Advances in Geosynthetic Clay Liners (GCLs)

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ABSTRACT
Geosynthetic Clay Liners (GCLs) have been available for five decades now, yet engineers and lining designers are still specifying low grade GCLs from the 1980s for their projects. When GCLs were first created they were stitched bonded together restricting their use to flat applications only. Needlepunched GCLs were created in the late 80s to allow them to be used in slope applications. Over the years thicker textiles have been used in GCLs with much higher peel and tensile values as well as more weather resistant GCLs. These higher grade GCLs have been made and proven by academia to be quite effective over original low grade GCLs. Yet time and after time, project tenders keep using the old 'copy & paste' over & over again to specify low grade GCLs when more effective GCLs are readily available to protect our environment based on their proven performance done in numerous research testing. This paper and presentation will summarize recent research publications and the advances in GCLs. Engineers need to upgrade their GCLs specifications in landfill and mining base designs as well as lining requirements for projects in the far north.

RÉSUMÉ
Les revêtements géosynthétiques en argile (GCL) sont disponibles depuis cinq décennies maintenant, mais les ingénieurs et les concepteurs de revêtements continuent de spécifier des GCL de faible qualité datant des années 1980 pour leurs projets. Lorsque les GCL ont été créées pour la première fois, elles étaient assemblées, limitant leur utilisation aux applications plates uniquement. Les GCL aiguilletés ont été créés à la fin des années 80 pour permettre leur utilisation dans les applications en pente. Au fil des années, des textiles plus épais ont été utilisés dans les GCL, avec des valeurs de pelage et de traction beaucoup plus élevées, ainsi que des GCL plus résistants aux intempéries. Ces GCL de qualité supérieure ont été fabriqués et prouvés par le monde universitaire comme étant très efficaces par rapport aux GCL originaux de faible qualité. Pourtant, à maintes reprises, les appels d'offres de projets continuent d'utiliser l'ancien « copier-coller » encore et encore pour spécifier des GCL de faible qualité alors que des GCL plus efficaces sont facilement disponibles pour protéger notre environnement sur la base de leurs performances prouvées lors de nombreux tests de recherche. Cet article et cette présentation résumeront les publications de recherche récentes et les progrès des GCL. Les ingénieurs doivent mettre à niveau leurs spécifications GCL dans la conception des décharges et des bases minières, ainsi que dans les exigences en matière de revêtement pour les projets dans le Grand Nord.

1 INTRODUCTION

Geosynthetic Clay Liners (GCLs) come in various forms and performance grades. From stitched bonded GCLs to needlepunched GCLs to glued bentonite onto a geomembrane. Stitched bonded GCLs which were introduced and made in the 1980s were the infancy of GCLs, however they could only be used in flat applications due the fact that the top fabric had no interlocking strength to the bottom fabric. Stitched bonded GCLs are still made and available on the market, however as mentioned, should only be used and deployed in dry flat conditions. GCLs that have glued bentonite directly to a geomembranes have been found to have a lower permeability bentonite performance due to the introduction of the glue. Needlepunched GCLs entered the market in the late 1980s to address slope stability challenges by providing an interlocking peel strength between the top and bottom fabrics of the GCL and was shown by numerous laboratory and field testing studies that needlepunched GCLs could be used in steep slope applications without any internal shear failures. In applications where numerous geosynthetics materials and layers are used, it should be mentioned that a slope failure will occur between certain geosynthetic materials and/or soils before a high peel strength needlepunched GCL will fail internal.

Needlepunched GCLs over the decades have improved since the late 1980s to have high peel strength values with increased textile thicknesses to ensure their performance in steep applications while ensuring their low permeability performance is upheld.

