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Using Geosynthetic Clay Liners in Landfill Engineering (version 3)

ea/br/e/std/v1

Contents

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. This document is not intended to be an exhaustive design manual but we recommend that any designer or EA Agency Officer involved in assessing GCLs for engineering purposes is familiar with this document. This guidance document has been developed in association with an industry working group, consisting of the British Geomembrane Association and BTTG Testing and Certification.

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 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. 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 GCLs 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.

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. Needle punched (reinforced) GCLs are primarily used in the UK for there high internal shear strength, therefore this document addresses the parameters associated with these products. Where these parameters are not appropriate to the other manufacturing processes (unreinforced) alternative testing methods need to be used to demonstrate their suitability.

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 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 1 (m^3 m^{-2}) 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.

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 is the predominant method used to help hold the clay in place and increase the GCLs 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 in your design. Geotextiles of woven and non woven type can be used in the manufacture of GCLs. Clay particles can escape through some open woven (particularly slit film) and thin non-woven geotextiles, or detach from glued geomembranes. This escape can increase the permeability of the GCL; decrease the friction between it and adjacent 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 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).

Needle punched GCLs contain the clay element and reduce the potential for its migration which may otherwise occur through swelling or point loading once hydrated.

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 bentonite. 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. 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. However there is the potential for cation exchange and the resulting reduction in the swelling, and increase in its permeability characteristics. Ensure that compatibility is confirmed by testing and or with the manufacturer. You must ensure you purchase unmodified sodium bentonite GCLs, as the term 'natural' has various interpretations.

Calcium montmorillonite is a weathering product of 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 (g m^{-2}) to equal the very low permeability achieved by sodium montmorillonite.

Sodium activated montmorillonite is a calcium montmorillonite/bentonite that has been treated with soda ($NaCO_3$ x 10 H_2O) 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. Cation exchange is easier that in a natural sodium bentonite.

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

Where you propose using calcium bentonite, 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 GCLs 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 bentonite.

Sodium montmorillonite swells on contact with water or water vapour to up to fourteen 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 is enhanced. The swelling property of the clay must be an essential part of your testing programme as it's the property fundamental to a GCLs 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 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 unreinforced products.

There is 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 m^2 of sodium bentonite. In the past there has been pressure to reduce dosage rates to as little as 3000 g 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 less sensitive locations. Accordingly, when calculating dosage rates, you must consider the following factors:

- the sensitivity of any receptors (groundwater)
- the effectiveness of the attenuation layer
- the quality and testing rate of the manufacturers quality control (see section 5)
- 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 etc.)
- the nature of the hydrating permeate
- 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 unreinforced 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 needle punched GCLs pushing the geotextiles apart, and allowing bentonite migration and subsequently loss of integrity.

3.0 CE marking & manufacturers quality Control (MQC)

Since the late 1980's the CEN TC 189 committee has standardised testing methods and procedures to encourage continuity and consistency across the industry. Since the early part of 2002 it has become a mandatory requirement to CE mark geosynthetic products to demonstrate compliance with the European Construction Products Directive (Council directive 89/106/EEC) (CPD). Since October 2002, it has been a mandatory requirement to CE mark geosynthetics within the majority of EU member states. The CPD provides for four main elements:

- a system of harmonised technical specifications
- an agreed system of attestation of conformity for each product family
- a framework of notified bodies
- the CE marking of products

The CPD does not aim to harmonise regulations, but the methods of testing and the way in which manufacturers of products report on their performance values and the method of conformity assessment.

CE marking is a *passport* that enables a product to be legally placed on the market within any member state. *CE marking does not mean that the product is suitable for an end us*e. It simply means that the manufacturer has complied with the regulations set out within the CPD and that it must report on the harmonised declared values set out within the standards.

For geosynthetics, there are several standards published by CEN TC 189 for CE marking based on product applications. EN 13492 and EN 13493: Geosynthetics barriers – characteristics required for use in the construction of solid waste disposal sites and geosynthetic barriers. Characteristics required for use in the construction of liquid waste disposal sites, transfer stations or secondary containment, are the applications standards that considers the use of GCL's in landfill engineering and identifies the characteristics that a manufacturer should report on a CE declaration based on a particular function. The testing that needs to be performed on a product depends on the function that the product is required to perform within the application of barrier. Table 1 within EN 13492 and EN 13493 identifies the relevant characteristics that a manufacturer must publish on a CE declaration in line with specific functions. The 'harmonised characteristics' within the table are those which a manufacturer is required to publish on a CE declaration, although the table identifies other characteristics which a designer may wish to consider.

