Geomembrane Use in Transportation Systems

ROBERT M. KOERNER AND BAO-LIN HWU

Included in this review paper is a brief introduction to geomembranes, their production, the resulting properties, and the current market demand. This introductory information is followed by a discussion on proper design philosophy, including a set of minimum recommended values based on installation survivability. The heart of the paper involves the review of the current areas of geomembrane use in transportation systems. As with all geomembrane applications, the primary function is as a barrier. In the applications cited, the barrier is intended to contain surface water, groundwater, or liquid pollutants. A wide range of applications is emerging whereby the different geomembranes can be used to excellent advantage and in a cost-effective manner. A summary table for each use area is also included. The conclusion gives an idea as to possible future trends.

According to ASTM, a geomembrane is defined as an essentially impermeable membrane used with foundation, soil, rock, earth or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system. The majority of geomembranes are thin sheets of flexible polymeric materials manufactured by one of the following three methods:

- Extrusion (nonreinforced),
- Calendaring (nonreinforced or reinforced), and
- Spread coating (reinforced).

The reinforced geomembranes have a fabric scrim or fabric substrate integrated within the separate piles or beneath the surface coating. Subsequent factory fabrication of geomembrane sheets leads to panels that are made as large as possible so as to expedite field placement and minimize field seaming.

Concerning the type of polymer, it should be recognized that all geomembranes are made from compounds that are blends of a primary resin (or resins) and other ingredients. For example, Haxo (*1*) gives the proper composition, as is shown in Table 1. With this table in mind, Table 2 is presented indicating the major generic types of geomembranes currently in use in North America.

The use of geomembranes in subsurface construction work has grown rapidly (*2*) to the point where current annual sales in North America are about 33 million yd^2, as shown in Table 3. Table 3 is arbitrarily divided into transportation, environmental, and geotechnical uses. Easily seen is that the environmental-related uses of liquid, solid, and vapor containment are the largest by far (80 percent), followed by transportation and geotechnical uses (about 10 percent each). It may also be noted that the types of geomembranes do not include thermoset materials (which today are seldom used) and are essentially nonreinforced PVC, reinforced CPE or CSPE, and semicrystalline PE. Most of the last group is HDPE.

The focus of this paper is completely on transportation-related uses. From Table 3 it may be seen that PVC is the material most used for transportation-related applications, followed closely by CPE/CSPE, and finally HPDE. The reason for the comparatively low use of HDPE with respect to environmental applications is that chemical resistance is not usually a compelling criterion (water versus leachate) and ease of constructability takes precedence. The specific uses of geomembranes in transportation applications will be described after a discussion of properties and design methods.

Geosynthetic Research Institute, Drexel University, Rush Building, West Wing, Philadelphia, Pa. 19104.

GEOMEMBRANE PROPERTIES AND DESIGN METHODS

As with any engineering material, a geomembrane's properties must be measured in an organized and quantifiable manner. Fortunately, ASTM has taken a leadership role in this regard with the formation of Committee D-35 on Geosynthetics. Carroll (*3*) gives a historical perspective of ASTM's involvement, as well as descriptions of other important Standards groups (e.g., AASHTO Task Force 25). It should be noted, however, that the individual states' involvement in geomembranes is very limited. Few make any mention of geomembranes in their regularly published specifications.

The major properties of geomembranes can be broken down by category (e.g., physical, mechanical) in such a way that a total perspective of a specific geomembrane can be obtained. Broad generalities as to what is typical, however, are difficult to make. Table 4 gives a recent compilation (*2*) in which the ranges are seen to be very broad. The importance of a particular value within this range comes into view when design is considered.

Design with geomembranes should be focused on its primary function and the related mechanism. As such, a traditional factor-of-safety equation can be formulated:

$$FS = \frac{\text{Allowable (test) property}}{\text{Required (design) property}} \tag{1}$$

A test method, if it adequately models the reality of the situation, gives the allowable property in Equation 1 directly (e.g., thickness, tensile strength, puncture resistance). If the test method is not accurate, a reduced value becomes necessary. This can sometimes be obtained by a semiempirical technique (*4*).

TABLE 1 MAJOR COMPONENTS IN POLYMERIC LINERS

Component	Composition in Parts by Weight		
	Thermoset	Thermoplastic	Semicrystalline
Polymer or Alloy	100	100	100
Oil or Plasticizer	5 - 40	5 - 55	0 - 10
Fillers			
carbon black	5 - 40	5 - 40	2 - 5
inorganics	5 - 40	5 - 40	-
Antidegradants	1 - 2	1 - 2	1
Crosslinking Agents			
inorganic	5 - 9	0 - 5	-
sulfur	5 - 9	-	-