2 THE IMPORTANCE OF A SCRIM-REINFORCED DOUBLE NONWOVEN GCL

Double nonwoven GCLs offer a more robust material compared to low peel strength Nonwoven/Woven GCLs, however double nonwoven GCLs need to be scrim-reinforced (scrim = woven). Not all double nonwoven GCL are scrim-reinforced. Not having a woven (scrim) fabric in a double nonwoven GCLs can lead to numerous known material failures under certain conditions. All double nonwoven GCLs should have a bottom scrim-nonwoven fabric.

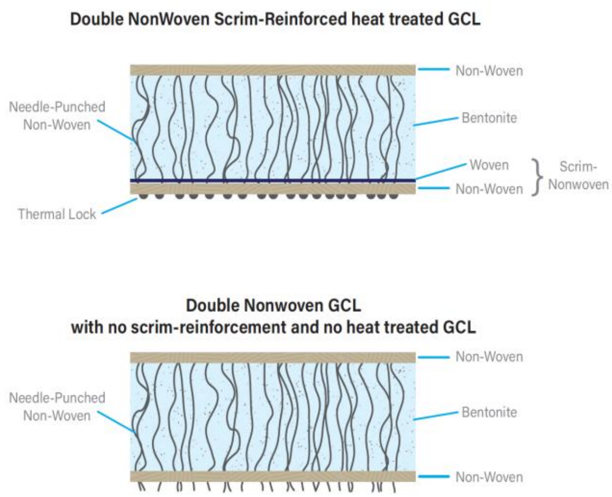

Figure 1. Cross-section of a Scrim-Reinforced Double Nonwoven GCL vs a Double Nonwoven GCL with no scrim-reinforcement.

Consequences to not having a scrim-nonwoven bottom fabric in a double nonwoven GCL can lead to an internal piping loss of the bentonite through a nonwoven fabric if the subgrade that the GCL is resting on is not compacted properly. In hydraulic head conditions such as ponds, the bentonite will be squeezed out of the nonwoven fabric if the subgrade contains voids, rocks, and/or gravel. Not all subgrades are prepared as per GCL construction guideline requirements issued by manufacturers due to either terrible site conditions and/or the lack of attention to details by the contractor(s) or project engineer(s) on site. In cases where the subgrade is rough in nature and/or not prepared according to acceptable guidelines for a GCL then a bottom scrim-nonwoven fabric is of the outmost importance.

Numerous research papers over the past couple of decades have continuously shown that not having a scrim-reinforced bottom nonwoven fabric (scrim-nonwoven) leads to internal loss of the bentonite. Rowe and Orsini's paper in 2002 at the Clay Geosynthetic Barriers conference in Nuremberg clearly showed the importance of a scrim-nonwoven bottom fabric in a GCL in their paper.

"Under high hydraulic gradients, GCLs with conventional woven or nonwoven carrier geotextiles experienced internal erosion, which resulted in an increase in hydraulic conductivity of at least one order of magnitude. However, GCLs with a scrim-reinforced nonwoven geotextile carrier layer sustained hydraulic gradients of up to 70m of water head) without measurable internal erosion for the cases examined". (Rowe Orsini 2002).

As Dr. Rowe mentions in numerous of his paper presentations over several decades "luck is fickle". A double nonwoven GCL that is NOT scrim-reinforced and deployed over a badly prepared subgrade will experience internal bentonite erosion in a hydraulic head condition. A double nonwoven GCL that is NOT scrim-reinforced needs to rely on the shear luck of a properly prepared subgrade with no issues to ensure that the bentonite remains in place. This author holds Rowe and Orsini's research paper from 2002 to be one of the most basic yet important early GCL research study findings since it clearly shows that a GCL liner, or any liner for that matter, is only as good as the subgrade it's resting/lying on. Drawings and guidelines issued on a lining project can be clear as much as they want but site conditions can throw a wrench into all the proper planning going before construction starts. Once construction starts, weather, a contractor's lack of attention, no full-time site supervision by the engineering firm, and terrible site conditions just to name a few all take over in no time. One can design as much as they want but designer and material specifiers need to be prepared by specifying materials that can take the physical abuse (ex. weather, substandard subgrade, contractor's deployment team) once the project starts.

