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Geosynthetic Clay Liners (GCLs) vs. Compacted Clay Liners (CCLs) in Landfill Applications – A South African Standpoint

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Abstract

Waste containment facilities in South Africa make use of different lining systems to prevent the migration of leachate and gases from contaminating the underlying ground water sources. These lining systems can be either natural compacted clay liners (CCLs) or geosynthetic materials such as geosynthetic clay liners (GCLs), and a geomembrane made up of high-density polyethylene (HDPE). One of the primary purposes of the GCL or CCL is to serve as a secondary barrier system to supplement the primary HDPE liner to form a composite lining system to prevent any form of leakage. The selection between CCLs or GCLs depends on the classification of waste containment facility, environmental conditions, and economic viability. This paper summaries the important geotechnical characteristics such as composition, hydraulic conductivity and constructability of GCLs and CCLs based on published research findings. This paper also compares geosynthetic clay liner and compacted clay liner based on certain criteria such as thickness, availability of materials, installation, quality control, and vulnerability to damage.

Keywords: *GCL's, Bentonite, Contamination, Landfill, Conductivity*.

1. Introduction

For waste management, South Africa is governed by the waste hierarchy where disposal of waste at landfill sites is the last resort. However, majority of waste in South Africa does make its way to landfill sites and therefore, adequate provisions need to be in place to control the effects of disposal to prevent environmental contamination. As with landfill sites in many other countries, for South Africa, the primary concern is the handling of the leachate that is produced because of waste disposal. The South African regulations attempt to prevent the risk of leachate migration to the ground by ensuring that an engineered landfill consists of a physical separation barrier between the waste body and the groundwater system. This barrier is ultimately constructed using a liner system (DWAF, 1998).

These liners are installed as composite systems in South Africa to contain and redirect the leachate produced at landfill sites. These systems are implemented according to various design considerations, class of waste and regulatory requirements and are are typically composed of a primary liner in the form of an HDPE membrane and a secondary liner in the form of CCLs or GCLs. The primary purpose of this liner is to act as a secondary barrier should the primary barrier fail (Koerner, 1993).

CCLs and GCLs are employed as liners due to their low permeability characteristics, environmental impact, slope applications, availability, self-sealing properties (for GCLs) and cost factors to serve as a hydraulic barrier which minimises and prevents the migration of leachate (Maubeuge, 2012).

The following chapters in this paper focuses on the secondary liners in the form of CCLs and GCLs and zooms into their characteristics pertinent to landfill applications.

2. Composite Clay Liners – CCLs

Traditionally, the impermeable barrier system used in landfill sites in South Africa constituted of natural soils, typically clays. South Africa, being a rich-clay country, these barriers occurred as a natural clay stratum, compacted soil liner or an amended clay liner known as CCLs for the specified requirements (Heckroodt, 1991).

Clay has been adopted in waste containment by various regulatory institutions due to its low permeability attributes and availability. CCLs typically consist of a compacted clay layer ranging from 300mm to 1500mm depending on the quality of clay and the requirements of the landfill site combined with a synthetic geomembrane. The clay component provides low hydraulic conductivity, while the geomembrane enhances puncture resistance and durability (DWS, 2021).

The thickness of the clay layer may vary depending on site-specific factors such as soil composition, groundwater depth, permeability of underlying geology, and anticipated waste types and volumes. Geotechnical investigations and hydrogeological studies are conducted to assess these factors and determine the appropriate thickness of the clay liner to achieve effective containment of leachate.

Composition

The composition of the CCL in landfills in South Africa is dependent on the type and quality of clay found within or near the site to ensure that the use of a CCL is feasible. The composition of the CCL can include the following:

- Bentonite – this is a montmorillonite clay formed from weathering of volcanic ash and is most extensively used in CCLs attributed to its high swelling capacity when hydrated. The swelling property allows the bentonite to create a seal to prevent migration of liquids and contaminants from the waste body. Sodium bentonite is commonly used to due to its significant swelling properties when hydrated, creating a dense and impermeable layer.

- Kaolinite – another clay mineral that is used in CCLs however, this does not have the same swelling properties as bentonite, but kaolinite does exhibit low permeability and acceptable sealing properties. This clay is often used in combination with bentonite or other clay minerals.

