GEOSYNTHETICS FOR CONTAINMENT OF SPECIAL WASTE

by

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ABSTRACT

Requirements for the prevention and control of pollution in the Province of British Columbia are enacted in the Waste Management Act of 1981-82. Special waste is a term that describes several categories of material, including leachable waste, and is regulated in the Special Waste Regulation of the Act which describes both minimum siting standards for facilities and operational requirements. The regulations require that two liners be constructed of impervious materials, and allow for use of either clay or synthetic liners for this purpose. In addition the landfill must include a system for collection and removal of leachate and a leak detection system. These performance standards for the Province of British Columbia represent the minimum requirements for design and are described in the paper. Aspects of designing with geosynthetics to satisfy such performance standards are then discussed.

Keywords: geosynthetics, geotechnical design, waste containment

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INTRODUCTION

The rapid growth which has taken place in the use of geosynthetics for lining of waste containment facilities may be attributed to three major factors. Firstly a strong, market-led drive by manufacturers of geosynthetic products to develop and improve geomembranes and seaming techniques that has led to satisfactory programs of quality assurance for field installation; secondly, a clear preference for systems that incorporate flexible membrane liners in the United States to satisfy permitting requirements; thirdly, the development of Standards Tests to quantify material characteristics.

The responsibility of the designer rests in specification of materials that will ensure containment of the waste, and the detection and collection of any leachates from it. Yet there are few guidelines for design, and any critical evaluation of performance is limited by a lack of well-documented case records and a short history of the technology. Two demands arise in this situation. The first concerns a framework of reference for design, which are the provincial regulations, and raises the question of how they compare with other similar standards. The second involves selection of materials to meet the specified criteria, and therefore use of data from Standards Tests.

The objective of this paper is to examine the minimum requirements for design in the Province of British Columbia, established in the Special Waste Regulations of the Waste Management Act, and compare them to minimum requirements of the U.S. Environmental Protection Agency. Thereafter the use of synthetic liners to meet these performance standards, based on material properties from Standards Tests data, is reviewed.

LINERS FOR WASTE CONTAINMENT FACILITIES

CLAY LINERS

Site selection to utilize natural clay strata, or the alternative of importing clay, has formed the main approach to placement of barriers of low permeability for waste containment facilities. Attenuation capacities and the influence of clay mineralogy on permeability favor montmorillonite over illite and kaolinite. Compaction wet of optimum produces sigificantly lower magnitudes of permeability than compaction dry of optimum, (Mitchell et al., 1965). Problems associated with drying of compacted layers, and development of fissures represent the main difficulties associated with installation.

GEOSYNTHETIC LINERS

Geosynthetic liners may comprise a sequence of geomembranes, geonets and geotextiles that are placed in layers to effect a barrier. Compatibility of polymers and leachate constituents seems to be leading to high density polyethylene as a preferred material for many applications. Site fabrication of panels by welding of individual rolls is the typical approach to field installation. Problems associated with imperfect seams, and the potential for puncture, represent the main difficulties associated with installation.

DESIGN OBJECTIVES

The framework of reference for design, namely provinicial regulations, embodies the philosopy for containment. Objectives are typically ones of complete containment, with recognition of the difficulties in achieving such a goal reflected in restrictions on siting of facilities with respect to watersheds, acquifers and local soils. Installation of a groundwater monitoring system is required to establish that the quality of groundwater is not affected by any leakage.

PERFORMANCE STANDARDS FOR LINERS

B.C. PROVINCIAL REGULATIONS: DESIGN OBJECTIVES

In British Columbia, technical considerations and measures that would be required to ensure solid waste landfills operated in accordance with the Pollution Control Act, 1967 were established by a public inquiry carried out in 1973. The results of the inquiry were reported by the Ministry of Environment, Water Resources Service (1975), as pollution control objectives for municipal type waste discharges. It was intended that the objectives form a minimum standard that would be subject to review and ammendment to reflect new information from research, monitoring programs and changes in technology.

The Waste Management Act of 1982 further provides for the prevention and control of pollution in the Province of British Columbia. Leachates are liquids which have percolated through or drained from confined wastes. Leachable waste is one of several categories of material termed "special waste", and is regulated in the Special Waste Regulations of the Act (1988) which describe both minimum siting standards for facilities and operational requirements. The objective of the operational requirements, and the associated additional requirements, is to provide for secure containment of the special waste.

