DESIGN AND CONSTRUCTION OF GEOSYNTHETIC CLAYLINERS

[1]Dr D.K. Maharaj, [2]Vikram Singh ,[3]HiteshKhullar

[1]Director and Principal ,[2]Student , [3]Student
[1]Department of Civil Engineering ,
GNITMullana ,Ambala ,India

***Abstract*:**Over last few years, Geo-synthetic clay liners have gained widespread popularity as substitute for compacted clay liners in cover systems and composite bottom liners. A geosynthetic clay liner is a factory produced mineral sealing mat which mostly consists of two layers of non-woven geotextile with on intermediate layer of sodium bentonitepowder.Geo-synthetic clay liners are mainly used for landfill copings, sealing ponds, bottom and to seal for wastes. Geo-synthetic clay liner must be properly designed in a manner consistent with anticipated field condition, Mechanical and hydraulic forces various criteria like hydraulic conductivity , chemical stability and strength parameters must be consider for designing the geosynthetic clay liners .This paper presents many key design criteria that should be addressed for proper hydraulic and mechanical performance of geo-synthetic clay liner such as calculation of leakage rates and shear stability. There are other factors like effects of confining stresses on permeability, freeze/ thaw cycling stability evaluation and cation exchange which will be presented as well . Geo-synthetic clay liners considered here are products fabricated using a bentonite clay layer sandwiched between geotextiles or to a geo-membrane.This paper also presents the construction guidelines for geosynthentic clay liners.

IndexTerms–Geosynthetic ,Sandwitched, leakage rate, clay ,liner,Geotextile,mechanical force, Freeze/thaw

I. INTRODUCTION

Geosynthetic clay liners represent a relatively new technology (developed in 1986) that is currently gaining acceptance as a barrier system in municipal solid waste landfill applications. GCL technology offers some unique advantages over conventional bottom liners and covers. For example , GCLs are fast and easy to install, have low hydraulic conductivity and have the ability to self- repair any rips or holes caused by the swelling properties of the bentonite from which they are made. Here some of important criteria for the design of geosynthetic clay liners are presented which must be considered .

2.GCL Strength Properties

2.1Wide-Width Tensile Strength—GCL's, as a composite material, are occasionally placed under wide-width tensile stress conditions and must be evaluated accordingly. Steep short slopes of canals, ponds and secondary containment facilities are situations where the GCL is contained at the top of slope in an anchor trench and tensile stresses may be imposed along the length of the slope. Based on limit equilibrium there are several models available to determine the induced stresses which must be counterpointed against the GCL's tensile strength .

2.2 Internal Shear Strength—GCLs are commonly divided into reinforced and unreinforced types. The reinforced GCLs have fibers, threads or yarns that connect the upper and lower geotextiles that form the two exterior surfaces of the GCL. Therefore, the internal shear strength of GCLs will be greatly influenced by the needled or stitched fibers that penetrate through the thickness of the GCL. In its hydrated state the bentonite itself will offer some, but very limited, shear strength by itself. These various components provide an internal shear strength that can be impacted by the degree of hydration of the clay, the normal load acting on the GCL, the type and amount of fiber reinforcement and the shear strain that has occurred across the thickness of the GCL. This section will elaborate on various aspects of internal shear strength.

2.2.1Bentonite Shear Strength—The clay, in particular, bentonite, that forms the hydraulic barrier component of GCL's has a hydrated shear strength that is influenced by the degree of hydration and the normal loading. The shear strength of hydrated clays has been evaluated by Olson (1974) who produced a series of effective stress failure envelopes. From Olson's work, the lower limit of the effective shear strength of bentonite clay is approximately 35 kPa at a normal load of approximately 275 kPa. The shear strength can be increased by decreasing the percentage of bentonite in the clay but at a cost of increased permeability. At lower normal loads, the degree of hydration increases and the shear strength decreases to zero at no normal load. At somewhat higher normal loads, Daniel, et al. (1993) showed that the drained friction angle of the bentonite clay in GCLs approaches seven degrees.

2.2.2 Internal Reinforcement Strength—Needled punched fibers or stitched yarns that penetrate through the thickness of a reinforced GCL contribute the major portion of shear strength as the geotextile surfaces move differentially apart. The amount of shear strength added by the reinforcement at low strains may also be influenced by the anchorage or tensioning of the fibers to the geotextiles. Here the internal total stress peak shear strength data is compared to the effective shear strength of bentonite as determined by Olson, (1974). As expected, the majority of peak shear strength of the GCL is due to the contribution of the reinforcement fibers. This contribution is seen to be significant across the full range of normal loads.

