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Project Summary

Quantification of Leak Rates Through Holes in Landfill Liners

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A study was undertaken to evaluate the rate at which liquids leak through flaws in the flexible membrane liner (FML) component of composite FML-soil liners. The variables studied were: flaw size and shape, FML type and thickness, the influence of a geofabric between the compacted soil and the FML, the conductivity of the soil subbase, the liquid head, and the liquid characteristics. Testing was done in 60 cm diameter permeameters. Soils were compacted in the permeameter and overlain with the FMLs to be tested with either round holes, slits, or seam flaws. A 15 cm layer of gravel was placed over the FML to provide ballast, and a head chamber was used to apply as much as 100 cm of head on the FML. Tests were conducted with a gravel subbase to determine the influence of the flaw alone on the flow rate followed by soil subbases having nominal conductivities of 1×10^{-4} cm s^{-1} and 1×10^{-6} cm s^{-1}. A calculational procedure was developed to simulate the flow rates through the permeameters and was modified to allow calculation of leak rates under field conditions.

The flow of liquids through flaws in FMLs was primarily dependent on the size and shape of the flaw, the liquid head, and the hydraulic characteristics of the subbase. It was nearly independent of the liner thickness, liquid properties, and the presence or absence of an underlying geotextile.

Variability in flow rates through seam flaws and slits was much greater than that through round holes due to the variable hole sizes that could result if the seam or one side of a slit was displaced relative to the other. As a result, the average leak rates through slit and seam flaws over a gravel subbase increased over twelve fold when the flaw length was increased by a factor of 3, from 5 to 15 cm.

For soil subbases, the head loss across the system may be divided into the head loss as the liquid enters the hole, the head loss across the hole in the FML, the head loss as the liquid flows laterally between the FML and the soil, and the head loss through the soil. The head loss, in the liquid flowing laterally between the FML and the soil, depended on the width of the gap between the two media. The gap widths for the 10^{-4} and 10^{-6} soils were estimated from the permeameter data to be 0.015 and 0.002 cm, respectively. Thus, less permeable soils containing greater amounts of clay form a better seal with the FML and allow less lateral flow of liquids. Gap widths and resultant flow rates were also decreased by overburden pressure from simulated layers of waste or liquid head.

In the final report evidence is presented which indicates that erosion of the subbase can occur just below a flaw in a FML, particularly when the liquid head is large, as would occur in a lagoon, and when the subbase conductivity is greater than 10^{-6} cm s^{-1}.

Graphs are presented from which permit writers can estimate the potential leakage rates from field installations.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A variety of flexible membrane liners (FMLs) have been utilized in the past for lining landfills and surface impoundments. Typically, they range in thickness from 0.06 to 0.25 cm and are marketed in various size sheets and rolls. The materials are installed and seamed in the field to conform to the shape of the impoundment. They are usually installed over a clean, smooth, compacted soil and often are covered with a protective soil layer before waste is placed in the surface impoundment or landfill. In some installations, a fabric or geotextile is placed on top of the subgrade to protect the FML from being punctured from below.

In the past, despite these precautions, leaks have been detected in many of the facilities lined with FMLs. These leaks may be a result of imperfect seaming, rips, punctures, tears that occur during or after installation, or failures that result from subsidence or shear failure of the supporting soil after installation. Also, failure may result from chemical incompatability and solvent attack which may dissolve either the plastic or the plasticizer. Facilities that have functioned well for years will FMLs have been known to fail rapidly when exposed to chemicals for which they were never intended.

At the present time, there is a dearth of knowledge on leakage rates through flaws in FMLs. It is, therefore, important that these leakage rates be quantified and the principles governing leakage rates be understood so that predictions of leakage rates can be made. The leakage rate may be affected by the following parameters:

1. The type of FML,
2. The FML thickness,
3. The size and shape of the flaw,
4. The characteristics of the subbase material,
5. The presence or absense of a geotextile between the subbase and FML,
6. The head of liquid above the flaw, and
7. The characteristics of the liquid to be retained.

The thrust of this research was to evaluate the effect of each of the above factors on leakage rate through flaws in FMLs. Physical measurements of flow rates were made and used to develop a calculational procedure for predicting leakage from any given set of input parameters.

Materials and Methods

Samples of several thicknesses of FML materials were obtained for testing. The materials included the following: 0.05 and 0.08 cm (20 and 30 mil) thicknesses of polyvinylchloride (PVC); 0.08, 0.20, and 0.25 cm (30, 80 and 100 mil) thicknesses of high density polyethylene (HDPE); 0.08 cm (30 mil) ethylene propylene rubber (EPDM); and 0.09 and 0.11 cm (36 and 45 mil) thicknesses of chlorosulfonated polyethylene (CSPE, trade name Hypalon). Each was cut into square pieces 66 cm on a side to fit in specially constructed round permeameters. Each permeameter had an inside diameter of 57.2 cm and a height of 30.5 cm. Each permeameter was filled with a subbase consisting of either gravel having a conductivity of 10^{-1} cm sec^{-1}, a sandy soil having a conductivity of 10^{-4} cm sec^{-1}, or a clay soil having a conductivity of 10^{-6} cm sec^{-1}. The permeameter with appropriate subbase was overlain with a FML section having the desired flaw and fitted with a head tank. Fifteen cm of gravel were placed above the FML to serve as ballast and as much as 95 cm of the permeating liquid to be tested was added. Several permeameters and head tanks were modified to simulate liquid depths in excess of 1 m and large overburden pressures. The majority of tests were run with water as the permeant while a lesser number employed simulated landfill leachate and waste xylene as the permeant. Each permeameter was equipped with a water stage recorder used to measure changes in water level in the head tank. When the flow rate was very small, 14 cm diameter stand pipes were used to increase resolution. Checks of the conductivity of the subbase soils without the presence of any FML were made periodically to document any intrinsic changes in conductivity.