In the engineered landfill industry such as lining the bottom of waste cell closures (HDPE/LLDPE over a GCL application), numerous papers and field testing studies have shown that double nonwoven GCLs that are not scrim-reinforced will shrink and lose their recommended 6 to 12 inch overlap over time in conditions where no cover soil is applied over a double lining system (cover soil over a HDPE/LLDPE – GCL). These double nonwoven GCLs that lack scrim-reinforcement have been shown to shrink as much as 24 inches over a two-year period with no cover soil applied over these liners. The same field studies clearly show that double nonwoven scrim-reinforced GCLs did not shrink at all over the same time period and kept their original overlap width. (Bostwick Rowe Take Bruchman 2010). This shrinkage issue of double nonwoven GCLs that are not scrim-reinforced is one that this author personally witnessed in mining applications in South America on several sites. Rather disheartening to provide a known fact solution to users that they must use a scrim-reinforced double nonwoven GCL instead of a double nonwoven GCL that is not scrim-reinforced. Yet users would rather sidestep the issue and keep repeating what they have always done in the past. Use the same material in a known material failure under the same conditions as a previous liner deployment. A material that can't perform under a certain condition, however, let us bury the liner, put it out of sight, and out of our minds with the full knowledge that the liner will not have a protected overlap whatsoever.

Geosynthetic Clay Liners can be made and obtained in various different forms. From non-reinforced GCLs with low to no peel strength values to reinforced high peel strength value GCLs. From GCLs with thin geotextiles on both top and bottom fabrics to thick top and bottom fabric GCLs. A design engineer must state the thickness of the geotextiles that he/she wants in a given GCL. Failure to list the geotextile thickness in a GCL specification leads to suppliers and distributors providing exactly what was specified. If garbage is specified, then expect garbage to be made, provided, and sent to your project site as garbage. This author's own manufacturing plant can make a cheap as borscht GCL if one specifies a low grade GCL. Low grade GCLs such as low peel strength GCL with a thin nonwoven fabric / bentonite / thin woven bottom fabric cross-section are economically available, however they can only be used in certain conditions (flat conditions). They can only be deployed in the most crystal clear weather conditions on smooth as a newborn's bottom subgrade. Unfortunately, beautiful site conditions do not exist in the real world. Late day thunderstorms arrive on job sites, snow, cold temperatures, overnight rain events on exposed GCLs, the presence of stubborn groundwater, and contractors that have no liner deployment experience are just few items that do exist during GCL deployment projects. For these reasons alone, higher grade GCLs must be specified and used on projects to safeguard against the possible damaging effects. Using a standard low grade GCL such as a nonwoven / woven GCL will not be able to withstand these damaging effects. Hence the reason to use a scrim-reinforced double nonwoven GCL to ensure the GCL liner upholds its excellent low permeability performance it truly has.

3 GEOSYNTHETIC CLAY LINERS IN POND APPLICATIONS

Research after research show the importance of having a scrim-reinforced double nonwovens GCLs over conventional nonwoven/woven GCLs or double nonwoven GCL that are not scrim-reinforced. Research aside, this author stumbles into ponds on a yearly basis, as shown on Figure 2, that fail to hold water due to the shear fact that double nonwoven GCLs that weren't scrim-reinforced were used over badly prepared subgrades. In one case shown herein, the GCL used was a standard low peel strength nonwoven/woven GCL with a bentonite mesh size of 16. Without reviewing the actual cause of the failure since either the woven fabric failed due to rocks being present in the subgrade or the shear size of the bentonite used in the GCL was too large to act as monolithic bentonite gel during hydration or the lack of proper cover soil weight over this specific GCL, one fact that is known as mentioned in this paper herein, a scrim-reinforced double nonwoven GCL at minimum should always be used in pond applications to ensure an effective liner performance over a badly prepared subgrade. The project was specified with an even higher grade GCL than the minimum scrim-reinforced double nonwoven GCL that is highly recommended as a minimum. However, with most projects, the local general contractor will always retreat to the lowest price provided and hence paid for his/her lack of knowledge and/or lack of communicating his/her changes without notifying the project engineer and ultimately the owner of the project. This author did notify the project engineer for the record when this decision was done/known, to protect the geotechnical engineer of record on the project to ensure of the change and their subsequent 'not responsible' if a failure occurs. A failure did occur, the liner (GCL) failed to do its purpose, to act as a clay barrier (liner). Having a scrim-reinforced double nonwoven GCL protects all parties from a badly prepared subgrade.