An accrediting body audits the levels of control within the manufacturing process -The manufacturer is then issued with a certificate of factory production control under the guidelines identified within the EN application standards. The accrediting body should then perform regular checks on the manufacturer to ensure that the system is functioning adequately. A manufacturer is required to publish a CE declaration once a product has been CE marked. The declaration identifies properties and tolerance limits relevant to the areas of application and functions highlighted. It also contains a durability statement.

A manufacturer must supply a CE declaration for product delivered to site in accordance with EN 13492 and EN 13493 (identified within this report for this application). The values and tolerances should then be used for evaluation of conformity with the specification in accordance with CEN/TR 15019: On-Site quality control. It must be noted that not all reported characteristics are suitable for conformity testing, and that some test data must be supplied by the manufacturer.

3.2 Manufacturer's quality control data

It is essential that all of the material delivered to site complies with the agreed specification. The quality of the product plays a significant role in the degree of protection afforded by the GCL. Your design report should include information from the manufacturer, on the nature (test types, test frequency, quality standards) of the quality control undertaken on the material in the factory.

Products should be tested in the factory to detect needle fragments and these should be removed prior to the product leaving for the site. Only use products that are inspected to such an extent that the risk of needles being present within the product can be considered as negligible and thus needle free.

3.3 Product Packaging & Identification

Each roll of GCL delivered to site must have a label complying with EN ISO 10320 affixed to it. An EN ISO 10320 label should detail the following:

a) The manufacturer’s name, address, and telephone number.

b) Product identification (product manufacturer's name address and telephone number, production plant location, product name and type).

c) The GCL roll number.

d) The roll length and width in metres.

e) The roll weight in kilograms.

GCLs shall be delivered to site in packaging, which will protect the product from damage during handling, storage. Packaging must be suitable to protect the product from UV degradation. Product must be kept in appropriate packaging until such time that it is required for installation.

The GCL shall be clearly and indelibly marked with the product name along the edge of the roll at regular intervals no greater than 5m.

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.

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 8 - 35%. 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.

4.1 Transport and delivery

Safely delivering your GCL to site is your supplier's responsibility.

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. 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 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 decides 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 or a stinger bar. 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). 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 its 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, stack height should be no more than 4 rolls.

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

- precipitation
- standing water
- ultraviolet radiation
- chemicals
- vandalism, animal and plant infestation
- puncture
- Any other environmental condition that could impact on its 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 [4]	VDG P69/XRD		Once per batch from bentonite supplier	> 300 mg/g or >70%
Swell index/free swell of clay[1]		D 5890	As above	Average
Water absorption[1]	DIN 18132	E 946	As above	As above
Fluid loss of clay[1]		D 5891	As above	Maximum
Moisture content of clay[2]	EN 11465	D 2216	Every 50 tonnes or every 5,000m^2	Average Value
Mass per unit area of finished GCL	EN 14196	D 5993	5,000 m^2	Average per roll
Mass per unit area of bentonite[3]	EN 14196	D 5993	20,000 m^2	Average per roll
Tensile strength of GCL machine direction[6]	EN ISO 10319	D 4595	10,000 m^2	Average per roll
CBR[6]/ puncture resistance of finished GCL	EN ISO 12236	D 6241	50,000 m^2	
Peel strength[5] - needle punched GCL	EN ISO 13426-2	D 6496 Appendix	5,000 m^2	Average per roll
Index Flux		D 5887	25,000 m^2	Maximum value

Notes

1) The tests on the bentonite are to be performed on the as received materials before fabrication into the GCL product.
2) Depending on the use of water in the production, the value is measured as described with[1] in absence of water in the production, or measured at bentonite taken from the final GCL when using water in the production.
3) Can be calculated from Mass per Unit area values of final GCL minus Nominal Mass per Unit area of geotextiles
4) Results are a comparison with a standard sample of known composition.
5) The values obtained using EN ISO 13426-2 are not comparable with ASTM D6496.
6) The maximum value should be reported.

