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## LFE3 - Using geosynthetic clay liners in landfill engineering

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## 1.0 Introduction

This document is aimed at people who design or assess proposals which include a geosynthetic clay liner (GCL) for environmental protection. It aims to provide a clear framework on how to use GCLs. We don't intend this document to be prescriptive, you shouldn't consider it to be a specification for, rather a set of minimum requirements, guidance notes and check lists to assist both you and us. We suggest you use it when preparing your liner design and method statements for submission to us.

Ultimately, it is your responsibility to ensure that your site's design, construction and operation meet our required levels of environmental protection. By granting you an environmental permit and accepting your working plan and method statements, we are not relieving you of this fundamental responsibility. Accordingly, as the permit holder, you must carefully and in detail consider your proposals to ensure your site adheres to the applicable pollution control objectives.

GCLs have become popular in landfill engineering (and other environmental engineering applications) due to their easy installation and the fact they can be self-financing if there is a void space saving. However, these materials are deceptively simple and are not the panacea they appear to be. It is essential you carefully assess any design relying on a GCL, you must also carry out thorough, independent Construction Quality Assurance (CQA) on the GCL's installation. As with any manufactured product, if poorly installed the environmental and economic costs can be significant.

As we set out in our [policy on landfill engineering](#), you must adopt an approach of landfill by design. This involves a site specific design backed up with appropriate technical scientific engineering theory and a quality approach to installing GCLs and other structural elements. Figure 1 outlines some of the advantages and disadvantages of GCLs.

**Figure 1. Advantages and disadvantages of GCLs**

GCLs Advantages	GCLs Disadvantages
<p>a) Void space saving over traditional, more robust systems</p> <p>b) Relatively easy to install</p> <p>c) May self heal minor punctures (&lt; 25mm).</p> <p>d) Ready availability</p> <p>e) GCLs have a range of applications including liner protection and vertical lining as well as capping and basal lining system applications.</p>	<p>a) GCLs are generally 7 - 10mm thick when hydrated, as such they lack robustness and should normally only be used as one element of a lining system. Using stronger geotextiles or geomembranes can increase robustness.</p> <p>b) GCLs may become more permeable when exposed to high concentrations (&gt;70%) of neutral polar organics such as acetone, methanol and glycol, and some organic acids, some strong mineral acids can damage the structure of the clay minerals.</p> <p>c) Permeability may increase over time. Sodium cations in the clay structure may be preferentially exchanged for other ionic species such as calcium.</p> <p>d) Non reinforced GCLs normally have low shear strengths and suffer from clay migration when saturated. Reinforced GCLs will behave similarly if the reinforcing element is damaged by unequal loading.</p>

## 2.0 Material properties

The definition of a geosynthetic clay liner (GCL) we use in this document is a factory-manufactured geosynthetic hydraulic barrier consisting of a layer of clay attached to or sandwiched between geotextiles or geomembranes. We refer to GCLs that are held together by needle punching or sewing (stitching), and thermal bonding to reduce the potential for clay migration, and exhibiting high internal shear strengths are referred to as reinforced GCLs. We refer to GCLs constructed using other methods such as chemical adhesives, exhibit low internal shear strengths and more potential for clay migration when hydrated, as non-reinforced GCLs.

### 2.1 Permeability/flux

GCLs have very different properties from welded flexible membrane liners (FMLs) and compacted clay liners (CCLs). As a result, you will need to carefully consider the system in which you propose to use a GCL. The breakthrough time for reinforced GCLs (that is, the time it will take a wetting front to pass through the unsaturated material) is a matter of days, rather than the 16+ years for a wetting front to pass through a one metre thick clay liner of permeability  $1 \times 10^{-9}$  m/s, under a two metre head (1 m of leachate + 1 m saturated clay).

The cation exchange capacity (CEC) of a GCL is small when compared to a clay liner. In essence, where a barrier is required that requires either an absorptive capacity or a long breakthrough time, a GCL alone will not provide adequate protection. In these circumstances, a design will also need a low permeability attenuation layer. Flux (flow) is a more appropriate unit to measure and compare with other products, rather than permeability or thickness. The thickness of the clay element of a GCL is particularly difficult to measure, and is often assumed. Flux is described in terms of volume per area over time, for example  $\text{m}^3 \text{m}^{-2} \text{y}^{-1}$ . This means a flux value of 1 means one cubic metre of water will pass through one square metre of GCL in a year.

Typically, GCLs are quoted as having permeabilities ranging from  $1 \times 10^{-10}$  to  $1 \times 10^{-12}$  m/s, meaning it takes one second for a molecule of water to travel a distance of  $1 \times 10^{-10}$  to  $1 \times 10^{-12}$  metres. Theoretically, under the same head of liquid it should take the same amount of time for a leachate to pass through a metre thick clay layer with a permeability of  $1 \times 10^{-9}$  m/s as a 10mm thick hydrated GCL of permeability  $1 \times 10^{-11}$  m/s. Once through the 1m clay layer however, the combined head 2 metres (1.0m of leachate + 1.0m of saturated clay) head of flux would be 200 times greater than the GCL. Under a 1 metre head the flux for the GCL would be  $1 \times 10^{-11}$  cu.m/sq.m/sec. (0.315 litre/sq.m/year) and the clay would be  $2 \times 10^{-9}$  cu.m/sq.m./sec. (63.0 litre/sq.m/year). Geomembrane/clay GCLs low flux of  $7 \times 10^{-14}$  is provided primarily by the membrane element but should be modified to take into account flow through minor damage (pin holes) and flow through overlaps of  $5 \times 10^{-11}$  cu.m./sq.m./sec. You must provide calculations of total flow for your design, particularly if groundwater risk assessment calculations are required.

### 2.2 Geotextiles/geomembranes used in GCL manufacture

The purpose of the geotextile or geomembrane component of a GCL is to:

- provide strength
- carry the clay component and prevent its escape and movement in both dry and hydrated state
- provide a suitable medium to enable the needle punching or close stitching of the geotextiles together to restrict the clay's expansion and thereby reducing its permeability and potential to migrate.

Needle punching and stitching are the methods used to help hold the clay in place and increase the GCL's internal shear strength.

You should consider the types of geotextiles/geomembranes used in GCL manufacture in relation to your overall design. Geotextiles are usually made of polypropylene, but you must specify the exact type of fibre (for example, HDPE) in your design. Geotextiles of woven and non woven type can be used in the manufacture of GCLs. Clay particles can leak through some open woven (particularly slit film) and thin non-woven geotextiles, or detach from glued geomembranes. This leakage can increase the permeability of the GCL, decrease the friction between it and adjacent layers, and create blockages in adjacent drainage layers. Geomembranes can be either rough or smooth, and are usually made of polyethylene or polypropylene but again, you must specify the exact type in your design.

You must carry out site and product specific interface shear testing to confirm the suitability of any product regarding slope stability.

The tensile strength of both reinforced and non-reinforced GCLs depends upon the strength of the carrier material. For reinforced GCLs, the internal shear strength is provided by the density of needle punching or stitching. Your design must specify the required strength (including a suitable factor of safety). You must verify this strength in accordance with your CQA plan (see section 6).

Reinforced GCLs contain the clay element and reduce the potential for its migration which may otherwise occur through swelling, point loading or gravitation once hydrated. Unequal loading of both types of GCLs can cause lateral migration of hydrated bentonite into, for instance low pressure zones beneath an FML wrinkle or away from higher loading points

The geotextile must be sufficiently robust to withstand the pressures put on it by clay expansion on saturation. If it's not possible to immediately cover the geotextile with a confining layer you should test the GCL for this property. You must include this in your CQA plan if applicable.

In the past, problems have arisen where stitched seams (associated with the end of one roll and the start of the next) have occurred within a GCL roll. Such seams or joints have torn or 'blown apart' allowing the clay to escape. We therefore recommend that no seams or joints between geotextiles are allowed within a GCL roll.

If however, you can demonstrate that such joints present no threat to the integrity of the GCL either during its manufacture, storage, installation or operational life, we may consider accepting them.

