GEOSYNTHETIC DESIGN CONSIDERATIONS FOR DOUBLE LINER SYSTEMS

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ABSTRACT

The "minimum technological requirements" of the Hazardous and Solid Waste Amendments of 1984 require a double liner system in most hazardous waste land disposal cells and surface impoundments. Ensuing guidance recommended the use of two flexible membrane liners (FML). Each FML in a landfill and the bottom FML in a surface impoundment is covered by a leachate collection/removal (LCR) system to aid in preventing leachate from standing on the FMLs. This paper reviews design considerations for the FML and LCR systems within the double liner system.

Potential failure modes for geosynthetic FMLs and LCRs are described in this paper and design procedures are reviewed for each of the failure modes. Each design procedure calculates the actual service stress or flow conditions and compares this required performance to the limiting performance of the component itself. The limiting performance is typically obtained from laboratory testing. A Design Ratio (DR) is defined as the ratio of the laboratory limiting performance divided by the calculated service performance.

OVERVIEW

On November 8, 1984, the Resource Conservation and Recovery Act (RCRA) was amended by the Hazardous and Solid Waste Amendments (HSWA). Among the provisions that went into effect were minimum technological requirements for hazardous waste land disposal facilities. HSWA requires new units and lateral expansions of existing facilities to use two liners with a leachate collection system above (in the case of a landfill) and between such liners.

Draft EPA Minimun Technology Guidance (MTG) (1,2) for liners and LCRs was published on May 25, 1985. Proposed codification of the MTG is outlined in the Federal Register, Vol.51, No.60, March 28, 1986.

The MTG standard 'double-liner' system for a landfill is shown on Figure 1 and consists of a primary LCR and FML system over a secondary LCR and a composite FML/clay secondary liner. The primary LCR minimizes the amount of leachate that is allowed to stand on the primary FML. The primary FML must be designed to allow no more than de minimis quantities of leachate to pass through the liner. The secondary LCR collects leachate that has passed through the primary FML and in this fashion bears 'witness' to the integrity of the primary FML. The secondary FML/clay liner must be designed to prevent greater than de minimis quantities of leachate from leaving the system during the minimum 30-year post-closure monitoring period.

MTG MINIMUM DESIGN PROPERTIES

The draft MTG provides minimum standards for each of the components within the recommended double liner system. Shown on Figure 1, these are as follows:

