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LANDFILL STABILITY : STATIC AND DYNAMIC GEOSYNTHETIC INTERFACE FRICTION VALUES

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ABSTRACT:

The base liner system of modern landfills include several layers of soil and geosynthetic materials. The several geosynthetic/geosynthetic and soil/geosynthetic contact surfaces, usually represent potential locations of sliding movement in case of instability. Due to the scarcity of land, and economic reasons, modern landfills are being constructed with relatively steep side slopes. As a result, it is necessary to obtain proper estimates of the shear strength properties of geosynthetic interfaces in order to perform reliable stability analyses. This paper describes some of the commonly used landfill liner configurations and discusses the interface shear strength properties of different geosynthetic liner components. Experimental methods to estimate both the static and dynamic frictional properties are presented. Finally, some of the factors that influence the shear strength parameters of geosynthetic interfaces are discussed.

INTRODUCTION:

The design of a modern solid or hazardous waste landfill includes a multi-layered bottom liner and leachate system to contain and detect the flow of leachate. The liner system is typically composed of several layers of geosynthetics and compacted clay material. The function of containment is provided by the liner system, typically consisting of geomembrane and/or compacted clay liners. The leachate collection and removal system (LCRS) consists either of a layer of granular aggregates or geocomposite drainage layers.

Regulatory Requirements and Practice:

In the United States the USEPA (United States Environmental Protection Agency) prescribes the regulatory requirements for landfill configurations at a national level. In addition, many states have their own regulatory bodies that may prescribe additional requirements. For base liners of municipal solid waste (MSW) landfills the current USEPA guidelines require the use of a minimum 60-cm (2-ft) thick clay liner with a minimum permeability of 1×10^{-7} cm/s, overlain by a minimum 0.75-mm (30-mil) thick geomembrane. If a geomembrane made of high density polyethylene (HDPE) is used, then the minimum thickness of the geomembrane must be 1.5 mm (60 mil). In the case of hazardous waste landfills, double liners, consisting of a top liner (e.g. a geomembrane) and a composite bottom liner (a combination of a geomembrane overlying at least 90 cm (3 ft) of compacted soil material, having a minimum permeability of 1×10^{-7} cm/s [Sharma and Lewis, 1994] are required.

Liner Materials

In all cases the use of alternative liner configurations (from what is prescribed in the regulations) are permitted, provided that it is demonstrated that the performance of the alternative design is equivalent to or superior than that of the prescribed configuration. A commonly used alternative configuration includes a geosynthetic clay liner (GCL) in the landfill base liner system. Currently available GCLs fall in two categories. The first includes GCLs that are manufactured with a layer of bentonite held between two layers of geotextiles. The second consists of a layer of bentonite adhering (usually by means of some glue) to a geomembrane sheet. Bentonite is a tradename for clays formed primarily from the mineral montmorillonite. The most common type of this material is sodium montmorillonite. Such soils have very low permeability, on the order of 1×10^{-9} cm/s.

GCL materials are commonly incorporated in landfill liner systems at sites where clay material having a minimum permeability of 1×10^{-7} cm/s is not economically available. It is also common to use GCLs in liners on side-slope areas of landfills, where the placement and compaction of 60 cm (2 ft) thick clay material pose difficulties. Sometimes combinations of GCL and compacted clay are used. Generally, the thickness of the clay material is reduced in such cases. Some typical landfill base liner configurations (including LCRS) are shown in Figure 1.