Figure 2. Two ponds lined in the summer of 2018. Five kilometers apart. One with a mesh 16 bentonite (top picture – liner failed) and one with a mesh 30 multi-component GCL (bottom picture – liner performed).

Geosynthetic Clay Liners (GCLs) are great liners and have numerous successful installations in pond applications and other high hydraulic head conditions (lakes, dams), however one must specify the appropriate GCL. At minimum, a scrim-reinforced double nonwoven GCL must be used in pond applications. A recommendation that this author states over and over again. A statement made over and over in academic research papers. Yet time after time, projects get specified with a complete lack of important items listed in the material specifications and/or contractors just purchase the lowest possible item and force their decision onto a weak project engineer who accepts the change of material selection and/or are not told of the liner selection change. Buyer beware. Not every GCL is made alike and the reason why so many different types of GCLs are made available from one specific manufacturer is because not all projects are alike and unfortunately not all designers/buyers are alike. As mentioned, if a buyer wants cheap, then cheap will be made and offered with a condition that either guidelines are followed exactly as listed or accept the consequences.

4 THE IMPORTANCE OF THE GEOTEXTILE IN A GCL.

While the basis for the use of a Geosynthetic Clay Liner (GCL) is the low permeability provided by the sodium bentonite clay layer, the geotextiles play a critical role in protecting this constituent. Yet as mentioned previously in this paper, some project specification neglect to state the required geotextile properties when requesting a GCL on their project(s). The top fabric and/or "cap" fabric in a GCL is always a nonwoven fabric. This top fabric nonwoven polypropylene geotextile can be as thin as say 100 g/sqm to as thick as a 300g/sqm nonwoven "cap" fabrics to not only provide a thick cushion textile for the bentonite but to provide a high peel strength value during the needlepunching process to provide a reinforced GCL for either rough site conditions or steep slope applications. With high peel value GCLs one might consider a higher dry bentonite content in the GCL to offset the high needlepunching process or as called by some researchers 'bundles'. "Bundles" are the strands of textile introduced thru the bentonite to interlock with the bottom "carrier" geotextile. The more bundles that are introduced, the more fabric openings are contained in the GCL and hence the importance to have small mesh size dry bentonite in the GCL to act a monolithic bentonite gel to achieve a low permeability liner.

The bottom fabric of a GCL known as the carrier geotextile can be either a woven, a nonwoven, a scrim-nonwoven (a textile that has a woven and a nonwoven needlepunched together prior to the manufacturing of a GCL), a coated woven, a coated nonwoven, a coated scrim-nonwoven, or a glued geomembrane applied to the carrier geotextile. All of these carrier geotextile can be as thin as say 100 g/sqm to as thick as 300 g/sqm or more depending on certain GCL being specified and made. The carrier textile of a GCL is by far the most important element of a Geosynthetic Clay Liner. Failure to provide a properly prepared subgrade may result in an internal loss of the bentonite, hence the importance of the carrier geotextile. At minimum a scrim-nonwoven geotextile must be the carrier geotextile of a GCL as mentioned previously.