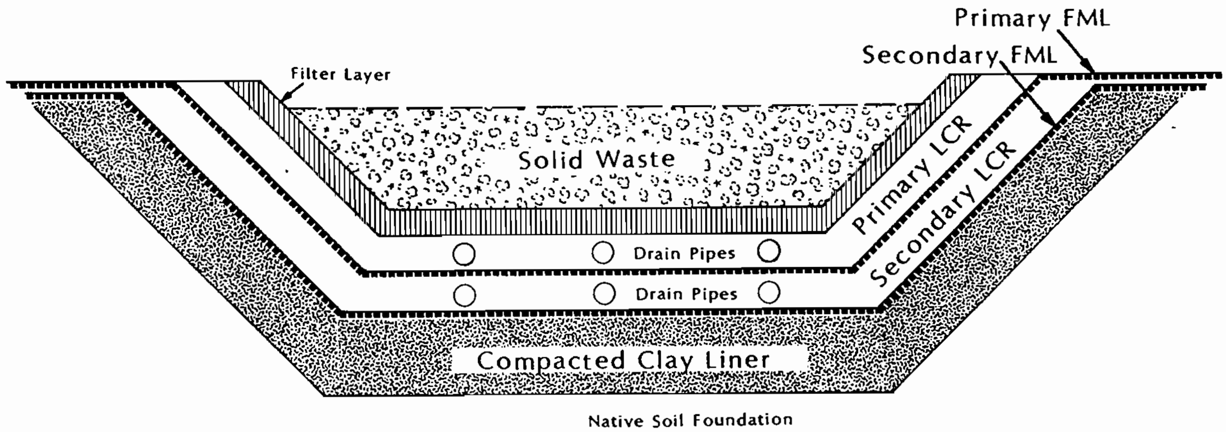

Figure 1 MTG Double-Liner System

o Primary LCR: This system is placed above the primary FML and is separated from the waste by a filter layer. It consists of a minimum of 30 centimeters (cm) of drainage stone having a minimum hydraulic conductivity of 10^{-2} cm/second. A 15-cm thick filter layer is placed between it and the waste, and an internal pipe drain system must be designed to keep less than 30 cm maximum head of leachate acting on the primary FML .

o Primary Liner: The primary liner must be of synthetic material at least 0.75 millimeters (mm) thick. This liner must be designed to allow no more than de minimis quantities of leachate to pass through to the secondary LCR. A composite soil/FML primary liner is allowed under proposed codification.

o Secondary LCR: This witness system has the same minimum properties as the primary LCR but lacks the overlying filter layer.

o Secondary Liner: This is a composite FML/clay liner having an FML with the same minimum thickness as the primary FML, 0.75mm, and an underlying clay having a maximum permeability of 10^{-7} cm/sec and a minimum thickness of 90 cm. The secondary FML is typically of the same material and thickness as the primary FML.

DESIGN CONCEPT - FML

A large number of failure scenarios can be developed for an FML. These failures have in common the generation of large tensile stresses within the FML. Design for these failure mechanisms is based on the stress-strain curves for the particular polymeric material used in forming the FML. For HDPE, the short term stress vs strain curves yield a well defined yield stress while for other polymers such as PVC or CPE, the stress vs strain curves show no distinct yield, Figure 2. Allowable stress limits for such curves are based on a limiting strain level. In both cases, the design philosophy is that a significant amount of FML deformation capacity remains even if the yield stress or strain is reached.

Figure 3 presents four tensile failure mechanisms for an FML. All mechanisms can be quantified on the basis of free-body diagrams that sum the forces or stresses parallel to the surface of the FML. These mechanisms include the following:

o Dead Weight - The self weight of the FML places the FML in tension as it is draped down the sideslope. A high value of DR, greater than 10, insures that excessive elongation of the FML does not occur during placement of the FML. Fortunately, the minimum MTG thickness is normally adequate to generate this level of DR unless extremely steep slopes are present.

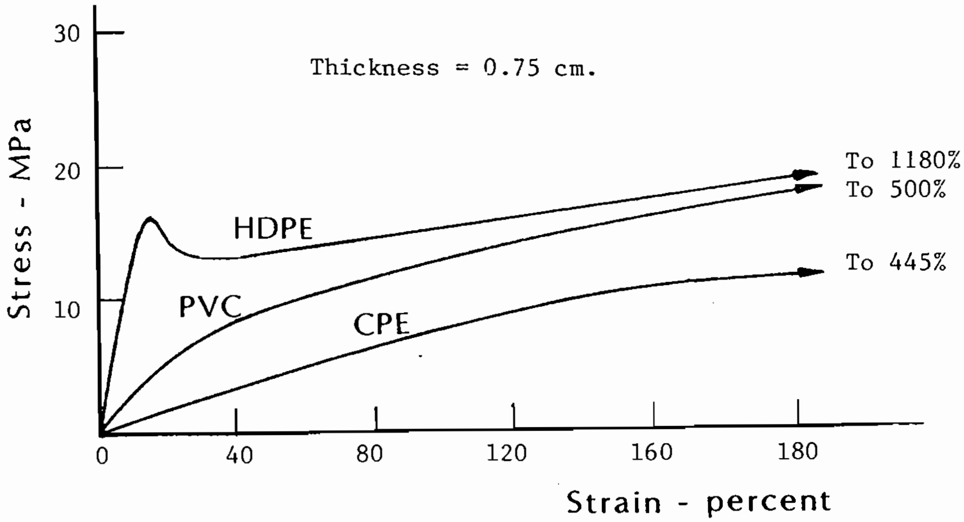

Figure 2 Stress vs Strain for FML

o Sliding Stability - Each synthetic layer forming the liner systems forms a potential shear failure plane. Shear is transferred to and from each layer through the friction or adhesion that exists between that layer and the adjacent layers. Shear stresses in excess of that which can be transferred by these surface forces must be resisted in tension by that layer. This reduces the shear stresses transferred to underlying layers.