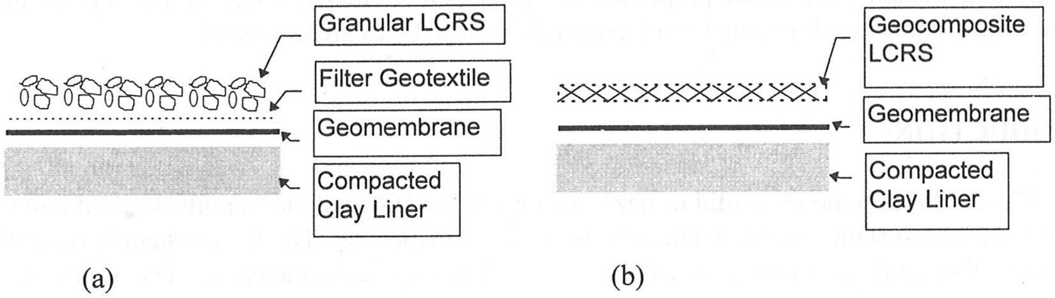

Figure 1. Typical landfill base liner configurations showing leachate collection and removal system and lining system: (a) including granular LCRS and (b) including geocomposite LCRS.

Leachate Collection and Removal System

Current federal regulations require the LCRS to be capable of removing the maximum anticipated volume of leachate generated in the landfill. The regulations in the state of California require the LCRS to be designed for twice the anticipated volume of leachate. In addition the head of leachate on top of the liner system (i.e. the head within the LCRS) should not exceed either the thickness of the LCRS, or 30 cm (1 ft), whichever is smaller. A geosynthetic LCRS usually consists of a geonet and a geotextile. Very often the two materials are combined into a single product called geocomposite, in which the geonet is heat bonded to a geotextile on one or both of its surfaces. Accordingly, the geocomposite is commonly called "single-sided" or "double-sided".

INTERFACE FRICTION CONSIDERATIONS

From the forgoing discussions it is clear that a landfill liner system can have many different configurations that are determined by the design engineer based on the prevalent site conditions, the requirements of the unit under consideration and the guiding regulations. In all cases, however, the designed liner system is likely to include a number of different geosynthetic/geosynthetic and soil/geosynthetic interfaces. Only the geosynthetic/geosynthetic interfaces are discussed in this paper. The common geosynthetic interfaces considered in the designs discussed so far include:

- geotextile / geomembrane;
- geonet / geomembrane;
- geotextile / geonet; and
- GCL / geomembrane.

In addition, the geosynthetics can have different characteristics that can influence their surface properties. For example, the surface of a geomembrane may be smooth or textured. The texturing, which may be done either during the manufacturing of the HDPE sheets through co-extrusion, or through spraying of additional material after the sheets have been produced, are useful in increasing the surface roughness, and therefore the interface friction angle of these geomembranes. Similarly, the orientation of the geonet strands that form the mesh, with respect to the direction of shearing motion, can influence the friction angle. This is explained in detail in the next section.

The liner interfaces, consisting of both geosynthetic/geosynthetic and soil/geosynthetic surfaces, usually represent potential locations of sliding movement in case of instability. Economic needs, as well as scarcity of suitable space, require modern landfills to be built to considerable heights and with steep side slopes. Very often the stability of the liner system is a critical item in the analysis and design of a landfill. The most commonly used procedure for seismic design of landfills includes stability analyses under earthquake loading conditions and deformation analyses, if necessary.

Experiments to Estimate Interface Friction Angles

It is necessary to obtain proper estimates of the shear strength properties of geosynthetic interfaces in order to perform reliable stability analyses. Both static (or monotonic) and dynamic interface shear properties can be determined through experiments. The most common methods to obtain static interface shear properties of geosynthetic interfaces are tests using: tilt table, direct shear device (using specimens of different sizes), pull-out box, and ring-shear device. Gilbert et al. (1995) have compiled the advantages and disadvantages of using different static shear test methods. Laboratory estimation of dynamic friction angles of geosynthetics is not a common procedure. There have been some recent research studies dealing with the different experimental methods. The most common of these are the use of cyclic direct shear devices and shaking table apparatus. De (1996) has performed a study to compare the results from different types of cyclic shear tests.