### 2.3 Clay used in GCL manufacture

The clay layer is the only component which serves as a hydraulic barrier in a reinforced GCL (the geotextile makes no contribution). It is therefore essential the clay layer is fully characterised through manufacturer's quality control and CQA testing. Swelling clays can undergo ion exchange whenever they come into contact with liquids or vapours containing ionic species which can replace the sodium in sodium bentonites. It is important therefore to consider at the design stage, the required lifetime over which the material needs to maintain its pollution prevention properties.

The clay used in the manufacturing process can be in powder or granule form depending on the manufacturing process adopted. The three main types of clay used in GCLs are:

**Sodium montmorillonite** is the predominant clay mineral component of the clay normally used in GCL manufacture. It is the major component of natural sodium bentonite, named after the main source Fort Benton in Wyoming, USA. The clay is a weathering product of volcanic ash deposited in marine environments. Extensive deposits occur in both Wyoming and Dakota. Its advantages are its very high swelling and therefore, very low permeability characteristics. Its disadvantage is the potential for cation exchange and the resulting reduction in the swelling, and increase in its permeability characteristics. You must ensure you purchase unmodified sodium bentonite GCLs, as the term 'natural' has various interpretations.

**Calcium montmorillonite** is a weathering product volcanic ash deposited in a freshwater environment. It is the main component of natural calcium bentonite. It does swell on contact with water but not to the same extent as sodium montmorillonite. Its advantages are its reduced cation exchange capacity thereby maintaining its low permeability. However, it requires very high dose rates ( $\text{g m}^{-2}$ ) to equal the very low permeability achieved by sodium montmorillonite.

**Soda activated montmorillonite** is a calcium montmorillonite/bentonite that has been treated with soda ( $\text{NaCO}_3 \times 10 \text{H}_2\text{O}$ ) to produce an artificial sodium montmorillonite/bentonite. Its effectiveness is proportional to the degree and consistency of calcium replacement and removal in the activation process.

As a low permeability barrier, natural sodium montmorillonite has the best characteristics and as such is the clay type normally used in GCLs. Bentonites contain between 60% and 90% montmorillonite. However the clay in a GCL should have an active sodium montmorillonite content of >70%, the remaining minerals being quartz and illite, the latter of which is also a clay mineral.

Where you propose using calcium montmorillonite, you must provide evidence showing how you will achieve the required permeability bearing in mind the disadvantages mentioned above. Your proposal should also outline your envisaged QA testing regime to verify the GCL's integrity. We will refer such proposals to our local geotechnical expert to consider, and possibly refer to a regional or national expert before we accept it. We have no automatic presumption against using calcium montmorillonite.

Sodium montmorillonite swells on contact with water or water vapour to up to seven times its dry volume. This expansion reduces the pore spaces between the clay particles, reducing the overall permeability of the clay layer within the GCL. By confining the clay between geotextiles by needle punching or sewing, the pore size reduction enhanced. The swelling property of the clay must be an essential part of your testing programme as it's the property fundamental to a GCL's low permeability.

Bentonite allowed to swell freely (may achieve high moisture contents and take the form of a gel providing a comparatively high permeability value. However, the gel form has a very low shear strength and consequently may migrate away from pressure points. Reinforced GCLs can be manufactured in such a way so as to restrict swelling and migration so the clay does not reach the gel stage. You must take this into account when considering using non-reinforced products.

There are a number of design issues regarding the dosage rate of clay required per square metre of GCL. GCLs suitable for landfill engineering purposes generally have an average of 4000 - 5000g  $\text{m}^{-2}$  of sodium bentonite. In the past there has been pressure to reduce dosage rates to as little as 3000 g  $\text{m}^{-2}$ . which is near the minimum amount that provides an acceptable flux through the GCL. However, there are a number of factors relevant when determining an acceptable dosage rate. The approach of landfill by design suggests that dosage rates may vary depending on the proposed application. This means sensitive locations will require higher dosages than at less sensitive locations. Accordingly, when calculating dosage rates, you must consider the following factors:

- the sensitivity of the any receptors (groundwater)
- the effectiveness of the attenuation layer
- the quality and testing rate of the manufacturers quality control (see section 5)
- the quality and testing rate of the manufacturing quality assurance
- the proven quality of the clay in terms of its pollution prevention potential (activity, cation exchange capacity, attenuation capacity,
- the quality of the installation and the quality of the construction quality assurance (see section 6)

- the need for a robust lining system
- the nature and variability of the waste types
- the nature of the application (lining, capping and so on)
- the nature of the hydrating permeant
- a material and site specific risk assessment (which should address any other site specific factors not covered above)

## 2.4 Additives

Some GCL manufacturers use additives to enhance certain characteristics such as initial swell and leachate resistance in reinforced GCLs, or in the form of glues in non-reinforced liners. The nature and suitability of these additives is difficult to ascertain, as a result we would prefer they were not used unless the manufacturer is able to demonstrate their nature, suitability, and long term durability. Manufacturers must provide details of all additives used in the manufacture of their GCLs. Where the additive is a polymer, you must ascertain the manufacturer has not used excess polymer during the manufacture of the GCL. Excess polymer can cause excessive swelling of the clay/polymer filling in reinforced GCLs pushing the geotextiles apart, and allowing the bentonite migration and subsequently loss of integrity.

## 2.5 Needle punching, stitching, thermal bonding and gluing

The components of GCLs are held together by either needle punching, stitching or gluing. The fibres used are usually polymers such as HDPE or polypropylene, and like the glues their chemistry and characteristics should form part of your design specification.

**Needle punching** is the process where fibres from the non-woven geotextile are drawn by barbed needles through the clay layer and a second geotextile, thus linking both the geotextiles and holding the clay filling in place. The fibres may also be fixed further to the geotextile or each other by heat or chemical sealing. To confirm the integrity of the seams, thread with a colour contrasting that of the geotextile is used. Products that require non-hydration of the bentonite component to prevent its migration are unlikely to be acceptable.

**Stitching or sewing** is the process where the geotextiles are sewn together at specified intervals, usually 50 mm or less.

**Thermal bonding** is the welding together of the fibres to the geotextile thereby holding the two geotextiles together.

**Gluing** is the process of attaching the clay element of the GCL to the membrane using glues.

### 3.0 Manufacturing quality control (MQC)

Manufacturers commonly use a range of European and American tests for the quality control of GCLs. This section is based on the ideas in ASTM D 5889, with some additional information regarding experience in the UK.

ASTM 5889 states "this practice (MQC) does not address manufacturing quality assurance, product acceptance testing, or conformance testing. These are independent activities taken by organisations other than the GCL manufacturer".

The quality control data therefore simply shows the product is a GCL and that certain testing has been undertaken. To have a high degree of confidence in the material, it is essential you carry out the correct suite and frequency of testing. You must provide us with a full audit trail of all materials and relevant test results if we request it.

GCLs must be properly manufactured, with a minimum level of quality control as determined by in-house testing of the final product. Table 1 suggests the types of tests, test methods and minimum test frequencies. Our staff will request full details on the quality control testing from the manufacturer of your chosen GCL - particularly the results relevant to installing the material on site.

Obviously, manufacturers may perform additional tests than required in Table 1. In this case the manufacturer's quality control plan will then take precedence over our baseline requirement. The tests, and methods must appear in your quality control plan and the QC report produced by the manufacturer. Each roll must be marked so the testing regime applied to it can be identified. You should also recognise that you may have additional tests or a greater frequency of testing than detailed in Table 1.

Components of the GCL, such as the geotextile/geomembrane must also have been through a QC programme. The manufacturer's geotextile QC programme should be available both to you as a customer, and us as a regulator.

Table 1 doesn't identify GCLs in terms of their suitability for use in pollution prevention situations. You should carry out these tests at the design stage if pre-existing relevant data does not show the GCL is suitable for your proposed use.

Each roll of GCL delivered to site must have a label, preferably complying with EN 30320, detailing the following:

- Manufacturer's product identification (product manufacturer's name address and telephone number, production plant location, product name and type).
- GCL roll number;
- roll length and width in metres.
- roll weight in tonnes

The information required outlined in this section should be available for each roll under the manufacturer's QC plan.

