A Review on GCL Performance in Geotechnical Engineering

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***Abstract*—**Over the past decade, geosynthetic clay liners (GCLs) have gained widespread popularity as a substitute for compacted clay liners in cover systems and composite bottom liners. They are also used as environmental protection barriers in transportation facilities or storage tanks, and as single liners for canals, ponds or surface impoundments. As a result, they are being investigated intensively, especially in regard to their hydraulic and diffusion characteristics, chemical compatibility, mechanical behaviour, durability and gas migration. In this paper, a review of the main findings is presented. From this work, a general insight is gained on outstanding effective factors on GCLs' different performances and will additionally be used to develop GCL applications. An accurate interaction analysis of this system will be a remarkable contribution to the field as it will allow GCLs to be more effectively applied to a wider range of geotechnical issues.

***Keywords*—** Geosynthetic clay liners, hydraulic and diffusion characteristics, GCL Performance

I. Introduction

OVER the past decade, design engineers and environmental agencies have shown a growing interest in the use of geosynthetic clay liners (GCLs) as an alternative to compacted clays in cover systems or in some cases bottom lining of waste containment facilities because they often have very low hydraulic conductivity to water (kwo10_10 m/s) and relatively low cost. Apart from environmental application, e.g. use as a component of liner or cover systems in solid waste containment, GCLs are also used as environmental protection barriers in transportation facilities (roads and railways) and geotechnical applications such as minimizing pollution of subsurface strata from accidental spills and seepage of chemicals from road accidents. GCLs are also used as secondary liners for underground storage tanks at fuel stations for groundwater protection, and used as single liners for canals, ponds or surface impoundments. This increased interest stems from two factors:

1. Better knowledge about the material performance, which resulted from a large body of research publications presented, in a rough chronological order, in the following: USEPA Workshop on GCLs (1993), International Symposium on GCLs, Nurnberg, Germany (1994), ASTM symposium on testing and acceptance criteria for GCLs, Atlanta, USA (1996), GeoBento, Paris, France (1998) and the Geotextile and Geomembrane special issue on GCLs (2000). In addition, a large number of papers on the subject of GCLs have also been published in refereed geosynthetic, geotechnical and geoenvironmental journals and conference proceedings.
2. Increased confidence of regulators and designers.

The present paper will summarize some of the main research findings that have occurred over the past decade.

II. Geosynthetic Clay Liners

GCLs are comprised of a thin layer of sodium or calcium bentonite bonded to a layer or layers of geosynthetic. The geosynthetics are either geotextiles or a geomembrane. Geotextiles-based GCLs are bonded with an adhesive, needlepunching, or stitch-bonding, with the bentonite contained by the geotextiles on both sides. The needlepunching process causes some fibres from the top geotextile to extend through the bentonite and bottom geotextile, bonding the entire structure together [63]. The fibres that are punched through the bottom geotextile either rely on natural entanglement and friction to keep the GCL together or are heated causing them to fuse to the bottom geotextile, potentially creating a stronger bond between the two geotextiles and bentonite (in this case they may be referred to as ''thermal locked GCLs''). Alternatively, the reinforcement can be carried out by sewing the entire geotextiles–bentonite composite together with parallel rows of stitch-bonded yarns.

For the geomembrane-supported GCL, the bentonite is bonded to the geomembrane using a nonpolluting adhesive and a thin open weave spun-bound geotextile is adhered to the bentonite for protection purposes during installation. Due to the flexibility of production and rapid innovation, the performance of the different types of GCLs may vary significantly. The primary differences between GCLs are the mineralogy and form of bentonite (e.g., powder versus granular, sodium versu calcium, etc.) used in the GCL, the type of geotextile (e.g., woven versus nonwoven geotextiles) or the addition of a geomembrane, and the bonding methods.

The main advantages of the GCL are the limited thickness, the good compliance with differential settlements of underlying soil or waste, easy installation and low cost. On the other hand, the limited thickness of this barrier can produce.