4.1 "Cap" Nonwoven in a GCL

The nonwoven cap of a GCL is constructed with a proprietary blend of high tenacity virgin staple fiber. This blend of fibers is extremely important as the cap component of a needlepunched GCL must provide both containment of the sodium bentonite clay while also acting as the source of the reinforcing fibers. A percentage of the cap nonwoven is constructed with fine, low denier fibers. A lower number refers to a smaller diameter fiber, while a higher number refers to a larger diameter fiber. Therefore, the use of smaller denier fiber will result in a larger quantity of individual fibers when the total mass and individual fiber length remain constant. The low denier fiber is used to obtain dense, uniform coverage of the nonwoven and to reduce the pore opening size in the finished nonwoven. A consistently dense nonwoven reduces the likelihood for bentonite extrusion and ensures uniform peel and shear strength properties. The balance of the cap nonwoven is made from a higher denier fiber. This fiber provides the reinforcing strength of the GCL reinforcement due to the larger denier and high tenacity (a measurement of strength). The higher denier fibers also provide structural integrity to the nonwoven itself when they are uniformly integrated with the lower denier fiber. The larger fiber may also increase the frictional resistance of the nonwoven as the fibers are more capable of locking into other surfaces than the smaller denier fibers. This blended fiber nonwoven is produced by thoroughly mixing and evenly distribution (Cross-lapping) the fibers for the first needlepunching phase. Manufacturing is performed on equipment which ensures uniformity by continuously monitoring the nonwoven "web" with beta gauges. The fibers are only lightly needled at this stage as the nonwoven must be loose enough to allow fibers to be needled from its web, through the bentonite and incorporated into the opposing nonwoven geotextile during the final production stage. Therefore the resulting nonwoven is relatively thick, typically exhibiting a tensile strength in the range of 20 lbs when tested according ASTM D4632.

It should be noted that a standard production nonwoven geotextile does not function well as the cap material as the fibers are needled too tightly to allow for the proper amount of fiber to be dislodged. While the physical properties of a standard production nonwoven geotextile are often specified for the cap nonwoven of needled GCLs, it is typically infeasible to adhere to these specifications due to the special requirements needlepunching demands of this material.

4.1.1 "Backing / Carrier" Scrim-Reinforced Nonwoven geotextile in a GCL

The backing nonwoven is produced in a very similar fashion as the cap nonwoven, however, a slit film woven geotextile acts as the base into which the loose fiber is needled. The result is a dimensionally stable nonwoven with high tensile strengths at lower elongation than standard nonwovens. This distinction is important as the backing serves several functions as well.

A GCL's dimensional stability is important when evaluated in the context of its use. A GCL produced with only nonwoven geotextiles is more free to elongate than a scrim reinforced GCL when subjected to differential settlement or elongative forces. If the fabrics of a nonwoven GCL readily elongate, the bentonite will proportionately thin out as the stretching occurs. The scrim reinforcement resists stretching and settlement induced deformation which helps maintain the consistency of the bentonite layer. Therefore, *the scrim reinforcement plays a key role in maintaining uniform hydraulic characteristics.*
During the manufacturing process, the scrim reinforced nonwoven resists contraction due to needling, thereby assuring uniform application of the bentonite and uniform internal strength. When an unreinforced nonwoven is used, bentonite densities can vary widely and affect needling efficiency.

4.2 Presence of rocks/stones/gravel in a subgrade

The presence of rocks and gravel in a subgrade are a common occurrence on specific sites where sand and/or a silty clay soils are not available. When rocks and gravel are the only available soils on site to prepare the subgrade for a GCL then the appropriate GCL must be selected and used. As mentioned previously, a double nonwoven scrim-reinforced GCL should be used in these type of site conditions (ex: Canadian Shield / Far North). Designers and specifiers working on projects that will have harsh site and weather conditions should ensure that their selected GCL contains a bottom fabric (carrier) that is scrim-nonwoven geotextile of at least 200 g/sqm minimum. Thicker scrim-nonwoven geotextiles are available as well as polypropylene coating can be added to the geotextile of a GCL.