o Waste Lift Stability - The placement of waste against the liner can produce significant downdrag forces on the liner system. DR values for such problems can easily fall below one (3) if lift heights exceed 3 meters.

o Settlement of Liner - Settlement of the subgrade beneath the liner system can lead to excessive strains within an FML (4). Such settlement could result from the collapse of a drainage line or the uneven densification of poorly compacted soils. The designer must predict subgrade settlements and verify that an adequate DR will exist under these conditions.

With the exception of settlement, these failure mechanisms are also appropriate for evaluation of synthetic LCR systems.

With the exception of the settlement mechanism, all of the above design concerns predict a tension force T acting in the plane of the FML at the shoulder of the sideslope. This force must be resisted by anchorage of the FML beyond the shoulder. Such anchorage is commonly provided by running the FML beyond the shoulder and either burying the end of the FML in a trench or by simply placing sand on top of the FML. Typical FML anchor geometries are shown on Figure 4. The maximum anchorage tension, T_{max}, for the horizontal anchor is given by

$$T_{hor} = \frac{qL\tan\delta}{\cos\beta - \sin\beta\tan\delta} \qquad (1)$$

where δ is the friction angle between the subgrade soil and the FML. The maximum anchorage of the trench system cannot be rigorously calculated at present but can be bounded as follows:

$$T_{tch} = T_{hor} + \frac{(Ka+K')\tan\delta\,[0.5\,\gamma\,d^2 + qd]}{\cos\beta - \sin\beta\tan\delta} \qquad (2)$$

where d is the depth of embedment, Ka is the active earth pressure coefficient and K' is the at-rest or the passive earth pressure coefficient. The actual anchorage