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(1) Vulnerability to mechanical accidents, (2) limited sorption capacity, and (3) an expected significant increase of diffusive transport if an underlying attenuation mineral layer is not provided. Moreover, when hydrated with some types of leachates instead of pure water, bentonite will show a minor swelling that will result in reduced efficiency of the hydraulic barrier. Advantages and disadvantages of GCLs are summarized in Table 1.

As the use of the GCLs broadens, they are being investigated intensively, especially in regard to their hydraulic and diffusion characteristics, chemical compatibility, mechanical behaviour, durability and gas migration ([10]; [44] & [45]; [24]; [14]; [36]; [53]; [40]; [61], amongst many others).Please submit your manuscript electronically for review as e-mail attachments. When you submit your initial full paper version, prepare it in two-column format, including figures and tables.

III. HYDRAULIC CONDUCTIVITY, CHEMICAL COMPATIBILITY AND DIFFUSION

The hydraulic performance of GCLs depends in most cases on the hydraulic conductivity of the bentonite. The only exceptions are GCLs containing a geomembrane where the geomembrane is seamed during construction (e.g., with a cap strip). In general, laboratory hydraulic conductivities to water of different types of geotextile-supported GCLs vary approximately between 2_10_12 and 2_10_10 m/s, depending on applied confining stress (Fig. 1). [44] attributed the reduction in GCL hydraulic conductivity to lower bulk void ratios resulting from higher confining stresses. More importantly, they showed that there is a strong correlation between the bulk void ratio and the hydraulic conductivity, k, for a given permeant.

GCLs are often used to contain liquids other than water, in this case the evaluation of hydraulic conductivity of GCLs when acted upon by chemical solutions is of a paramount importance. Hydraulic conductivity to the actual permeant liquid is usually assessed by a ‘‘compatibility test’’ where the specimen is permeated with the liquid to be contained or a liquid simulating the anticipated liquid. GCL compatibility with various permeants has been studied by a number of researchers and evaluated for numerous projects ([54]; [47]; [48]; [44]; [43]; [48]; [52]; [53]; [40]). The GCL features, which influence their hydraulic conductivity with liquids other than water are: aggregate size, content of montmorillonite, thickness of adsorbed layer, prehydration and void ratio of the mineral component. Concentration of monovalent and divalent cations. When performing these tests, it is important to monitor the chemical composition in permeant influent and effluent and that sufficient pore volumes of the permeant has passed through the sample to ensure that chemical equilibrium has been reached. Furthermore, it is recommended that the height of the GCL be constant before terminating these types of tests. A detailed summary of issues related to GCL chemical compatibility is provided by [48] and [53] and [50] have developed these topics in detailed and comprehensive manner. The comparison of GCL versus CCL in terms of

TABLE I
ADVANTAGES AND DISADVANTAGES OF GCLS (MODIFIED FROM BOUAZZA, 1997)

Advantages	Disadvantages
Rapid installation/less skilled labour/low cos	Low shear strength of hydrated bentonite (for unreinforced GCLs)
Very low hydraulic conductivity to water if properly installed	GCLs can be punctured during or after installation
Can withstand large differential settlement	Possible loss of bentonite during placement
Excellent self-healing characteristics	Low moisture bentonite permeable to gas
Not dependent on availability of local soils	Potential strength problems at interfaces with other materials
Easy to repair	Smaller leachate attenuation capacity
Resistance to the effects of freeze/thaw cycles	Possible post-peak shear strength loss
More airspace resulting from the smaller	Possible higher long term flux due to a reduction in bentonite thickness under an applied normal stress
Field hydraulic conductivity testing not required	Possible increase of hydraulic conductivity due to compatibility problems with contaminant if not prehydrated with compatible water source.
Hydrated GCL is an effective gas barrier	Higher diffusive flux of contaminant in comparison with compacted clay liners.

actual performance is today one of the hot topics for the engineers involved in landfill design, construction, management and regulation. Moreover, when comparison between different products needs to be carried out, it is important to keep in mind that it is not possible to generalize about ‘‘equivalency’’ of liner systems since what is ‘‘equivalent’’ depends on what is being compared and how it is being compared [48]. Apart from their own features, the performances of liner systems are related to the contaminant amount, concentration and decay parameters, the aquifer characteristics and its distance from the bottom of the landfill, the efficiency of capping and drainage systems.

