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Geosynthetic clay liners in developing countries: an African perspective

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ABSTRACT: The South African Department of Water Affairs and Forestry (DWAF), tasked by the South African Government to act as the custodian of the country's water supplies, requires containment liners of varying degrees of complexity and performance for different classes of waste impoundment. Current regulations, contained in the DWAF's Minimum Requirements for Waste Disposal by Landfill (*Minimum Requirements*) documentation, adopt a risk-based structured approach to the complexity of the linings specified. All of these incorporate low-permeability soil layers, including Compacted Clay Liners (CCLs). In hazardous waste facilities, CCLs are combined with geomembrane layers to provide composite liners. Suitable CCL soil is not always economically available on a given site, and admixtures designed to lower the permeability of the in-situ soil cannot always be used, whether for economical or technical reasons. The practical difficulties of constructing competent CCLs in hot climates are illustrated. GCL products have become acceptable alternatives to CCLs. The DWAF conservative approach to the use of a GCL as an alternatives to a CCL is discussed.

1 INTRODUCTION: DWAF REQUIREMENTS FOR LINING SYSTEMS

In October 1998, the DWAF released the second edition of the Waste Management Series (DWAF, 1998) and in particular the document *Minimum Requirements for Waste Disposal by Landfill* (*Minimum Requirements*). Landfills are classified by use into G (General waste) and H (Hazardous waste) – further classified into high hazard waste (H:H sites – hazard rating 1-4) and lesser hazard waste (H:h sites – hazard rating 3 & 4). General sites are further classified by size into S (Small); M (Medium) and L (Large), and finally by site water balance, with B- indicating a negative water balance, and B+ a positive balance. The DWAF has made its waste management documents available on CD-ROM and this is available from the Department on request (contact Mr. Babs Naidoo on bda@dwaf.pwv.gov.za). It is worth noting that the International Solid Waste Association (ISWA) has adopted the SA *Minimum Requirements* as its model for developing countries.

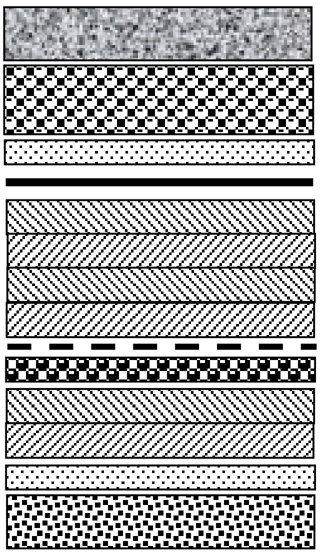

Figure 1. DWAF: Minimum lining requirements for H:H landfills and encapsulation cells (not to scale).

1.1 *Hazardous waste sites*

It is a requirement for a 2.0 mm thick flexible membrane liner in the lining system for H:H and H:h sites and in both systems the geomembrane is placed as a component of the primary liner (see Fig.1).

There is a further requirement for hazardous waste lagoon systems for liquid-containing impoundments. These require a double composite (*i.e.* flexible membrane liner and soil layer) liner system in which the primary and secondary composite liners are separated by a leakage detection and collection layer (See Figure 2.)

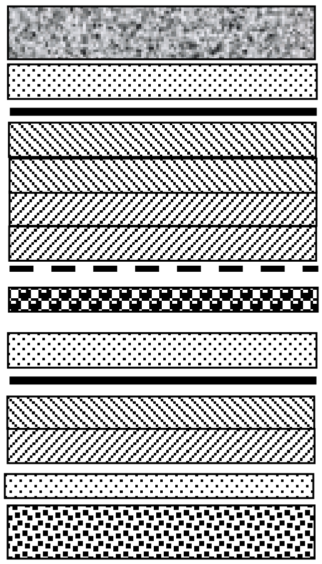

Figure 2. DWAF: Minimum lining requirements for hazardous waste lagoons (not to scale).