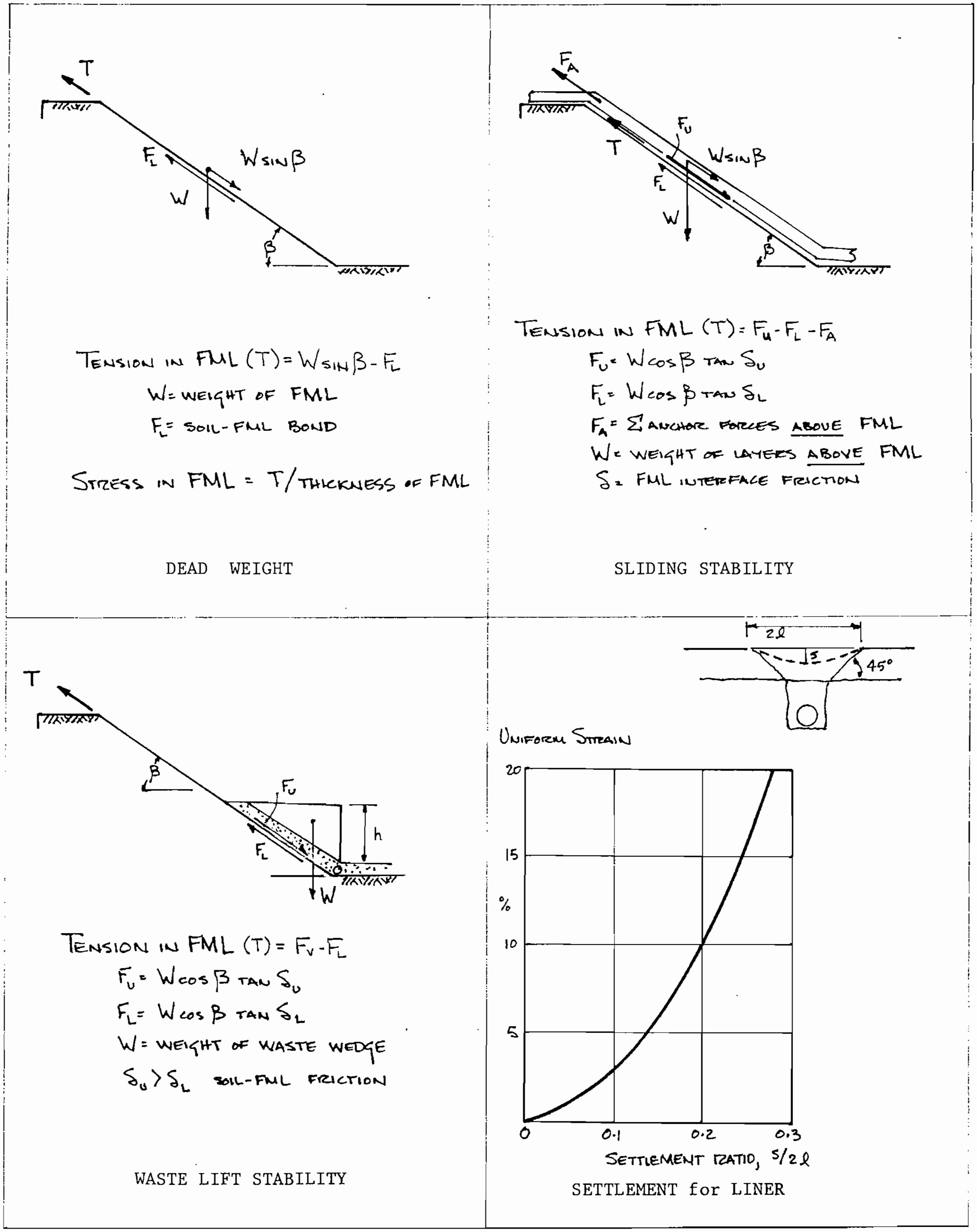

Figure 3 FML Tensile Failure Models

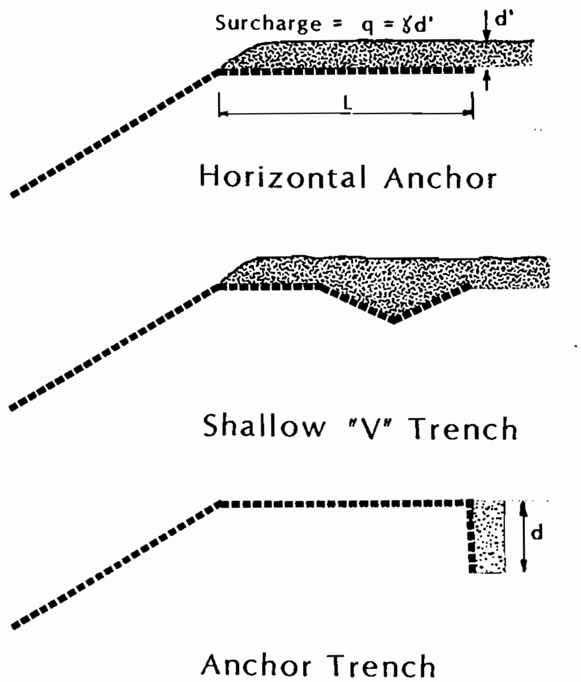

Figure 4 FML Anchorage

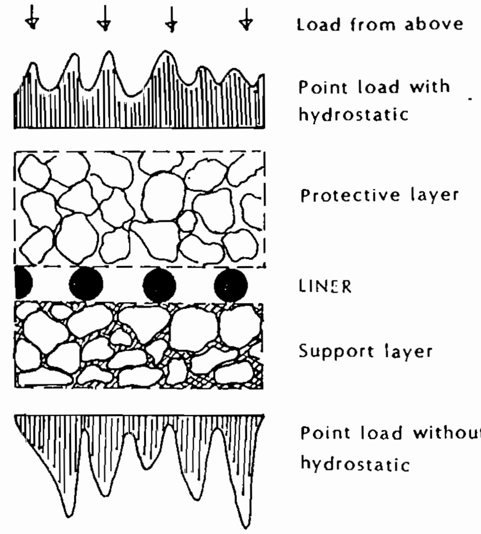

Figure 5 FML Compressive Stresses

capacity lies between that predicted by the two values of K'. The design is then based on the smaller anchorage force to predict DRs based on pullout and the higher anchorage force to calculate stresses in the FML itself.

In service, the FML is also subjected to large normal stresses due to the weight of the overlying waste. These stresses tend to push the FML into the void spaces within the underlying subgrade. Knipshield (4) portrays the stresses acting on a localized portion of the FML as shown on Figure 5. Large subgrade particle size may create void spaces large enough to generate localized failure. While this situation could be minimized by placing a geotextile beneath the FML, this would destroy the intimate contact bewteen the FML and the underlying clay. The limiting normal stress is determined from laboratory tests that simulate the field system described above.

DESIGN CONCEPT - LCR

Geosynthetic LCR systems play an important role in the facility by collecting leachate at any location on the liner and conveying it to a low point or sump where it can be removed. The design of the LCR based on in-plane flow is controlled by both the minimun MTG properties and the requirement that no more than 30 cm head of leachate may act on the underlying FML. The head acting on the FML is controlled by the rate at which leachate is being generated and collected within the system, the hydraulic properties of the LCR, and the spacing of the collector pipes within the LCR. These parameters are shown on Figure 6. Early work (5,6) related these parameters to the rate of leachate generation which is commonly not known. The maximum head acting on the FML is then given by