TABLE 2 CATEGORIES AND TYPES OF GEOMEMBRANES CURRENTLY USED

Category	Acronym	Name
Thermoset	IIR	butyl rubber
	EPDM	ethylene propylene diene monomer
Thermoplastic	CPE	chlorinated polyethylene
	CPE-A	chlorinated polyethylene alloy
	CSPE	chlorosulfonated polyethylene
	EIA	ethylene interpolymer alloy (XR-5)
	PVC	polyvinyl chloride
	PVC-OR	oil resistant polyvinyl chloride
Semi-Crystalline	HDPE	high density polyethylene
	HDPE-A	high density polyethylene alloy
	MDPE	medium density polyethylene
	VLDPE	very low density polyethylene
	LLDPE	linear low density polyethylene

TABLE 3 GEOMEMBRANE USE IN NORTH AMERICA IN 1987

Application Area		PVC	CPE/CSPE	HDPE	Others
Transportation Related -					
all uses combined	10%	1.5 (1.3)	1.2 (1.0)	0.4 (0.3)	0.2 (0.2)
Environmental Related					
liquid containment	22%	1.9 (1.6)	3.6 (3.0)	0.5 (0.4)	1.3 (1.1)
solid containment	53%	1.4 (1.2)	2.5 (2.1)	12.0 (10.0)	1.3 (1.1)
vapor containment	5%	0.6 (0.5)	0.5 (0.4)	0.4 (0.3)	0.4 (0.3)
Geotechnical Related					
all uses combined	10%	2.5 (2.1)	0.5 (0.4)	0.1 (0.1)	0.2 (0.2)
Subtotal	100%	7.9 (6.7) or 24%	8.3 (6.9) or 25%	13.4 (11.1) or 41%	3.4 (2.9) or 10%

NOTE: Values are given in millions of square yards; square meters are given in parentheses.
Total Use = 33,000,000 yd^2 100%
= 27,600,000 m^2 100%
= 297,000,000 ft^2 100%

The required property in Equation 1 is generally obtained by a design model, most of which have been adapted from geotechnical engineering analysis. For geomembranes in environmental liners and covers, a design guide by Richardson and Koerner (*5*) is available. Unfortunately, there is no such design guide for transportation applications per se, but this paper should help in this regard. A lower limit for the required properties in Equation 1 should focus on the installation survivability demands placed upon the candidate geomembrane. Table 5 provides insight as to the various required properties as a function of the anticipated demands placed on the geomembrane. It should be emphasized, however, that these are minimum values and cannot be used in place of rational design-generated values. If such design values come out

TABLE 4 MAJOR PROPERTIES OF GEOMEMBRANES AND TYPICAL VALUES (2)

Category and property	Approximate range of values Standard Units	International Units
Physical		
Thickness	10–100 mils	0.25–2.5 mm
Specific gravity	0.9–1.5	0.9–1.5
Weight (mass per unit area)	20–100 oz/yd^2	600–3000 g/m^2
Water vapor transmission	2–20 x 10^{-4} lb/ft^2-24 hr	1–10 g/m^2–24 hr
Mechanical		
Tensile strength at yield		
Unreinforced	5–25 lb/in.	1–5 kg/cm
Reinforced	25–100 lb/in.	5-20 kg/cm
Tensile strength at break		
Unreinforced	5–25 lb/in.	1–5 kg/cm
Reinforced	10–30lb/in.	2–6 kg/cm
Elongation at yield		
Unreinforced	20–100%	20–100%
Reinforced	10–30%	10–30%
Elongation at break		
Unreinforced	100–500%	100–500%
Reinforced	70–250%	70–250%
Modulus of elasticity		
Unreinforced	500–3,000 lb/in.^{2}	3.5–20 MPa
Reinforced	5,000–20,000 lb/in.^{2}	35–140 MPa
Tear Resistance		
Unreinforced	4–30 lb	2–15 kg
Reinforced	20–100 lb	10–50 kg
Impact Resistance		
Unreinforced	0.5–15 ft-lb	.05–2 kg-m
Reinforced	17–50 ft-lb	2–7 kg-m
Puncture Resistance		
Unreinforced	10–100 lb	5–50 kg
Reinforced	50–500 lb	25–250 kg
Soil to liner friction- (% of soil friction)	50–100%	50–100%
Seam strength (% of liner strength)	50–100%	50–100%
Chemical		
Ozone resistance	Varies with liner and location	
Ultraviolet light resistance	Varies with liner and location	
Chemical resistance	Must be specifically evaluated	
Thermal		
Hot climates or conditions	Usually no problem regarding material	
Cold climates or conditions	Decreases ductility, difficult to seam	
Biological		
Stability to microbe attack	Usually no problem	
Durability		
Water absorption	0–30%	0–30%
Aging	No standard procedure to evaluate over long time periods	

higher than those listed in Table 5, the design values must take precedence.

SPECIFIC TRANSPORTATION APPLICATIONS

Geomembranes have been used in numerous transportation-related applications. Although specific uses often do not cover extremely large areas, they can solve meaningful and often difficult problems. In the following paragraphs, each specific use will be described. A sketch accompanies each description as well as appropriate literature.