1.2 *General waste sites*

In the range of general waste facilities, landfills designated as being situated in a negative water balance area require 300 mm and 450 mm primary clay liners for medium and large sites respectively. Landfills located in areas having a positive water balance require a 300 mm primary clay liner in the case of small sites. In the case of medium sites, the lining arrangements are in line with those required for large B+ sites. For all GMB+ and GLB+ sites, leak detection and leachate collection layers are required beneath the primary liner and separated from it by a geotextile layer. There are numerous permutations and interested parties are referred to the *Minimum Requirements* for more detail.

GCL products have been freely available in South Africa since around 1995 and their application to supplement or replace the CCLs specified by the DWAF in waste disposal facilities is becoming increasingly common practise.

2 CAN GCLS REPLACE OR SUPPLEMENT CCLS?

Where a designer can show that a GCL is appropriate in a given design, the Department has permitted the use of GCLS as a partial (and in some circumstances total) replacement for the CCLs designated in the *Minimum Requirements*. Fig.3 illustrates where this has been allowed on a number of hazardous waste lagoon systems.

In such a system, where DWAF requires a double composite liner as shown in Figure 2, it is practically very difficult to successfully compact a 600 mm thick CCL primary lining to a required permeability of 10^{-7} cm/s over the leakage detection system, on a slope, without damaging the secondary geomembrane.

A properly constructed and installed GCL has been shown to be hydraulically equivalent to up to one metre of clay (10^{-7} cm/s), and when used in a composite liner system with either a CCL or geomembrane the reduction in leakage rate is remarkable. Koerner & Daniel (1995) provide a suggested method for assessing the technical equivalency of a GCL to a CCL. In terms of steady flux of water, the required GCL permeability for equivalence to a CCL is given in Equation (1) below:

$$(k_{GCL})\ required = k_{CCL}\, x\ \frac{t_{GCL}}{t_{CCL}}\ x\ \frac{h + t_{CCL}}{h + t_{GCL}} \qquad (1)$$

Where: k = Permeability, t = thickness of layer, h = depth of liquid ponded on the layer

*E.G., f*or equivalence to a 300mm thick compacted clay liner ($k = 10^{-7}$ cm/s), *(k_{GCL}) required* = 4.6 x 10^{-9} cm/s, provided GCL thickness is adequate and unit hydraulic gradient applies.

For equivalence to a 600mm thick compacted clay liner ($k = 10^{-7}$ cm/s) *(k_{GCL}) required* = 3.4 x 10^{-9} cm/s, subject to assumptions for the first example.

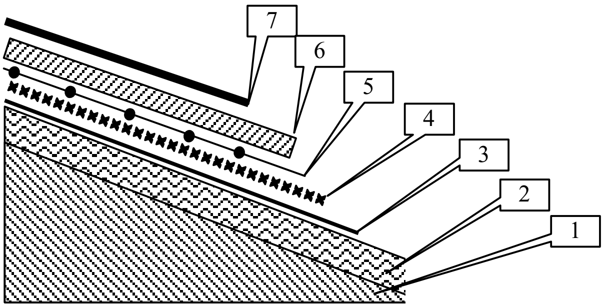

Figure 3. Typical SA hazardous waste lagoon lining layout, where a GCL has replaced a 600 mm thick CCL (not to scale):
1 = Compacted substrate; 2 = 300 mm CCL (1 x 10^{-7} cm/s); 3 = 1.5 mm HDPE geomembrane; 4 = HDPE geonet; 5 = PVC coated PES geomesh; 6 = Needle punched GCL (3 x 10^{-9} cm/s); 7 = 2 mm HDPE Geomembrane

3 INTERFACE SHEAR CONDITIONS

Depending on site conditions such as slope inclination, any secondary geomembrane used, as well as the loading conditions, construction is often hampered due to the low interface friction angle of many geosynthetics (especially when wet). In some applications, a slip-reducing grid has been included in the multiple layer design to both enhance slip resistance (depending on the nature of the PVC coated mesh), as well as reduce the risk of concentrated stress damage to the geosynthetic liners. To date, this “slip reducing” product has been a Polyester mesh which is PVC coated. A typical SA hazardous waste lagoon lining system is shown in Figure 3. When multiple geosynthetic layers are deployed as shown, it is essential that an analysis be done on the loads to be imposed on such a system and the friction values between the various components. Careful thought must also be given to the anchoring of the various constituents at the top of the incline and perhaps even in intermediate slope anchor trenches. There have (in the recent past) been several avoidable failures on waste impoundments with multiple geosynthetic linings, because of the designer not fully comprehending the low friction values between some geosynthetic products.