2.2.3 Large Strain Internal Shear Strength—Continued shearing of a reinforced GCL beyond its peak stress produces a residual strength. The residual strengths are also compared with Olson's effective stress failure envelope for montmorillonite and the peak strength values of a unreinforced GCL.Data presented by Scranton (1996) indicates that the residual strength of an unreinforced GCL is from 60 to 100% of the peak strength. The shear strength of a reinforced GCL approaches that of an unreinforced GCL at large shear displacements.

2.2.4 Peak Versus Residual—It is often debated whether to design using the peak strength or the residual strength of a GCL. In this regard, one must consider the type of GCL, the overall system behavior, and the specific conditions under which the GCL will be used. One must also consider the internal strength of the GCL product, the interfaces against its outer surfaces, the interfaces of other adjacent liner components considering both short-term and long-term conditions, and the shear strengths of other liner components in the design. The application will also influence the selection of design strength values. Typically, at lower normal loads, the peak interface strength of a reinforced GCL with adjacent materials is less than the peak internal strength of the GCL. If these materials are sandwiched together to form the sealing system and then subjected to a shear stress, sliding will occur when the applied shear stress exceeds the peak strength of the weakest material or interface. It is likely that once failure is initiated, displacement will continue along that particular slip plane; Marr and Christopher (2004). Design using the lowest peak strength assumes that the peak strength of the interfaces and materials do not change with time.

2.2.5 Creep—It is well known that polymeric materials in tension can fail in sustained load creep at lower stresses than their short-term tensile strength. Creep and aging of polymeric materials placed in tension are handled in reinforced soil applications by applying reduction factors to the peak strength of the materials. In the absence of long-term direct shear tests to determine the creep limit of the GCL reinforcement fibers or yarns (that is, the stress level above which the reinforcement will creep to failure within the design life of the project), a creep reduction factor of three has been recommended by Marr and Christopher (2004) based on creep reduction factors normally used for polypropylene (PP) fibers in tension. This value might be somewhat conservative due to anticipated composite bentonite-to-fiber reinforcement interaction that is not present in conventional creep tests used to obtain the stated reduction factor. Published papers by Koerner, et al. (2001) have shown that the majority of internal shear displacement occurs during the first 100 h of loading. In this regard, the initial 10 to 30 days after installation is critical. At the GCL landfill cover slope tests in Cincinnati (Scranton, 1996) reinforced GCLs have remained stable with little or no ongoing deformation on slopes as steep as 2H:1V since 1994. This implies a minimum slope stability factor of 1.5 when applied to 3H:1V slopes. Of course, these are at low normal stresses. Unfortunately, there are no similar studies conducted at high normal stresses. The latest study by Müller (2008) states that a GCL with defined resin properties and an antioxidant package of the fibers of a double sided needle-punched nonwoven GCL has a lower limit of functional durability of at least 250 years at 15°C.

2.3 Interface Shear Strengths—In addition to internal shear strength of GCL's, the designer must consider the interfaces between its outer surfaces and the adjacent materials (as well as all other interfaces of other adjacent liner components and their respective shear strengths). In all cases, it is recommended to test product specific materials to be used in the design and the applying site-specific conditions.

2.3.1 Shear Strength of NonreinforcedBentonite GCLs—For those GCLs which have bentonite bonded to a geomembrane, a critical interface will be against or within the bentonite. As mentioned previously if the bentonite is hydrated (as it will be under most situations), the shear strength will vary from approximately zero to seven degrees depending on the normal stress. As such, this type of GCL usually deploys a field placed geomembrane against the exposed surface of the bentonite thereby encapsulating the bentonite between two geomembranes. The encapsulated and relatively dry bentonite has a significantly higher shear strength than when hydrated. In this case emphasis is then transferred to the geomembrane (smooth or textured) surfaces.

2.3.2 Interfaces With Woven Geotextiles—The typical woven geotextile used with GCL's is of the slit (or split) film type. This material with whatever is placed against it must be evaluated for its shearing resistance. Again, site-specific and product-specific conditions must be used in conducting the direct shear test. It is important to communicate the orientation of this woven geotextile, i.e., up or down, to the field installer.

The designer must also assess whether or not hydrated bentonite might extrude through the openings between the filaments of the woven geotextile. Vukelic, et al. (2008) has evaluated this situation in the laboratory and found that the shear strength of the interface can decrease appreciably when hydrated bentonite extrudes through the fabric's openings onto the adjacent material.

