Geosynthetic interface shear resistance testing

LANDFILL GUIDANCE GROUP
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1. Introduction

Current guidance and advice concerning geosynthetic interface shear resistance testing is provided within the Industry Code of Practice 'Earthworks in landfill engineering' (Ref. 1) and Environment Agency R&D Report P1-385/TR1 (Ref. 2) together with approved CQA plans. The existing test (BSEN ISO 12957-1 Geosynthetics - Determination of Friction Characteristics - Part 1: Direct shear test) provides an index test method to enable the comparison of different materials against a standard sand. BS 13493 also states that site specific testing should be carried out to establish the friction characteristics between all the materials used.

Appendix A provides guidance on the testing procedure. The proposed testing methodology modifies BSEN ISO 12957-1.

The aim of this code of practice is to provide guidance on the method of testing, testing frequency and the interpretation of the results for design purposes for both geosynthetic/geosynthetic and geosynthetic/soil interfaces.

2. General

Operators must use the services of a suitably experienced civil or geotechnical engineer or an engineering geologist to carry out the liner design.

Your design engineer must revisit the liner Stability Risk Assessment (SRA) using interface shear parameters obtained from laboratory testing on the materials chosen for the contract to demonstrate the robustness of the liner design.

You should discuss your proposals with the Environment Agency before you start any construction works on your landfill.

Geosynthetics supplied to site must have a CE marking.

3. Testing frequency

The minimum frequency of tests should comply with Table 1. Some geomembranes are more variable than others and this should be taken into account when deciding the number of tests to be carried out.

Whilst this does not guarantee the interface shear strength between different products it should reduce the variability. Therefore, the number of tests to be carried out between a geosynthetic and geosynthetic should as a minimum be 1 test for every 10,000m^2 for each interface.

Consideration must also be given to the internal shear strength of geosynthetics that are composite structures, such as GCLs and geodrains.

The testing frequency must reflect the confidence in the interface shear strengths used in the analysis. It is necessary to establish how the design interface shear parameters have been obtained.

A. Are they derived from published sources of generic values for the geosynthetics e.g. EA report TR1 (Ref. 2)?
B. Are they derived from unpublished generic values for the geosynthetics in the designer's database?
C. Are they derived from test values in the particular manufacturer's database for similar geosynthetics?
D. Are they based on test values from previous works on the site for similar geosynthetics from a different manufacturer?
E. Are they based on test values (at least 4 sets) from previous works on the site for the particular geosynthetics from the same manufacturers?

The actual Factor of Safety (FS) chosen will depend upon several factors including consequences of the failure (risks to people, environment, infrastructure, etc.) and the ease of repair (cost, accessibility, availability of materials, timescale, etc.).

The actual FS used in the design must be justified in the SRA. The test frequencies in Table 1 are considered to be a minimum.

Table 1: Risk hierarchy for deciding test frequency

Source of strength data	FS on an interface Analyses based on peak strengths	Number of test sets required per 10,000 m^2 of interface
A or B		4
C or D	FS ≥ 1.75	1
	FS up to 1.75	2
	FS < 1.50	4
E	FS ≥ 1.40	1
	FS < 1.40	2

The FS in Table 1 is the critical Factor of Safety based on worst credible interface shear strength and water/gas pressures as discussed/justified in the SRA.

4. Water pressures (Test/Analysis)

The water pressures in the veneer analysis are commonly expressed as a Parallel Submergence Ratio, PSR where

PSR = perpendicular height of water above the geotextiles / perpendicular height of soil above the geotextiles

= hwater/hsoil = 0 for dry conditions
= 1 for saturated soil

The permeability of the cover soils requires consideration. Where no geosynthetic drainage is used below cohesive cover soils then it is recommended that the minimum PSR considered should be 0.5 (note that higher PSR values may be appropriate in certain cases). Where geosynthetic drainage is used below cohesive cover soils then it is recommended that the minimum PSR considered should be 0.05 (note that higher PSR values may be appropriate in certain cases). However, care must be exercised when using geosynthetic drainage beneath the cover soils in a cap veneer. There is evidence that whilst geosynthetic drainage can reduce the water pressures at the cover soil/drain interface, substantial water pressures can still remain in the cover soils above the geosynthetic drainage depending on the permeability of the cover soils.