The hydraulic conductivity of some GCL products available in South Africa is typically 3 x 10^{-9} cm/s. This seems to be a powerful argument to justify the use of a GCL when natural clay or modified soils are very expensive to provide in a given location.

It must be appreciated, however, that the DWAF *Minimum Requirements* are just that and that the Department may not automatically agree to the total replacement of a specified CCL. GCL products are, in comparison to thick clay layers, relatively fragile materials. The finest GCL available will be ineffective should construction machinery damage it when cover layers are placed. The DWAF will assess risk to the environment on a case-by-case basis and specifiers would be wise to submit concept plans to the Department before going to tender with a GCL as a sole replacement for a CCL.

4 WHERE DESIGN PROBLEMS START

It would seem obvious that it is incumbent on the SA specifier to appreciate that GCL products, geomembranes and the associated drainage and reinforcement geosynthetics are (like most construction materials) technical products, the qualities of which need to be understood, then properly specified and correctly applied.

It is regrettable that in SA, some engineers who have neglected to address these issues properly have frequently specified GCL linings as part of waste management facility lining systems that are poorly conceived. To compound this problem, contractors who have neglected to follow the most basic of proper installation techniques have then installed these products (see section 6).

It is not just GCL liners that are poorly treated. The Department stresses that the flexible membrane liner thickness requirements specified in the *Minimum Requirements* are *minimum* thicknesses. However, the SA Bureau of Standards (SABS) 1526 specification for geomembrane thickness allows a tolerance based on method of manufacture of the flexible membrane liner, with blown film being permitted a very generous thickness tolerance. This tolerance can extend to 15% above or below the nominal specified thickness, and is as wide as the notch requirements in certain environmental stress cracking test methods. Accordingly, the DWAF does not recognise the SABS allowable tolerance in its requirements.

Before this requirement was clarified, it happened on more than one occasion that a “2.0 mm HDPE liner” had been called for in a consulting engineer’s specification, without any further qualification (strange, but true . . .). The natural result of this was that some contractors priced on a 2.0 mm *nominal* thickness (where, with the 15% tolerance allowed by the SABS, the thickness priced on was somewhere between 1.70 mm and 2.0 mm. Others pricing on the same projects quoted on a 2.0 mm *minimum* thickness (with a 5% manufacturing tolerance, the manufacturer had to price on a 2.1 mm thickness). With a 0.40 mm pricing advantage, it does not require the cognitive skills of a brain surgeon to guess which tenderer the work was subsequently awarded to on some large projects!

4.1 *GCL issues not always addressed during design*

The GCL products listed above exhibit widely differing external / internal shear resistance and permeability characteristics under service conditions. SA Specifiers should thus ensure they are familiar with the issues surrounding the use of these materials. These topics include: -

- Chemical compatibility of the GCL, including the Bentonite, cover and carrier with the liquid or gas expected to encounter the barrier (*e.g.* EPA test method 9100).
- Hydrated internal shear values of the GCL. This is particularly important when the GCL is to be employed on inclined surfaces (*e.g.* ASTM test method D-6496).
- Shear values of the GCL with the materials above and below it. This is particularly important when the material is to be used in association with other geosynthetics (*e.g.* ASTM test method D-6243).

During and after construction, static loads from the materials above the GCL and dynamic loads from construction equipment will be transmitted through any cover material to the GCL below.

Hydrated Bentonite on its own usually exhibits very low shear strength. Consequently, large static loads can cause a "toothpaste" effect; *i.e.* the hydrated Bentonite will be laterally displaced between the cover and carrier layers or even extruded out through the geotextile. This mechanism is ameliorated when thicker nonwovens are used and the GCL is needle punched. The potential for lateral squeezing will depend largely on the GCL structural system (Koerner & Narejo 1995).