Figure 3. Subgrade full of rocks, stones, and gravel – an acceptable subgrade for a scrim-nonwoven carrier backed GCL but not for a woven only carrier GCL.

5 PREMATURE HYDRATION OF GCLS

What are the affects of "Premature Hydration" on GCL and what to do in these instances are commonly asked questions. While there are no definitive procedures to quantify a product's usefulness after this type of occurrence, or for determining whether or not the material should be removed and replaced, there are a few rules of thumb that can be followed to aid project personnel in formulating the proper plan of action. However, it should first be understood from where the remove and replace strategy originated in order to put it into proper context.

Figure 4. Premature Hydrated GCL on a landfill cell project from an afternoon thunderstorm/rainfall event.

5.1 Background

Prior to the invention of mechanically bound or "reinforced" composite products, or GCLs, bentonite clay was used as an *in-situ* waterproofing barrier system, i.e. constructed in the field. Later, others employed bentonite in a prefabricated product held together with glue. Both the in-situ system and the prefabricated product were delicate in nature due to their non-reinforced construction. Moreover, a small amount of moisture could hydrate the bentonite and essentially render the system or product useless if it were not properly confined. The bentonite was able to swell relatively freely and unconfined, delaminating the geotextiles and rendering it unable to perform as a hydraulic barrier. Even where the geotextiles did not entirely separate, the bentonite could absorb so much water and become so swollen that the bentonite would become very plastic, prone to displacement when subjected to light foot traffic or other localized construction stresses. This phenomenon was easily prevented by adding a modest amount of cover material (6 to 12 inches). However, when this cover material requirement was not achieved, these GCL product manufacturers suggested *"remove and replace GCL that is significantly hydrated before placement of overlying geomembrane or a minimum of 12 inches of approved cover soil".* By the time the reinforced GCLs entered the market, the practice of removal and replacement was commonplace and accepted as the only recourse when premature hydration occurred.

5.1.1 Low peel nonwoven/woven GCLs vs Double nonwoven scrim-reinforced GCLs

As mentioned, not all GCLs are made alike. Some have low peel strength values compared to double nonwoven scrim-reinforced GCLs that have higher peel strength performance and hence can withstand weather events such as rainfall and/or snowfall events. Higher peel strength GCLs can maintain not only their material strength but also their low permeability performance. Ultimately GCLs need to be covered immediately following deployment but other construction items and tasks are required at times, leaving the GCL exposed to the weather elements.

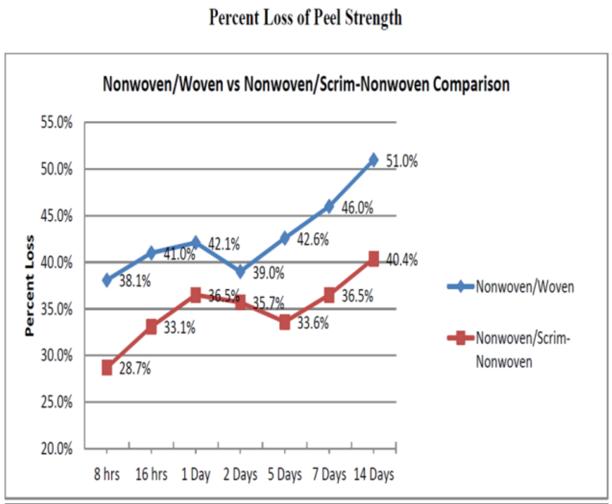

Figure 5. 100% prehydrated GCL samples. (Nonwoven/woven vs Nonwoven/Scrim-nonwoven GCL). Loss of Peel Strength in fully saturated condition vs time.