Factors Affecting Shear Strength Parameters

The shear strength behavior of geosynthetic interfaces are influenced by many different factors. The effect of some of the factors are discussed in the following sections. Other factors, such as specimen size, loading rate and experimental procedure, may also influence the results.

Normal stress

The shear strength behavior of many geosynthetic interfaces is dependent on normal stress. This dependence is most conspicuous in the case of interfaces involving geotextiles, GCLs and geonets. In general the friction angle obtained from tests under a relatively low normal stress is greater than that obtained from a test using higher normal stress [De (1996), Sharma et al. (1997)]. However, this behavior is highly dependent on the type of interfaces, and therefore it is very important to perform tests specific to design requirements. Sharma et al. (1997) recommend the use of two or three different line segments to describe the shear strength behavior of interfaces involving clay and geosynthetics. This approach also be used in the case of other geosynthetic interfaces. An example of this is shown in Figure 2 using results published by De (1996) from monotonic direct shear tests performed on geotextile over geonet interfaces. These particular tests were performed on geonet oriented in the transverse orientation, a term explained in the next section. As seen in the figure, the maximum shear stress for the specimens fell along a curved line.

An alternative approach would be to denote the shear stress parameters through a cohesion intercept along with a friction angle. However, it is clear from an inspection of the interfaces, that a geotextile / geonet interface cannot possess any measurable cohesion. Therefore, the approach recommended by Sharma et al. (1997) is used to show the normal stress dependent nature of the shear stress behavior.

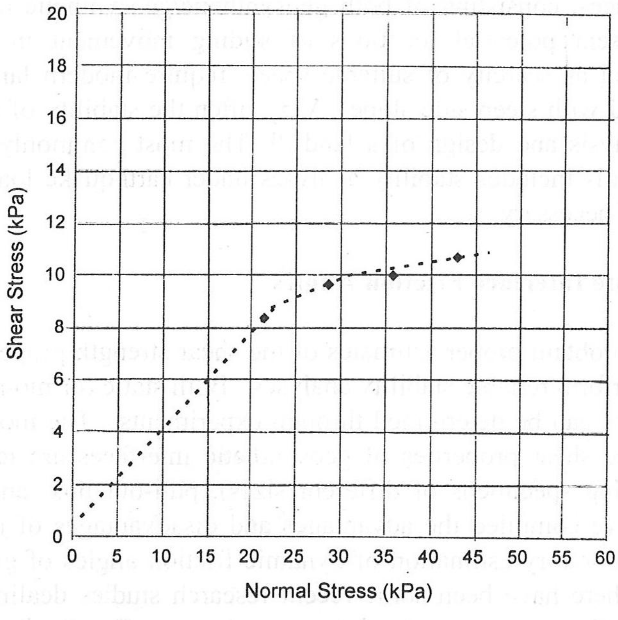

Figure 2. Shear versus Normal Stress from Direct Shear Tests: Geotextile over Geonet (transverse orientation)

Orientation of Geonet

The shear stress behavior of interfaces that include geonet has been found by several researchers [Mitchell et al. (1990) and De (1996)] to depend on the orientation of the geonet strands with respect to the direction of shear motion. De (1996) studied the shear behavior of three different orientations of a geonet. The orientations are explained in the schematic diagrams presented in Figure 3.

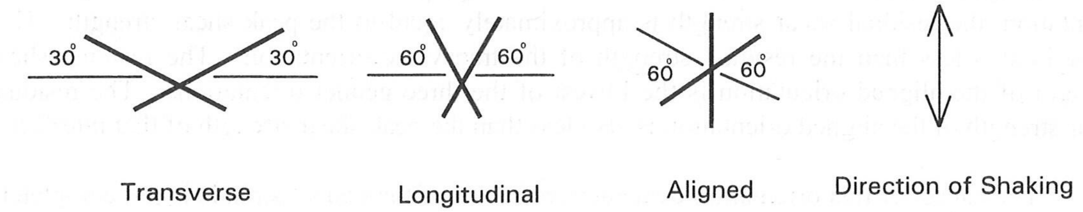

Figure 3. Orientation of Geonet Mesh

The orientation where one of the strands is along the direction of the force is termed aligned. The case where the strands are at 60° with the direction of the force is termed transverse. When the direction of the strands make angles of 30° with the force direction, the orientation is termed longitudinal.