- Illite – this clay mineral has moderate swelling properties however has a low permeability which makes it suitable for use as a liner system where a balance between permeability and swell capacity is required (Egloffstein, 2001).

Hydraulic Conductivity

The hydraulic conductivity of a material is often denoted by the symbol *K* and is the ability of a porous medium to transmit fluids under a hydraulic gradient. It is expressed in velocity (e.g. cm/s) and is governed by the regulatory requirements. The typical range for hydraulic conductivity for CCLs in South Africa ranges from 10^{-6}cm/s to 10^{-7}cm/s. This figure depends on the waste classification and daily rate of deposition of waste. Often, the thicker the clay layer, the better the hydraulic conductivity of the liner. The hydraulic conductivity of CCLs is typically determined through laboratory testing using permeameters or in-situ testing methods such as borehole permeability tests or field infiltration tests. Laboratory testing involves subjecting cylindrical or cubic samples of the clay liner to controlled hydraulic gradients and measuring the resulting flow rates (Fourie, 1998).

Environmental Implications

The use of CCLs in a landfill site is highly beneficial if suitable clay material is found within or near the site. This clay can be constructed in compacted layers to achieve the desired engineering and regulatory specifications. This CCL assists in creating an impermeable barrier that prevents the leachate and other contaminants from migrating and polluting groundwater sources (DWAF, 1998). However, should suitable clay not be found within the project site, numerous truckloads of clay will need to be imported to the site which has other environmental impacts relating to the vehicle emissions.

Physical Properties

CCLs are typically installed in 150mm – 300mm compacted layers and are built up to the required thickness – the CCL works optimally where the clay swells during contact with moisture and creates an impermeable barrier. However, in an arid/semi-arid climate like South Africa, materials are exposed to excessive heat which dehydrates the ground. Under dry conditions, the clay undergoes desiccation which causes cracking and hence increases the hydraulic conductivity of the CCL. This ultimately compromises the ability of the CCL to perform as required for the duration of its design life (Koerner, 1993).

Slope Stability

CCLs are known to be installed as barriers on slopes in landfill sites in South Africa. However, studies show that some failures in landfill sites are attributed to the internal and interface shear of CCLs on slopes. Laboratory testing is conducted to evaluate the shear strength properties of CCL materials under representative conditions. Direct shear tests, triaxial compression tests, and ring shear tests may be employed to determine parameters such as cohesion and friction angle. Testing is conducted on samples obtained from the field or prepared in the laboratory to assess the influence of factors such as compaction, moisture content, and clay mineralogy on shear strength (Saravanan, 2007).

CCLs may exhibit reduced slope stability due to the potential for cracking, erosion, and settlement. Slope angles for CCLs are typically limited to ensure stability and prevent slope failure. The interface between the CCL and adjacent materials influences slope stability. Understanding the shear strength properties of this interface is critical for assessing stability and implementing appropriate design measures. Geotechnical testing, interface shear strength analysis, and interface reinforcement techniques may be utilized to enhance slope stability and prevent erosion along the liner interface.

Construction

Before construction begins, the landfill site undergoes thorough site preparation to create a suitable foundation for the CCL. This may involve clearing vegetation, removing topsoil, and grading the site to achieve the desired slope and surface profile. Proper site preparation helps ensure uniform compaction and stability of the CCL. The construction of the CCL typically involves placing multiple layers (150mm to 300mm) of compacted clay material to achieve the desired thickness. The total thickness of the CCL depends on site-specific conditions, regulatory requirements, and engineering design considerations. The use of CCLs involves labour-intensive construction practices and stringent quality control measures to ensure that the layer meets the required specifications (Fourie, 1998).

3. Geosynthetic Clay Liners – GCLs

Before the widespread use of composite liner systems, it was common for geomembranes or compacted clay liners to be relied upon as the sole hydraulic barrier for landfill base liners and closures. However, since the 1980's, after significant technological advancements occurred, GCLs have been adopted as an alternative to CCLs due to its hydraulic properties, availability, transport and construction costs. GCLs can be in the form of a composite liner that consist of a thin layer of bentonite and two geosynthetic layers. The geosynthetic layers used are generally geotextiles. The bentonite – a clay material with high swelling and absorption properties – can be in a powdered or granular form – is laid over the carrier geotextiles and beneath the cover geotextile. The type of these geotextiles can be woven, non-woven or a combination of both, depending on the application. Some GCLs may be reinforced by needle-punching, adhesive bonding and combined with thermal bonding in their production. The thin layers of bentonite in GCLs have excellent impermeable properties toward liquids and GCLs have been used as a secondary liner with a geomembrane to form a composite liner system in landfills, and many other liquid containment purposes in South Africa and internationally (Fourie, 1998).