Performance standards relating to secure landfills for special waste require that a dual liner system be installed and maintained to

> "prevent any migration of wastes out of the landfill to the adjacent subsurface soil or groundwater during the operational life and after closure".

The regulations state that the two liners must be constructed of impervious materials, and allow for the use of either clay or synthetic liners for this purpose. The definition of an impervious material is made with reference to permeability, where a permeability less than or equal to 1×10^{-7}cm per second for a head of 0.305m of water is considered satisfactory. Liner thickness must prevent failure due to pressure gradients; contact with waste or leachate; climatic conditions; and installation and operational stresses. In all cases a clay liner must be at least 0.5m thick, or a synthetic liner at least 1.0mm thick.

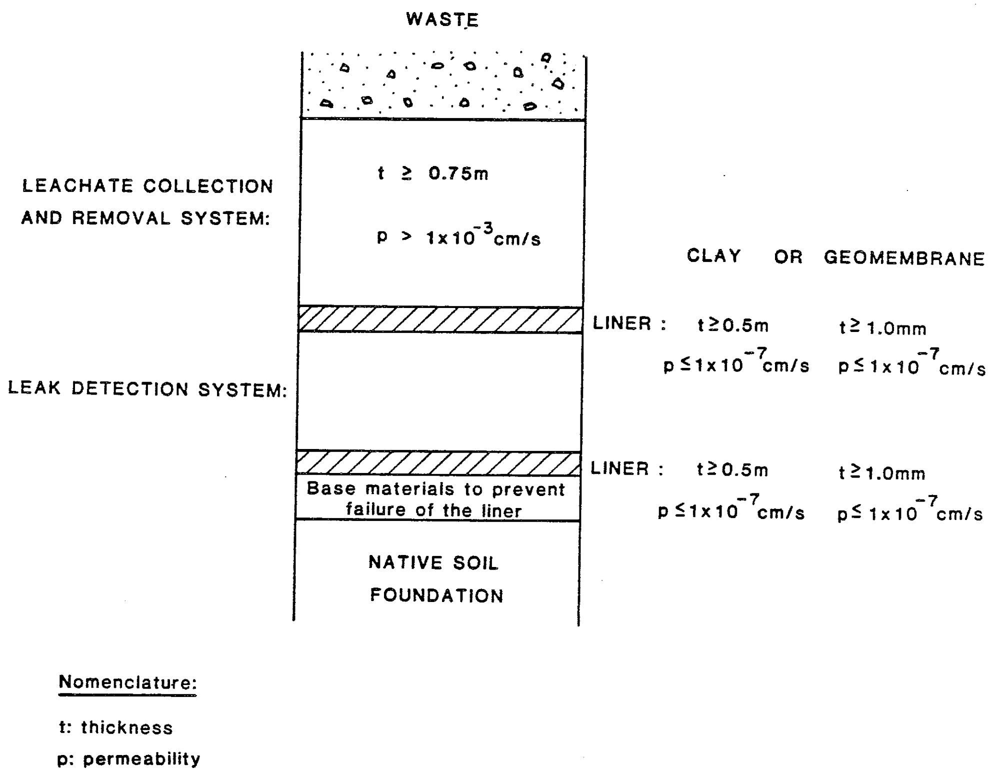

Fig. 1. Schematic profile of a dual liner system, B.C. Provincial Regulations.

The landfill must also include a system for collection and removal of leachate from the contained waste that is designed and installed above the upper liner to specified characteristics, and a system for leak detection. The system for leachate collection should be a drainage layer at least 0.75m thick, installed at slope greater than 2%, and with a permeability greater than 1×10^{-3}cm per second. While requirements for the leachate collection system are explicitly stated, those for the leak detection system which is located between the two impervious liners are not.

These performance standards for the Province of British Columbia represent the minimum requirements for design of base and side liners and are summarized in Figure 1.

(U.S.) ENVIRONMENTAL PROTECTION AGENCY: DESIGN GUIDANCE.