The difference in the shear behavior of the three orientations of the geonet is shown in Figure 4 which shows results from direct shear tests on the three orientations of the geonet tested against a geotextile. It can be seen that in each case the initial portion of the curves is an almost straight line culminating in a break, or peak shear stress, followed by a slight decrease in the shear stress.

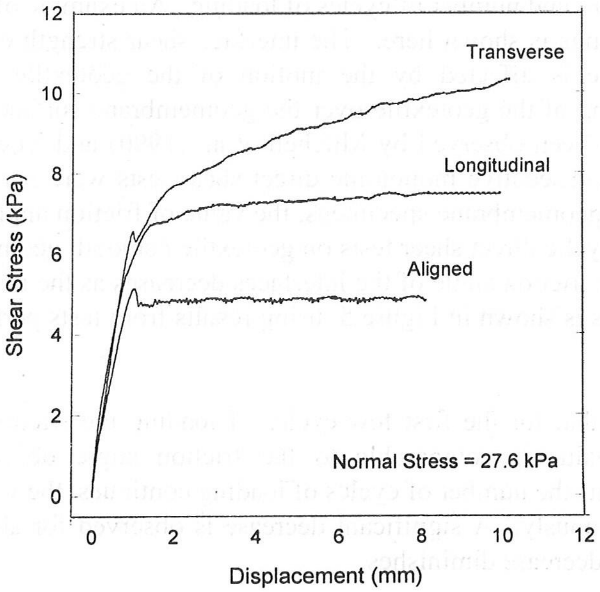

Figure 4. Shear Stress versus Displacement results from Direct Shear Tests: Geotextile over Geonet (transverse, longitudinal and aligned)

However, the nature of the curves after the break differ. For the transverse orientation, the shear stress continues to increase after the break. In the case of the longitudinal orientation, the stress continues to remain at about the same level where the break occurs. Finally, in the case where the strands are aligned in the direction of the force, there is a slight reduction in the shear stress.

This difference in post-peak behavior is reflected in the relative values of residual shear strengths of the three orientations. The transverse orientation has the highest value of residual shear strength, which is greater than its peak shear strength. In the case of the longitudinal orientation, the residual shear strength is approximately equal to the peak shear strength. This value is also less than the residual strength of the transverse orientation. The residual shear strength of the aligned orientation is the lowest of the three geonet orientations. The residual shear strength of the aligned orientation is also less than the peak shear strength of that interface.

The cause for this orientation dependent behavior of the geonet strands is not completely understood. It appears that an arrangement of the strands along or almost along the direction of the force leads to an elasto-plastic type behavior, whereas an arrangement where the strands face sideways to the direction of loading leads to a strain hardening effect.

From a practical standpoint, geonet orientation could play a significant role in liner interface behavior after sliding is initiated in the field. For the case of sliding along a geonet oriented transversely to the direction of movement, the amount of slip occurring after the shear strength of the interface is exceeded will be relatively small. However, where sliding occurs in a direction parallel to the direction of the strands, larger displacements can result following slippage, due to the relatively low value of residual shear strength.