5.2 Site Decision Solution

Reinforced GCLs are significantly different from the unreinforced GCLs and systems, as there are thousands of fibers extending from one geotextile through the layer of bentonite into the other confining geotextile. This mechanical bonding provides an inherent confining stress not found with unreinforced GCLs. When exposed to water, the swelling bentonite is unable to break the heated treated bond as shown in Figure 1, leaving the quality of the reinforced GCL essentially undiminished. Therefore, the typical removal and replacement practice is not necessary. As precipitation can fall in many ways, such as a heavy rainfall or a prolonged mist, and as the degree of GCL saturation will be dependent on this factor, the focus of the issue is most appropriately placed on subsequent installation procedures rather than hydration quantification. With a reinforced GCL such as double nonwoven scrim-reinforced GCL with a higher peel strength than a sub-standard GCL (nonwoven/woven), it is more often the activity that takes place over the hydrated material which causes the damage, not the hydration itself.

Premature hydration or partial hydration in and of itself is not necessarily a damaging event; it merely changes the installation conditions. The needlepunching and heated treated locked fibers differentiates reinforced GCLs, as it is not prone to delaminating, a phenomenon that can occur with unreinforced GCL products. That is not to say there aren't circumstances when the removal and replacement of the prematurely hydrated GCL product is necessary. Many site-specific factors influence the "to leave or not to leave" decision including the degree of UV exposure, the degree of hydration, the location of the hydrated material, the liner system profile, the differential loading that the effected area will be subjected to during the completion of the installation as well as by the construction techniques being utilized. All of these factors must be weighed for a site-specific decision to be made.

5.3 Acceptance Criteria

At a minimum, the GCL should not be torn, separated or otherwise physically damaged. Substantial indentations should not remain where walked upon nor should bentonite extrude through the fabrics when subjected to any other stress. Overlapped seams should be intact, including any accessory bentonite used in the laps. If the surface of the affected area has been subjected to direct flow, it should be checked for mass per unit area as prolonged turbulent flow may have the effect of "eroding" away some of the bentonite. Finally, the affected area should not be on a slope greater than 3H:1V.

If these basic conditions are met, the product will likely not require replacement. Once subjected to the design normal loads, the excess absorbed water will consolidate out of the compressed bentonite and be re-absorbed into the subgrade or drain into the lower drainage media. In some instances where the above conditions *are not met,* it may be possible to allow the hydrated material to air-dry to the extent where it would not require removal. Again, this is a site-specific determination.

5.4 Prehydrated GCL Conclusions

Rejecting and removing partially hydrated GCL can compromise an installation schedule even if only a small area is affected, without increasing liner quality or performance. Removing partially hydrated GCL is not logical if it is not damaged or will not be damaged by a quantified and predetermined installation and/or covering procedure.

Attempting to quantify the degree of hydration is very difficult. A sample with a modest moisture content may not "appear" to be in satisfactory condition whereas a sample with what could be considered an unacceptable moisture content (100% under a confining stress of only 5 psi is possible), may be deemed entirely acceptable. Each case of premature hydration tends to be unique and site specific. The subsequent remedy should be based on the conditions that exist at the location where the hydration occurs. In the absence of an all encompassing and industry accepted, quantifiable test procedure, a common sense approach must be applied when evaluating these relatively common situations.

As this is an installation-related phenomenon, the use of reinforced GCLs should be maximized to ensure the potentially damaging affects of premature hydration are minimized.

6 MULTI-COMPONENT GCLS FURTHER ADVANCES

At the beginning of this century, GCL manufacturers were starting to add membranes and/or polypropylene coatings to their products to protect themselves from the lack of attention to subgrade preparations and deployment sites in harsh conditions (tropic and arctic conditions). A GCL liner, any liner for that matter, is only as good as the subgrade it's resting on. Some site conditions and/or some contractors are unable to provide a smooth subgrade free of stones and gravel and/or are unwilling to read the installation guidelines. Hence the reason that GCL manufacturers started to provide membranes and/or coatings to the bottom side of their liner. As mentioned previously, bentonite can have internal erosion issues if the bottom fabric is a nonwoven fabric with no scrim-reinforced and/or doesn't have a membrane or coating in a badly prepared subgrade.