## 4.0 Transport, delivery, handling and storage

For optimum performance GCLs must be transported, handled and stored in a way that doesn't impair their chemical or physical properties. You must brief staff who will handle GCLs with the material properties and the activities that can damage the product. There are many recorded instances of damage being caused by untrained staff who didn't appreciate the consequences of their actions.

GCLs must be delivered and installed at or near the factory manufactured moisture content. The 'as manufactured' moisture content will depend on a number of factors including the actual method of manufacture and the type of clay. Reinforced GCLs are normally manufactured with moisture contents in the range of 10 - 40%. Above 50% moisture, you should express concerns to the manufacturer regarding the effect of the moisture on the physical stability of the clay. By following the procedures below, you should be able to easily install the GCL at or near the manufactured moisture content. If you find the moisture content of a roll to be 5% or more greater than the manufactured moisture content, you must investigate whether the GCL has been maltreated potentially damaging it or causing it to deteriorate.

### 4.1 Transport and delivery

Safely delivering your GCL to site is your supplier's responsibility. For safety reasons, your CQA Inspector should not accept delivery of rolls if they are stacked more than three high or can't be unloaded from the vehicle using stingers or spreader bars.

Your CQA Inspector must supervise any movement of the GCL around your site. The CQA Inspector must also visually examine each roll for damage. Any visible or suspected damage must be recorded and reported, such rolls should be tagged and segregated for further investigation. GCLs are packaged in individual rolls and are typically delivered to site in trucks. Each roll is individually wrapped and labelled by the GCL manufacturer.

To enable product tracking, you must record the roll numbers. Your CQA testing frequency must not be determined by the number of batches but rather on a statistically sound assessment of material variability.

You should treat with extreme caution any rolls which have been transferred from other jobs. Only use such rolls if accompanied by a complete history. In the past, such transfers have been made to allow previously rejected rolls to be reused.

You should either reject or quarantine any rolls delivered without complete packaging, labelling and documentation. If you decide to accept and quarantine such rolls, your CQA inspector must investigate the rolls to determine whether or not they are fit for use. . If your CQA inspector and engineer decide that such rolls or part rolls are suitable for use, you must provide us with written justification for doing so.

Before delivery, your CQA staff should prepare a suitable area for receiving and storing rolls.

### 4.2 Handling GCLs

Wherever GCLs are loaded or unloaded (at the factory, during delivery installation), it must be done in a manner which doesn't damage the GCL or it's packaging.

Best practice for handling GCLs is to use a spreader stinger bar (a bar protruding from the front end of a forklift or other equipment). The bars you use must be capable of supporting the roll's weight without any significant bending (significant means sufficient bending to cause creases or movement of the clay in the GCL). Failure to do so may subject the GCL to undue stresses resulting in clay migration or damage to the geotextile element. Under no circumstances may the GCL rolls be dragged, lifted by one end, pushed to the ground from the delivery vehicle, or otherwise unloaded in a way that could damage the GCL. Any small tears to packaging must be immediately repaired using tape and plastic sheeting.

### 4.3 Storage

You must store the GCL in its original, unopened packaging to prevent premature hydration. Your storage location must be somewhere where the GCL will not be damaged by site activities (such as construction traffic ). GCL rolls must always be stored lying flat, continuously supported and never standing on one end. Avoid storing rolls on blocks or pallets to eliminate the possibility of localised contact points which could cause product thinning.

It's essential your site plant and handling equipment does not damage the GCL or it's protective wrapper. In order to protect the GCL from adverse weather, cover all rolls with a tarpaulin or plastic sheeting. You may stack rolls during storage, provided you place them in a way that prevents them from sliding or rolling from the stack. Our recommended maximum stack height is three rolls.

The storage area must be smooth, dry, well drained, stable and should protect the GCL from:

- precipitation
- standing water
- ultraviolet radiation
- chemicals
- excessive heat (in excess of 70°C) and sparks
- freezing
- vandalism, animal and plant infestation
- puncture
- any other environmental condition that could impact on it's physical properties.

**Table 1 - Suggested tests and frequencies for manufacturing quality control of GCL**

Test description	European test method	ASTM Test method	Frequency of test	Report value
Montmorillonite content <sup>7</sup>	VDG P69/XRD		Every 50 tonnes	>70%
Cation exchange capacity (CEC)	Methylene blue test appendix A	D 837	As above	Comparison with above result
Swell index/free swell of clay <sup>1</sup>		D 5890	As above	Minimum and average
Water absorption	DIN 18132 Enslin Neff	Imbibition D5891	As above	As above
Fluid loss of clay <sup>1</sup>		D 5891	As above	As above
Mass per unit area of geotextiles	EN 965/ISO 9864	D 5261	20,000 m <sup>2</sup>	Typical and MARV <sup>6</sup> Also minimum/maximum/average values
Mass per unit area of bentonite	EN 965/ISO 9864	D5993	20,000 m <sup>2</sup>	
Tensile strength of geotextile or Grab tensile strength	ISO 10319	D4595 D4632	20,000 m <sup>2</sup> 20,000 m <sup>2</sup>	
CBR <sup>3</sup> / puncture resistance of finished GCL	ISO 12236	D4833	20,000 m <sup>2</sup>	
Mass per unit area of finished GCL <sup>4</sup>	EN 965/ISO 9864	D5993	5,000 m <sup>2</sup>	
Moisture content of clay from finished GCL <sup>5</sup>	DIN 18121	D 4643	5,000 m <sup>2</sup>	Maximum and average value
Grab tensile strength (MD and CD) of finished GCL <sup>2</sup>		D 4632	20,000 m <sup>2</sup>	MARV
Peel strength (only applies to needle punched products)	ASTM 4632 or manufacturers method		20,000 m <sup>2</sup>	Minimum value
Index flux	DIN 18130-1	D 5887	25,000 m <sup>2</sup>	Maximum value
Internal shear strength of GCL	Designer specified			

**Notes**

- 1) The tests on the bentonite are to be performed on the as received materials before fabrication into the GCL product
- 2) MD = Machine direction used during manufacturing process  
CD = Cross machine direction
- 3) A site specific requirement for subgrades outside the specification in this guidance.
- 4) Components from finished GCL product should not be separated and tested because the production process may alter the properties of the components
- 5) Dried bentonite should be defined as 0% moisture content
- 6) MARV = Minimum Average Roll Value.
- 7) Results are a comparison with a standard sample of known composition

## 5.0 GCL design and construction issues

GCLs are normally installed as part of a lining system. The interaction of the various elements of a lining system and the GCL is a complex problem which you must address at the design stage. You must consider the physical and chemical interactions between different elements of the system and ensure there are no stresses in the system which could threaten the integrity of any element of the liner. The physical and chemical issues are often closely related with matters such as interface friction angles, normal and shear stresses, assessments of the material life in the predicted environment, anchor trench pullout strengths and reactions to heat and chemicals in the leachate. Your design will need to take account of all of these issues and interactions.

Those issues already dealt with will not be covered again in this section.

### 5.1 GCL subgrade

An uneven subgrade may cause point loading on a GCL or bentonite migration, creating an area of higher permeability

The surface on which you lay a GCL must be smooth, flat and free from any materials which could threaten the physical or chemical properties of the GCL.

The subgrade should preferably consist of fine grained or graded soil with a maximum particle size less than the thickness of the GCL. Where you propose to use a granular material for the subbase layer, a non-calcareous rounded material with a grain size less than the thickness of the GCL would be best. Where soil testing identifies the grain size and degree of grading, use the following approach as a guide to selecting a subgrade size:

- in poorly graded soils (range of grain size is very small) 8mm is the maximum size permitted
- where the soil is well graded (range of grain size is large) then the maximum permitted grain size is 32 mm.
- more specifically where  $d_{60}/d_{10} > 15$ , the maximum grain size should be 32 mm. Where  $d_{60}/d_{10}$  is between 5 and 15, the maximum grain size should be 16 mm. Where  $d_{60}/d_{10} < 15$ , the maximum grain size should be 8 mm. ( $d_{60}$ =maximum grain size of smallest 60%,  $d_{10}$ =maximum grain size of smallest 10% of the soil.)