PSR can be reduced only if geocomposite drain is providing sufficient flow capacity in long and cross direction. The analysis must ensure that correct platens were used for the standard geocomposite in-plane flow capacity test (BS EN ISO 12958:2010) as this can significantly affect the performance. The analysis should demonstrate that geocomposite will provide sufficient flow capacity to ensure slope stability during construction and for the lifetime of the site. Therefore, adequate long term reduction factors must be considered.

The analysis must consider this water pressure and any gas pressures that exist and consider their effects on possible slip surfaces located in the cover soils above a geosynthetic.

5. Use of the laboratory results in veneer analysis/CQA

In order to assess whether the laboratory results are compliant with the design, the shear strength of each interface, based on the design values derived from the laboratory results, is calculated and compared with the required shear strengths from the design/analysis.

A single laboratory test suite cannot be used without modification to give the characteristic strength and hence the design strength.

Where the resultant factor of safety is less than that considered acceptable within the SRA you should discuss the results with the Environment Agency.

The following are suggested methods of deriving the characteristic strength parameters (BS material design strength parameters) from the laboratory quoted values of interface shear strength parameters.

Test Suites carried out ≤ 2

The Designers Guide to EN1997-1 (Ref. 3) provides guidance in Example 2.1 (page 41) on the selection of characteristic values of parameters from test results of local samples ie:

$$\tan\delta'_k = \tan\delta'_{Lab,\ mean}\,(1 - k_n V_{\tan\delta'})$$

where: $\tan\delta'_k$ = the characteristic value of $\tan\delta'$
$\tan\delta'_{Lab,\ mean}$ = the mean of the laboratory measured values of $\tan\delta'$
$V_{\tan\delta'}$ = the coefficient of variation of the derived values
k_n = a statistical coefficient which depends on the number of test suites carried out.

Similarly:

$$\alpha'_k = \alpha'_{Lab,\ mean}\,(1 - k_n V_{\alpha'})$$

Schneider (Ref. 4) recommends average values for the coefficient of variation of the effective shear strength parameters for SOILS of:

- 0.4 for $V_{c'}$ and 0.1 for $V_{\tan\varphi}$'

Assuming that similar values apply to geosynthetics would give:

- 0.4 for $V_{\alpha'}$ and
- 0.1 for $V_{\tan\delta}$'

Assuming that k_n = 1.2 (for test suites ≤2) then applying the above equations gives:

EC7 $\tan\delta'_k$ = BS material $\tan\delta'_{design} = 0.88(\tan\delta'_{lab\ mean})$ and

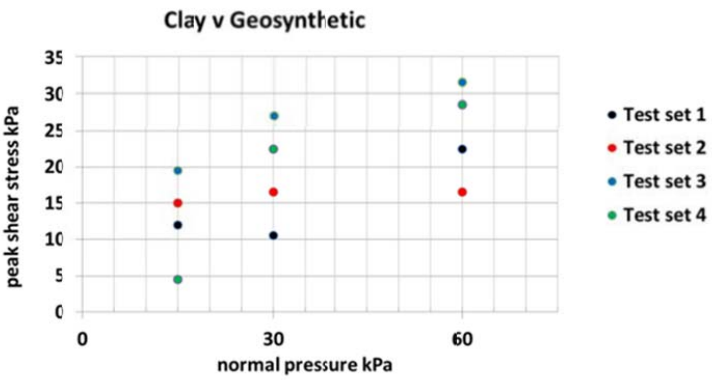
EC7 α'_k = BS material $\alpha'_{design} = 0.52(\alpha'_{lab\ mean})$

These are the values to use in the software to decide whether or not the required shear strength is available on the interface being analysed and hence whether or not the material has met the specification