In the United States, the scope of the Resource Conservation and Recovery Act of 1976, which sought to protect groundwater, surface water, air and land from contamination by solid waste, was broadened by the Hazardous and Solid Waste Ammendments of 1984. Groundwater in particular was seen as a vulnerable resource, and standards were introduced for certain land disposal facilities to include double liners; leachate collection systems; and groundwater monitoring. Design guidance to fulfill these obligations is set out in a document, EPA/530-SW-85-014 (1985), which identifies two particular double liner systems as preferred but does not exclude alternative double liner systems. Discussion below is limited to the preferred systems, illustrated in Figure 2.

The guidance for design strongly recommends a use of clay and synthetic liners in combination. A permeability less than or equal to 1 x 10^{-7}cm per second is required for compacted clay liners. Recommended values of liner thickness vary for clays, being 0.9m (36in) or determined from a consideration of breakthrough time. A synthetic liner must be greater than 0.76mm (30mils) thick, or 1.14mm (45mils) thick if left uncovered for longer than three months.

Again the landfill must include a system for collection and removal of leachate from the contained waste that is designed and installed above the upper liner, and a system for leak detection. A primary system for leachate collection is specified as a drainage layer comprising a granular drain at least 0.3m (12in) thick overlain by a graded granular filter at least 0.15m (6in) thick. The layer should be installed at a slope greater than or equal to 2%, and have a permeability not less than 1 x 10^{-2}cm per second. A secondary sytem for leachate collection is also specified to the same criteria as the primary layer, but excludes the graded filter. Provision is specifically made for innovative leachate collection systems incorporating geonets if they can be shown to be equivalent to or better than the granular drains.

MINIMUM STANDARDS

In the case of the B.C. Provincial Regulations and the U.S. EPA guidance, standards are conceived as minimum requirements for design. There is no restriction on the maximum thickness of materials, or number of layers which may be placed.

SPECIFICATION OF GEOSYNTHETICS TO PERFORMANCE STANDARDS

Emphasis in both the B.C. Provinicial Regulations and the U.S. EPA guidance is placed firmly on two parameters for design: cross-plane permeability of the liners to prevent migration of leachates; and in-plane permeability of the drainage layers to facilitate collection of the leachate. A schematic illustration is given in Figure 3.