If you wish to use materials with larger grain sizes than our above recommendations, you must demonstrate their suitability by using the materials in a trial pad.

You may use protection geotextiles to overcome problems with poor quality subbases, but again you must first demonstrate their suitability

You must trim and compact all subgrade to provide a firm smooth surface free of all debris, roots, and sharp objects.

Firm in this context means that indentations can't easily be made in the surface. For clays the shear strength of the clay must be  $>40\text{kN m}^{-2}$ . For other materials such as sand, the material must be  $>90\%$  of its maximum dry density to ensure no movement will occur during or after placement.

Smooth in this context means there should be no sharp angles in the subgrade which exceed + 25mm under a 1000mm lath (for example at changes of grade due to rutting), and no rounded irregularity should exceed + 50mm under a 3000mm lath).

You must not lay GCLs against any subgrade rich in calcium or any other substances which could exchange ions with the sodium in the GCL.

Your CQA inspector must carry out a complete visual inspection of the subgrade surface once it is finished. Any surface irregularities discovered during the inspection must be further checked using a lath. Your CQA inspector should confirm the subgrade's suitability as required by your CQA plan.

## 5.2 GCL anchor trenches

You must design anchor trenches to hold the GCL in place during construction and the full design life of your site. The required depth and width of anchor trenches will vary with the stresses which are likely to be placed on the GCL. As a guide, trenches are generally in the order of 300 - 500mm wide and 500mm to 1000mm deep.

GCL are normally laid down the face and across the base of the trench but not up the back wall. The trench edges must be smooth to prevent damage. The trench doesn't form part of the pollution prevention liner, but rather is an engineering necessity to hold the liner in place.

The anchor trench backfill material you use must be fully characterised, your specification must include the following as a minimum:

- a full description of the material to BS5930
- the source of the material (National grid reference, type of and reason for excavation)
- the grain size distribution of the material
- the shape and angularity
- an assessment of the material in fulfilling its objective
- an assessment of the materials chemical compatibility with the GCL.

You must well compact the backfill to minimise water ingress and to prevent GCL pullout.

Where a slope exceeds 70 metres or the roll length, or where the forces created by the GCL's weight approach the internal shear strength of the material, intermediate anchor trenches will be required. This is to prevent the forces created by the weight of the GCL exceeding its tensile strength, causing it to stretch or tear.

## 5.3 Slope stability

Your engineering design must consider slope stability. Generally speaking, slopes shouldn't exceed 1v:3h unless you've carried out a slope stability analysis which demonstrates there is a factor of safety (FOS) of 1.5 or more. Your slope stability analysis should consider the interface friction angles of the saturated GCL with the other components of your design.

Your design may need anchor trenches for every roll of material with low friction angles.

Some low-weight, split-tape woven geotextiles in GCLs can allow bentonite to escape and lubricate interfaces with resulting consequences for slope stability. You must assess the suitability of your geotextile with regard to slope stability. The internal shear strength of the GCL must be sufficient to withstand the forces likely to be imposed by your design. If internal shear strength is an important component in the design, you should carry out testing at the design and CQA stages to demonstrate the material meets the required standard.

We have a presumption against using products in basal lining systems requiring the benefit of non hydrated bentonite components. It is generally assumed that permeation, stress cracking and damage will create enough pathways to allow the bentonite to hydrate during the life span of the design. You must demonstrate that where the clay element of a product must remain unsaturated in order to provide sufficient resistance to sliding, this can be achieved throughout the life of the design.

## 5.4 Chemical and landfill gas compatibility

You must consider the chemistry of the subgrade. For example, is it calcareous or likely to transmit groundwater or water vapour of high ionic strength. Sodium in a GCL's clay minerals may be replaced by other ions through adsorption. This in turn will affect the swelling characteristics of the clay, causing micro cracking and thereby increasing the GCL's permeability.

Consequently, you should assess the use of a GCL against the likely permeants in the hydration stage and also in the operational and post operational/restoration stages. In capping situations, GCL dehydration can occur during droughts, causing microcracking of the clay. Subsequent heavy rainfall may then flush more ions through the microcracks in the GCL, accelerating ion exchange and increasing permeability. (see 5.10.)

Landfill gas, vapours and condensates can all adversely affect a GCL if they contain substances harmful to either the clay, geomembrane or geotextile layers. Dry GCLs present no barrier to landfill gas and may be problematic if they are installed where hydration can't be guaranteed. Hydrated GCLs present a similar barrier to landfill gas as any other clay liner, gas permeability depends on the physical and chemical properties of the particular material. If you plan to use a GCL as a landfill gas barrier, you must consider installing a gas collection layer on the waste side of the GCL to provide a preferential pathway.

## **5.5 GCL installation issues**

Most manufacturers have guidelines for installing their product, however, the detail contained in these documents varies greatly and isn't necessarily consistent between manufacturers. We recommend you consider the manufacturer's guidance as a starting point and (depending on the site's sensitivity and the degree of detail needed) build up detailed installation guidance for your staff.

After preparing an area to be lined, your CQA Inspector must inspect the area to ensure the slope and anchor trench have been prepared in accordance with the specification, and are suitable to accept the GCL. Your CQA Inspector must keep a record for the final validation report.

To prevent damage or early hydration of you must not install the GCL during adverse weather conditions such as strong wind, snow or rainfall.

Assuming weather conditions are favourable, your CQA Inspector may approve the GCL installation to proceed. You must only lay the GCL on areas approved by your QA Inspector on the installation day and in accordance with your panel layout diagram.

During installation, your CQA Inspector must ensure the GCL is placed in the anchor trenches in accordance with the drawings. The CQA inspector must also ensure the GCL is laid parallel to the direction of the slope, and is free from kinks and folds. The CQA Inspector is responsible for identifying any damage caused during delivery, storage or handling, and making sure it is either repaired, covered with a new sheet, or if necessary removed and replaced with a new sheet.

Once laid, your CQA Inspector must inspect the whole surface of the GCL, checking for variations in colour, thickness, needle punching and sewing density, or any areas which suggest material or installation problems.

For GCLs which have different physical properties on their different faces, 'way up' criteria can be important. Some designs require you to maximise interface friction, such as in multi-element sidewall lining systems or where the pollution prevention properties of a material depend on 'way-up'. If this applies to your design, you must specify in your working plan and CQA plan in order to minimise confusion. We recommend that where 'way-up' is not important that you clearly state this in your design and CQA submissions.

### **5.5.1 Joints and overlaps**

During installation, the GCL should be placed in the anchor trench and laid parallel to the direction of the slope. Joints between panels are usually formed by overlapping the panels by a minimum of 250 mm and sealing, usually with bentonite powder or paste (sometimes called 'accessory bentonite'). Some products have edges impregnated with bentonite to facilitate jointing, where you propose these materials, you should consider whether you can reduce the amount of accessory bentonite needed. It is possible to use other jointing, such as glue, although these alternative methods are uncommon. If you propose an alternative

jointing method, it must be technically justified by your designer. Overlaps must be flat with no wrinkles to avoid creating bypass routes for leachate. In exceptional cases or in awkward corners, GCLs can be slit and overlapped, and covered with another panel of GCL. You must overlap the panel slit by at least 300 mm. Laboratory testing has shown the permeability of this type of joint is close to the permeability of the GCL itself. This method may not be suitable for FML/bentonite products unless you can find a method of fixing the panel in place.

You should take care when using bentonite powders or granules if your GCL is adjacent to a leak detection/collection layer. This is particularly true if you're using geosynthetic drainage, as blocking of the drainage filter geotextile or the drainage channels can occur.

The presence of loose bentonite powder may affect seam welding of overlying HDPE geomembranes. You must be careful to avoid contaminating the upper surface of the GCL.

If your design includes any transverse joints, you will need an anchor trench for each new sheet down the slope. You should seal the sheets in the same way as for parallel joints. Overlaps must be at least 1500 mm from any transverse joints (across the slope) and 300 mm for parallel joints (down slope) to cater for possible movement. Joints should be overlapped in a roofing tile fashion, that is, in the direction of the fall. If settlement is likely to be significant (particularly when capping biodegradable wastes where significant settlement is likely), you must submit a detailed settlement prediction, you should also increase the overlaps to allow for the predicted settlement.. This is true for all capping media where settlement is likely to occur.