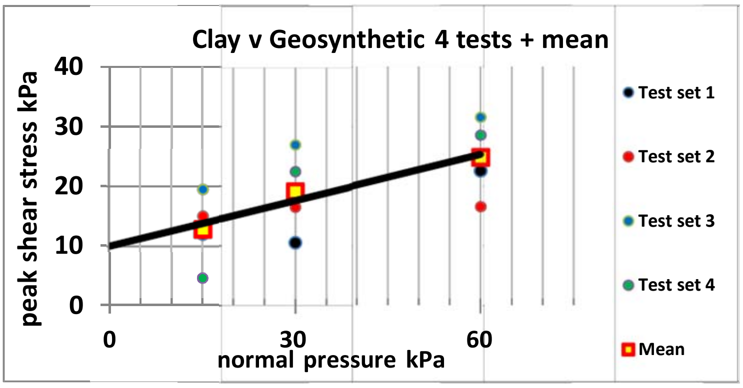
Test Suites carried out > 2

For the method see Reference 4.

The results of shear stress versus normal pressure are plotted. A typical suite of tests could give the following results:

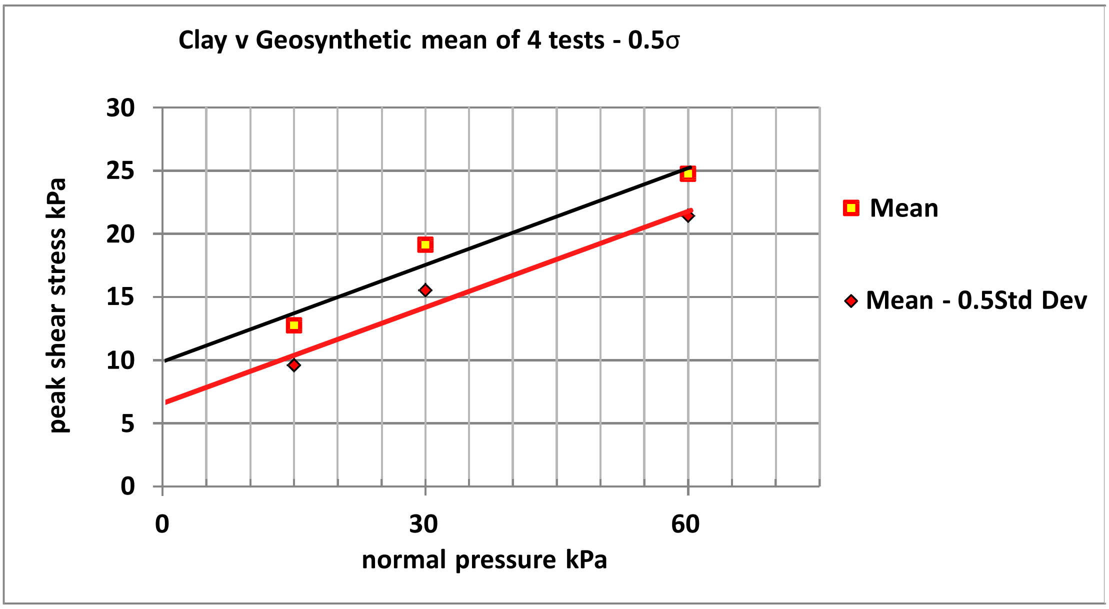


For a number of suites of tests, plot the mean at each normal pressure:



For a number of suites of tests plot the mean at each normal pressure – 0.5σ

Where σ = standard deviation



For the above example the characteristic interface shear parameters are therefore

α_k= 6.6 kPa and δ_k = 14.2^o

12. References

1. Industry Code of Practice, 2012, LFE4/LGG104 -Earthworks in landfill engineering[1]

2. Jones, D.R.V. and Dixon, N. (2003) Stability of Landfill Lining Systems: Environment Agency Report No. 1, Literature Review R&D Technical Report, P1-385/TR1

3. Frank et al, The Designers Guide to EN1997-1. Eurocode 7: Geotechnical Design – General Rules: Thomas Telford, London: 2004: pp41 - 51

4. Schneider H. R. Definition and determination of characteristic soil properties. Proceedings of the 14th International Conference on Soil Mechanics and Geotechnical Engineering, Hamburg, 1997, 4, 2271 – 2274

5. ASTM D5321/D5321M-13 Standard Test Method for Determining the Shear Strength of Soil-Geosynthetic and Geosynthetic-Geosynthetic Interfaces by Direct Shear

6. BSEN 12957-1 Geosynthetics- Determination of Friction Characteristics - Part 1: Direct shear test.

[1] Note that guidance document LFE4 was produced by the Environment Agency and has now been withdrawn. An Industry Code of Practice (LGG104) to supersede LFE4 is being finalised at the time of writing.