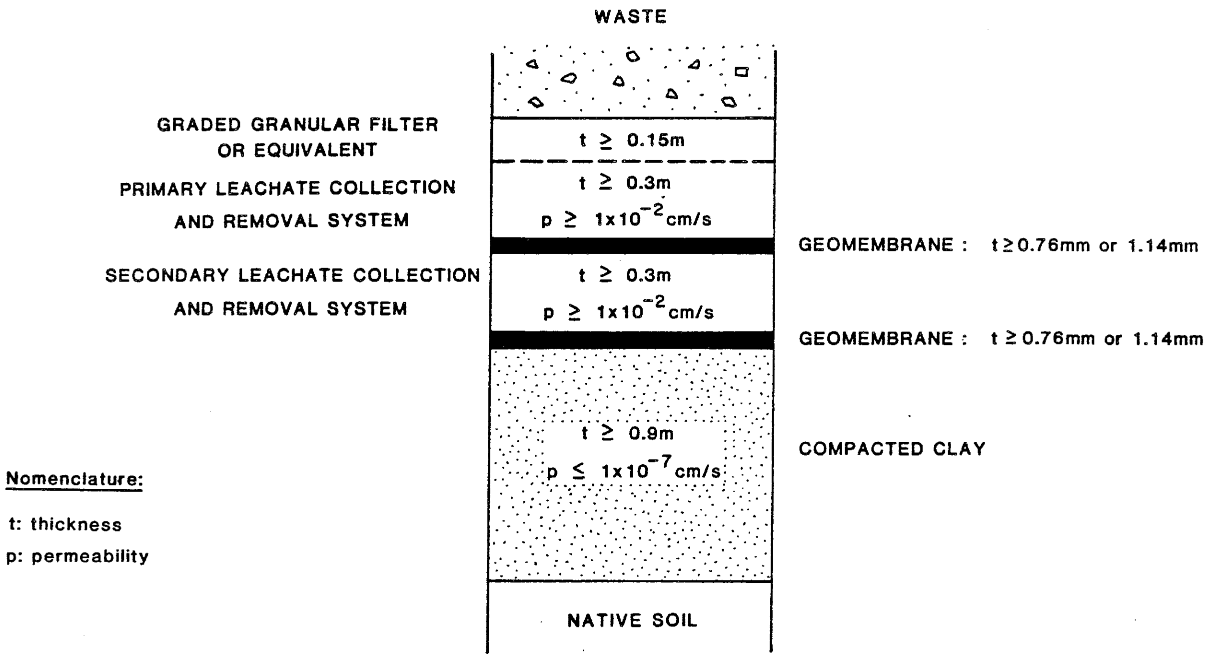

Fig. 2a. Schematic profile of an FML/composite double liner system, U.S. EPA.

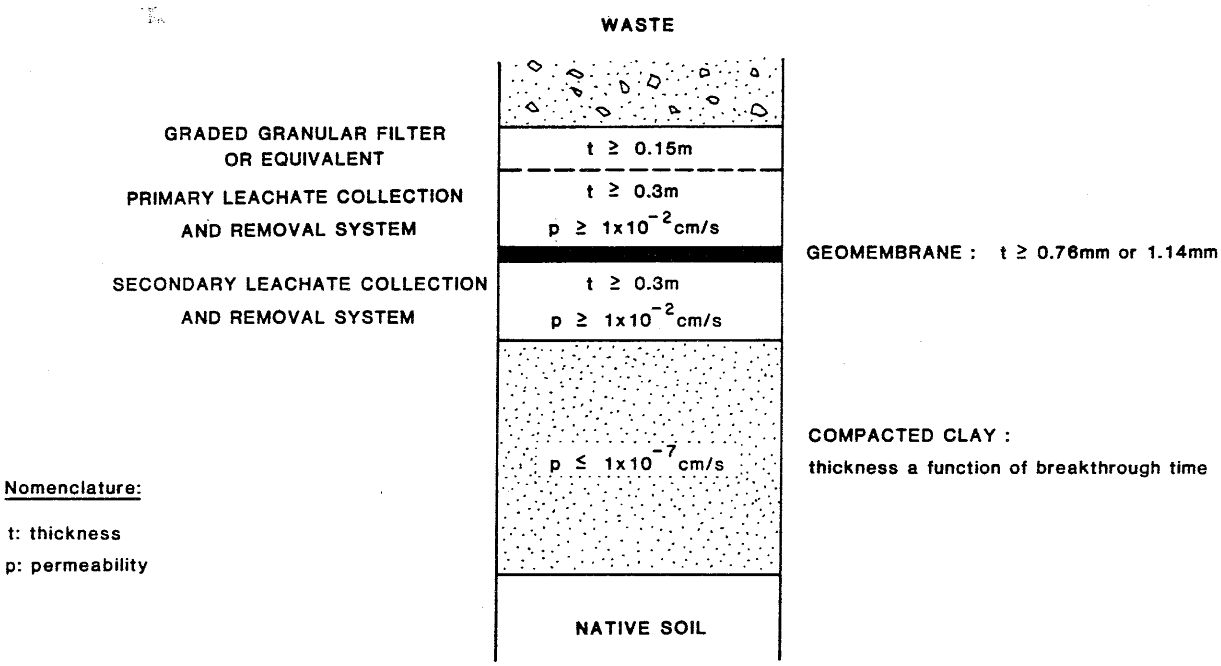

Fig. 2b. Schematic profile of an FML/compacted soil double liner system, U.S. EPA.

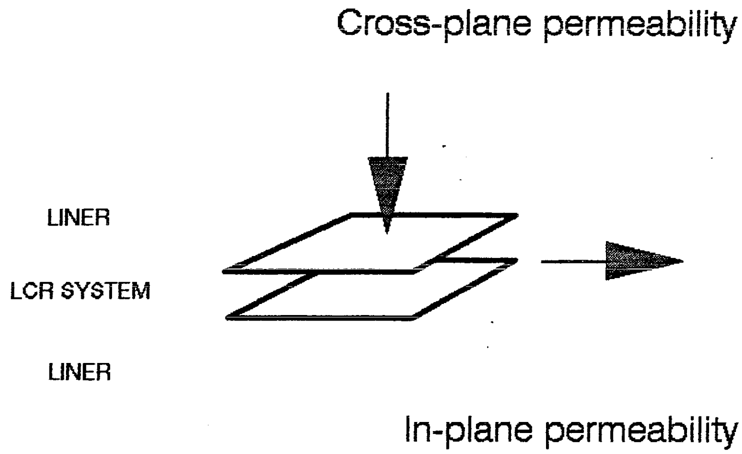

Fig. 3. Cross-plane and in-plane permeability.