### **5.5.2 Pipe penetrations**

Your design should avoid penetrating the GCL with pipes or other structures. Where such penetrations are absolutely necessary, such as caps, you must agree the manner in which you will install them with us before beginning. Penetrating a basal liner is not normally acceptable.

### **5.5.3 Placing subsequent layers**

Your method for placing subsequent layers must be in accordance with your CQA plan, and should consider the load bearing capacity of the GCL in its saturated state. You should place a minimum of 300mm thickness of cover material immediately after laying the GCL, so that adequate loading of the GCL is provided and you achieve the confining pressure required prior to hydration.

You must maintain the 300mm over areas likely to be tracked by dozers spreading protection or other layers. You should spread the material in the direction of overlaps on low angle slopes, and up slope on steeper slopes. You must exercise extreme caution when placing materials on top of non-reinforced GCLs. You must use the correct equipment to prevent separating the components of the GCL.

### **5.5.4 Trafficking on the GCL**

At no time during installation or placing the protective layer may you allow plant or equipment to travel on the unprotected surface of the GCL. Even repeated walking on the GCL's surface may cause damage. Where you expect repeated traffic over the covered GCL, you should place an additional thickness of protective soils. 600mm is an appropriate amount of additional protection.

Overlaps are particularly sensitive to disturbance by traffic, you should provide alternative routes wherever possible. Where traffic may reduce the thickness of protective cover, such as where loss of traction causes dumptruck wheels to spin, you should increase the cover thickness as appropriate.

### **5.5.5 Sampling, transporting samples and laboratories**

Sampling and testing of GCLs should be to the highest standards to ensure test results are representative of the materials on site. For material conformance testing, your CQA Inspector should take enough sample material for the required tests. For example, mass per unit area testing requires a sample 0.5m wide and a roll width long (normally 4 - 5m), while samples for permeability testing may only need to be 500mm x 500mm. For large suites of tests, you may need to take a sample 1.0m wide and a roll width. You should discuss the exact amount of sample material required with your chosen laboratory. You should include the details of the amount of sample material required in your CQA plan.

It is essential that samples reach the laboratory undamaged. We recommend therefore that you roll larger samples onto a piece of the roll's packaging tube, and that you pack smaller samples flat. Following these recommendations will prevent creasing or folding of the GCL. Package the samples in sealed plastic bags, label them (see below) and store them in a cool place. If the material is manufactured in a continuous process, you can take samples from the end of a roll to minimise wastage. If the GCL has bentonite impregnated edges to facilitate jointing they should be discarded for normal testing. If the GCL sample is likely to lose any of the powder or granules from the clay layer, you should tape the open sample edges.

The label on the sample should include the following information:

- site name and location (for example, Perfect site, Greentown, Paradise)
- date sample taken and sealed.
- name of sampler (for example, QA Inspector or Expert consultants Ltd.)
- material manufacturers name (for example, ClayRug Ltd)
- material type, trade name and product name/number (GCL, ClayRug, K8)

Once packaged, you should send your samples to your chosen UKAS accredited laboratory. It is important to realise that laboratories are accredited for particular tests. If a lab is not

accredited for all the tests you require, we recommend you choose the laboratory with the largest number of relevant accreditations.

The laboratory report must contain full information with sufficient detail to allow us or others to independently verify the calculations. Details of failed tests and the reasons for such failures should also be included.

We advise that your CQA staff take duplicate samples in case the originals are lost or test failures occur. You should package and label these samples as above and store them in a cool place to prevent moisture loss. There is no need to keep these duplicates once we have accepted your final validation report.

## **5.6 Damage and repair**

In the event of damage occurring to the GCL, you must assess whether the damage threatens the integrity of the material. In general, any tear, particularly if under tension constitutes a significant material defect in that it is likely to form a locus for further tearing. Your CQA engineer should undertake a technical assessment of any damage. The technical assessment should include a consideration of the magnitude and direction of any stresses, and the consequences of failure. You must include their findings and solutions in the final validation report. If the defect is more than 1m<sup>2</sup>, you must agree the engineer's assessment with us before continuing.

Damaged areas must be covered by a GCL patch at least 300mm larger in all directions than the damaged area. Clear the repair area of all debris and have it swept clean. Bentonite granules or powder must be packed into tears in such a way so as not to produce a mound in the GCL. Patches should be attached to the parent GCL, preferably using epoxy resin which will ensure the material doesn't move during placing of the cover material. Bentonite should be placed around the perimeter of the area at a rate of 0.5 kg per metre. A second method of attaching patches to place bentonite between the patch and the parent GCL and then using 75 - 100mm staples to hold the patch in place. . You must not use staples with FML/bentonite products, or if you are placing a geomembrane adjacent to the GCL. You should consider the possibility staples corroding and the effects that would have.. You should only choose a repair method after carefully considering it's effectiveness in the particular situation you face.

Your QA inspector should give each area of damage a sequential reference number. You should produce and keep a site plan showing the location and reference number of each area of damage. You must also keep a record of the location, size and repair details of every patch.

When your CQA staff are satisfied the GCL installation and any damage repairs are properly completed, your QA inspector should issue written approval for the protective layer to be placed. The QA inspector must oversee the placing of the protective layer. If you propose to use any materials or methods in placing the protection layer which are different from your original specification, you must agree them with us before commencing. We may ask you to carry out site trials to demonstrate the suitability of your new proposal.

## **5.7 Post placement saturation of the GCL**

It is fundamental to a reinforced GCL's performance of that the bentonite is saturated with clean water under confined conditions. In moist ground conditions, the clay in geotextile-based GCLs will attract moisture from the surrounding materials. This process normally takes a few days and must be complete before any leachate is allowed to accumulate on the lining system.

It is preferable that GCLs are not hydrated with leachates as this may severely affect the GCL's properties. However, evidence shows that some leachates have little or no effect on GCL performance. Where you plan to hydrate the GCL with leachate, your designer must demonstrate there will be no impairment of the GCL's properties.

Reinforced GCLs should not normally be installed above a geomembrane in caps, as this will isolate the GCL from the moisture available from the waste. This would mean that in drought situations there is a risk of dehydration and potentially, accelerated ion exchange during subsequent re-hydration.

Hydrocarbons will not hydrate a GCL and therefore will pass quickly into the environment if GCL hydration has not previously occurred .

You must prevent the GCL from becoming saturated during laying, or prior to placing the subsequent layers, as shrinkage of the clay on drying can be considerable. Early hydration can cause increased permeability and stresses within the GCL that could ultimately lead to failure. Stress on a hydrated GCL can cause bentonite to migrate away from stressed points. Your design must show how you will prevent early hydration of the GCL.

## 5.8 GCL protection and confinement

Where a GCL forms the uppermost part of a basal lining system or cap, you must place a protective mineral layer or protection geotextile and confining layer over the GCL. The properties of the mineral layer/geotextile must be sufficient to ensure that no damage is caused to any element or characteristic of the GCL.

You should exercise caution when placing protective granular materials on a sloping element of a lining system as there is the potential for:

- slope failure of the lining components due to the weight increase;
- damage to the liner during and after placement as granular materials themselves tend to slip, and require replacement by the operator, usually after the installer and CQA staff have left the site. The installation of protective cover should also receive full CQA supervision.

Where you are using protective geotextiles on the sidewall elements of a lining system, your designer must submit technical calculations, including factors of safety, to us to demonstrate the protector will continue to perform for the design life of the GCL.

### 5.8.1 Mineral protection layers

Where you are using granular materials for the protection layer, you should ideally use a non-calcareous rounded material with a grain size less than the thickness of the GCL. Where soil testing has identified the grain size and the degree of grading of the soil, you should use the following approach:

- in poorly graded soils (range of grain size is very small) 8mm is the maximum size permitted
- where the soil is well graded (range of grain size is large) then the maximum permitted grain size is 32 mm.
- more specifically where  $D_{60}/D_{10} > 15$  32mm maximum grain size,  $15 - 5$ , 16mm is maximum, and  $< 5$ , 8mm is the maximum grain size. ( $D_{60}$  = maximum grain size of smallest 60%,  $D_{10}$  = maximum grain size of smallest 10% of the soil.)