Factors affecting cyclic shear behavior

The factors that may affect the cyclic shear behavior of geosynthetic interfaces include frequency, normal stress, and number of cycles of loading. An example of the dependence on the number of cyclic loadings is shown here. The interface shear strength of a geotextile / smooth geomembrane interface is affected by the motion of the geotextile on the geomembrane. Specifically, the rubbing of the geotextile over the geomembrane surface causes the latter to be smoothened. This has been observed by Mitchell et al. (1990) and Yegian and Lahlaf (1992), who noted that when consecutive monotonic direct shear tests were performed using the same geotextile and smooth geomembrane specimens, the value of friction angle appeared to decrease. De (1996) performed cyclic direct shear tests on geotextile / smooth geomembrane interfaces and found that the dynamic friction angle of the interfaces decreases as the number of cycles of shear loading increases. This is shown in Figure 5, using results from tests performed at four different levels of normal stress.

It can be seen that for the first few cycles of loading the friction angle has a value of about 12.5°. This value is comparable to the friction angle observed under monotonic conditions. However, as the number of cycles of loading continues, the value of dynamic friction angle decreases continuously. A significant decrease is observed for about the first 25 cycles, after which the rate of decrease diminishes.

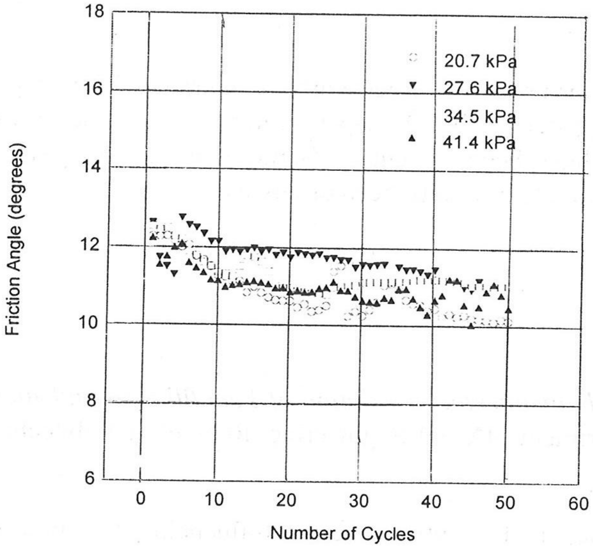

Figure 4. Variation of Friction Angle with Number of Cycles from Tests on the Direct Shear Device: Geotextile over Smooth Geomembrane

Conversely, cyclic direct shear tests on a geonet / smooth geomembrane interface yields dynamic friction angle values that appear to increase with the number of cycles. The results from such tests on the aligned orientation of the geonet are shown in Figure 5. It is believed that such behavior is due to local surface deformations caused on the smooth geomembrane due to stress concentrations on the nodal contact points of the geonet. Further studies, including experiments performed on other orientations of geonet, have been presented in De (1996) and De and Zimmie (1997).

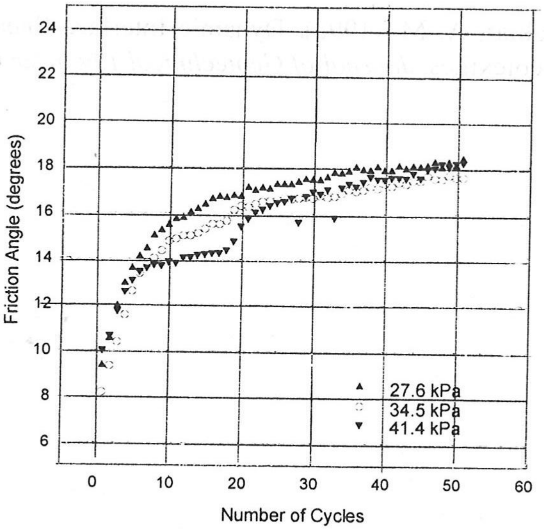

Figure 5. Variation of Friction Angle with Number of Cycles from Tests Using the Direct Shear Device: Smooth Geomembrane over Geonet (aligned)

CONCLUSIONS:

The interface shear behavior of geosynthetic interfaces is an important parameter in the design of landfill liner systems. In this paper various testing procedures for the estimation of interface friction angle have been presented. Some of the factors that influence the values of static and cyclic friction angle have also been discussed.

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