Industry Code of Practice

Geosynthetic Interface Shear Resistance Testing

Appendix A - Shear Box Tests with Geosynthetics

Test Procedure - Guidance

1. General

The test shall be carried out in accordance with EN ISO 12957-1 modified as necessary by this document.

This document needs to be read in conjunction with EN ISO 12957-1. Sample/specimen preparation shall be carried out in accordance with BS 1377.

2. Parameters

	Parameters	Units
σ	Normal stress	kN/m^2
τ	Frictional stress	kN/m^2
d_r	displacement rate or displacement velocity	mm/h
t_f	total estimated elapsed time to failure	minutes
t_{50}	time required for the specimen to achieve 50% consolidation under the specified normal stress	minutes
t_{90}	time required for the specimen to achieve 90% consolidation under the specified normal stress	minutes
d_f	estimated horizontal displacement at failure	mm

3. Sampling, labelling and required documents

3.1. Sampling

- Taken from geosynthetic products and soils which are designed/used for the project;
- Representative samples (free of contamination, surface changes or other damages);

- Size of the geosynthetic specimens for 3 tests: length (in down slope direction) 3 x 50 cm, width 40cm;
- Sample volume of the soil: approximately 50kg (for test devices with a 0.30m x 0.30m shear box) although this will depend on the height of the soil within the shear box. The volume of soils required for each individual test should be agreed with the laboratory;
- The number of specimens depends on the amount of tests and has to be agreed. For each shear test a new specimen should be used;
- EN ISO 9862 provides a geosynthetics sampling protocol.

3.2. Sample Identification & Labelling

The sample identification shall include:

i. Site name;

ii. Sample ID;

iii. Roll identification number;

iv. Date sampled;

v. The annotation on the sample of machine direction and cross machine direction;

vi. The orientation and way-up during installation;

3.3. Additional documents required by the laboratory

- For geosynthetics the technical data sheet, the date of manufacture of the sample and the roll numbers must be provided;
- For soil samples, the particle size distribution (d_{85}), the allowable range of the proctor density and for cohesive soils, the soil conditions, the allowable range of moisture content and the Liquid and Plastic Limits.
- Test schedule (as required by the Construction Quality Assurance (CQA) Plan) providing instructions on the test including the layers of geosynthetics and clay preparation and test rate, as appropriate.

4. Laboratory pre-test checks and testing device

4.1. Pre-test checks

The testing laboratory shall allow in their rates for:

- In the case of geosynthetics: inspecting visually each sample on arrival for damages, imperfections and other irregularities.
- In the case of geotextiles: additionally determining the sample thickness and the mass per unit area and comparing the results with the information given on the product data sheet.
- In the case of soils: visually checking that the soil description matches the sample delivered.

4.2. Testing device

The following information for the shear box test device must be documented:

- Shear box device: Preferably shear box devices with a moveable upper framework and a nominal shear/contact area of 900 cm^2 should be used (shear box device see DIN 18137-3 and BS EN ISO 12957-1).

  Fixed head machines are in use, however, and they are accepted although it is acknowledged that a moveable framework will give more realistic results.
- Displacement velocity: varies from 0.3 to 300 mm/h (see Section 8).
- Normal stress : Range from 10 to 500 kN/m^2 but;

  A normal stress range which covers the project conditions must be used

  A normal stress below 10 kN/m^2 can result in unrealistic shear values

  A normal stress of 20 kN/m^2 represents approximately a 1m thick soil layer, two additional higher normal loads have to be tested, and usually 40 and 60 kN/m^2 are taken into consideration for capping.

