GEOSYNTHETIC CLAY LINERS FOR THE PETROLEUM STORAGE, CONVEYANCE & REFINING INDUSTRY

The benefits of utilizing a GCL versus compacted clay in containment applications will be discussed in the paper. Some of the benefits discussed will be the GCLs lower permeability of $5x10^{-9}$ cm/s, better composite liner leakage protection, resistance to the effects of freeze-thaw cycles, resistance to differential subsidence and lastly the ease and speed of installation. Examples of applications where GCLs have been successfully used includes; Tanks Containment facilities, Runoff or Stormwater protection, Wastewater impoundment's, Engineered Wetlands, Landfill liners, Remediation or Landfill caps and Biotreatment Pad liners. Design issues regarding the use of a GCL will also be discussed.

GEOSYNTHETIC CLAY LINERS FOR THE PETROLEUM STORAGE, CONVEYANCE, & REFINING INDUSTRY

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ABSTRACT

Geosynthetic clay liners (GCLs) are manufactured barrier layers containing high quality sodium bentonite clay attached or adhered to geotextiles or a geomembrane. The GCL's low permeability and high strength make it an ideal replacement for containment or capping projects with petroleum, storage, conveyance, or refining industries.

This paper will discuss the benefits of utilizing a GCL versus compacted clay in containment applications. Some of the benefits to be compared include the GCL's lower permeability (5 x 10^{-9} centimeters per second (cm/sec)) and corresponding better composite liner leakage protection, secondly, the GCL's greater resistance to differential subsidence and freeze-thaw, and lastly, the ease and speed of installing the GCL. Additionally, the GCL will not effect the operation of a conventional cathodic protection system.

GCLs have been used as primary or secondary containment in bulk tank farms, process fluid ponds, and pipeline liners. GCLs are also used to cap petroleum-impacted soil or waste; and used as a primary liner in bioremediation pads or constructed wetlands. This paper will provide case studies presenting some of these applications.

MATERIAL PROPERTIES

A GCL is a high quality, high-swelling sodium bentonite clay adhered or attached to manufactured geotextiles or flexible geomembranes. GCLs have been manufactured since the mid-1980's, initially used in double-lined landfill liner systems (Koerner, R.M., 1996). The structure of interlayer sodium cations makes sodium bentonite hydrophilic (water attracting). The sodium cation clay structure readily accepts water molecules so that little free-water space is available in the clay voids, hence, maximum water permeabilities of 5 x 10^{-9} cm/sec are readily obtained using GCLs. GCLs contain clays that have high swell index characteristics of at least 24 ml per 2 grams of bentonite using ASTM Method D-5890, and maximum fluid loss values of 18 ml using ASTM Method D-5891. All GCLs contain an industry standard minimum of 3.65 kilograms of sodium bentonite clay per square meter of material as measured using ASTM Method D-5993.

There are unreinforced and reinforced GCLs available for use. Unreinforced products are manufactured using either adhesives and/or pressure. These products incorporate the use of a geotextile or flexible geomembrane to carry the bentonite layer. The unreinforced GCL is used on slopes gentler than 10:1, such as on the flat areas around and under aboveground tanks, fluid containment basins, and remediation covers. The reinforced GCLs are manufactured by needlepunching or stitch bonding the top and bottom geotextiles together to encapsulate the sodium bentonite layer. The physical bonding of the geotextiles enhances the GCLs internal resistance to shearing and creep.

One of the unique benefits of GCLs is its self-healing capability. Should the GCL be punctured, the bentonite will flow into the puncture area and seal the puncture. Research has shown that GCL bentonite will self-seal punctures up to 25 mm in diameter.

Field quality assurance is minimized when using GCLs because the GCL is a pre-manufactured product certified by the manufacturer to meet the design performance requirements. By contrast, field quality assurance is critical to the performance of a liner project when constructing a compacted clay liner (CCL).

DESIGN ISSUES

The design of a GCL barrier layer is similar to other geosynthetic barrier layers. Some issues that have to be taken in account for reliable design of GCL barrier layers are discussed in Table 1.