Multi-Component GCLs have either a geomembrane glued to the main needle-punched GCL or an added polypropylene coating where the main needle-punched GCL is bathed/dipped into a holding tank during the manufacturing of the main GCL and hence the coating becomes an integral part of the GCL to avoid having an added shear plane that a glued membrane will have.

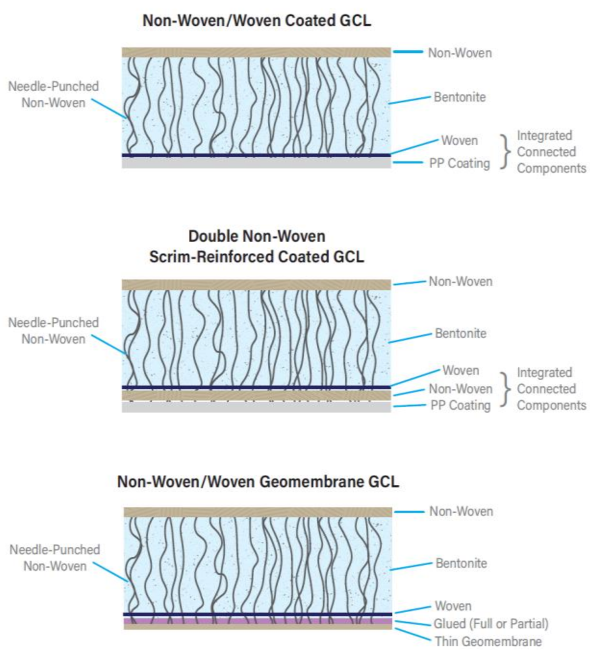

Figure 6. Cross-section of coated GCLs vs glued geomembrane. Glued Geomembranes introduce an additional slip plane to be concerned with in slopes applications versus coated GCLs where the coating is an integral part of the actual GCL. PP – Polypropylene.

Multi-Component GCLs offer the ultimate safeguard against badly prepared subgrades and offer an excellent resting base for the sodium bentonite clay layer to ensure a low permeability liner being achieved.

7 SUMMARY

This paper is a summary that not all Geosynthetic Clay Liners are made alike and that higher grade GCLs are available to protect against harsh working conditions as well as having a built-in subgrade enforcement as a protection to badly prepared subgrades. Double nonwoven scrim-reinforced GCLs as shown in Figure 1 offer a protection against internal bentonite erosion, they can handle high hydraulic head conditions over badly prepared subgrades, they avoid shrinkage issues in applications where no cover soil is applied over them in double liner applications (GM over GCLs), and they offer a lower bulk ratio when the needlepuched fibers are heat treated and locked to offer a higher peel strength as well as a higher peak shear (higher angle of friction) than a conventional non-heat treated nonwoven fabric. As mentioned above, researchers and research studies over the last couple of decades have shown the advantage of a double nonwoven scrim-reinforced GCL over standard conventional nonwoven/woven GCLs. Yet the bulk of specifications being issued on projects to this day are still using outdated GCLs made over decades ago.

Geosynthetic Clay Liners have advanced over the decades and University studies as well as full scale testing sites have shown the benefits of higher grade GCLs over low grade conventional GCLs. Designers and specifiers need to start requesting thicker geotextiles, sodium bentonite sourced from Wyoming (especially in North America), higher peel and tensile strength values, and ensure that the backing "carrier" textile in a GCL contains a scrim-nonwoven at a minimum.

Scrim-nonwoven carrier geotextiles in a GCL provide so many known benefits to woven or nonwoven carrier geotextile GCL, however the bulk of specified GCLs in projects to this day lack any demand reference to using them. The additional cost from a woven or nonwoven backing geotextile in a GCL to a scrim-nonwoven backed carrier geotextile is rather small if not rather insignificant compared to the numerous known added benefits that a scrim-nonwoven carrier provides to ensure a low permeability performance GCL liner to protect our environment.

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