  The device should be able to provide a constant normal stress reading.

5. Sample/specimen preparation, specimen installation and fixing

5.1. Fixing of the geosynthetic specimen to the lower box

The lower box is, corresponding to the designated shear plane, filled with plates until the plates or the nail plate is on a level with the edge of the box unless, exceptionally, a soil is used as the lower shear plane when it is evenly installed with a thickness of at least 50mm.

If a nonwoven geotextile or a geomembrane is used as the lower shear plane this material is fixed to the lower shear box.

The geosynthetic specimen must be clamped at the "pull-out side" of the lower box by means of a terminal strip.

- Furthermore an additional planar fixing on the stiff base is recommended, so that strains within the specimen during the mobilisation of shearing resistance are minimised.
- The fixing materials must not influence the properties of the tested side of the geosynthetic.

A two-dimensional fixation is recommended for the following materials:

Geomembranes:	Assembly on an elastomer plate (thickness: 2 to 5 mm) which is fixed on a bearing plate between the specimen and stiff base.
Geosynthetic clay liner: stiff	Assembly on a nail plate between the specimen and base. Note - nail point excess length < half the specimen thickness in the loaded condition.
Geosynthetic drain/nonwovens:	For mechanically bonded and thermally bonded nonwovens: fixation with double-faced adhesive tape placed on the stiff base, or other acceptable adhesive. For geosynthetic drain: fixation with a nail plate, a friction sheet plate, a rough emery paper plate or similar. Note: nail point/ roughness elements < half the specimen thickness in loaded condition.

5.2 Fixing of the geosynthetic specimen to the upper box

The specimen must be placed in the upper box in such a way that it lies flush on the bottom.

The material has to be installed according to the layer system intended for construction. Should no information for this be available a layer of BS EN ISO 12957-1 standard sand has to be installed in the upper box above the specimen or a friction plate has to be laid in (see below):

The specimen must be clamped at the “pull-out side” of the upper box by means of a terminal strip. If a soil is placed above the specimen no other clamping is possible. Alternatively a specimen can be fixed two-dimensionally, so that tensile strains within the specimen during the mobilisation of shearing resistance are minimised. The fixing materials must not influence the properties of the tested side of the geosynthetic. Typically these would be:

For mechanically or thermally bonded nonwovens:	use aluminium oxide abrasive sheet (P80 type in accordance with ISO 6344-2)
For geosynthetic drains:	use Velcro strip placed on a plate or a nail plate. Note - nail point excess length < half the specimen thickness in the loaded condition.
For a geosynthetic clay liner:	use a friction sheet plate or a nail plate Note - nail point excess length < half the specimen thickness in the loaded condition.

5.3. Installation of soils

Sample/specimen preparation shall be carried out in accordance with BS 1377 for soils.

Cohesive soils are compacted in the upper box. The thickness of the soil layer should be at least 50 mm. However, the thickness and hence volume of soils required for each individual test should be agreed with the laboratory.

In order to achieve a steady distribution of the shear stresses in the soil body a plate with teeth or cutting edges has to be placed above the soil to be tested.
The moisture content of the soil shall be determined during specimen preparation. It must approach the upper limit of moisture content as specified by the designer.

The dry density must be specified by the designer.

6. Gap adjustment

The gap is the distance between the top side of the lower specimen and the lower edge of the upper box.

The height of the gap must be adjusted depending on material used.

Where soil is installed in the upper box the gap must be minimised to avoid escape of the soil, whilst not being too small to cause squeezing of the geotextile.

In the case of less compressible geosynthetics in the lower box, with soil in the upper box, it is generally sufficient to adjust the gap width to between 0.5 to 1 mm, after having applied the normal stress.

In the case of less compressible geosynthetics in the lower as well as in the upper box the gap dimensions are achieved by adding the specimen thickness after having applied the normal stress and the gap width of between 0.5 to 1 mm.