Natural materials, such as compacted clays for the liners and gravels for the drains, are familiar, as are test methods to establish the permeability of these soils to water. The new challenge lies in using material properties reported for geosynthetics in a proper and informed manner to provide secure containment. Cross-plane permeability of a geomembrane is derived from a measure of water vapor transmission since the permeability of laboratory specimens cannot be measured directly; in-plane permeability is determined from a measure of transmissivity. A brief outline of these test methods is given below.

<u>WATER VAPOR TRANSMISSION</u>

The water vapor transmission of a material is determined using ASTM Standard Test Method E96-80 (1987), which allows for two methods of testing on a sample at least $30cm^2$ in plan area. A schematic illustration of the test is given in Figure 4.

"In the Desiccant Method the test specimen is sealed to the open mouth of a test dish containing a desiccant, and the assembly placed in a controlled atmosphere. Periodic weighings determine the rate of water vapor movement through the specimen into the desiccant.
In the Water Method, the dish contains distilled water, and the weighings determine the rate of vapor movement through the specimen from the water to the controlled atmosphere."

ASTM E96-80 (1987)

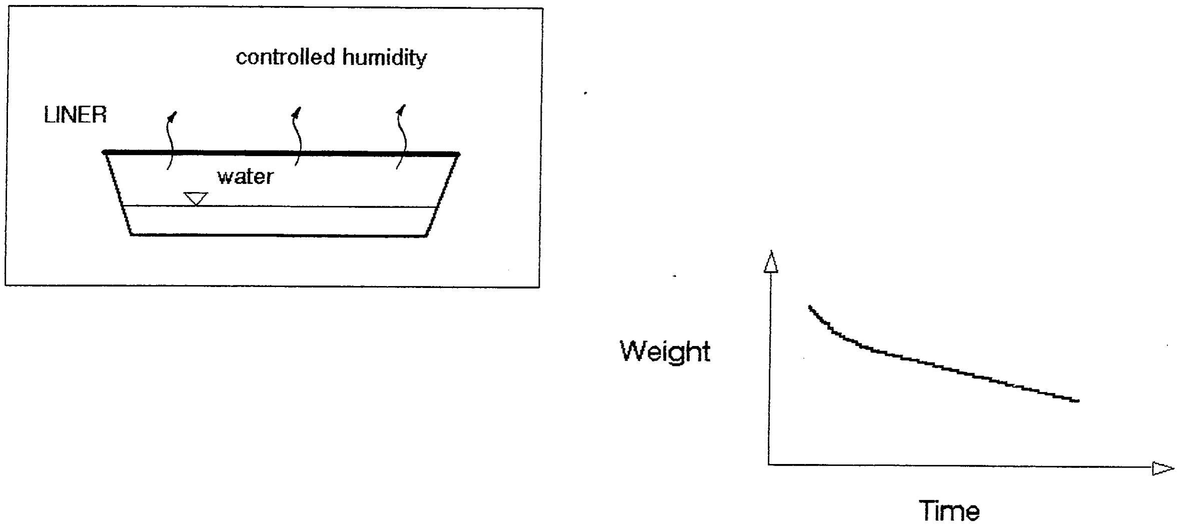

Fig. 4. Water vapor transmission test.