$$H_{max} = \frac{L\sqrt{c}}{2}\left[\frac{\tan^2\alpha}{c} + 1 - \frac{\tan\alpha}{c}\sqrt{\tan^2\alpha + c}\,\right] \quad (3)$$

where c is defined as the inflow rate divided by the hydraulic conductivity of the LCR. This method has been supplemented by an alternate procedure (7) that is based on the percolation velocity of the leachate. The maximim leachate head using this method is given by

$$H_{max} = \frac{L}{2n}\left[\sqrt{\frac{e}{K} + \tan^2\alpha} \;\; -\tan\alpha\right] \quad (4)$$

where e is the percolation velocity based on conversion of the annual percipitation rate into a uniform velocity (cm/sec).

A synthetic LCR may be composed of a homogeneous material, e.g. a thick nonwoven needled geotextile, or a composite formed of a core that provides planar flow capacity and a surface geotextile that acts as a filter to prevent the adjacent soil from intruding and blocking the core. The planar flow capacity of the LCR is defined by Darcys equation as

$$q = K_p \ i \ A \qquad (5)$$

$$q = K_p \ [dh/L] \ W \ t \qquad (6)$$

where K_p is the permeability in the plane of the LCR, dh is head loss, L is flow length, W is the width of the flow path, and t is the thickness of the LCR. Equation (6) is typically expressed as

$$q = \theta \ [dh/L] \ W \qquad (7)$$

where θ is defined as transmissivity and is equal to the product of K_p and t (8).

The transmissivity of an LCR can be reduced by compression of the core and intrusion of adjacent geotextiles or geomembranes due to soil pressure. These effects can occur elastically as normal loads are increased on the LCR or plastically over time in the completed cell. Laboratory data are shown on Figure 7 for a typical synthetic LCR. These data reflect only the elastic reduction of transmissivity. Long-term tests are rarely performed to evaluate the future reduction in transmissivity due to plastic deformations. Procedures (3) have been presented, however, for estimating these losses based on an analysis of core and filter material creep properties.