Prevention of Upward Groundwater Movement in Railroad Cut

As seen in Figure 1 this project, described by Lacey (*6*), used a scrim-reinforced CSPE geomembrane on the soil subgrade and beneath the railroad ballast to prevent upward flow of groundwater into a railroad cut. A needle-punched nonwoven geotextile was used above the geomembrane to provide puncture resistance from the ballast above. Waterproof seals were required at each of the concrete cantilever retaining walls paralleling the cut. These particular details were critical in the total performance of the system. It should be cautioned, however, that high porewater pressures often occur in railroad applications and the need for pressure-relief wells may be required.

Waterproofing of Transportation Tunnels

Water seeping into all types of transportation tunnels is a constant problem. When tunneling in rock by blasting, a shotcrete layer is often placed as soon as possible. This has been called the New Austrian Tunneling Method (NATM). By

TABLE 5 RECOMMENDED MINIMUM PROPERTIES FOR GENERAL GEOMEMBRANE INSTALLATION SURVIVABILITY (2)

Property and Test Method	Required Degree of Survivability			
	Low	Medium	High	Very High
Thickness (D-1593) mils (mm)	20 (0.50)	25 (0.63)	30 (0.75)	40 (1.00)
Tensile D-882 (1.0" (25 mm) strip) lb/in (kN/m)	30 (5.2)	40 (7.0)	50 (8.7)	60 (10.5)
Tear (D-1004 Die C) lb (N)	5 (22)	7.5 (33)	10 (45)	15 (67)
Puncture (D-3787 mod.) lb (N)	20 (90)	25 (110)	30 (130)	35 (160)
Impact (D-3998 mod.) ft-lb (J)	10 (7)	12 (9)	15 (11)	20 (15)

Notes:

"Low" - refers to careful hand placement on very uniform well graded subgrade with light loads of a static nature - typical of vapor barriers beneath building floor slabs.

"Medium" - refers to hand or machine placement on machine graded subgrade with medium loads - typical of canal liners.

"High" - refers to hand or machine placement on machind graded subgrade of poor texture with high loads - typical of landfill liners and covers.

"Very High" - refers to hand or machine placement on machine graded subgrade of very poor texture with high loads - typical of reservoir covers and liners for heap leach pads.

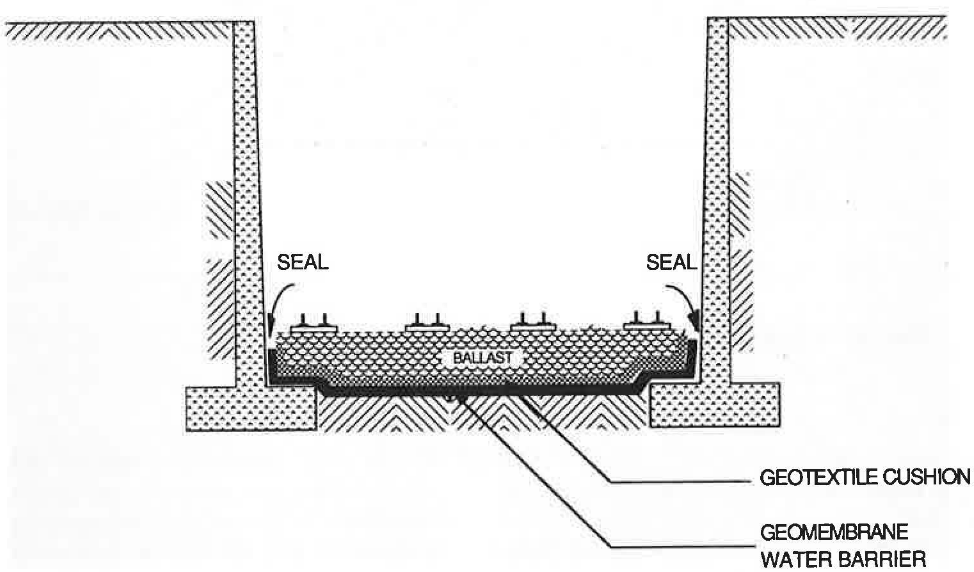

FIGURE 1 Upward movement of groundwater in railroad cut (relief of porewater may be necessary).

attaching a thick needle-punched nonwoven geotextile to the shotcrete, followed by a geomembrane, and then the final concrete liner, an excellent waterproofing system is achieved. As seen in Figure 2, the geotextile intercepts the seeping water and then drains into appropriate underdrains. Frobel (7) has used PVC geomembranes for this type of application.

Prevention of Contamination in Railroad Refueling Areas

A spread-coated butyl geomembrane has been used on a needle-punched nonwoven geotextile as a barrier against entrance of diesel fuel into the subsurface. The concept was first presented