In the case of compressible geosynthetics the load dependent squeezing of the geosynthetics has to be considered. The gap width which has to be adjusted is achieved by adding the compacted specimens thickness after having applied the normal stress and the gap width of between 0.5 to 1 mm. In the case of compressible geosynthetics the degree of squeezing under test load has, if necessary, to be determined in advance.

7. Water submergence

The water conditions during the test for example whether the test is to be carried out in dry or flooded conditions must be specified by the designer.

8. Displacement rates

The rate of displacement must be specified by the designer in accordance with the following, and notified to the test house.

8.1 Undrained test (cohesive soil on geosynthetic)

The shear box test cannot be carried under perfect undrained conditions but the following may be used to give an estimate of the undrained interface shear parameters.

Apply the horizontal shear load at a maximum rate of 60 mm/hour (1 mm/minute).

8.2 Drained test (geosynthetic on geosynthetic)

The rate of displacement should be sufficiently slow that insignificant excess pore pressures exist at failure.

In the case of GCL products a preconsolidation time of at least 24 hours under load is required.

In the absence of any material specification, use a maximum displacement rate of 60 mm/hour (1 mm/minute).

8.3 Drained test (cohesive soil on geosynthetic)

Select the appropriate displacement rate so that insignificant excess pore pressures exist at failure.

The following equation shall be used as a guide to determine the estimated minimum time required from the start of the test to failure:

$$t_f = 50t_{50}$$

Where:

t_f = total estimated elapsed time to failure in minutes

t_{50} = time in minutes required for the specimen to achieve 50% consolidation under the specified normal stress

If the square root of time method is used, t_{50} can be calculated using the following expression:

$$t_{50} = t_{90}/4.28$$

Determine the appropriate displacement rate from the following equation:

$$d_r = d_f/t_f$$

Where: d_r = displacement rate in mm/min (adjust pro-rata for rate in mm/h)

d_f = estimated horizontal displacement at failure in mm

t_f = total estimated elapsed time to failure in minutes

The magnitude of the estimated displacement at failure is dependent on many factors. As a guide, use:

- d_f = 12 mm for material that is normally or lightly over-consolidated fine-grained soil
- otherwise use d_f = 5 mm.

8.4 Drained test (cohesionless soil on geosynthetic)

Select the appropriate displacement rate so that insignificant excess pore pressures exist at failure.

Determine the appropriate displacement rate from the following equation:

$$d_r = d_f/t_f$$

- For clean dense sands which drain quickly, a value of 10 minutes may be used for t_f.
- For dense sands with more than 5% fines, a value of 60 minutes may be used for t_f.

If excess pore pressures are not anticipated a displacement rate of 60 mm/hour (1mm/minute) may be used.

9. Documentation

The following information shall be reported:

- Client;
- type and name as well as photographs of the specimens if required before and after the test;
- test device and adjustment of the test system (including schematic diagrams), clearly stating if the device has either a fixed or moveable head;
- test side and test direction, specimen dimensions, as well as specifications such as mass per unit area, thickness, etc.;
- installation process (and fixation) of the geosynthetic specimens;
- installation process and installation parameters of the tested soils as well as information regarding the type of the wall friction reduction;
- gap width;
- consolidation times, normal stresses and displacement rates;
- procedures for measured value acquisition of forces, stresses, displacements and deformations;
- data of the individual shearing stage in a τ-σ diagram including the recording of the chosen failure and/or sliding values, including numerical data for displacement and τ forces;
- failure and/or sliding values including the corresponding limiting conditions for the failure and/or for the sliding state in a τ-σ diagram including the correlation or variation coefficient, respectively;
- peak and large-strain friction angles and adhesions;
- changes of the surface or structure of the geosynthetics, for example material abrasion in the case of geomembranes, rearrangement of fibres in the case of geotextiles and soil residues at the geosynthetic (if required including photographs, see above), sketches or test specimens);
- special supervision during the test process and after the test, for example to displace the sliding surface into the soil; and
- any anomalous or significant behaviour during the test.

For shear tests carried out with soils:

- An enclosure has to be added to the above, which shows photos of the soil and, if available, a corresponding compaction curve.