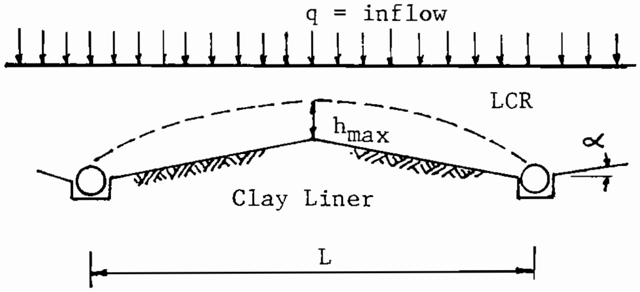

Figure 6 Calculation of Drain Pipe Spacing

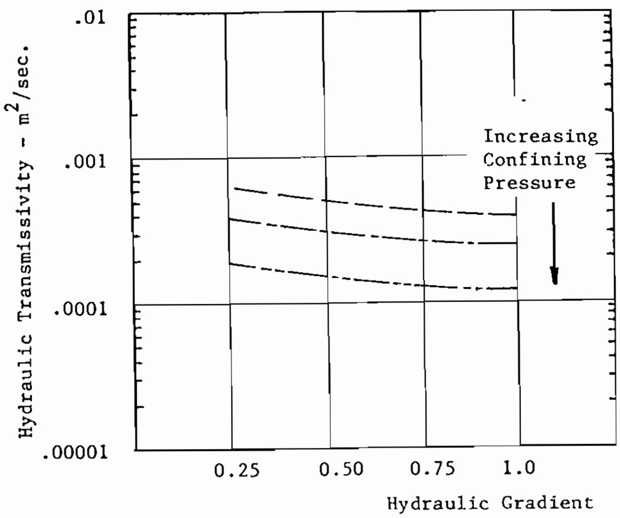

Figure 7 Transmissivity Data
Synthetic LCR

Leachate must first flow through the filter layer of a synthetic LCR before it can be drained away. The filter layer must be selected so that it will filter out the soil particles from the adjacent soil and yet not become clogged by these same soil particles. No true design procedure is at present available to evaluate filtration and clogging potential. There are, however, index tests that indicate the tendency of a given fabric to filter or be clogged by a given soil.

The filtering ability of a fabric has traditionally been related to the Apparent Opening Size (AOS) of the fabric. The AOS is defined as the diameter of glass beads with 5% retained in the fabric after shaking. AOS is appropriate for woven and lightweight fabrics but is questionable for heavy weight nonwoven fabrics. In general, filter criteria guidelines are of the form

$$O_{fabric} = \lambda \ d_{soil} \qquad (8)$$

where O_{fabric} is usually the AOS of the fabric, d_{soil} is a soil particle diameter obtained from a grain size analysis, and λ is an emperical factor. One example of this concept is the filtration criteria by Giroud as presented in Table 1. This method (9) incorporates grainsize data and relative density of the soil. Assuming the fabric manufacturer supplies the AOS for the fabric, the filtration design requires knowledge of fundamental properties of the site-specific soil.

Table 1 Geotextile Filter Criteria (9)

Relative Density, Dr	$1<CU<3$	$CU>3$
Loose(Dr<50%)	$O_{95}<(CU)(d_{50})$	$O_{95}<(9d_{50})/CU$
Intermediate (50%<Dr>80%)	$O_{95}<1.5(CU)(d_{50})$	$O_{95}<(13.5d_{50})/CU$
Dense(Dr>80%)	$O_{95}<2(CU)(d_{50})$	$O_{95}<(18d_{50})/CU$

Where Dr is relative density, d_{50} is the grain size corresponding to 50% passing, O_{95} is still equal to the AOS of the geotextile, and CU is the coefficient of uniformity(d_{60}/d_{10}) of the soil.