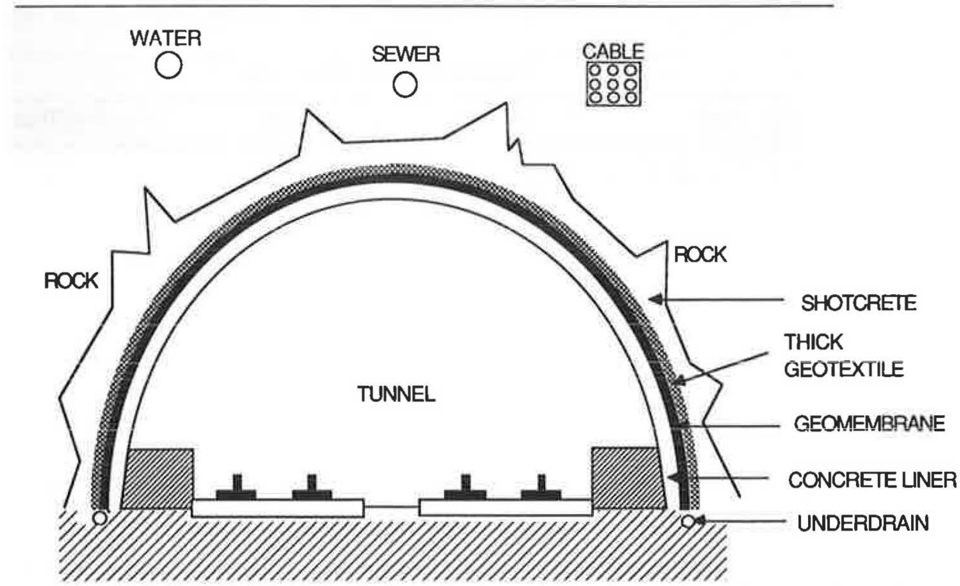

FIGURE 2 Tunnel waterproofing after NATM construction.

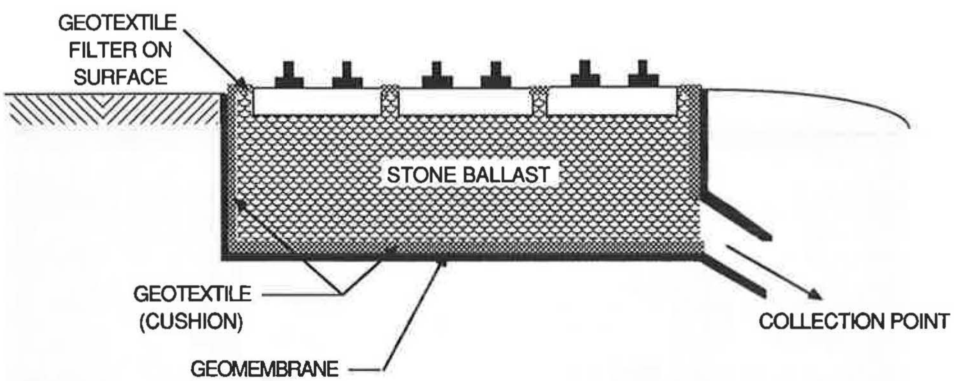

FIGURE 3 Railroad refueling areas.

by True Temper, Inc. As shown in Figure 3, the sides and bottom of the cross section were covered in this manner, and the surface had only a geotextile covering. The enclosure requires periodically spaced outlet drains for removal of the collected diesel fuel. The geotextile on the geomembrane faces inward against the ballast, thereby providing the necessary puncture protection.

Moistureproofing of Railroad Subgrades

Pumping of soil subgrades due to heavy, cyclic loads is a common railroad problem that rapidly contaminates ballast. Ayres (*8*) has given a good description of geomembrane use to prevent this occurrence. A geotextile cushion above the geomembrane for puncture resistance is again seen in Figure 4, which describes this application. As noted before, however, the high porewater pressures created in many railroad environments may require pressure-relief wells beneath the geomembrane.

Control of Expansive Soils (Vertical Infiltration)

Many parts of the world contain expansive, fine-grained soils that swell to alarming proportions when water is absorbed. To eliminate moisture from moving downward in the roadway cross section, a geomembrane has been used as shown in Figure 5. A geotextile is necessary (as a cushion) above and, depending on the quality of the subgrade, perhaps below the geomembrane. Sheffield and Steinberg (*9*) have reported on such applications in Mississippi and Texas.

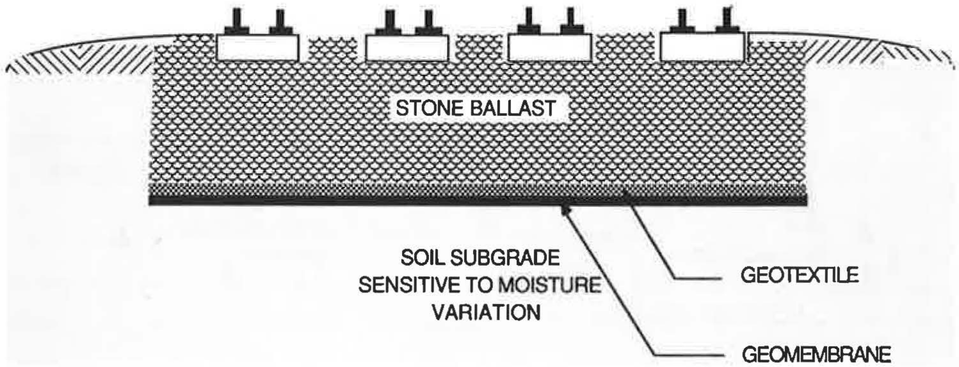

FIGURE 4 Soil subgrade moistureproofing (relief of porewater may be necessary).