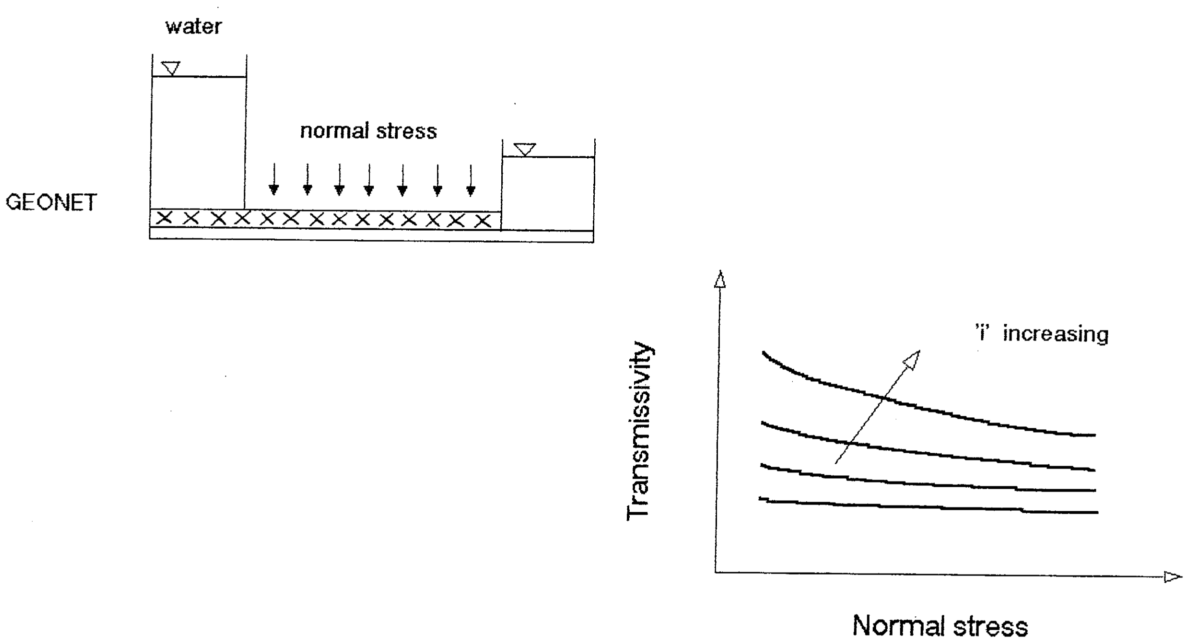

Fig. 5. Hydraulic transmissivity test.

Periodic weighings of the dish assembly are plotted against elapsed time to monitor the development of a nominally steady state, for which the data points fall on a straight line. Water vapor transmission rate (WVT) is the slope of the straight line given by

$$WVT = G/tA$$

where:
G = weight change,
t = time,
A = area of test specimen.

An average equivalent permeability of the specimen is calculated from the time rate of water vapor tansmission by unit vapor pressure difference, and is given by

$$k = (WVT/\Delta p) \,.\, t$$

where:
Δp = vapor pressure difference,
t = specimen thickness.

Generally the variation of water vapor transmission with membrane thickness and type of polymer indicates that HDPE gives the best resistance to migration of water vapor. This is attributed to its high degree of crystallization, which makes permeation difficult. It should be noted that WVT indicates the porosity of a liner to diffusion of a vapor (driven by a gradient of concentration) and not to flow of liquid (driven by an hydraulic gradient). Water vapor transmission rate is converted to an equivalent permeability in the reporting of the results to ASTM specification.

HYDRAULIC TRANSMISSIVITY

The transmissivity of a material is determined using ASTM Standard Test Method D4716-87 (1987), on samples at least 10 x 20 cm in plan area. A schematic illustration of the test is given in Figure 5.

"The hydraulic transmissivity is determined by measuring the quantity of water that passes through a test specimen in a specific time interval under a specific normal stress and a specific hydraulic gradient. The hydraulic gradient and specimen contact surfaces are selected by the user."

ASTM D4716-87 (1987)

Once uniform flow through the saturated specimen is observed, a record is made of the time for $0.0005 m^3$ of water to pass or the quantity of flow after fifteen minutes, whichever is larger. Hydraulic transmissivity (Θ) is given by

$$\Theta = (Q.L) / (W.H)$$

where:
Q = average quantity of flow per unit time,
L = specimen length,
W = specimen width,
H = difference in total head across the specimen.

The trend in variation of transmissivity with compressive stress for varying hydraulic gradients is also illustrated schematically in Figure 5 for a geonet. At the low confining stresses and low hydraulic gradients which are characteristic of waste containment facilities the relationship should be predominantly linear and horizontal, and indicative of a core structure in the geonet that is resistant to collapse.