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

The surface upon which the GCL is installed should be smooth and free of debris, roots, sticks, and sharp rocks/boulders larger than 50 mm. Site specific compaction requirements should be followed in accordance with the project plans and specifications. At a minimum, the level of compaction should be such that installation equipment or other construction vehicles that traffic the area of deployment do not cause significant rutting. In applications where the GCL will be subjected to a hydraulic head that exceeds the cover soil confining stress, subgrade surfaces consisting of gravel or granular soils may not be acceptable due to their large void content . For these applications, the top 150 mm of the subgrade soil should possess a particle size distribution where at least 80 percent of the soil is finer than 1 mm with a maximum particle size of 12 mm.

Directly prior to deployment of the GCL, the subgrade shall be final-graded to fill in any remaining voids or desiccation cracks and proof-rolled to ensure that no sharp irregularities or abrupt elevation changes exist greater than 25 mm. The surfaces to be lined shall be maintained in this condition, free of standing water. If required, the subgrade preparation and surface should be inspected and certified by a CQA inspector prior to GCL placement. Upon approval by the CQA inspector, it should be the installer's responsibility to indicate to the engineer any change in the condition of the subgrade that could cause it to be out of compliance with any of the requirements of the project specific specification.

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 GCLs 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. With the advent of Eurocode 7 all future stability analysis should follow this code ensuring the utilization ratio is below 1.

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

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 GCLs clay minerals may be replaced by other ions through adsorption. This in turn will affect the swelling characteristics of the clay, and may increase the GCLs 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 micro cracking of the clay. Subsequent heavy rainfall may then flush more ions through the micro cracks in the GCL, accelerating ion exchange and increasing permeability. This effect can be avoided by ensuring the correct thickness of cover soil (see 5.9).

Landfill gas, vapours and condensates can all adversely affect a GCL if they contain substances harmful to either the clay 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 may consider installing a gas collection layer on the waste side of the GCL to provide a preferential pathway. Whilst GCLs may not have as low gas permeability as a polymeric geomembrane, consideration must be given to the fact GCLs are self healing and not as susceptible to damage due to settlement as polymeric geomembranes are. This is particularly relevant where the cap is connected to penetrations such as landfill gas and leachate extraction points.

5.5 GCL installation

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

You must not install the GCL during adverse weather conditions such as snow or heavy continuous rainfall, due to the possible presence of standing water on the subgrade.

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 CQA 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.

During installation, your CQA Inspector must inspect the whole surface of the GCL, for 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 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 300 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 alternatives 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. 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.

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 within 24 hours of laying the GCL, so that adequate loading of the GCL is provided and you achieve the confining pressure required prior to hydration. Unreinforced GCLs require immediate cover, whereas this is not critical for reinforced GCLs due to the internal confinement created by needle punching.

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 unreinforced 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 GCLs 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 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 dump truck wheels to spin, you should increase the cover thickness as appropriate.

5.5.5 Sampling, transporting samples and laboratories

Note all samples must come directly from the CQA inspector.
It is essential that samples reach the laboratory undamaged.

The label on the sample should include the following information:

- Site name and location
- Date sample taken and sealed.
- Name of sampler
- Material manufacturers name
- Material type, trade name and product name/number

Once packaged, you should send your samples to your chosen UKAS accredited laboratory. It is important to realise that sampling is in accordance with the ASTM D6072 and laboratories are accredited for particular tests. If a laboratory is not accredited for all the tests you require, we recommend you choose the laboratory with the largest number of relevant accreditations. Please note all tests must be carried out by a UKAS accredited laboratory.

The laboratory report must contain full information with sufficient detail to allow us or others to independently verify the calculations.

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 $1m^2$, 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 placed on top of the parent GCL. Bentonite should be placed around the perimeter of the area at a rate of 0.4 kg per metre.

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 inspector is 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 needle punched GCLs performance 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.

It is preferable that GCLs are not hydrated with leachate as this may severely affect the GCLs properties. However, evidence shows that some leachate has 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 GCLs properties.

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.

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 and or confining layer over the GCL. The properties of any cover must be sufficient to ensure than no damage is caused to 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 tends to slip. The installation of protective cover should also receive full CQA supervision.