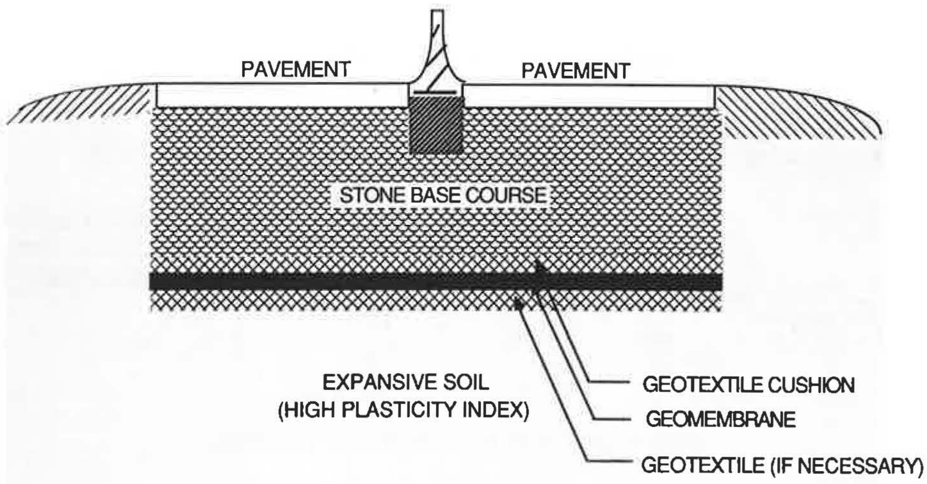

FIGURE 5 Control of expansive soils.

Prevention of Frost Heave

Upward migration of groundwater within a capillary zone will meet an elevation in the soil profile at which freezing conditions can exist. When this occurs, ice lenses will grow continuously, lifting everything located above them. Seen in Figure 6 is a possible remedial scheme using a geomembrane barrier with a geotextile or geonet drain beneath it. If a geonet is used, its underside must have a lightweight geotextile filter for protection (*2*). The geotextile or geonet drain must be connected to an underdrain beyond the limits of the area concerned. The underdrain could well be a synthetic edge drain composite.

Prevention of Enlargement of Karst Sinkholes

Many limestone formations are reactive when water comes in contact with them. This well-known solution phenomenon is called karst topography or sinkhole formation. As seen in Figure 7, the key to prevention of enlargement of an existing sinkhole is to prevent rainwater and snowmelt from entering the soil subgrade. This can be accomplished using a geomembrane with proper protection from the stone base above and, depending on the quality of the subgrade, from below.

Protection of Frost-Sensitive Soils

The concept of a membrane-encapsulated soil layer (MESL) has been pioneered by the Cold Regions Research Laboratory of the Corps of Engineers (*10, 11*) for the protection of frost-sensitive soils. Placed and maintained at their optimum water content, the encapsulated soils are suitable for light roadway use as shown in Figure 8. Without encapsulation, however, they would become saturated and lose their strength. The moisture barrier needed to prevent this can be one of those listed in Table 2, but is usually a nonwoven geotextile impregnated by an asphalt emulsion or elastomer spray. Various techniques have been described by Meader (*12*).

Protection of Friable Soils

The same MESL concept has been used to preserve the moisture content of friable soils in arid regions (*3*). Here the problem is the inverse of that in frost-sensitive soils in that drying

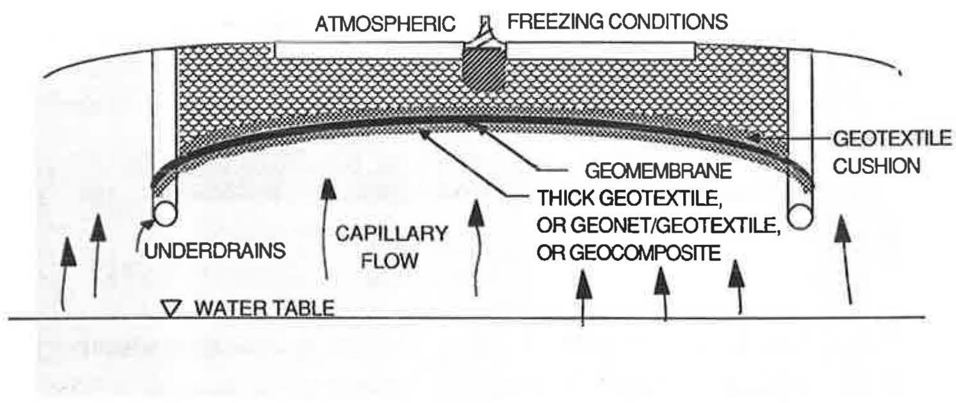

FIGURE 6 Prevention of frost heave.

