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A Review of Key Factors on Geosynthetic Clay Liners' Performance as Liner System

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Abstract— Geosynthetic clay liners (GCLs) as a substitute material to compacted clay liner (CCLs) can be employed as landfill leachate barriers, waste water impoundments and any other liquid impediments. They have some advantages in their shape, availability, easy in installation and mainly hydraulic performance. However, the hydraulic performance of GCLs as liquid barricade depends on some factors. In this paper, a review of some key factors that affected the GCLs performance as leachate and liquid barrier will be presented and discussed in order to provide a critical view of GCLs behavior.

Keywords — GCLs, hydration, internal-erosion, self-healing.

I. INTRODUCTION

MORE than decades, geosynthetic clay liners (GCLs) have extensively been accepted to substitute compacted clay liners (CCLs) since they have more benefits over CCLs specifically their hydraulic ability, availability, transport and construction cost. GCLs can be in form of a composite liner that consist of a thin layer of bentonite and two geosynthetic layers. The geosynthetic layers used are generally geotextiles [1], [2]. The bentonite which can be in powder or granular form is laid over carrier geotextiles and beneath cover geotextile. The type carrier and cover geotextile can be all woven, non woven and combination of woven and nonwoven which depend on the purposes. Some of GCLs may be reinforced by needle-punching, adhesive bonding and combined with thermal bonding in their production. The thin layers of bentonite in GCLs are more impermeable toward water compared to the CCLs [1], [2] and the GCLs have been used layering them with geomembrane to form a composite liner system at the base of sanitary landfills, and many other liquid containment purposes in some developed countries [3]-[6].

In order to perform as leachate or liquid barriers, some key factors such as hydration, internal erosion and self healing are significantly affecting the hydraulic conductivity performance of GCLs. Thus, to get a clear picture, some researches on those entire factors that have been conducted in the previous years will be discussed in this paper.

II. HYDRATION OF GCLS

The ability of the GCLs to reach their maximum hydraulic performance depends on their degree of saturation. GCLs must be sufficiently hydrated typically using water to function as a liner system for an impediment for any liquid contaminant [4]. After being hydrated, the bentonite particles will swell and attach to each other. The hydration process of the GCLs can take place immediately after the GCLs are being placed on underlying subgrade which contains water such as soil. Watering the GCLs is not required as long as the subgrade has adequate moisture content. During the hydration process, the GCL will absorb the water from the subgrade, swell and make the GCLs water impermeable.

The hydration process of GCLs has been investigated extensively by placing the GCL on some different subgrade such as sand which contains different level of moisture content. It was reported by Daniel *et al.* [7] that the GCLs could absorb more than 80% of the water from their subgrade after being laid for less than 2 months. Unfortunately, the moisture content of the subgrade during and after hydration process was not reported. Additionally, the precipitation and humidity factors which were suspected to have significant influence on the hydration rate also have not been mentioned on the report.

Anderson, Rayhani, and Rowe [8] investigated the GCLs hydration phase by placing the GCLs on the sand subgrade which has about 8-10% moisture content. The result showed that the rate of hydration process was relatively fast. The GCLs took up 100% of moisture content in less than 24 hours and absorbed 140% after being placed for 60 days. In addition, Rayhani *et al.* [9] also believed that the method of GCLs' bonding during production which are needle-punching, adhesive bonding and or combined with thermal bonding also have an influence on the hydration process of GCLs. The type of bentonite also has been reported to contribute toward hydration process of the GCls [10]. Regrettably, the moisture content of the subgrade, precipitation and humidity level during the experiment was not conveyed in all reports.

Rayhani *et al.* [9] suggested that the subsoil grain size distribution and initial moisture content also contributed to the degree and rate of hydration. They also investigated the GCls' hydration under isothermal condition at room temperature and

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it was found that the rate of GCL hydration was slightly lower when silty sand was used as a subsoil compared to sand. Meanwhile, Anderson, Rayhani, and Rowe [8] stated that when the GCLs were placed on a sand subgrade and confining pressure was applied on the sample, the water content balance of the GCL decreased corresponding to the increasing of the confining pressure.

During construction, the GCLs are potentially exposed to the open air or direct sunlight which causes the GCLs encounter daily thermal cycle. Since the previous studies did not mention any daily thermal cycle, nevertheless, Rowe, Bostwick, and Take [11] found that daily sun exposure also considerably contributes to the hydration of the GCLs while resting on silty sand and sand subsoil. In order to minimize the effect of daily thermal cycle, it was recommended to shield the GCL using a protection layer or soil cover after installation. However, all previous studies on GCLs' hydration have not considered yet the impact of protection layer or soil cover that can be significantly affect the internal temperature of GCLs, moisture content and hydration process during daily thermal cycles.

