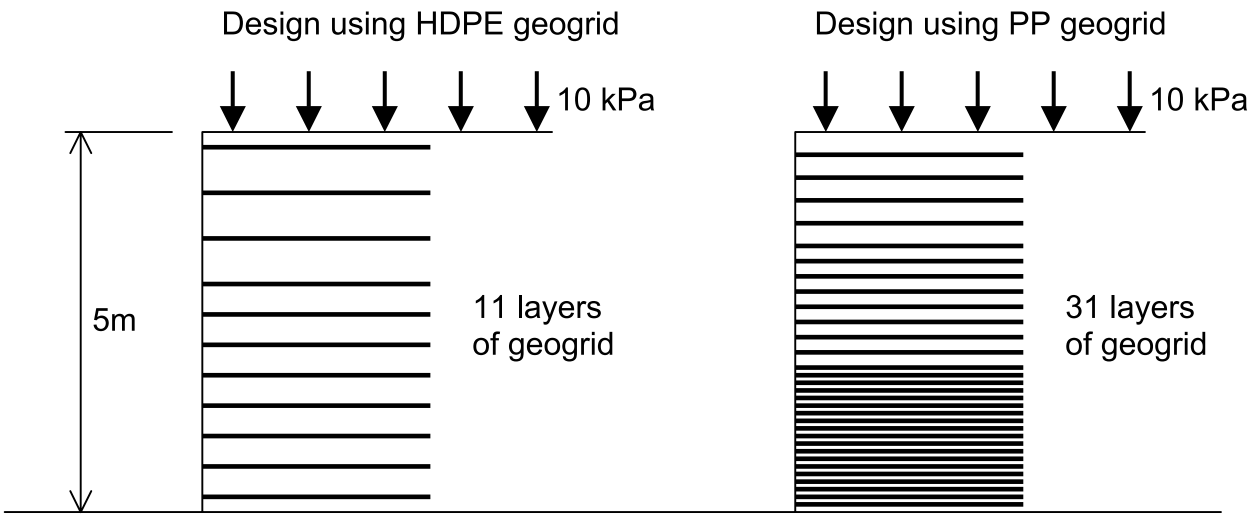

Figure 4 Design of 5m high retaining wall comparing HDPE and PP geogrids

4.0 PROPOSED ACTION

Following discussions held at the 1st Nationwide Seminar on Geosynthetics Testing Technology in Shanghai in June 2001, it was decided that CCIGS would set up committees to look into specification and testing of geosynthetics. One of the proposed committees would look at soil reinforcement, aimed at developing better guidelines and specifications than currently exist. It was acknowledged that design should be taken into account in doing this, because the design process determines which parameters are likely to be most important. This process could lead to the publication of a National Design Guideline.

Appendix A attached to this paper summarises some ideas in relation to definition of design parameters and appropriate testing, which could be considered by this committee. One concern mentioned at the Shanghai Seminar was the lack of appropriate testing being carried out by many local manufacturers in China. One proposal in Appendix A is to include a default list of design parameters in the Guideline which a designer could use to make a reinforced soil design, when the only available information is single rib tensile (QC) strength. The default values are realistic, but on the conservative side. The only way a manufacturer could use and publish better data would be to carry out appropriate independently verified testing.

For any particular product a full or partial set of this data should be established, which could 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 (GEO) 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. GEO is in the process of finalising Geoguide 6, which will provide comprehensive and up-to-date guidance to reinforced fill design.

5.0 CONCLUSIONS

(1) Parameters required for design of reinforced soil structures are well established, and can only be determined by carrying our appropriate testing.

(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, and shows the importance of identifying polymer type when assessing design strength.

(4) 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.

REFERENCES

BSI (1995) BS 8006:1995. *Code of practice for strengthened/reinforced soils and other fills*. British Standards Institution, London.

BSI (1978) BS 2782:Part 4:Method 452B:1978. *Determination of carbon black content of polyolefin compound*. British Standards Institution, London.

BSI (1995) BS 1377:Part 7:1995. *Methods of test for soil for civil engineering purposes*. British Standards Institution, London.

Chinese Test Standard for Geosynthetics (1999) GB/T 17689-1999. *Plastic Geogrid*. China.

GEO (2002). *Reinforced fill product certificate No RF 1/02*. Geotechnical Engineering Office, Civil Engineering Department, Government of Hong Kong SAR.

GEO (2002) Draft. *Geoguide 6, Guide to Reinforced Fill Structure and Slope Design*. Geotechnical Engineering Office, Civil Engineering Department, Government of Hong Kong SAR.

Dobie, M J D (2001). *Testing and Specification of HDPE and Polypropylene Geogrids for Reinforced Soil Structures.* 1st Nationwide Seminar on Geosynthetics Testing Technology, Shanghai, China.

GRI (1987) GRI GG1-87. *Geogrid rib strength*. Geosynthetics Research Institute, USA.

GRI (1990) GRI GG5-90. *Geogrid pullout behaviour*. Geosynthetics Research Institute, USA.

ISO (1999) BS EN ISO 13431:1999. *Geotextiles and related products - determination of tensile creep and creep rupture behaviour*. International Organisation for Standardisation.

ISO (2000) DD EN ISO 13438:2000. *Geotextiles and related products – screening test method for determining the resistance to oxidation, Method B*. International Organisation for Standardisation.

ISO (1996) BS EN ISO 10319:1996. *Geotextiles - Wide-width tensile test*. International Organisation for Standardisation.

ISO (1996) BS EN ISO 10321:1996. *Geotextiles - tensile test for joints/seams by wide-width method*. International Organisation for Standardisation.

ISO (1994) BS EN ISO 9000 series. *Quality systems*. International Organisation for Standardisation.

APPENDIX A

SUGGESTIONS BASED ON DISCUSSIONS AT SHANGHAI SEMINAR IN JUNE 2001

Following the 2001 Shanghai Seminar on Specification and Testing of Geosynthetics, 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 (see below). 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.

Design feature	Parameter	Testing required	Test method	Chinese 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
Connect-ion	f_j	Connection testing	ISO 10321 NCMA Manual	
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	

(2) Currently, the Quality Control 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 for the time being 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/stretched, 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}		4.0	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 this 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
- Resistance to oxidation
- 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 quality control (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

Reinforcement property	**Test method**	**Comments**
Tensile strength	Single rib 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, and should be well dispersed.