5.8.1 Mineral protection layers

Only the amount of GCL that can be anchored, inspected, and covered should be installed the same day or prior to any prehydration. In cases where the GCL is the sole hydraulic barrier, the GCL should be covered with the specified thickness of cover soil ≥ 300 mm following deployment. Care must be taken in the overlap areas. During the soil covering overlaps may not be separated. The preferred direction of soil placement is in direction of the overlaps. On slopes a downhill soil placement is typically not recommended due to necking and interface shear strength concerns. The soil should carefully be placed uphill ensuring that the overlap areas are not separated or soil is being pushed into the overlap area. The slope stability must be ensured at all times.

Where GCL is used in conjunction with a geomembrane component it should be covered with the geomembrane as soon as possible after placement to protect it. If it is covered with a geomembrane without any further confining stress and water ingress occurs, the GCL should be investigated. As a minimum for the base and slope the moisture content should be below 50%, on slopes the peel strength should also be tested to ensure the internal friction angle of the GCL has not been compromised. A prehydration of an unconfined (less than 300 mm soil) GCL due to subsoil moisture combined with high surrounding temperatures might cause a movement of the GCL, as seen for unreinforced GCLs. When construction and installation is halted at the end of the day, the GCL must be protected from inclement weather overnight. It is further recommended to place the specified soil confining stress over the sealing system within the same day as the placement of the GCL occurs. When a geomembrane is being installed over the GCL, the leading edge of the GCL should be folded back under the geomembrane so that the geomembrane extends beyond the GCL a minimum of 600 mm. The leading edge of the membrane is subsequently weighted with sand bags or suitable ballast to safeguard against wind uplift and to prevent runoff water from undermining the liner. When GCL is used with no overlying geomembrane the soil cover should be placed within 800 - 500 mm of the leading edge of the GCL. The leading edge can then be covered with plastic sheeting that is folded under the exposed edge approximately 500 mm. Sand bags or suitable ballast should be placed on the protected liner to hold the plastic in place and to partially confine the GCL. The next morning the ballast and the plastic must be removed and subsequent rolls of GCL be placed.

Cover soil placed directly on the GCL should not damage or puncture the GCL. It is recommended that the soil is well graded and particle sizes range between fines and 25 mm. Fine soils and soils with a uniform soil distribution curve are recommended. Appropriate placement methods should be used at all times to protect the GCL. Compatibility of GCL with the soil should be verified. Backfill should be pushed across the seams from top to bottom to prevent the cover material from lodging between the overlapped panels. Only after the cover material has been placed should the GCL be allowed to fully hydrate. Once full hydration has occurred no vehicles should be allowed to traffic the area directly above the GCL unless ≥ 300 mm separation exists between the GCL and the vehicle to adequately distribute the vehicle load for a short period time of pass-over. If frequent traffic is expected over a GCL lined area it is recommended to increase the soil cover to at least 600 mm.

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:

5.9 Desiccation cycle effects

GCLs may not withstand repeated hydration and dehydration cycles if cation exchange can take place 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 that is a lower permeability soil, (such as 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, that is less than 1 metre, 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.

5.10 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 GCLs don'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 leachate 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 leachate 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.

6.0 Construction quality assurance (CQA)

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.

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

- Detail & experience of the CQA inspector.
- A summary of the GCL 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.
- 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 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 CQA plan.
- supervision by CQA Engineer
- testing procedure and reports of field tests
- remedial action on GCL 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 encounters 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 CQA 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.

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.

Where testing indicates a roll doesn't conform to the agreed specification, you should quarantine pending further investigation and assessment for use.