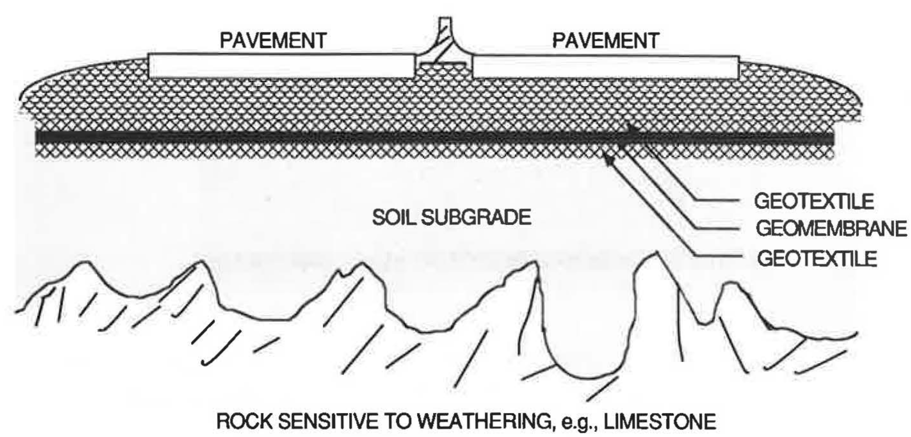

FIGURE 7 Prevention of karst-type sinkholes.

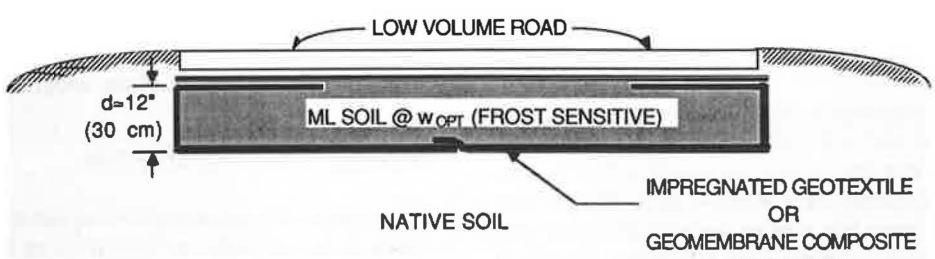

FIGURE 8 Maintenance of optimum water content.

causes the friable soils to simply fall apart. As shown in Figure 9, the concept is as previously described, but the encapsulated zone will probably be deeper than with frost-sensitive encapsulated soils.

Control of Expansive Soils (Horizontal Infiltration)

As was described earlier, moisture entering expansive soils beneath pavements can occur horizontally as well as vertically. To seal off the potentially affected zone, vertical barriers can be deployed as shown in Figure 10. As described by Sheffield and Steinberg (*9*) and in Phillips Fibers Corporation literature, the geotextile-geomembrane curtains can be installed with new pavement or with pavement overlays.

Secondary Containment of Underground Storage Tanks

As shown in Figure 11, underground fuel storage tanks in many states are requiring secondary containment. Using a

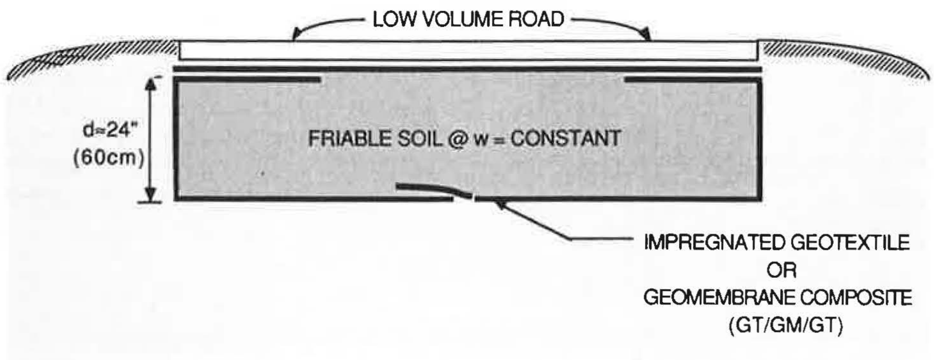

FIGURE 9 Maintenance of constant water content.