Clogging of the fabric by soil grains occurs with time. The clogging potential of a given fabric and soil is evaluated in the laboratory using the gradient ratio test or longterm flow tests. The equipment for this test consists of a soil column resting on a geotextile as shown schematically in Figure 8. The test does not reproduce <u>in-situ</u> conditions and as such is only an index test. As water is run through the column, the fabric becomes clogged and a hydrostatic pressure gradient develops across the fabric. If the gradient ratio, as defined on Figure 8, exceeds 3, then there is a potential for clogging of the fabric by the soil. Recent studies (10) have shown that the gradient ratio test may not predict clogging in many critical applications.

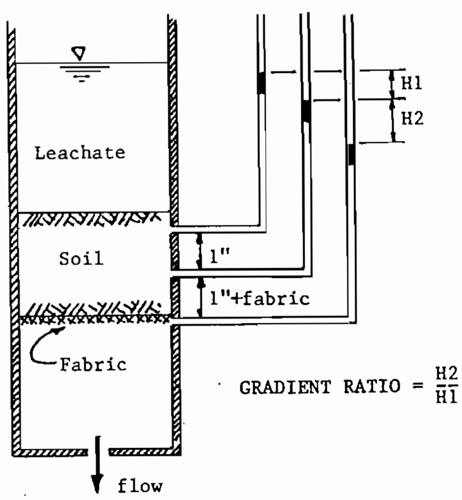

Figure 8 Gradient Ratio Test - Clogging

Long term flow tests use the same apparatus as the gradient ratio test but measure the actual flow rate of leachate passing through the sample over an extended time period. Typical data from a long-term test are shown on Figure 9. The slope of the curve is the focus of attention. If the slope continues to be negative, then the fabric will eventually clog. The combination of an acceptable flow rate and a final slope of zero indicates an acceptable soil/fabric combination.

ADDITIONAL CONSIDERATIONS

Additional geosynthetic components are used in building interior ramps, berms, drainage standpipes, and the cap structure. These ancillary components are not reviewed in this paper.

The designer must also verify that the synthetics used to build the system are resistant to chemical attack from the leachate. While beyond the scope of this paper, guidelines for chemical evaluation are presented elsewhere (11). The designer must also be aware of the need for a better assesment of long-term creep performance of the synthetics, hydraulic problems related to biological growth within an LCR system, and field construction quality control problems. These unknown long-term performance factors and the impact of a failure in these facilities force today's designer to use Design Ratios significantly higher that conventional designs require.

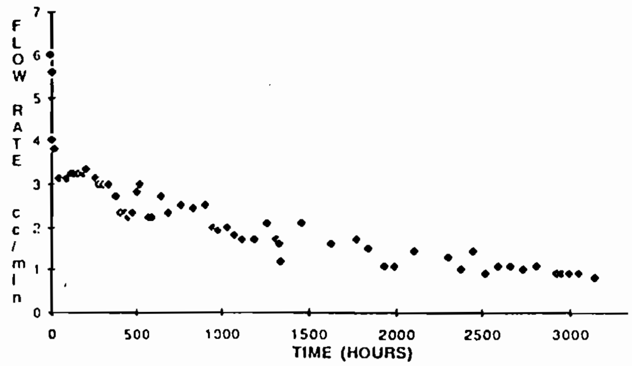

Figure 9 Long Term Flow Test - Clogging

SUMMARY

This paper elaborates on the basic design considerations needed to verify the mechanical and hydraulic performance of the FML and LCR components for double-liner systems for both landfills and surface impoundments. The designs are based on estimates of actual field stress and hydraulic conditions and on laboratory measures of the limit capacities of the synthetic components. These procedures are valid for both short and long-term conditions if appropriate laboratory tests are used.

ACKNOWLEDGEMENT

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