INSTALLATION ISSUES

GCL is typically manufactured in rolls 4.4 to 4.6 meters wide and 45.7 meters long, and weigh upwards of 1,200 kilograms, so applicable offloading and installing equipment should be used that can withstand the heavy roll loads. GCL is typically offloaded from flatbed trailer trucks using either a spreader bar, carpet pole (stinger), or properly positioned lifting straps (usually 3 are positioned equidistant across the roll).

- Normal Installation

  The GCL panels are usually deployed onto a prepared subgrade using a spreader-bar attached to a rubber-tired deployment vehicle such as a front-end loader, forklift, wheeled or tracked excavator, or rubber-tired ATV. The deployed GCL panels are normally overlapped 150 to 300 mm depending upon the application. If the GCL is not self-seaming (i.e., needlepunched products), then a thin layer of granular sodium bentonite is applied in the overlap seam at a typical rate of 0.45 kg of bentonite per lineal meter. Self-seaming GCLs (i.e. Claymax) do not require the additional sodium bentonite.

- Protrusions

  GCLs are installed around protrusions by cutting an undersized hole around the protrusion, fitting the GCL into place, and placing about 1-2 kg of granular sodium bentonite per 300 mm of circumference around the protrusion and GCL interface. A product called bentonite mastic can also be applied as a paste onto the GCL/protrusion junction.

- **Tank Ringwalls or Tank Chimes**

  There are various methods to properly install GCLs onto tank ringwalls both underneath and outside the tank area. The most common approach is to excavate a pilot trench around the ringwall and place approximately 3 kg of granular sodium bentonite per lineal meter of ringwall circumference. Following bentonite addition, the GCL panels are placed up to the junction with the ringwall structure. Another 0.75 to 1.0 kg of granular bentonite per lineal meter is placed at the GCL/ringwall junction. A typical 600 mm wide strip of GCL panel is then placed up the ringwall 150 to 300 mm and overlapped on the basal GCL panel at least 300 mm. This overlap strip is fastened onto the ringwall using bentonite mastic or in some cases concrete fasteners. This approach can also be used for new tanks or for retrofitting existing tank ringwalls or chimes.

  The GCL is then covered with at least a 300-mm lift of sand or soil and leak detection appurtenances and, if needed, permanent electrodes are installed. Cathodic protection (CP) anodes are usually installed into the subgrade below the GCL before the GCL is installed. Horizontal CP systems are not likely needed for a GCL barrier layer system because the sodium bentonite is fully conductive. See May (1992) for more discussion regarding compatibility of GCLs with CP systems.

- **Sideslopes and Berms**

  On sideslopes, GCLs can be either run-out over the crest of the slope, or anchored into the crest by employing an anchor trench. The depth and width of the anchor trench is dependent on the length of slope and normal and/or dynamic shearing forces.

- **Initial Hydration**

  GCLs will almost always hydrate normally over time from the mass transfer of normal soil moisture into the bentonite structure. For tank containment applications, it is almost always necessary to initially hydrate the GCL after placing the necessary soil cover on top. This initial hydration can be done by “flooding” the cover soil with water enough to provide a wetting front that contacts the GCL and hydrates it to over 100 percent by weight water (Daniel, 1993). The authors recommend hydrating the GCL after covering with the soil. Take special care to apply enough water on the berm areas so that the GCL on the berm is adequately hydrated.

MAINTENANCE ISSUES

- **Moisture Retention**

  One concern of the GCL in tank containment applications is long-term moisture retention of the GCL. Daniel and Shan (1993) have observed that GCL moisture contents of 100 percent by weight are needed. There has been controlled moisture retention studies using bentonite mats that have measured sufficient moisture in the GCL even after the overlying soil is almost completely dried out. Bennett and Luettich (1989) reported on a GCL moisture retention study where drought conditions were simulated with different soil thickness and moisture contents. The study reported that at a GCL confining stress of 3.5 and 8.0 kPa (about 200 and 450 mm thick soil layer), the GCL moisture content exceeded 240% by weight even though the overlying soil contained final moisture contents of only 1% and 5% by weight.

If moisture retention is a long-term maintenance concern, the authors suggest adding water to the overlying soil every 3 to 6 months at a site-specific rate that depends upon the evapotranspiration rate, and field capacity of the cover soil. This maintenance watering can be conducted using portable sprinklers, or by flooding the in-situ leak detection system that may or may not be required as part of the tank containment. The authors recommend that enough water be applied to the cover soil that a "wetting front" of water penetrates the cover soil and hydrates the GCL to moisture contents exceeding 100% by weight.