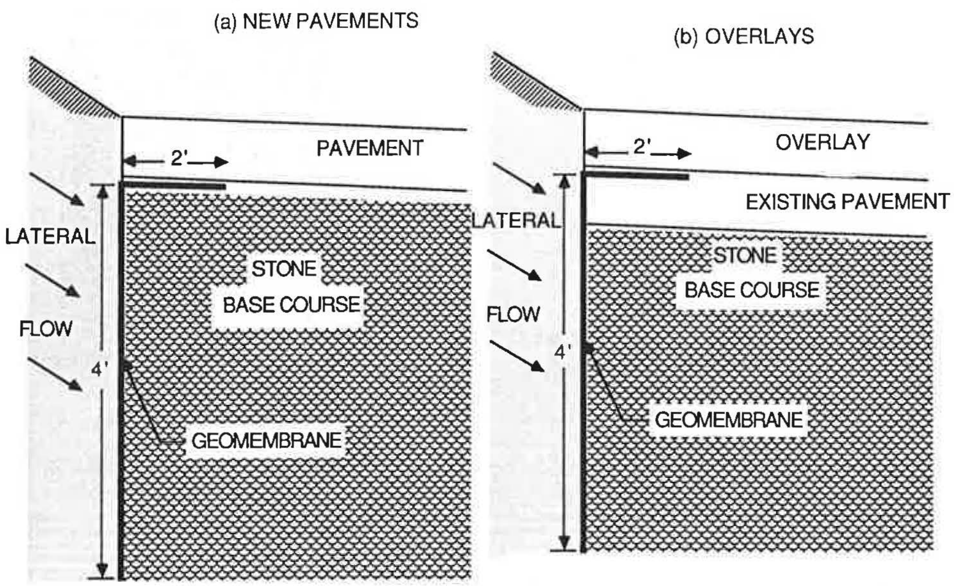

FIGURE 10 Prevention of stone saturation from sides.

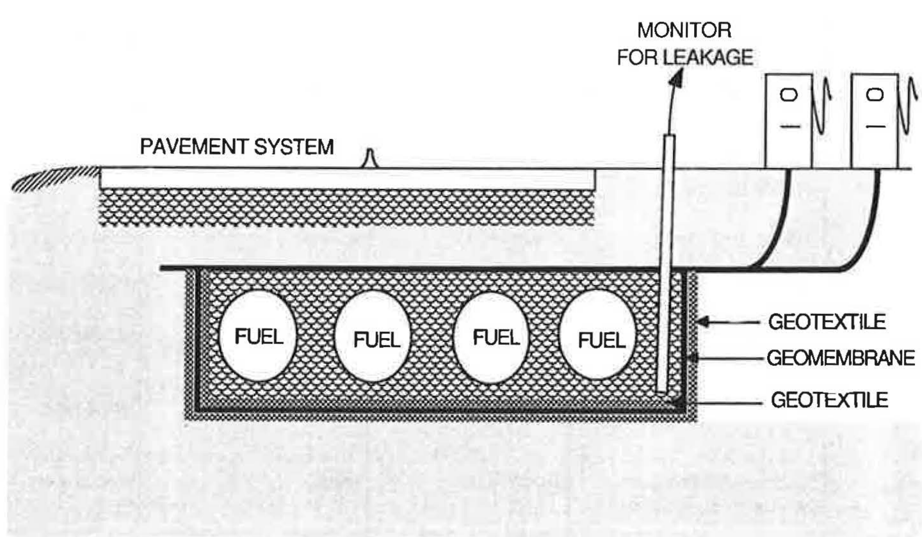

FIGURE 11 Secondary containment of underground storage tanks.

hydrocarbon-resistant geomembrane between two geotextiles, a secondary liner system with internal leak detection (the bedding stone) is formed. Such systems have been marketed by at least two organizations, Seamans, Inc. and MPC, Inc. A different scheme, by Total Containment, Inc., uses a geonet leak detector around the tank, with an encapsulating geomembrane on the outside.

Waterproofing of Walls

As shown in Figure 12, a number of schemes can be envisioned whereby surface water is kept from behind retaining walls. The reasons for this are numerous (e.g., to avoid corrosion of metal reinforcement strips or to provide relief of hydrostatic pressures). Many types of geomembranes are possible, but

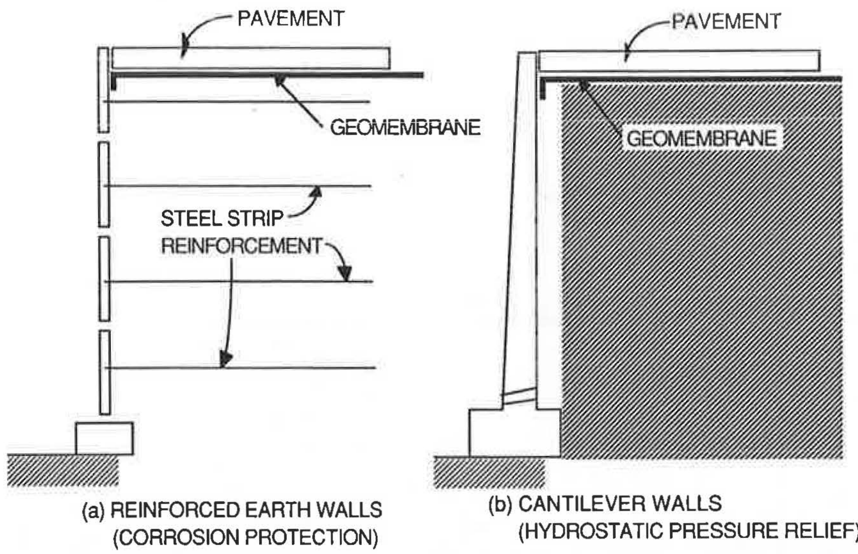

FIGURE 12 Waterproofing of walls.