PARTIAL FACTORS OF SAFETY

Values for water vapor permeability and hydraulic transmissivity which are established from ASTM Standards Tests represent ultimate values. Partial factors of safety must be incorporated in any design approach to establish allowable values for design from these ultimate values. Such partial factors of safety may be used to account for material variations, environmental factors and time factors that will cause performance in the field throughout the life of the facility to be different from that measured in the laboratory in a relatively short period of testing.

Consider the cross-plane permeability of geomembranes. The regulations summarized in Figures 1 and 2 are expressed as a permeability for water as the migrating fluid. The ASTM test is conducted using water vapor, yet liquids other than water may result in very different vapor transmission values. It would therefore seem appropriate to obtain data for the anticipated leachate characteristics, or attempt to apply some partial factor of safety to data for water vapor in a specific analysis of liner permeability. This concern, of course, applies as much to clay liners as it does to synthetic liners. In addition, geomembranes are manufactured in batches and delivered to site. The potential for small variations in the physical properties of each roll would suggest a partial factor of safety to account for extrapolation of laboratory data on a small test specimen to field values on installed panels may also be appropriate.

Consider now the in-plane permeability of geonets. Partial factors of safety are at present recognized which account for elastic deformation of adjacent membranes into the core space of the geonet; creep deformations influencing the core space of the geonet; chemical clogging; and biological clogging. Recommendations for each factor are usually expressed as a range of values, and selection should be based on the characteristics of the leachate and containment facility. The approach for selection of material properties for design is summarized in Figure 6.