- Damage Repairs
  If the GCL gets damaged due to maintenance issues or additional construction, a patch of GCL should placed over the damaged area with about 300 mm of overlap in all directions. Granular bentonite should be used in the overlap if required by the manufacturer.

APPLICATIONS

There are a number of proven applications using GCLs in the petroleum industry. These applications are summarized below.

Tank containment – The principal application for GCLs in the petroleum industry. Over one million m^2 of GCL has been installed in the past 10 years in petroleum storage tanks. GCL has provided secondary containment for tanks containing among others, crude, Bunker C oils, aviation fuel, gasoline, diesel, and MTBE.

Runoff or stormwater protection – GCL has been installed in stormwater collection channels and impoundments in order to contain hydrocarbon-impacted runoff from impacting groundwater. Typically, GCL is installed as a sole barrier layer in these applications where compacted clay is too expensive, or geomembranes are not necessary.

Wastewater impoundments – GCLs are used as primary or secondary barrier layers in wastewater ponds or structures to help protect the underlying groundwater. Most applications contain a primary polyethylene geomembrane underlain by a GCL.

Engineered wetlands – GCLs are being installed in shallow engineered wetlands to reduce percolation and water loss. Roots have been shown not to impact the permeability of hydrated GCL, so engineers are increasingly specifying GCLs in this application.

Landfill liners – Most GCL worldwide is used as a secondary bottom liner in GCL/HDPE composite liners for municipal solid waste (MSW) landfills. GCLs are also used as primary or secondary liners in non-RCRA industrial landfills for containing petroleum-impacted wastes or debris. GCLs have been used in RCRA Subtitle C landfills as secondary barriers replacing a portion or all of the compacted clay requirements.

Remediation or landfill caps – GCLs are commonly used to cover old landfills or impacted soil areas as part of a closure or remediation project. GCL is cost-effective versus using compacted clay and has better long-term hydraulic performance in caps where desiccation, freeze-thaw, and/or differential settlement may be an issue.

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Biotreatment pad liners – GCLs has been used as primary or secondary barriers for fixed or temporary biotreatment pad liners in active operations or during site remediation. The GCL is easy to install and minimizes the time to complete construction of these structures.

CASE STUDIES

A brief discussion of relevant projects related to the petroleum industry are discussed below.

MTBE tank containment – Approximately 15,000 m^2 of unreinforced GCL was used as the primary containment liner in a new MTBE tank farm constructed in 1993 at a San Francisco Bay Area refinery. The tank project was part of the refinery's Clean Fuels Program.

Bulk tank containment, Rocky Mountain area – Approximately 13,000 m^2 of reinforced GCL was used for retrofitting a bulk tank farm in Grand Junction, Colorado. The project was conducted in January 1998 under occasional sub-freezing temperatures.

Texas refinery tank farm containment – Over 100,000 m^2 of GCL has been used for secondary containment around new and existing tanks at a large Texas refinery. The GCL has been used in lining tank farms containing crude and refined petroleum products. These projects have been on going between 1991 and 1997.

Major airport fuel tank containment – Approximately 38,000 m^2 of reinforced GCL was used for retrofitting a tank farm containing aviation fuel at the JFK Airport in New York State. The GCL was installed in 1992 as part of the requirements set up by the New York State Dept. of Environmental Conservation (NYSDEC). One design issue was the veneer stability of the 1:1 to 1.5:1 berms. Geosynthetic reinforcement was utilized in some areas where asphalt cover veneer was observed to creep because of the steep berm angles.

Remediation waste cover – Approximately 60,000 m^2 of geomembrane-backed GCL was installed over stabilized refinery and petroleum waste at a refinery in Utah. The project was completed in 1998. Extensive compatibility testing between the stabilized waste and the GCL bentonite was conducted during the project design.

Refinery landfill cover – Approximately 25,000 m^2 of reinforced GCL was installed as a secondary barrier cover for the closure of a RCRA-regulated landfill in the San Francisco Bay Area. The GCL was overlain by 60-mil HDPE and geocomposite drainage blanket (GDB). The landfill waste was composed of municipal solid waste, construction debris and petroleum-impacted waste. This project was completed in 1997.

