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Comprehensive review of geosynthetic clay liner and compacted clay liner

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Abstract. Human activity inevitably produces waste materials that must be managed. Some waste can be reused. However many wastes that cannot be used beneficially must be disposed of ensuring environmental safety. One of the common methods of disposal is landfilling. The most common problems of the landfill site are environmental degradation and groundwater contamination caused by leachate produced during the decomposition process of organic material and rainfall. Liner in a landfill is an important component which prevent leachate migration and prevent groundwater contamination. Earthen liners have been widely used to contain waste materials in landfill. Liners and covers for municipal and hazardous waste containment facilities are often constructed with the use of fine–grained, low plasticity soils. Because of low permeability geosynthetic clay liners and compacted clay liners are the main materials used in waste disposal landfills. This paper summaries the important geotechnical characteristics such as hydraulic conductivity, liquid limit and free swell index of geosynthetic clay liner and compacted clay liner based on research findings. This paper also compares geosynthetic clay liner and compacted clay liner based on certain criteria such as thickness, availability of materials, vulnerability to damage etc.

1. Introduction

Disposal of waste in an acceptable manner has been growing concerns to the public. One of the most significant concerns has been the possible contamination of groundwater from leachates generated by wastes. Landfilling is one waste management strategy adopted to dispose the waste in an effective and safe manner. Liner in an landfill plays an important role to prevent contaminant migration in to groundwater. Liner should have hydraulic conductivity less than 10^{-7} cm/sec and its minimum thickness should be 600mm suggested by USEPA (United states of environmental protection agency). Some authors ([1] [2] [3], suggest the other important functions of liners are to control pollutant migration for long term and should have low swelling shrinkage. These quality are satisfied by low permeably clayey soil at varying compaction. The most commonly used materials in sanitary landfill are compacted clay liner (CCL) and Geosynthetic clay liner (GCL). The main reason in using such materials is their low hydraulic conductivity which limits or eliminates the movement of not only the leachate from bottom of landfills but also the generated gases from the final cap of waste dumps.

Compacted clay liners are less expensive and it has good attenuation capacity. Hence it is used in most of the landfills. Though it has lot of desirable qualities for liners such low permeability and good attenuation capacity it has own demerits such as high swelling and shrinkage thus causing instability issue ([6][7]). On the other hand GCL has low hydraulic conductivity and can be easily installed. It has good resistance against any environmental degradation (e.g free-thaw and wet-dry cycling) [8]. Geosynthetic clay liner (GCL) made up of thin layer of sodium bentonite or calcium bentonite sandwiched between two layers of geosynthetic materials.. Bentonite in GCL are made of granular or powder. GCL occupies minimum thickness of 5-10 mm. On the other hand CCL occupies 0.75-1m thick in the landfill.

GCL has numerous advantage compared to CCL in terms of low hydraulic conductivity. It need less skill labour for installation and less expensive. It also occupies less space compared to CCL. During freeze/thaw cycles GCL has good resistance hence it can be easily rectified. It also has good healing capacity when damaged during handling and installation. The small hole during installation are healed by bentonite in the GCL. It can be easily transported in the form rolls of 0.75 m in diameter and 4-6 m long. GCL proves to be less expensive compared to CCL where clay soil is far away from the landfill site.However CCL has large attenuation capacity compared to GCL because of its large thickness and it also inert to most of the permeant liquids that comes into contact. And also there is a possibility of geosynthetic component in GCL being degraded in the long term. According to Giroud (1996) some fungi and bacteria may catalyse the hydrolysis of polysters in GCL [11]. This paper summaries some important geotechnical properties such as hydraulic conductivity, Attereberg limits such as liquid and free swell index of GCL and CCL. It also presents the comparison of GCL and CCL.

2. Hydraulic conductivity of GCL and CCL

Hydraulic conductivity is an important component which controls leachate migration. In the case of GCL, the hydraulic performance mainly depends upon the hydraulic performance of bentonite. Bentonite occurs as a product of weathering, through chemical transformation from acid volcanic glass tufa (volcanic ashes), which has been deposited in sea water (Na-bentonite) or in fresh water (Ca-bentonite). High quality bentonite contains 65% to 95% montmorillionite mineral by weight [12]. Numerous research dealt with hydraulic performance of CCL and GCL when permeated with inorganic liquids ([13], [14], [15], [16], [17], [18],[19]) and also organic liquids ([20] [21] [22] [23]). Based on their experimental study it was found that permeabilty increased as concentration increased for clays with high plasticity. The hydraulic conductivity of clay when permeated with the high concentration liquid increases in significantly as that of when permeated with water ([24],[25] [26]). Most of the research either deals with bentonite or GCL. Jo et al. (2001) experimented the permeation of single species salt solutions such as LiCl, NaCl, KCl, $CaCl_2$ etc with GCL. The other study was the long term hydraulic performance of GCL with inorganic solutions such as calcium chloride, sodium chloride and potassium chloride [17]. GCL performance was investigated with permeation of non-standard liquids [26]. Bentonite hydraulic conductivity increases with increase in $CaCl_2$ solutions. Varying concentrations of $CaCl_2$ was permeated with GCL and was found that hydraulic conductivity of GCL increased as concentration of $CaCl_2$ increased[15].