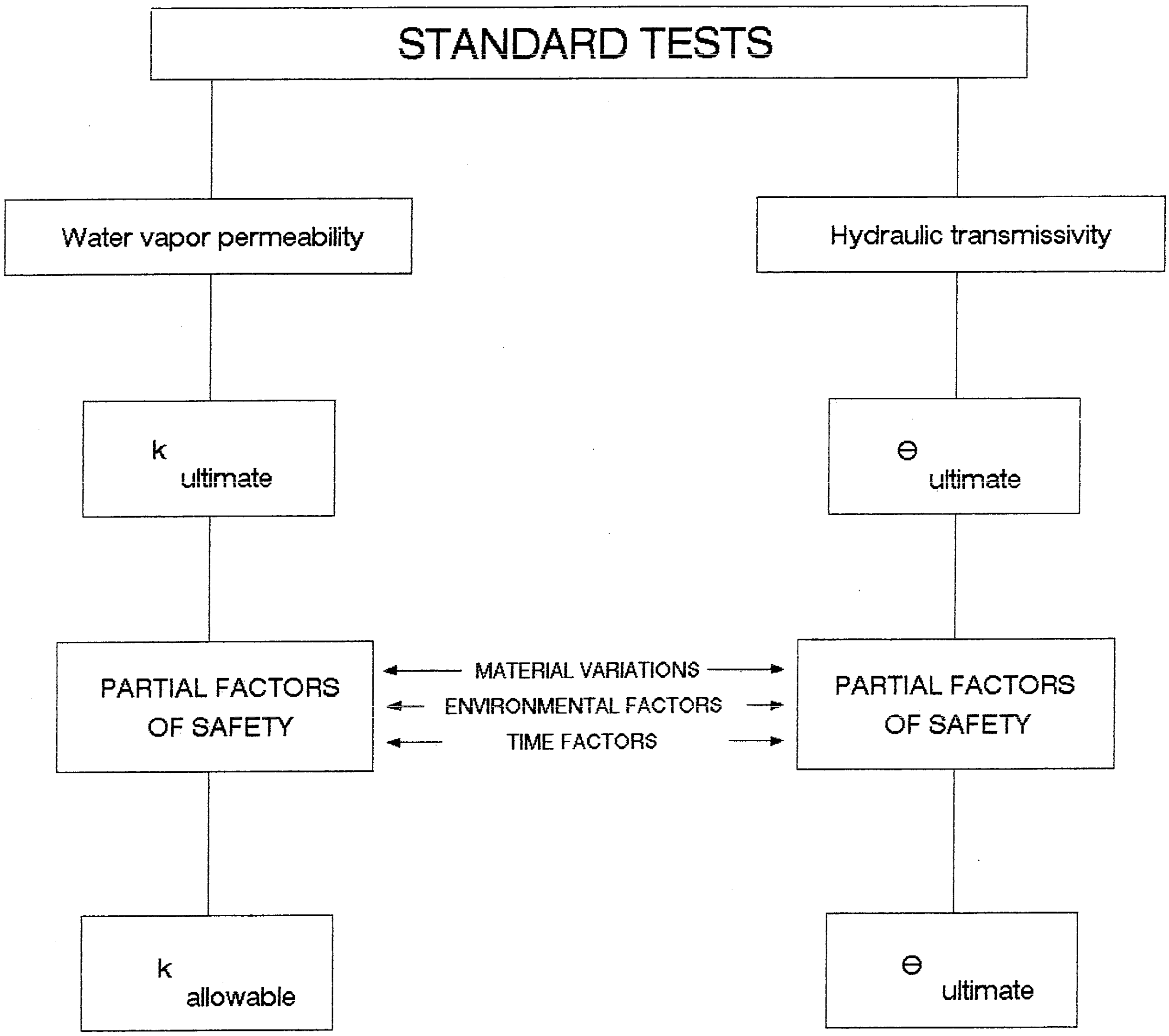

Fig. 6. Selection of material properties for design.

DISCUSSION

Regulations and guidance for the design and installation of landfill facilities are continuously evolving. Currently there is recognition of geosynthetics in the regulations for the Province of British Columbia, in the form of specified minimum requirements. Recognition of geomembranes as impervious liners is explicit, with the requirement that any synthetic liner must be thicker than 1.0mm and exhibit a permeability to flow of water not less than 1×10^{-7}cm per second. While there is implicit recognition of geonets in the U.S. EPA literature as an equivalent granular drainage layer, the B.C. regulations do not describe what constitutes a minimum requirement of a leak detection system or the physical characteristics of such a system.

A comparison of the minimum requirements of the B.C. Provincial Regulations to U.S. EPA guidance indicates

- a similarity of approach based on double liners, a leachate collection and removal system, and a leak detection system;

- a tendency for clay liners to be less thick, and synthetic membrane liners to more thick;

- an upper leachate collection and removal system that is thicker, though comprised of a less porous medium;

- a lower leak detection system for which no requirements are specified.

Given this local recognition of geosynthetics, any preliminary design requires specification of materials based on product information supplied by the manufacturer from Standards Tests. Geomembranes for landfill applications are quoted with equivalent water vapor permeabilities in the range 1×10^{-11} to 1×10^{-13}cm per second. Typical values of thickness are 20, 30, 40, 60, 80, and 100 mils (0.5mm to 2.5mm). Geonets are quoted with hydraulic transmissivities in the range 0.3×10^{-3} to $3.0 \times 10^{-3}$$m^3$/s per meter. The capacity for fluid transmission of a granular drain with a permeability of 1×10^{-2}cm/s and 0.3m thick, is $3.0 \times 10^{-5}$$m^3$/s per meter.

A comparison of B.C. Provincial Regulations to current specifications for geosynthetics therefore shows that ultimate values of material characteristics from Standards Tests clearly exceed the stated minimum requirements. The regulations make no mention of acceptable partial factors of safety, but guidance as to what are considered reasonable values based on current knowledge of material characteristics and predicted performance are available in the literature.

CONCLUSIONS

The objective of this paper has been to set up a framework of reference for selection of geosynthetics, and in particular geomembranes and geonets, to meet the Special Waste Regulations of the Waste Management Act of the Province of British Columbia. The following conclusions may be drawn.

1. The regulations compare well with similar guidance for design of waste containment facilities issued by the U.S. Environmental Protection Agency. Requirements for equivalent water vapor permeability of liners are identical, and the specified minimum thickness of a geomembrane is greater for conditions of coverage soon after installation. There are however no specific details given for a leak detection system between the liners.

2. The range in values for properties of many geomembranes reported from Standards Tests are interpreted as being in well in excess of regulatory requirements.

3. These values from Standards Tests are ultimate values from laboratory tests, to which partial factors of safety should be applied for any comparison with regulatory requirements and for design.

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