2.3.3 Interfaces With Nonwoven Geotextiles—For the nonwoven geotextile component of GCLs, and for those GCL's with nonwoven geotextiles on both upper and lower surfaces, extrusion of hydrated bentonite to the opposing interface(s) is unlikely if the weight of the geotextile(s) is adequate.

3. GCL Hydraulic Properties

3.1 The flow rate or flux, (q) of fluid movement through a saturated GCL is measured under a given normal load. The thickness of the saturated bentonite depends on the normal load and is measured in this test. Knowing the flux and bentonite thickness, the hydraulic conductivity (routinely called permeability) of the bentonite portion of the GCL can be evaluated .

3.1.1 GCL Barrier—The flow rate that liquids pass through a GCL can be quantified to evaluate the effectiveness of a GCL barrier system. The flow rate, Q, through a hydrated GCL is conventionally calculated using Darcy's Law as follows:

$$Q = K ((h + t_{GCL})/t_{GCL}) A$$

where:

Q = flow rate or flux, (cm3/sec)

K = permeability of the bentonite, (cm/sec)

tGCL = effective thickness of the GCL, (cm)

h = height of the liquid above the GCL (cm), and A = total area (cm2).

3.1.2 Geomembrane/GCL Composite Barrier—The flow rate through a GM/GCL composite, based on a defect in the geomembrane, is assumed to be similar to a GM/CCL composite for which the following equations have been derived, Giroud (1997).

- Circular Defect, $Q = C_{qo} i_{avgo}\, a^{0.1} h^{0.9} K^{0.74}$
- Square Defect, $Q = C_{qo} i_{avgo}\, a^{0.2} h^{0.9} K^{0.74}$
- Infinitely Long Defect, $Q = C_{q4}\, b^{0.1} h^{0.45} K^{0.87}$
- Rectangular Defect, $Q = C_{qo} i_{avgo}\, b^{0.2} h^{0.9} K^{0.74} + C_{q4} (B - b)\, b^{0.1} h^{0.45} K^{0.87}$

where:

C_{qo} = quality of GCL-geomembrane contact ($C_{qogood} = 0.21$, $C_{qopoor} = 1.15$),
i_{avdo} = average hydraulic gradient (dimensionless),
a = area of the defect (m^2)
h = head acting on the liner (m),
K = permeability of the GCL (m/sec),
b = side length of a square defect (m),and
C_{q4} = quality of geomembrane-to-GCL contact for the infinitely long case ($C_{q4good} = 0.42$, $C_{q4poor} = 1.22$).

3.1.3 Effects of Confining Stress on Permeability—Increasing confining stress on a porous material, such as highly compressible hydrated sodium bentonite, decreases the hydraulic conductivity . With increasing confining stress, several detrimental aspects of hydrated sodium bentonites can be prevented; the main one being shrinkage of the bentonite creating cracks that would increase the hydraulic conductivity. These effects can occur as a result of dehydration of the bentonite or, for example, high concentrated calcium solutions that are extremely aggressive to sodium bentonite .Higher confining stresses mitigate this effect, and the hydraulic conductivity can possibly remain unchanged. In landfill liners beneath a waste mass, GCLs subjected to high confining stresses are felt to be less vulnerable to increases in hydraulic conductivity than GCLs in low confining stress applications, e.g., less than 20 kPa.

3.2 Cation Exchange

3.2.1 If a liquid containing significant electrolytes [for example, potassium (K+), calcium (Ca++), magnesium (Mg++), and aluminum (Al+++) cations] percolates down to and through a GCL, these positively charged cations will preferentially exchange with the sodium

(Na+) cation in the bentonite of the as-manufactured GCL. This is referred to as cation exchange. It is somewhat controlled by the role of RMD, the ratio of monovalent to the square root of divalent ions. The phenomenon results in reduced swelling capacity and increased hydraulic conductivity of the bentonite. The higher the charge (or valence) of the cation, the more preferential and readily it will exchange with the Na+ cations within the bentonite structure. It should be recognized that most soils contain an abundance of salts that contain significant concentrations of K+, Ca++, Mg++, or Al+++. The least favorable cations with regard to exchange of Na+ in bentonite are the polyvalent cations. They have a charge of +2 or more. Free available calcium or magnesium from the surrounding soil will produce an ionic exchange within the sodium bentonite of the GCL within a time period of a few years depending upon site-specific conditions

4. Additional Design Considerations

4.1 Freeze/Thaw Cycling—The critical property of a hydrated GCLs insofar as freeze-thaw behavior is concerned is the increase in permeability. Daniel, et al. (1997) used a rectangular laboratory flow box and subjected the entire assembly to ten freeze-thaw cycles. The permeability showed a slight increased from 1.5 × 10-9 to 5.5 × 10-9 cm/sec. Kraus, et al. (1997) report no change in flexible wall permeability tests of the specimens evaluated after twenty freeze-thaw cycles. Podgorney and Bennett (2006) examined the long term performance of GCL's exposed to 150 freeze/thaw cycles and found no appreciable increase in permeability.