TABLE 6 SUMMARY OF GEOMEMBRANE USE IN TRANSPORTATION SYSTEMS

Application No.	Description	Type of Liquid	Movement of Liquid	Implementation Status
1	flooding of railroad cut	groundwater	upward	limited use
2	waterproofing tunnels	groundwater	inward	regular use
3	railroad refueling areas	diesel fuel	downward	limited use
4	moisture proofing railroad subgrades	surface water	downward	unknown
5	control expansive soils (vertical infiltration)	surface water	downward	regular use
6	prevent frost heave	groundwater	upward	conceptual only
7	prevent karst sinkholes	surface water	downward	conceptual only
8	maintain water content - (frost sensitive soils)	surface and groundwater	inward	regular use
9	maintain water content - (friable soils)	moulding water	outward	limited use
10	control expansive soils - (horizontal infiltration)	groundwater	lateral	regular use
11	secondary containment	hydrocarbons	outward	regular use
12	wall waterproofing	surface water	downward	limited use

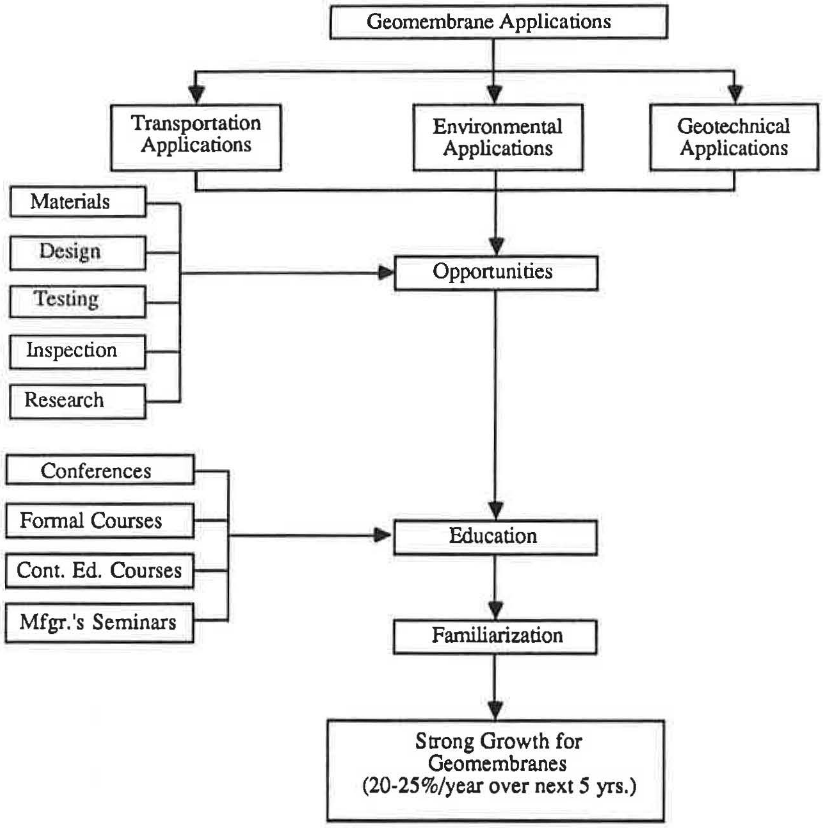

FIGURE 13 Conceptual implementation of geomembranes in subsurface applications.

all must be adequately protected if they are at or near the surface and if heavy loadings are anticipated.

SUMMARY AND CONCLUSIONS

Presented in this paper was a brief overview of geomembranes as they pertain to transportation applications and 12 specific application areas. These uses are summarized in Table 6 along with their approximate implementation status. With the exception of applications 3 and 11, all provide barriers to surface water or groundwater. As such, chemical resistance should not be a formidable concern and most of the polymer types listed in Table 2 should be adequate, taking into consideration mechanical properties, seamability, and cost. For applications 3 and 11, chemical resistance to hydrocarbons must be ensured.

A number of the applications presented require puncture protection of the geomembranes. This can be provided by placing a geotextile against the geomembrane, or by forming a geotextile-geomembrane composite by spread coating or postfabrication bonding. A number of these composites are commercially available. In some cases a geotextile is required on both sides of the geomembrane.

The type of geotextile generally preferred in these applications is a relatively thick needle-punched, nonwoven type. Thus a cushioning action is visualized in providing puncture resistance. Although such a mechanism is certainly obvious, other geotextiles might also be acceptable. For example, a woven or heat-set, nonwoven geotextile might also be feasible by virtue of its load-spreading capability. Investigations in this regard seem warranted.

Geomembrane seams are always of concern from the point of view of both strength and moisturetightness. These concerns are obviously site-specific situations and, in many cases, "absolute" tightness is not a necessity. In this regard, having to seam bonded geomembrane-geotextile composites is often not a detriment, and they can be mechanically seamed (e.g., by sewing) or sometimes merely overlapped.

In conclusion, the use of geomembranes for all types of subgrade applications is an exciting and growing field. As shown in Figure 13, many opportunities exist for all segments of the profession and related industries. It is felt that with a broad-based educational effort, there will come widespread familiarization and continued strong growth for geomembranes in the future.

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