The material supplier usually provides information on the mechanical properties of geosynthetics in isolation. Shear friction angles between geomembranes and other construction materials such as geotextiles; geogrids and soils are seldom determined and SA designers have been known to rely on extremely limited commercial publications. This course of action has its inherent risks, as the duty of care and responsibility for the design remains with the designer. Furthermore, the test methods available through the South African Bureau of Standards specifications are considered incomplete and these documents could well do with updating.

Some SA suppliers and designers have turned to ASTM, DIN, or ISO Standard Methods of testing. However, they remain in an awkward position in that there are very limited facilities for competent testing within South Africa at this time (and none at all for chemical compatibility testing to US EPA 9100).

5 A TYPICAL PROBLEM ASSOCIATED WITH CCL CONSTRUCTION IN HOT CLIMATES

Picture 1 shows one of the reasons why it is very difficult for a contractor to install a competent CCL in hot, dry climates. The cracked material shown is 300 mm thick low-permeability clay specially imported onto site at considerable cost. The lining layout on this project is illustrated in Figure 3. As if the cracks shown were not bad enough, on one occasion a labourer was noted brushing dust and sand into the cracks. He had been instructed to do this “in order to close them”! The lack of skills illustrated in section 6.2 are not limited to GCL installations, and it is likely that the situation demonstrated is common to much CCL construction in South Africa.

Picture 1. Typical CCL desiccation cracking experienced in hot, dry climates.

6 GCL PRODUCTS USED IN SOUTH AFRICA

Worldwide, GCL products have been used in low permeability lining systems since 1986 (Heerten *et al*, 1995) and there are several international manufacturers, exporting a number of different kinds of GCL to South Africa.

6.1 *Adhesive bonded*

The GCL consists of adhesively bonded Bentonite sandwiched between two geotextiles. Alternatively, the Bentonite is bonded to a geomembrane. There are no yarns or fibre connections connecting the upper and lower geotextiles. The adhesive is water-soluble, so once hydrated this kind of GCL cannot transmit shear forces between the layers above and below it.

6.2 *Stitch bonded*

The GCL consists of Bentonite powder contained by stitch bonding or sewing in the machine (long) direction, connecting the upper and lower geotextiles. Sometimes plastic ties are also incorporated. In the past, a lining contractor imported a consignment of this type of material, but found it so unsatisfactory that the exercise was never repeated.

6.3 *Needle punched*

To date, the robustness of this kind of GCL has found most favour in South Africa – partly due to the abuses that are imposed on the material by the practises listed in section 6. Typically, these products consist of Bentonite powder encapsulated by a high density of needle-punched fibres (around 2.5 million per square metre), which extend from the upper nonwoven geotextile cover, through the Bentonite and lower geotextile(s). On some products, these fibres are then thermally locked into place to enhance peel (and therefore shear) strength.

Such a GCL would typically have a hydrated internal shear strength of ≥ 45 kPa (per ASTM D6243). This translates to a capacity for this type of product to permanently resist the shear forces imposed by over four metres of cover soil with a unit weight of 20 kN/m^3, on an incline of 33°, without internal failure occurring, including over the long term (Heerten *et al*, 1995). Some products of this type are also self-sealing along the long edges of the roll (dimensions typically 4.5 m x 35 m) and this can lead to installation that is simpler and more reliable on site, when compared to products that have to be joined using Bentonite pastes and powders. This is important given the situation described in Section 6.

7 SOME ISSUES THAT AFFECT GCL USE IN SOUTH AFRICA

7.1 *Legacies of the past and problems of the present*

The education policy of the former government of South Africa has left South Africa with a large pool of unskilled labour. These people, with an almost complete lack of any kind of proficiency, often end up employed as casual labour on construction sites. When the growing problem of a deficiency of site management skills evident in much of the SA construction industry is added, abuse of GCL products becomes a problem.

This situation has arisen due to the emigration of a considerable section of SA's skilled design and construction staff. These people are leaving South Africa for two key reasons: -

- The change in employment security in a country where since the advent of the *New South Africa*, the construction industry has experienced such a major downturn that many of the major construction companies have survived only by finding work outside of South Africa's borders.
- Skilled civil engineering workers (whose skills and work ethic are much in demand overseas) are leaving SA.