While the moisture in the bentonite of the GCL can indeed freeze, causing disruption of the soil structure, upon thawing the bentonite is very self-healing and apparently returns to its original state. In this regard, it is fortunate that most GCLs have geotextile or geomembrane coverings so that fugitive soil particles cannot invade the bentonite structure during the expansion cycle. Thus, the bentonite does not become "contaminated" with adjacent soil particle

4.2 Total Settlement and Differential Settlement—GCL's (as with all geosynthetics in a layered liner system) will often be subjected to total settlement and/or differential settlement. Typical landfills will settle 10% to 30% of their initial thicknesses and waste piles are anticipated to do likewise. If a GCL is in the cover cross section it will necessarily settle likewise. In this regard, total settlement can probably be accommodated (depending on site-specific conditions like contouring), but differential settlement is of concern. GCL's have been laboratory evaluated for their performance in an out-of-plane deformation mode thereby simulating differential settlement. LaGatta (1992) used large-scale tanks with deformable bases to measure water breakthrough. Values for different GCL's were from 10 to 15% tensile strain.

Conclusion

The important factors for designing geosynthetic clay liners have been presented above. These factors must be carefully studied and evaluated for the proper and efficient performance of the clay liners. It has been found from the study that shear strength can be increased by decreasing the percentage of bentonite in the clay but at a cost of increased permeability. At lower normal loads, the degree of hydration increases and the shear strength decreases to zero at no normal load. Other factors like total settlement and differential settlement , freeze thaw cycle , cation exchange criteria , hydraulic properties and shear strength of geosynthetics must be considered for proper designing

References

Daniel, D. E., Shan, H. Y. and Anderson, J. D. (1993), "Effects of Partial Wetting on the Performance of the Bentonite Component of a Geosynthetic Clay Liner," in Proceedings of the Geosynthetics 1993 Conference, Roseville, MN, pp. 1483-1496.

Daniel, D. E., Trautwein, S. J. and Goswani, P. K. (1997), "Measurement of Hydraulic Properties of Geosynthetic Clay Liners Using a Flow Box," in Testing and Acceptance Criteria for Geosynthetic Clay Liners, ASTM STP 1308, edited by Larry W. Well, ASTM, pp. 196-207.

Giroud, J. P. (1997), "Equations for Calculating the Rate of Liquid Migration Through Composite Liners Due to Geomembrane Defects," Geosynthetics International, Vol. 4., Nos. 34, pp. 335-348

Kraus, J. B., Benson, C. H., Erickson, A. E. and Chamberlain, E. J. (1997), "Freeze-Thaw Cycling and Hydraulic Conductivity of Bentonite Barriers," Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 123, No. 3, pp. 229-238.

Marr, W. A. and Christopher (2004), "Slope Design Using Geosynthetic Clay Liners in Liner Systems," Proceedings, EuroGeo, Munich, Germany, pp. 189-192.

Müller, W., Jakoba, I., Seeger, S. and Tatzky-Gertha, R. (2008), "Long-Term Shear Strength of Geosynthetic Clay Liners," Geotextiles and Geomembranes, Vol. 26, Issue 2, pp. 130-144.

Olson, R. E. (1974), “A Shearing Strength of Kaolinite, Illite, and Montmorillonite,” Journal of the Geotechnical Engineering Division, ASCE, Vol. 100, No.GT11, pp.

Podgorney, R. K. and Bennett, J. E. (2006), “Evaluating the Long-Tem Performance of Geosynthetic Clay Liners Exposed to Freeze-Thaw,” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 132, No. 2, pp. 265-268

Scranton, H. B. (1996), “A Field Performance of Sloping Test Plots Containing Geosynthetic Clay Liners,” Master of Science Thesis, University of Texas, Austin, TX.

Vukelic, A., Szavits-Nassan, A. and Kvasnicka, P. (2008), “The Influence of Bentonite Extrusion on Shear Strength of GCL-to-Geomembrane Interfaces,” Journal of Geotextiles and Geomembranes, Vol. 26, No. 1, pp. 82-90.