Composition

GCLs are manufactured in a factory by placing bentonite (granular or powder) between two geotextile layers with the unit weight of the bentonite added being ±4.5kg/m^2. The geotextile layers provide mechanical support, reinforcement, and filtration properties for the bentonite clay core. The product is stitch-bonded or needle-punched which enhances it structural integrity (Herlin, 2002).

- Bentonite Clay – The core component of GCLs is bentonite clay, a naturally occurring, highly expansive clay material known for its excellent hydraulic barrier properties. Bentonite clay has a high cation exchange capacity, allowing it to absorb water and swell, effectively sealing off pathways for fluid migration.

- Geotextile Layers – Bentonite clay is encapsulated between two layers of geotextile fabric, forming a sandwich-like structure. The geotextile layers also act as filter fabrics, allowing water to pass through while preventing the migration of fine clay particles. Geotextile materials used in GCLs are typically woven or non-woven fabrics made from synthetic polymers such as polypropylene or polyester.

- Stitching or Bonding – The geotextile layers are stitched or bonded together around the edges to form a cohesive, durable liner system. Stitching or bonding helps secure the geotextile layers in place and prevents separation or delamination during installation and operation. Various stitching patterns and bonding methods may be employed, depending on the specific requirements of the application and manufacturer's specifications (Herlin, 2002).

Hydraulic Conductivity

One of the desired properties of utilising a GCL in containment applications is the hydraulic conductivity of the bentonite layer – upon swelling, the GCL creates an impermeable layer that prevents the migration of contaminants through the liner system. The permeability of GCLs varies depending on factors such as the type and quality of bentonite clay used, the thickness of the clay layer, the properties of the geotextile layers, and the hydration state of the bentonite clay. Generally, the permeability of GCLs falls within the range of 10^{-7} to 10^{-9} cm/s (Egloffstein, 2001).

Environmental Implications

GCLs offer long-term containment of contaminants within landfill cells which fulfils the mandate of the regulatory requirements even under the warm and dry climatic conditions in South Africa. The self-sealing properties of bentonite clay within GCLs help maintain the integrity of the liner system by sealing small defects and preventing the migration of fluids. This enhances the overall effectiveness of landfill containment systems and reduces the risk of environmental contamination over time.

The use of GCLs in landfill sites also minimizes habitat disruption and land degradation. GCLs require less excavation and earthmoving activities during installation, resulting in reduced disturbance to natural ecosystems and wildlife habitats. The prefabricated nature of GCLs reduces the need for on-site soil excavation and compaction, resulting in lower energy consumption and reduced carbon emissions associated with construction activities. Additionally, GCLs use less natural clay material compared to CCLs, preserving natural resources and minimizing environmental impact.

Physical Properties

GCLs are relatively thin composite elements in a liner system with an average thickness of 7mm. The mass of the GCL is attributed mainly to the mass of the bentonite layer with an approximate mass of 4000g/m^2 – depending on the grade and application. Contrary to CCLs, GCLs are not as drastically affected by the arid South African climate; laboratory testing has shown that GCLs do not undergo an increase in hydraulic conductivity because of desiccation and cracking due to climatic conditions.

Wetting and drying cycles causes the GCL to swell and shrink however, the desiccation of a wet GCL does cause cracking but upon rehydration of the GCL, the bentonite swells and the material self-heals (Koerner, 1993).

Slope Stability

GCL technology can be installed on steep slopes, sometime exceeding 2:1. Depending on the configuration of the barrier system, GCL technology can provide considerable shear strength. A geotextile-backed GCL, with bentonite attached via stitch bonding, provides additional internal resistance to shear in the clay layer. Needle punching yields an even stronger, more rigid barrier. These GCL configurations provide enhanced interface friction resistance to the adjoining layer, an important consideration for landfill slopes. The self-sealing properties of bentonite clay help maintain slope integrity and prevent erosion, allowing for steeper slope angles and more efficient land use (Herlin, 2002).