You should test the suitability of materials with larger grain sizes than those recommended above by trialing the materials in the same context as will occur on site or by building a trial pad prior to construction.

The minimum thickness of a mineral protection layer must be at least 300 mm. Protection layers must also be free of all debris, roots, sharp objects and any other item which may under the stress of the emplaced waste or overburden penetrate or tear the GCL .

You should avoid using calcareous materials such as limestone quarry fines in protection layers because of the potential for cation exchange between calcium and sodium.

You must specify the mineral you plan use as the protection layer in your CQA plan. The specification should include as a minimum:

- A full description of the material to BS5930
- The source of the material (National grid reference, type of and reason for excavation)
- The grain size distribution of the material
- The shape and angularity
- An assessment of the material in fulfilling its objective as a protective cover.
- An assessment of the materials chemical compatibility with the GCL.

Mineral layers may need to be thicker on sidewalls (by a factor of 1.5 to 2.0) to increase their stability and provide for an element of thinning due to erosion. When placing mineral layers on side walls, you'll need to take care not to open joints in the process. Placing mineral on the side wall from the toe of the slope upwards, using a backacter bucket rather than a dozer blade will help prevent this.

### **5.8.2 Geosynthetic protection layers**

Where you propose using geosynthetics to protect the liner, you must first agree this with us.. There are several geosynthetic materials you can use to protect a GCL, including geotextiles, and mats made from reconstituted waste materials such as tyres, or whole tyre blankets. You should avoid using combustible materials in peripheral drainage/venting systems adjacent to geotextiles. We require at least the following information before you use geosynthetic protection layers:

- The detailed specification of the material
- Evidence of its protective capabilities for the material it is intended to protect and where necessary, the results of cylinder testing,
- Details of the manufacturer's quality control procedures and results
- Details of how you will quality assure the material on site.
- Geotextiles alone are unlikely to provide the confining pressure required by a GCL before hydration and will therefore require an additional confining layer which will need to be assessed and specified.
- Drainage composites may also be used to protect as well as drain.
- Evidence of the physio-chemical and durability properties of the geosynthetic demonstrating a lifetime greater than the GCL.

### **5.8.3 Installing the protection and confining layers**

You should place the protection layer as soon as possible after you lay the GCL, and in any event before rainfall and/or the end of the working day in which you lay the GCL. You should place the layers in such a way as to cause no damage to the GCL itself. Granular materials should be placed on the GCL by machine bucket primarily. You should only allow spreading by dozer as a secondary measure, however it may be unacceptable to use spreading on side slopes due to the stresses this would place on the GCL.. At the end of each working day, you should cover the leading edge of the GCL with a suitable material, such as plastic sheeting to prevent premature hydration.

On sidewalls, you should place materials from the toe of the slope upwards to prevent slippage. Carefully place materials over joints and patches to avoid displacing them. Although not possible on side slopes, the direction of spreading should be from overlying panel to underlying panel to prevent displacing the GCL and disturbing the overlaps..

## 5.9 Freeze thaw effects

The permeability of reinforced GCLs appears to be unaffected by repeated freezing and thawing.

## 5.10 Desiccation cycle effects

GCLs may not withstand repeated hydration and dehydration cycles without losing performance. Where sodium bentonite is the predominant clay mineral, the repeated wetting after desiccation may provide more opportunity for ion exchange of sodium by calcium from the wetting permeant. This will reduce the swelling capacity of the clay, and increase its permeability.

The effects of desiccation are probably restricted to caps where confining pressures are less, and drying and wetting of overlying soils more common. To avoid this situation soils placed above the GCL should have moisture retention characteristics (such as a silty sand) and be at least one metre thick. You should avoid calcareous soils, but bear in mind that even clay soils will contain some calcium ions. Capping proposals incorporating thin soil covers above and FML barriers immediately beneath a sodium bentonite GCL will not normally be acceptable. Thin soils can also contribute to root penetration of GCLs unless the carrier or overlying component is an FML or has a rooting barrier.

## 5.11 Attenuation layers

Where you propose a GCL as an alternative to a clay liner, or adsorption capacity is a required to protect the environment, you should recognise that a GCL doesn't have the same physical or chemical properties as a clay liner. Both the adsorption capacity and breakthrough time differ significantly from a remoulded clay liner, accordingly you will need to construct an attenuation layer which will provide the required properties. The specification of the attenuation layer should be site specific both in its thickness and chemical properties. There are however a number of guidelines you can use to provide a framework for both designers and regulators:

- At the design stage the proposed attenuation material must be characterised in terms of its attenuation properties with the cation exchange capacity (CEC) and adsorptive capacity (Kd) quantified.
- The proposed attenuation material must have a low permeability to ensure that the CEC and Kd are not bypassed (a fissured clay would for example allow leachates to pass through without any attenuation).
- The attenuation layer may be a fully characterised in situ layer (where you propose in situ clays, you must demonstrate that the required properties exist throughout the layer both laterally and vertically) or an engineered layer laid to an agreed specification (any engineered attenuation layer must have sufficient bearing capacity to support the layers above)
- The attenuation layer (remoulded or in situ) is a part of the lining system and a quality assurance scheme should be included in your CQA plan (see section 6.0)
- The required amount of attenuation capacity can be determined from the predicted volume and nature of the leachates over the required lifetime of the landfill site). Where you use geomembranes, it is important to recognise they do not present perfect barriers and damage can occur during site operation, in addition pin hole leaks will only activate a small volume of the attenuation layer.

Experience has shown that at environmentally sensitive sites, attenuation layers up to 500mm can be necessary.

## 6.0 Construction quality assurance (CQA)

Waste Management Paper No. 26B advocates that a quality approach is vital to successfully implementing a landfill development. Quality assurance has a role to play in all aspects of landfill engineering. Whilst QA techniques do not guarantee you have carried out the works in accordance with the specifications, they give confidence that you have met the following requirements:

- Effective mechanisms are in place to ensure the construction of the engineered systems will be to the standards and specifications agreed with the Environment Agency and that quality materials and workmanship are employed
- The design, construction and quality assurance processes are well documented for the purposes of regulation and provide public confidence in the works.

Where we specify containment systems in your environmental permit, we require validation by a suitably qualified and experienced independent engineer that you have carried out the specified works to the agreed standards.

### 6.1 Construction quality assurance plan (CQA plan)

You must submit an acceptable proposed CQA Plan to us. You will later need to incorporate your CQA plan into your eventual working plan. Similarly, we will incorporate elements of your CQA plan into your environmental permit if we decide to grant one.

With regard to GCLs, your CQA plan should include the following information:

- A summary of the GCL manufacturer's and geotextile manufacturer's quality control procedures with a list of characteristics of the liner material (see section 3.0).
- Records of the delivery handling and storage of the GCL on site prior to installation (see section 4.3).
- The equipment and techniques used for handling and restraining the GCL on the site (see section 4.0).
- Details of the experience/training of the installation staff.
- Details of the conformance tests (see section 6.0) to be undertaken by the CQA engineer on the liner material delivered to the site.
- Rejection criteria of the GCL panels e.g. unacceptable physical characteristics, limits on thickness tolerances.
- The remedial action to be taken in the event of non-compliance with any part of the specified criteria.
- Written certification by the CQA Inspector confirming the suitability of the sub-grade prior to lining including details of testing (see section 5.1).
- The method of emplacement, test types and test frequencies for the attenuation layer (see section 5.10)
- A proposed panel layout for the GCL (it is accepted that the panel layout may vary from that of the actual installation, the objective is to ensure that panel alignments will achieve the pollution control objectives).
- Measures to be taken to protect the placed liner if inclement weather occurs during installation (see section 5.5.2).
- Specified installation and joining techniques, in conformity with manufacturer's recommendations (see section 5.5.4).
- Procedure for inspecting, testing and sampling joints
- Rejection criteria of the laid GCL if test results fail.
- Records of the source roll for each panel should be recorded along with the time/date of installation, weather conditions and site operatives.
- Means of protecting/covering the GCL (see section 5.8)

- The proposed level of supervision and quality control.
- The proposed format and contents of the Validation report (see section 7.0)
- Approval forms for the subgrade and cover
- Procedure for repairing damaged GCL (see section 5.6)
- Procedure for liasing with us
- Procedure for ensuring that the GCL does not exceed the manufactured moisture content by more than + or - 5% (see section 4.3)
- Procedure for saturation of the GCL if necessary (see section 5.7)
- Measures to ensure that the GCL is covered to ensure adequate protection and confinement (see section 5.8)

Our staff will visit your site during liner installation on a regular basis to monitor your adherence to your CQA plan. This will provide us with a working knowledge of the structure and allow us to pick up any faults not noticed by your CQA staff. The responsibility for establishing and implementing the CQA plan lies solely with the permit holder.