Table 2 Conformance testing

Test description	European test method	ASTM test method	Minimum frequency of test	Report value
Mass per unit area of GCL	EN 14196		1 per 1,000 m^2	As specified in the CQA plan
Mass per unit area of clay component of GCL at manufacturers stated moisture content	EN 14196	D 5993	1 per 2,500m^2	As above
Peel strength[3] (for needle punched products only) (MD only)	EN ISO 13426-2	D 6496 (Appendix)	1 per roll, 2,000 m^2 or 500 on slopes >1:3	As above
Moisture content of clay	DIN 18121	D 2216	1 per roll or 2,000 m^2	≤50%
Swell index/free swell of clay		D 5890	As above	≥24ml
Water absorption	DIN18132 Enslin Neff	E946	As above	≥500%
Tensile strength (MD only)[1]	ISO 10139	D 4595	As specified in the CQA plan	As specified in the CQA plan
CBR[1]/puncture resistance of finished GCL	EN 12236	D 6241	As above	As above
Mass/unit length of bentonite in overlaps[2]	On site visual inspection and/or weighing		1 per 5 panel overlap	≥0.4kg/linear metre
Index Flux		D5887	1 per10,000 m^2 But at least 1 per site	As specified in the CQA Plan
Montmorillonite content	XRD		1 per 20,000 m^2 But at least 1 per site	>70%
Montmorillonite content	VDG P69 (See Appendix A)		1 per 1,000m^2	Same as MQC

1) The maximum value should be reported

2) On-site visual inspection for impregnated GCLs, on-site weighing of additional bentonite to overlaps without impregnation

3) The values obtained using EN ISO 13426-2 are not comparable with ASTM D6496

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.

You should include the following information as a minimum in your validation report:

- 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);
- 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 CQA 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.

Appendix A

Methylene Blue VDG P69

VDG P 69 is a testing procedure coming out of the "Verein deutscher Gießereifachleute" which means "Association of German Casting or Foundry Companies".

Preparing a methylene blue solution:

A 0.5% solution has to be made. In order to prepare 1000 ml methylene blue solution 5 g of methylene blue (in the condition at delivery) have to be solubilised completely as possible. Therefore an Erlenmeyer flask with 600 ml water (room temperature) is used.

After 24 hours the solution will be decanted in a 1000 ml volumetric flask, the residuum cooked in 100 ml water and after having cooled down it has to be filtrated through an ashless filter into the flask and filled up to 1000 ml with cool water. It is recommended to prepare a solution corresponding to the monthly requirement.

The methylene blue solution has to be stored light protected. The concentration of the solution has to be defined depending on the bentonite before use (at least double determination):

Determination of the methylene blue value

Correction factor of the methylene blue solution

Manufacture of methylene blue solution

Calculation of the solution concentration with a standard bentonite (twice):
Example:
0.5 g bentonite (basic/standard) = 24 ml consumption (dried)

$$E = \frac{A}{B} \qquad = \frac{24ml}{0,5g} = 48ml/g$$

$$F = \frac{D}{E} \qquad = \frac{315mg/g}{48ml/g} = 6,56mg/ml$$

6.56 mg/ml - MB-solution concentration

Meaning:

- A = Consumption of MB-solution of the standard bentonite indicated in ml
- B = standard bentonite indicated in g
- D = Default MB-value of the standard bentonite indicated in mg/g
- E = Calculated MB-consumption of the standard bentonite indicated in ml/g
- F = Concentration of the MB-solution indicated in mg/ml

Methylene blue value of the bentonite to test

- The weighed bentonite must be heated in a flask with 50 ml distilled water and
  5 ml Na_4 $P_2 0_7$ (saturated solution $Na_4P_2O_7$. 10 H_2O = mix: 57 g/1000 ml H_2O),
- Stir the solution by cooling,
- Add 10 ml 1n H_2SO_4 (1n H_2SO_4 = mix: 14 ml conc. H_2SO_4 + 486 ml dem. H_2O),
- Add approx. 80 % of the expected amount of methylene blue,
- Stir for 30 minutes,
- Use a glass bar to add drops onto the filter paper,
- Add 1 ml MB-solution at a time until reaching the end point
- The colour change (the so called halo effect) shows the saturation of the bentonite (see fig. 1 VDG leaflet).

Calculation of the methylene blue value – example:

$$G = \frac{A \times F}{B} \qquad = \frac{31ml \times 5{,}625mg/ml}{0{,}4947g} = 352mg/g$$

352 mg/g equivalent to approx. 82 %
(indication: 300 mg/g equivalent to 70 %)

Meaning:

A = consumption of MB of the bentonite to be tested indicated in ml

B = standard bentonite weight to be tested indicated in g

F = concentration of the MB-solution indicated in mg/ml

G = MB-value indicated in mg/g