RCRA landfill cover – Approximately 200,000 m^2 of unreinforced and reinforced GCL was utilized as a secondary barrier layer on two highly regulated RCRA landfills in the San Francisco Bay Area. The GCL was overlain by 80-mil HDPE and geocomposite drainage blanket. The use of the GCL saved the landfill owner a substantial amount of money over using 450 to 600 mm layer of compacted clay. The use of the GCL also helped accelerate the construction into one season.

Soil remediation cover – Approximately 3,000 m^2 of unreinforced GCL was used to cover petroleum-impacted soil at a California State Conservation Camp in Jamestown, California. The high concentrations of hydrocarbons and high costs of offsite disposal made the GCL a feasible option to cap the material in place instead of using bioremediation, soil venting, or offsite disposal. The project was completed in 1994.

Soil bioremediation liner – Approximately 8,000 m^2 of unreinforced GCL was used as a base liner for a temporary bioremediation project at a closed US Navy bulk loading facility in the Torrance, California area. The GCL was used as a primary liner to control the migration of fuel hydrocarbons into the groundwater during bioremediation. The project was constructed and completed in 1994.

SUMMARY

GCLs have a proven track record in the petroleum industry as primary or secondary barriers for secondary containment, fluid storage, runoff control, remediation covers, landfill liners and covers, and engineered wetlands.

GCLs provide a superior manufactured clay barrier layer that is self-healing and not affected by freeze-thaw, and differential settlement. The GCL is easily installed around protrusions, and in difficult site conditions and weather. Conventional cathodic protection (CP) systems can be used with a GCL barrier layer.

Maintaining a GCL's long term hydraulic performance in tank containment systems requires minimal upkeep such as insuring proper moisture content.

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Table 1. GCL design issues.

Design issues	Suggested design activities
Freeze-thaw	This design issue should not affect the performance of the GCL (see Kraus, et al, 1997, and Hewitt and Daniel, 1997), however, freeze-thaw could affect overlying drainage systems and vegetation growth.
Root penetration	If deep-rooted shrubs or trees are planted, CETCO recommends digging a pilot hole first through the GCL, installing the vegetation, then backfilling with granular bentonite at the junction of the GCL and trunk.
Differential settlement	Most GCLs can withstand over 10 percent tensile strain before hydraulic conductivity increases (see LaGatta et al, 1997), therefore, this should not be a critical design issue for most GCL applications. If settlement is still a concern, increase overlap of panels to 300 to 450 mm to minimize panel overlap “pullout.”
Static and dynamic loading	In most instances, GCLs will behave properly under high normal or dynamic loads (i.e. dynamic truck traffic) once covered with at least 300 mm of protective soil cover. If needed, geosynthetic reinforcement layers (geogrids and/or high strength geotextiles) can be utilized in critical load situations on truck ramps or berms where high traffic is anticipated. See Richardson (1997) for more discussion about GCL loading and stability issues.
Subgrade preparation	Subgrade needs to be prepared so that protrusions greater than 13 millimeters are minimized. Additionally, subgrade should contain minimal voids caused by coarse-grained soil material. If the project dictates a cushion separation layer between GCL and subgrade, a 150-mm sand mattress layer or geosynthetic cushion material can be specified.
Veneer stability	Steep sideslope applications (containment berms or caps) should be designed to provide adequate factor of safety between the GCL and veneer cover soil. Slope length, slope inclination, soil composition, normal and/or dynamic loading should be evaluated to determine whether veneer reinforcement is necessary.
Chemical compatibility	Design using subgrade and cover soils that do not have elevated leachable Ca^{++} and Mg^{++}. Conduct tier 1 (ASTMD6141) and 2 (hydraulic conductivity) compatibility tests on soil leachate. Soil leachate can be generated using simulated rainwater mixed with soil similar to EPA Synthetic Precipitation leaching procedure (SPLP). If tier 2 tests indicate a higher than anticipated hydraulic conductivity, then design a GCL with a chemical resistant bentonite or use a composite laminate GCL. See Ruhl and Daniel (1997) for discussion on how GCL bentonite can react with chemical permeants.