Construction

The installation of GCLs is relatively simple but require stringent installation practices to ensure proper placement, alignment, and performance of the liner system. Before installing GCLs, the landfill site must be properly prepared to provide a stable foundation for the liner system. Site preparation activities may include clearing vegetation, removing debris, grading the subgrade to achieve the desired slope and compaction, and installing drainage features as needed to manage surface water runoff.

Prior to installation, the surface of the subgrade should be inspected to identify any irregularities, debris, or sharp objects that could damage the GCL or compromise its performance.

GCL panels are typically prefabricated off-site and delivered to the landfill in rolls or sheets. During installation, the panels are rolled out and aligned on the prepared subgrade according to the project design and layout specifications. Care should be taken to ensure proper alignment, overlap, and sealing between adjacent panels to achieve a continuous liner system. Seams between GCL panels must be properly prepared and joined to create a watertight barrier. This may involve overlapping the panels by a specified distance and applying a compatible adhesive to bond the geotextile layers together.

GCL panels should be anchored and secured to prevent movement or displacement during and after installation. Anchoring methods may include using stakes, nails, or other mechanical fasteners to secure the panels to the subgrade or adjacent structures.

The performance of the GCL in landfill applications depends on a key factor which is the interaction between the GCL, and the leachate produced. Leachates contain dissolved salts, organic compounds, and potentially heavy metals derived from decomposing waste. These substances can chemically interact with the clay minerals in the GCL. For example, certain ions present in the leachate can exchange with ions in the clay structure, altering its composition and reducing its swelling capacity. This chemical alteration can compromise the GCL's ability to maintain a low hydraulic conductivity and effectively block the passage of leachate. The chemical and physical properties of the GCL need to be compatible with the leachate to prevent any degradation of the GCL upon reaction with the leachate during the short- and long-term exposure.

Certain GCLs where granular bentonite is used, require hydration once installed. The hydration is imperative to ensure that the GCL is not over nor under hydrated – this could affect the performance of the GCL should it not be hydrated according to the specifications.

Once installed, GCLs should be covered and protected to prevent damage from exposure to sunlight, weathering, and mechanical abrasion. Protective measures may include covering the GCL with a layer of soil, geotextile fabric, or other protective materials to shield it from environmental factors and ensure long-term performance (Kaytech, 2013).

4. Comparisons between CCLs and GCLs

As discussed above, both CCLs and GCLs have many benefits and shortcomings as well. The advantages and disadvantages are highlighted in table 1:

Table 1. The comparison between CCLs and GCLs

	CCLs	GCLs
Advantages	• Cost effective – if clay is available within the site. • Labour intensive – creates employment in South Africa. • Simple construction method • Thicker layer resists puncture	• Rapid installation • Very low hydraulic conductivity • Lower costs • Excellent freeze/thaw properties • Excellent self-sealing properties • Manufactured to a high quality. • Lower volume consumed by liner. • Easy to repair. • Enhanced slope stability • Minimal environmental impact • Long term performance • Withstands differential settlement
Disadvantages	• Higher hydraulic conductivity • Limited slope stability • Environmental impact – land degradation • Labour intensive • Longer construction times • Susceptible to desiccation and cracking • Difficult to repair if damaged	• Complex installation process • Possible ion exchange – increasing hydraulic conductivity. • Easily punctured during or after installation • Could be costly if required to be imported.

Based on the above and past research, the use of GCLs is far superior to that of CCLs. In a country like South Africa where employment is a major challenge, using CCLs assists in the governments mandate of creating employment however, this can also be a disadvantage where the construction time of such a project is prolonged increasing the costs. GCLs on the other hand provides for a much quicker installation. A cost comparison between a CCL and GCL is difficult as there are various factors that determine the cost of such.

5. Conclusion

This paper presented an overview of CCLs compared to GCLs in the South African context. It has been noted that there are numerous advantages of GCLs over CCLs. These include better resistance to the arid/semi-arid climate of South Africa, better self-healing properties, less vulnerability to damage from differential settlement, less consumption of landfill space, easier and faster to construct and greater ease of quality assurance. GCLs will probably cost less than CCLs for many if not most sites. The major disadvantage of GCLs is the greater vulnerability to puncture damage. Although GCLs are not without limitations, their favourable properties are sufficiently advantageous to be used as containment barriers in the South African landscape if installed correctly and relevant chemical and physical property tests are conducted and approved.

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