The quality assurance engineer must keep a daily log recording, where appropriate, the following information:

- placing low permeability material and sub-grade layers
- conformity to panel layout design
- records of the delivery handling and storage
- type of equipment used. Note any mechanical breakdowns since previous visit
- weather conditions and whether the works are being undertaken with the weather windows specified within the working plan.
- supervision by CQA engineer
- testing procedure and reports of field tests
- remedial action on GCL defects or weld defects
- personnel on site
- placement of temporary protection to installed GCL
- contact (site visits, phone calls etc) by regulatory or other parties interested in the construction
- any other matters detailed in the CQA plan

If our staff encounter any problems on site, they will initially discuss them informally with your QA Inspector or engineer. If we have any significant reservations regarding liner installation or testing procedures, we will discuss them with you and an Environment Agency geotechnical expert. We will confirm in writing any follow up action we require you to take.. If we can't resolve a problem, we may seek written advice from an independent consultant.

Any deviation from your agreed CQA plan requires our prior approval. You should report any deviation from your contractor's method statement to us. Regular visits may identify problem areas, you should identify these areas on a plan and carry out additional testing if necessary. We have encountered many problems due to differences between the agreed CQA plan and the contract documents. Therefore, we strongly recommend you make every effort to avoid such discrepancies. Where problems do occur, we will normally default to your agreed working plan.

## 6.2 Conformance testing

Conformance testing forms part of the overall CQA process. You must carry out this testing to provide confidence that the GCL you have installed the site has the same properties as the GCL properties you agreed with us. Conformance testing also shows that the required properties are consistent across the whole of the GCL. The specification of the GCL must form part of your CQA plan.

On site conformance testing has been used on a number of sites can be a very useful way of rapidly supplying test results. You should accept that conditions are unlikely to be the same as an off-site laboratory and a balance needs to be struck between the amount of on-site and off-site testing. You should consider the drop in testing quality against the benefits of a rapid turn round. Whatever ratio of testing you finally arrive at, it is essential that the on site laboratory works to carefully controlled standards that are set down in your CQA plan.

Conformance testing should establish at an early stage of the works that the GCL being installed is likely to comply with the specification by using the higher frequency methods of testing shown in Table 2.

Any GCL or accessory bentonite which fails to meet your CQA plan's requirements should be immediately reported to us together with a technical assessment by your CQA Engineer of its significance and any remedial actions considered necessary. Any GCL you lay prior to receiving test results is entirely at your own risk.

Your CQA Engineer should order further testing as necessary in order to maintain the quality of the GCL or where additional testing for other parameters is relevant to the design and/or installation.

Tables 2 suggest a staged approach to conformance testing which is intended to be cost effective. There may however be site specific factors which indicate a need for a different conformance testing regime. We will consider proposals from you where variations are required, provided they are based on sound science and technical calculations.

If you need to carry out methylene blue testing, it is essential (if a good correlation is required) to use the same test method and the same batch of methylene blue.

Where testing indicates a roll doesn't conform to the agreed specification, you should reject it.

**Table 2 Conformance testing**

Test description <sup>(1)</sup>	European test method	ASTM test method	Minimum frequency of test <sup>(2)</sup>	Report value
Mass per unit area of GCL	EN 965	D 5993	1 per roll or 500 m <sup>2</sup>	As specified in the CQA plan
Cation exchange capacity (CEC) Montmorillonite content	Methylene blue ( see appendix A)		As above	Comparison with a standard sample of known montmorillonite content <sup>(3)</sup> .
Thickness of GCL <sup>(4)</sup>	Visual inspection of whole roll during placement			As specified in the CQA plan
Peel strength (for needle punched products only)	Manufacturer's method	D 4632	1 per roll or 500 m <sup>2</sup> <sup>(2)</sup>	As above
Mass per unit area of clay component of GCL	EN 965	D5993	1 per 2500m <sup>2</sup> <sup>(2)</sup>	As above
Moisture content of clay	DIN 18121	D4643	As above	≤50%
Swell index/free swell of clay		D5890	As above	≥24ml
Water absorption	DIN18132 Enslin Neff	D5891/ Imbibition.	As above	≥600%
Tensile strength or Grab tensile strength (MD and CD) of GCL	ISO 10139	D4595  D4632	As specified in the CQA plan <sup>(6)</sup>  As above	As specified in the CQA plan <sup>(6)</sup>  As above
CBR/puncture resistance of geotextile	BS6906/ EN 12236	D 4833 D 5514	As above	As above
Mass/unit length of bentonite in overlaps <sup>(5)</sup>	visual inspection and weighing		1 per 40 metres overlap	≥0.5kg/linear metre
Index flux	DIN 18130	D5887	1 per 10,000 m <sup>2</sup>	As specified in the CQA Plan
Montmorillonite content	XRD VDG P69		1 per 10,000 m <sup>2</sup>	Comparison with standards of known composition <sup>(7)</sup>

(See notes below) Geomembranes should be tested in accordance with Guidance on the use of geomembranes in Landfill Engineering. Table 1

**Notes**

(1) Test types should be taken in the following order of preference: ISO, EN, Country specific tests (DIN, ASTM etc) unless for technical reasons a particular test is required. This table may change in the future once CEN testing has been introduced.

(2) Test Frequencies of GCL delivered to site should be proportional to MQC testing already carried out by the manufacturer. The frequencies in table 2 assume that the MQC testing frequency is in accordance with Table 1. If, for example, MQC testing is at a higher frequency than Table 1 then CQA testing (Table 2 ) may be reduced proportionately.

E.g. If MQC frequency for Mass per unit area is every 1,000 sq.m. then 1 per 5 rolls for CQA is required

2,000	2 per 5 rolls
3,000	3 per 5 rolls
4,000	4 per 5 rolls
5,000+	every roll

If the MQC testing is less than in Table 1 then CQA testing frequencies (Table 2) should be increased accordingly.

(3) Methylene Blue test results are in units of mg MB/g and provides a value of CEC and consequently an indication of montmorillonite content. Results should be looked at in conjunction with other test results, in itself there is no pass or fail result. The test is also subject to variation because of the differences in materials used and the observations made. Manufacturers should provide a suitable reference sample for the product delivered. 100milliequivalents/100gms = 100% of the reference sample.

(4) Variability in thickness may be a result of additional needle punching or lack of clay, the former may decrease index flux the latter increase it. Where thickness appears to be variable a check against mass per unit area which should identify the cause.

(5) Some GCLs have additional bentonite added to overlap areas necessitating a reduced or non addition of bentonite.

(6) These tests are to be used where the design requires the GCL to have specific requirements. Minimum test frequencies should be 1 per 10,000 sq.m

(7) Results are indicative only and should be looked at in conjunction with the results of other test methods.

## 7.0 Validation report

The validation report presents the final 'as built' record of the works and acts as our permanent record. It must provide a comprehensive record of the construction and be clearly understandable, particularly in terms of the technical detail. You must specify the form of documentation and means of presenting results in your CQA plan.

The information in the validation report should mirror the agreed CQA plan (see 6.1 above) and include all information relevant to the construction. Given you will require validation reports when surrendering your permit, and possibly after that, you should not rely record keeping of outside bodies.