III. INTERNAL EROSION OF GCLS

GCLs have the potential to exhibit internal erosion when confronted with large hydraulic gradient that is caused by leachate or liquid that collects above the liner during their application as composite liner system for a landfill or the sole liner for a pond and lagoon. The loss of bentonite particles that separate from each other and are moved away by the flowing water may reduce the GCLs performance and augment their hydraulic conductivity. According to Stark [12], bentonite migration could also occur in a non-uniform normal stress zone. This zone is generally developed by GCL's wrinkles and resulting to a space under the GCLs. This would lead the bentonite migrating into the unsupported space under the wrinkles. Moreover, Fox [13] found that dynamic loading caused by movement by heavy equipment like a bulldozer on a lesser soil cover depth could also significantly damage the GCLs after installation. Fox, De Battista, and Mast [14] also believed that increasing cover soil particle size and rate of loading will increase the amount of bentonite migration in GCLs. However, all those previous research did not consider the effect of subgrade on the performance of GCLs toward internal erosion.

Rowe and Orsini [15] conducted research on internal erosion occurrence of some types of GCL that were laid on three different subgrades (gravel, geonet and sand) and posed by high hydraulic gradient. They reported that high hydraulic gradient could trigger an internal erosion of GCLs when placed over gravel or geonet. Meanwhile, there was no indication of internal erosion of the GCLs placed on sand subgrade even when an extreme gradient was applied during the experiment. It has also been reported that a scrim-reinforced nonwoven geotextile carrier layer has a better hydraulic performance than a single light-weight (woven or nonwoven) geotextile carrier [15]. However, it has not yet been considered if an additional protection layer such as soil or gravel spread on the GCLs could have any effects on the GCLs.

Dickinson and Brachman [17] believed that the GCL was much more susceptible to failure from internal erosion when a geotextile protection layer was installed above the GCL. This would allow the large head to act on the thinnest part of the GCL as a result of the increased transmissivity between the gravel and GCLs. On the other hand, Stark, Choi, and Akhtarshad [16] suggested using compacted clay liner sandwiching the bentonite between two geomembrane to diminish the occurrence of internal erosion. This is because the clay liner will reduce the amount of hydration, stress concentration and make the geometry of the site smoother.

However, all the suggestions made above can be implemented but the previous experiments have been conducted under the specific conditions and materials; consequently, an experimental verification should be carried out for specific design purposes in different conditions that could be vary in each site.

IV. SELF HEALING OF GCLS

During its application as landfill liner, GCLs may deal with some situations which possibly trigger the damage of the GCLs and reduce their sealing performance. The thickness of GCLs is subjected toward static pressures that causes GCLs thinning non-uniformly. Sharp materials might puncture the GCLs and reduce the capability of the GCLs as liquid barriers. Anderson *et al.* [18] investigated the self-healing properties of bentonite during rehydration by creating some artificial holes and reported that the bentonite could seal up a hole up to 25 mm but failed to fill the 75 mm hole. According to Sivakumar Babu et al. [19], it only needs 15 days to seal up a hole measuring 30 mm in diameter but the durability of the recovered area was limited. It could only hold up water of no more than 1 m of the hydraulic head. Shan and Lai [18] did not mention in detail of any physical changes during the rehydration process, but the previous researchers indicated that the self healing process happened during rehydrated period of GCL.

Sivakumar Babu *et al*. [19] conducted another experiment to investigate the self-healing capacity with desiccation cracks or punctures of the GCLs for the case. The test also considered the influence of temperature, swell percentage, swell pressure and also void ratio. This experiment was undertaken since Shan and Lai [18] stated that swell percentage tests or direct measurements of hydraulic conductivity or permittivity were helpful to assess the self healing capacity of GCLs. The results showed that the tested GCLs have good self-healing properties. It was also claimed that the method of binding the GCL components, i.e., stitch-bonding or needle-punching, had a significant influence on the self healing of the GCLs. Again, Sivakumar Babu *et al*. [19] also did not discuss any changes in the appearance of the crack or puncture areas during the self healing process. The permittivity test was also conducted after the swelling phase and self healing of the GCLs. GCLs have also been able to seal a gap when a solid object is inserted into the GCLs without having any effect on its hydraulic performance.

It is quite clear that the GCLs have an ability of self healing once they are punctured or get any cracks. In addition, needle-punched and stitch-bonded GCLs had a better self healing performance than other binding method of GCLs such as adhesive bonding. Whereas, the previous research did not try to look at any possibilities of the GCL's self healing performance when the water or liquid still passed the holes.

V.SUMMARY

It can be summarized that the performance of GCLs relies on some factors which are hydration, internal erosion occurrence and self healing. The hydration of GCLs can begin immediately after the GCLs are being laid on the subgrade with certain moisture content. It has also been recommended that a protection layer such as soil should be applied to minimize the effect of daily thermal cycle that might be influence the hydration process. Regarding the internal erosion, some researchers believed that the type of subgrade contributed significantly toward occurrence of internal erosion. It has been investigated that the sand subgrade can perform better in preventing the GCLs from bentonite migration even when under an excessive hydraulic gradient. Lastly, the previous researches have proven the ability of the GCL to conduct self recovery when a number of holes of different diameters up to 30 mm in diameter were created in the sample although the durability of the recovered area was limited. Additionally, the GCLs could seal up a gap completely when a solid objected was punched into the sample without any rise in hydraulic conductivity. Nevertheless, the self healing performance of GCLs towards any puncture or defects during continuous the flow is still being questioned since all the previous experiments have only shown that the recovery process were took placed during the rehydration phase.

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