Gleason et al. (1997) permeated different concentrations of $CaCl_2$, NaCl and Methanol with different forms of Bentonite. One was Ca- Bentonite and another was Na- Bentonite. The result shows that Ca Benoite has better resisting capacity as that of Na Bentonite. Higher concentration of calcium chloride results significant increase in hydraulic conductivity. Quality of clays an another important parameter studied by the researcher. Two bentonite one with higher quality and another with lower quality was permeated with water and $CaCl_2$ solutions. It was found that hydraulic performance of bentonite with higher quality was very much less than low quality bentonite when permeated with water but increases rapidly when permeated with $CaCl_2$ [16]. It was also found that high quality bentonite has higher resistance to chemicals compared to lower quality bentonite. Diffuse double increases with increase solute concentration. This results in flocculation of clays which leads to increase in hydraulic conductivity[28].

3.Liquid limit of GCL and CCL

Behaviour of clay was investigated by experimenting its consistency limits (Atterberg limits) [29]. Some researcher focussed on the Atterberg limits of clays of low plasticity (CL) and clay of high plasticity (CH). Plastic limit and liquid limit of CL increased with increase in solute concentration [30,31]. Plastic limit and liquid limit of low plastic soil increased on testing with NaOH. Increase in plastic limit and liquid limit could be attributed due to the formation of swelling compounds [32]. Increase in consistency limit of CL clay with increase solute concentration can be attributed with dispersion of clay particles. Increase in electroyte concentration increases consistency limit of Marine clay. This may be due to dispersion of clay particles [33]. On the other hand clay with high plasticity its liquid limit decreases with increase in solute concentration [25, 28,34, 35,36]. Similar results were obtained with GCL. Its liquid limit decreased with increase in solute concentration. This is attributed due to flocculation and reduction in thickness of DDL on increase of electrolyte concentration. LL of GCL decreased from 530 to 96 when NaCl concentration increased. But its hydraulic conductivity increased from $10^{-9}$to 10^{-6} cm when solute concentration increases [34].

4.Swell index of GCL and CCL

Many researcher focussed on correlation of hydraulic conductivity of bentonite with that swell potential [14,26,35,37,38,39].Swell index of bentonite depends upon solute concentration and cation valency. The swell index of GCL decreased when concentration of electrolyte increased. On the other hand there is increase in hydraulic conductivity of GCL when concentration of permeant fluid increased. Hence strong correlation exist between hydraulic conductivity and Swell index. Increase in hydraulic conductivity is correlated with decrease swell index when permeaed with higher solute concentration.

On the other hand few literatures are only available in case of swell index of CCL. Increase in solute concentration results decrease in thickness DDL and flocculation of clay particles which results decrease in swell index[14,16,40]. Volume changes of bentonite was studied on exposure of slat solution such as NaCl, $CaCl_2$, KCl and re exposed to water [7]. Chemicals tends to decrease the thickness of DDL results in clay to flocculate [8].

5. Comparison of GCL and CCL

Table 1 : Comparison of GCL and CCL

Characteristic	Geosynthetic clay liners	Compacted clay liners
Composition	Bentonite, adhesives geotextiles and Geomembranes	Native soils or blend of soil and bentonite
Thickness	Approximately 12 mm; consumes very little landfill volume	Typically 300 to 600 mm; consumes more landfill volume
Hydraulic conductivity	Less than 10^{-8} cm/sec	$\leq 1 \times 10^{-7}$ cm/s
Speed and ease of construction	Rapid and simple installation	Slow and complicated construction
Vulnerability to damage during construction from desiccation and freeze-thaw	GCLs are essentially dry; GCLs cannot desiccate during construction; not particularly vulnerable to damage from freeze-thaw	Compacted clay liners are nearly saturated; can desiccate during construction; vulnerable to damage freeze-thaw.
Vulnerability do damage from differential settlement	Can withstand much greater differential settlement than compacted clay liner	Cannot withstand much differential settlement without cracking
Materials	Materials easily shipped to any site	Suitable materials not available at all

		sites
Cost	Reasonably low, highly predicable cost that does not vary much from project to project	Highly variable-depends greatly on characteristics of locally soils
Ease of repair	Ease of repair with patch place over problem area	Very difficult to repair, must mobilize heavy earth-moving equipment if large area requires repair
Experience	Limited to novelty	Has been used for many years
Regulatory approval	Equivalence in meeting performance objects	Compacted clay liners are usually required by regulatory
Fissures	Cannot develop fissures if moisture available	May develop fissures
Weight	Light weight	Large weight

6.Conclusions

- Hydraulic conductivity of both GCL and CCL increases with increase in salt solution concentration for clay with high plasticity but hydraulic conductivity decrease for low plasticity clay soils when concentration of salt solution increased.

- As chemical concentration increased GCL liquid limit is decreased. However liquid limit of CCL made up of low plasticity clay increased with increase in chemical concentration and it decreased with increase in chemical concentration is due to dispersion and flocculation of clay particles.

- Swell index of GCL also decreased with increase in electrolyte concentration. However swell index of CCL was available only in few literature. Decrease in swell index with increase in solute concentration was due to flocculate formation of clay particles and decrease in DDL thickness.

- Finally GCL and CCL were compared based on criteria such as hydraulic conductivity, cost, vulnerability etc.

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