You should include the following information as a minimum in your validation report (most of the items below apply to both the GCL and the attenuation layer):

- a summary of the works undertaken
- details of the CQA presence actually supervising the works (Date, times etc - this should be extracted from the daily logs.
- all of the information collected specified in the CQA plan (see section 6.0) and other sections of this guidance.
- the results of all tests (passes and failures)
- weather conditions;
- delivery of materials;
- plant and labour;
- roll numbers deployed;
- panels installed;
- areas of non-conformance;
- repairs;
- records of site meetings;
- progress photographs;
- any other relevant information
- as built drawings (see below)

The as-built drawings must detail the following:

- construction details including levels and slope angles for the attenuation layer, the GCL and the confining layer;
- locations and identification marks of each GCL panel;
- locations of damaged areas;
- locations of samples;
- locations of penetrations.

Your validation report must contain a statement by your CQA engineer that the works have been carried out in accordance with the working plan (and the method statements and specifications attached to it) and that the validation report (including the drawings and appendices) represent a fair and accurate record of the works.

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## Appendix A - Method for determining the methylene blue value of bentonite

(This test has been developed from the Dutch CUR Recommendation number 33, the source is acknowledged with thanks)

### Purpose and application

This methodology describes how you must determine the absorption of methylene blue by bentonite. The test has been developed for landfill engineering applications where you need to assess the montmorillonite content of clays used in geosynthetic clay liners and bentonite enhanced soils.

### Principle

A bentonite sample dispersed in water must be titrated with a methylene blue solution until a light blue 'halo' appears round a dark blue coloured drop of bentonite suspension on filter paper.

### Requisites

Apparatus: i) analytical balance with a measurement inaccuracy of 0.01 g  
ii) combined magnetic stirrer/hot plate  
iii) drying oven ( $93\pm 3$ )°C and ( $110\pm 5$ )°C  
iv) burette  
v) tripod.

Equipment: i) 300 ml wide-necked Erlenmeyer  
ii) plastic rod  
iii) 1000ml measuring flask  
iv) magnetic stirrer rod  
v) 1 litre polyethylene bottle with screw closure  
vi) 10ml sampling pipette  
vii) 5 ml sampling pipette  
viii) round paper filter with a centre line of 150 mm  
ix) drying scales.

Raw material: i) distilled water  
ii) methylene blue ( $C_{16}H_{18}ClN_3S \cdot x H_2O$  ( $x = 4$  to  $5$ )) p.a  
iii) 0.5 % methylene blue solution  
iv) sulphuric acid 2.5mol  
v) peptisator (saturated solution of tetrasodium diphosphate  $Na_4P_2O_7 \cdot H_2O$ )

## 2.4 Preparation

### 2.4.1 Methylene blue solution

Weigh five grams of undried methylene blue, to an accuracy of 1 mg (A). Dissolve this quantity in 600ml lukewarm distilled water. Decant the solution after 24 hours into a one litre measuring flask. Boil the residue in 100ml water and after it has cooled add to the remainder of the solution in the measuring flask. Then fill the measuring flask up to one litre with distilled water.

Dry around one gram methylene blue (Bv) to constant weight at  $(93 \pm 3)$  °C (Bd). Then calculate the strength of the methylene blue solution in mg  $C_{16}H_{18}ClN_3S_3 \cdot 3H_2O$  per ml, to an accuracy of 0.001 mg MB/ml. Keep the methylene blue solution in a dark room.

#### 2.4.2 Bentonite

Weigh the dry weighing scale (F). Take a representative part sample of the bentonite of around 500 g and determine the weight of the scale with the sample (G). Keep the remaining part of the bentonite sample. Dry the part sample for at least 24 hours to constant weight in a stove of  $(110 \pm 5)$  °C. Then determine the weight of the scale and the dried sample (H). The mass determinations must be carried out to an accuracy of 0.1 g. The moisture content (D) of the bentonite must be calculated accurately to 0.1 %.

#### 2.5 Execution

Weigh 500 mg (E) undried bentonite and transfer this to an Erlenmeyer. Add to this 50 ml of water and 5 ml of peptisator. Then place the Erlenmeyer on the hot plate and stir the contents for 10 minutes. Then heat the whole thing until it boils.

Turn off the hot plate when the liquid is boiling. The bentonite must then be fully in suspension. Wait until the liquid has cooled to room temperature and add 2 ml  $H_2SO_4$  (2.5 mol) and stir the suspension for half a minute. Then add 80 to 90 % of the anticipated final use to methylene blue solution and stir the suspension for  $(120 \pm 10)$  seconds.

Place two pieces of filter paper on top of each other, onto which the liquid must be dotted. Titrate the cooled bentonite suspension with the methylene blue solution and stir the liquid regularly. Every 2 minutes dot a drop from the suspension onto the filter paper using a plastic rod. To determine the end point of the titration, add 1 ml of the MB solution each time, stir the suspension for  $(120 \pm 10)$  seconds and dot again.

Do not add any more MB solution to the suspension when the first halo is seen (the light blue coloration around the dark blue dot). Stir the suspension for  $(120 \pm 10)$  seconds and then dot a drop of the suspension onto the filter paper. If the halo remains, then the end point has been reached. Otherwise another 1 ml must be added and the procedure repeated until the end point is reached.

Note the quantity of MB solution used as the number of ml added at the point when the halo is not quite visible (V).

During the gradual addition of the MB solution the colour of the liquid circle (halo) on the filter paper changes as follows:

- colourless, when the bentonite is not saturated with methylene blue
- light blue, when the bentonite is just saturated (end point)
- blue, when free methylene blue is present.

For a better recognition of the end point it is recommended that the same point be dotted a few more times.

#### 2.6 Calculations

Calculate the concentration of the MB solution in mg MB/ml, from:

$$C = \frac{A \times B_d \times m_{MB \cdot 3H_2O}}{K \times B_v \times m_{MB \cdot 0H_2O}}$$

where:

C is the concentration of the MB solution, in mg MB/ml;

A is the quantity of methylene blue weighed, in mg (solution);

Bv is the quantity of methylene blue weighed, in mg (before drying);  
 Bd is the weight of the methylene blue after drying, in mg;  
 mMB. 3H<sub>2</sub>O is the molecular weight of MB with 3 molecules of water of crystallisation (= 373.90);  
 mMB. 0H<sub>2</sub>O is the molecular weight of MB with 0 molecules water of crystallisation (= 319.85);  
 K is the volume of the measuring flask, in ml (= 1000 ml).

**Calculate the moisture content of the bentonite in % (w/w) with respect to the dry weight, from:**

$$D = \frac{G - H}{H - F} \times 100 \%$$

where:

D = the moisture content of the bentonite with respect to the dry weight, in % (w/w);  
 F = the weight of the scale, in g;  
 G = the weight of the scale and the wet sample, in g;  
 H = the weight of the scale and the dry sample, in g.

**Calculate the methylene blue value of the bentonite, accurately to 10 mg MB/g, from:**

$$MB = \frac{V \times C}{100 + D} \times \frac{E}{100}$$

where:

MB = the methylene blue value of the bentonite, in mg MB/g;  
 V = the quantity of MB solution used, in ml;  
 C = the concentration of the MB solution, in mg MB/ml;  
 E = the quantity of bentonite weighed, in g;  
 D = the moisture content of the bentonite with respect to the dry weight, in % (w/w).

### Example of calculation

weight moist methylene blue	A	= 5000mg
weight before drying	Bv	= 1000 mg
weight after drying	Bd	= 793 mg
MB concentration	C	= 4.635 mg MB/ml
ml used MB solution	V	= 30 ml
weight moist bentonite	E	= 0.506g
moisture content bentonite with respect to dry	D	= 14.4% (w/w)
MB value		= 314 mg MB/g
rounded		= 310 mg MB/g

### Remarks

1. Because of the accuracy required, titration must not be carried out in steps of more than 1 ml.
2. The methylene blue value gives an indication of the montmorillonite content.
3. Because of the strong colouring effect of methylene blue, this substance must be used with care.