This results in many construction sites being staffed at all levels by uninformed (and often unmotivated) people. Sectoral training programmes are in place to correct this, but it will be some time before any situation of normalcy can be anticipated.

7.2 *How the lack of technical skills affects GCL usage in South Africa*

On site, the authors have frequently noted the following (despite the detailed GCL handling and installation instructions that are issued to the purchasing contractor on receipt of an order): -

- GCL rolls being offloaded from delivery vehicles with one centrally placed sling. As a typical GCL roll mass is of the order of 600kg, this results in the roll "*breaking its back*", causing damage to the internal structure of the GCL.
- Rolls then stored on uneven ground (once again stressing the internal structure of the GCL)
- GCL storage areas in undrained low-lying areas that can be inundated thus causing premature hydration and subsequent displacement of the Bentonite gel when the material is installed.
- GCL stockpiles so high that the bottom rolls are compressed and deformed, thus once again stressing the internal structure.
- Rolls then lifted from the stockpile with (again) one centrally placed sling and transported to the deployment area.
- Rolls allowed to run unchecked down steep slopes, so that when the roll reaches its end, Bentonite powder is caused to fly out of the end as the roll "whips".
- During weather that is clearly changeable, so much GCL laid in advance of cover that there is no hope of cover being deployed in time if it rains.
- After such rain, the prematurely hydrated GCL then being worked over without any attempt to lay load-distribution boards, resulting in the hydrated Bentonite being extruded ("toothpasted") out from underneath the worker's feet.
- To avoid the above Bentonite extrusion problems, some designers allow the double composite liners installed to be completed without hydration of the GCL, which in turn is a significant concern particularly where strong waste liquids would be the first hydrating medium in the event of a geomembrane leak.
- It is however not the GCL alone or in isolation which is abused. Probably the most significant abuse lies in the applications where a GCL is expected to perform beyond its tested parameters in conjunction with the underlying drainage materials.
- In this regard, reference is made to the intrusion of GCL into geonets. Simple arithmetical calculations have been undertaken by some specifiers, to motivate why a GCL should be acceptable above drainage net without any intermediate supporting layer to minimise intrusion of the GCL into the net voids. No consideration is given to the form of extension nor the deformation of the drainage net itself under load nor even the intrusion of the geosynthetic material on the underside of the net into the net voids, further reducing the transmissivity performance.
- While this may seem to be a severe oversight, it is probably not the most common cause of failure of the drainage system. Wind blown and mechanically transported soil from the perimeter trenches deposited on the side walls readily works its way down the side slopes to the intersection with the floor area. At this point, the soil debris accumulates to due to a lower hydraulic gradient and easily blocks the drainage system.
- The authors have yet to see a South African design incorporating a geonet as a drainage layer below a GCL, where the flow characteristics attributable to the orientation of the net within the system has been taken into account in the design. Much research on this has been published and it has been shown that the reduction in flow can be reduced by as much as 80% if the net is not aligned correctly (Sieracke & Maxson, 2001).

8 CONCLUSIONS

- The South African DWAF will (depending on individual site circumstances) look upon GCL liners and other geosynthetics favourably when properly motivated, for use as a partial or complete replacement of the low-permeability soil and drainage layers within a competent lining system.
- Synthetic drainage layers are increasingly finding favour, particularly in lagoon systems and in the steeper wall areas where natural material may be unstable.
- The requirements of the materials discussed, as well as combinations and permutations thereof require special consideration, in particular when designers employ materials whose qualities they do not fully understand.
- While the revised edition of the Waste Management Series brings with it an opportunity for larger volumes of geosynthetics use, it also brings a suite of challenges to the designer and specifier, who are required to ensure the stability and durability of composite liner systems. The same can be said of the construction industry – particularly the specialist lining contractors, who will be required to work harder at ensuring that their site teams are properly qualified to install these multiple lining systems correctly.

9 ACKNOWLEDGEMENT

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