Because the subbases could not be compacted to exactly the same conductivity, a calculational procedure was developed to smooth the data and adjust them to selected conductivities for comparison. The procedure partitioned the total head loss into that which occurs as the liquid enters the hole, the head loss as the liquid flows laterally between the FML and the subbase, and the head loss through the soil. The procedure was calibrated using the permeameter data and then modified by removing the boundary conditions imposed by the permeameter walls to allow extrapolation to field conditions.

Results and Discussion

In tests of FMLs overlying a subbase having a conductivity of 10^{-1} cm sec^{-1}, the size and shape of the flaw were the primary determining factors in the leakage rate. Material type had a lesser effect with the PVC and CSPE materials having a somewhat slower leakage rate presumably due to the very flexible nature of these materials. The thickness of the FML and the presence or absence of an underlying geotextile made no difference in leakage rate. Data on the maximum anticipated leakage rates from various size and shape flaws over a very permeable gravel subbase are summarized in Table 1. This information may be used as a guide when designing the drainage system for a double lined facility to estimate the amount of liquid which may be necessary to remove annually. It can also be used to estimate the number and/or size of flaws present in an existing FML which leaks into a drainage system.

Table 1. *Average Leak Rates (M^3 YR^{-1}) From Different Size and Shape Flaws in 0.08 CM Thick HDPE Liner Over Gravel at Two Liquid Heads.*

Hole Size and Shape	Head (cm) 50	100
	m^3 yr^{-1}	
0.16 cm diameter	110	145
0.64	1482	2208
1.27	4257	6780
5 cm slit	—	79
15 cm slit	3866	5623
5 cm seam	404	325
15 cm seam	4702	7244

In tests employing soil subbases of various conductivities, it was found that flaw size and subbase conductivity were the predominant controlling parameters in determining the leakage rate through a defective FML. Leakage rates through slits and seam flaws were much more variable than those through holes due to the possibility of misalignment of the materials. The flow rates through holes in FML's overlying soils will be primarily controlled by the conductivity of the soil. The type of FML material and presence or absence of a geotextile had very little effect on the flow rates. The effects of FML thickness and the liquid properties of the permeant also had little effect on the flow rates. The calculational procedure used to smooth the permeameter data was modified by removing the confining permeameter walls to allow extrapolation to field conditions. Suitable changes for the liquid properties can be added to the calculational procedure if needed for permeants other than water. Predicted leakage rates from various sizes of holes in FMLs overlying soils of different conductivities are summarized in Table 2. The predicted radius of the wetted area are also given in Table 3.

Thus, the data presented can be used to estimate the potential leakage rate from a damaged FML under a given set of conditions. The data can also be used to estimate the number or size of flaws if the leakage rate is known. For those persons involved in the design and design review of new facilities, the calculational procedure and program presented in the final report will be of assistance in adequately designing the initial system and in designing an adequate monitoring system.

Table 2. *Calculated Leak Rates (M^3 YR^{-1}) for a Range of Hole Sizes in Flexible Membrane Liners Over Soils of Different Conductivities. The Values are Given for Three Heads*

	Hole diameter (cm)			
K_{sat}(cm/s)	0.08	0.16	0.64	1.27
	H = 0.3 M			
3.40 x 10^{-4}	19.30	31.50	43.20	50.60
3.40 x 10^{-5}	4.30	4.88	6.28	7.30
3.40 x 10^{-6}	0.54	0.60	0.77	0.89
3.40 x 10^{-7}	0.066	0.72	0.095	0.107
	H = 1.0 M			
3.40 x 10^{-4}	42.30	87.80	128.00	147.00
3.40 x 10^{-5}	12.80	14.80	18.70	21.40
3.40 x 10^{-6}	1.66	1.83	2.29	2.61
3.40 x 10^{-7}	0.20	0.22	0.28	0.32
	H = 10.0 M			
3.40 x 10^{-4}	167.0	438.0	1,030.00	1,170.00
3.40 x 10^{-5}	84.6	123.1	153.50	171.30
3.40 x 10^{-6}	14.3	15.6	18.80	21.00
3.40 x 10^{-7}	1.8	1.9	2.30	2.60

Table 3. *Calculated Radius of Wetted Area (M) for a Range of Hole Sizes in Flexible Membrane Liners Over Soils of Different Conductivities. The Values are Given for Three Heads*

	Hole diameter (cm)			
K_{sat}(cm/s)	0.08	0.16	0.64	1.27
	H = 0.3 M			
3.40 x 10^{-4}	0.24	0.31	0.36	0.39
3.40 x 10^{-5}	0.36	0.38	0.43	0.47
3.40 x 10^{-6}	0.40	0.42	0.48	0.51
3.40 x 10^{-7}	0.44	0.47	0.53	0.57
	H = 1.0 M			
3.40 x 10^{-4}	0.36	0.51	0.62	0.66
3.40 x 10^{-5}	0.62	0.66	0.75	0.80
3.40 x 10^{-6}	0.70	0.74	0.82	0.88
3.40 x 10^{-7}	0.78	0.82	0.91	0.97
	H = 10.0 M			
3.40 x 10^{-4}	0.70	1.14	1.75	1.86
3.40 x 10^{-5}	1.59	1.91	2.14	2.26
3.40 x 10^{-6}	2.06	2.15	2.36	2.50
3.40 x 10^{-7}	2.29	2.39	2.62	2.77

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The complete report, entitled "Quantification of Leak Rates Through Holes in Landfill Liners," (Order No. PB 87-227 666/AS; Cost: $18.95, subject to change) will be available only from:
National Technical Information Service
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