IV. LONG-TERM PERFORMANCE AND LIFETIME PREDICTION OF GEOSYNTHETICS

Over the past fifteen years, a significant effort has been made to understand the various degradation mechanisms that are relevant to the geosynthetics. Appropriate laboratory tests have been developed to evaluate the long-term quality of the products. Also a few generic specifications have been established at the regional or international levels to ensure product standards meet these durability criteria. Perhaps the next phase of the durability research should be to generate data from field-retrieved samples. Geosynthetics have been used for approximately 30 years. Characterizing existing field samples would be useful to confirm the aging process predicted from laboratory acceleration tests. Contrary, it would not be beneficial to characterize a field-retrieved geosynthetic sample in terms of life prediction of new products, if the formulation has been changed or improved. The improvement in resins, and particularly in additive packages, has been meaningful and it is entirely possible that the current generation of geosynthetic products will have far greater durability than older resins and additive packages. Selecting the appropriate laboratory acceleration tests is essential to ascertain the long-term behavior of these new products.

V.CONCLUSION

There is growing concern throughout the world about the contamination of groundwater as a result of human activities [3] since the failure to provide safe drinking water which groundwater is a leading source of its provision [1] and [61], is perhaps the greatest development failure of the 20th century [6].

Absolutely, adequate protection of groundwater quality must be a primary aim due to statistics published by UNICEF; covering the period 1980-2010; show that generally 60% of reported water-related fatal diseases such as diarrhoea and typhoid are lead to death.

Geosynthetic Clay Liners are regularly used in Australia in solid and liquid waste containment applications (Landfill barrier systems, odour control, gas emissions and leakage rates). GCL's have been accepted worldwide as a component of what is considered a "best practice" primary lining system design - i.e. a composite geomembrane/GCL.

Hydration of various GCLs from subsoil pore water and the soil mechanics and thermal interaction in a closed-system (i.e. constant mass of moisture and isothermal condition) will be studied in this master research. Several different types of GCLs, different scale of test cells, different load distributions and different compaction of subsoil will be selected for these series of tests. Periodic sampling tests are to be conducted to investigate a spectrum of experimental variables, hydration behaviour, soil mechanics and thermal transfer.

In these tests, the GCL will be periodically removed, measured, weighed, and returned to the test cell to track the evolution of hydration with time (several months). Meanwhile, the temperature of subsoil will be measured to trace the thermal mechanism of subsoil through thermometers placed in different depths of the subsoil. A measurement technique will also be employed to track the change in GCL thickness during hydration.

Hydration refers to the property that describes the rate which water can flow through pore spaces or fractures, and GCL hydration refers to supply and retention of adequate water in GCL tissues.

Due to GCL hydration characteristic, GCLs act as an excellent hydraulic barrier [3] and [46]. GCLs have been successfully used in numerous barrier system applications such as composite landfill liners, tailings ponds, dams, railway lines, etc. [1] & [9]. One of the more common applications for GCLs is in composite landfill liners. In this case, the GCL is used in conjunction with a geomembrane, other geotextiles, and granular drainage and protection layers to form a composite barrier system to prevent the contamination of the underlying groundwater from advective and diffusive transport processes.

Although some researchers such as [2]; [3]; [1] and [15] and [61]; [3] and [2]; have studied on the GCL, however, the focus on soil mechanics and thermal transfer in the subsoil layers is very limited. Thus, this master research aims to investigate on the subsoil thermal behaviour under Scanning Electron Microscope (SEM) observation for better understanding of interaction between GCL and subsoil.

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