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Project Summary

Field and Laboratory Testing of a Compacted Soil Liner

Bill R. Elshury, Gregory A. Sraders, David C. Anderson, James A. Rehage, Joseph O. Sai, and David E. Daniel

This project was initiated to provide information on the construction criteria that control the performance of compacted soil liners. The information generated by this study is intended to be used in regulating, designing, and constructing soil liners to meet the mandated maximum hydraulic conductivity of 1 x 10^{-7} cm per sec.

The construction criteria that have the greatest impact on soil liner performance were identified. A field liner was designed and constructed. After construction, the hydraulic conductivity of the liner was measured in the field using four 25-sq-ft (2.3-sq-m) sealed infiltrometers set in the liner surface and a 256-sq-ft (23.8-sq-m) lysimeter set in a gravel underdrain. Dye was introduced into one of the infiltrometers and a borehole, and the adjacent liner was dissected to expose the features of the liner that control its hydraulic conductivity.

An extensive program of laboratory testing of compacted specimens, prepared from the same soil as the liner, was completed. Test specimens were prepared using impact compaction, kneading compaction, and static compaction, with two levels of compactive effort for each time of compaction. Laboratory tests were also performed on samples of the field liner using several techniques.

This Project Summary was developed by EPA's Riske Reduction Engineering 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

In response to the widespread use of low-permeability compacted soil liners for hazardous waste facilities and the scarcity of performance data on such liners, the U.S. Environmental Protection Agency (EPA) initiated this project to develop a better understanding of the construction criteria that affect the hydraulic conductivity of compacted soil liners.

The principal purposes of this project were to:

- identify the construction criteria that control the hydraulic conductivity of compacted soil liners,
- measure the hydraulic conductivity of a field liner constructed with full-sized construction equipment, and
- determine the applicability of laboratory tests to in-the-field performance.

The research program began by identifying the construction criteria that are most influential in determining the hydraulic conductivity of compacted soil liners (Phase I). Based on the findings of the initial efforts, a program of construction and field testing of a series of small, 2-ft-thick (61-cm-thick) test liners, which were to be constructed using a variety of compaction equipment and various soil moisture contents, was planned (Phase II). A "trial pad" was built with full-sized construction equipment using two compaction techniques. The hydraulic conductivity of that liner was measured with both field and laboratory techniques. Laboratory hydraulic conductivity tests were conducted on samples of soil used to construct the liner. Dye was introduced into the liner at two locations, and morphological examinations were made to study the mechanisms of seepage through the liner.

After the trail pad was completed, the scope of the project was reduced and the trial pad, which was intended to be mostly for technique verification, became the only field liner constructed. The trail nature of the liner led to some choices during design and construction that would have been different had the other liners not been planned.

Field Liner

In general terms, the field liner consisted of two 6-in. lifts of clay compacted over an underdrain of clean coarse gravel, with a fabricated wall to impound 1 ft (30 cm) of water. The ponded area was about 32 ft (9.8 m) by 37 ft (11.3 m) in plan dimensions.

The liner was constructed of highly plastic clay (CH), which had an average liquid limit of 56, an average plasticity index of 41, 82 percent passing the No. 200 sieve, and 4 percent calcium carbonate. The clay fraction of the soil (about 42 percent finer than 2 μm) was predominantly smectite.

The liner was constructed in two portions with a padfoot roller that could be operated either in a static or vibratory mode. One of the two sections of the liner was constructed with 8 passes of the roller in the static mode, and the other was compacted by 3 to 4 passes of the roller in the vibratory mode. The roller had a single drum with 104 pads that were 3 in. (76 mm) high and had an end area of 21 sq in. (135 sq cm). The roller weighed about 15,950 lb (7240 kg); it could deliver a vibratory force of 26,500 lb (118 kN) at a frequency of 30.8 Hz and an amplitude of 0.040 in. (1.0 mm).

Construction testing of the static section (7 tests) gave an average moisture content of 15.7 percent with a standard deviation of 0.8 percent and an average dry density of 110.4 lb per cu ft (17.34 kN per cu m) with a standard deviation of 2.7 lb per cu ft (0.42 kN per cu m). All tests met the planned 95 percent of maximum standard Proctor dry density. Maximum standard Proctor dry density was 108 lb per cu ft (17.0 kN per cu m) at 17 percent moisture, and maximum modified Proctor dry density was 123 lb per cu ft (19.3 kN per cu m) at 12 percent moisture.

Construction testing of the vibratory-compacted section (30 tests) gave an average moisture content of 16.4 percent with a standard deviation of 1.3 percent and an average dry density of 108.9 lb per cu ft (17.11 kN per cu m) with a standard deviation of 6.3 lb per cu ft (0.99 kN per cu m). Five of the tests failed to meet the planned 95 percent of maximum standard Proctor dry density.

The pond was filled with water to a depth of 1 ft (30 cm) for 22 days, during which time several sets of measurements of hydraulic conductivity were taken with the lysimeter and the infiltrometers. Data from the observations are given in Figure 1. The average hydraulic conductivity of the portion of the liner compacted with the roller in the static mode was 3 x 10^{-5} cm per sec, and the average for the portion compacted with vibration was 1 x 10^{-4} cm per sec.

After the pond was drained, methylene blue dye was introduced into one of the infiltrometers and a borehole in the liner. The adjacent liner was later dissected. The dye penetrated over 80 percent of the thickness of the liner in thin, isolated channels that were separated by intact clods of clay with no dye staining.

Samples of the liner were taken before ponding using 3-in.- and 6-in.-diameter (76-mm- and 152-mm-) thin-walled tube samplers. Two hand trimmed block samples were taken after the pond was drained.

Laboratory Hydraulic Conductivity Tests

Samples of the soil used for the liner were compacted using 7 different procedures as listed in Table 1. The soil for one series of tests was prepared by air drying and passing it through a No. 4 sieve. The other samples were molded with soil that had not been predried and that had a maximum clod size of 0.75 in. (19 mm). Four compaction curves for soils compacted with impact compaction are given in Figure 2.

The compacted specimens were subjected to laboratory hydraulic conductivity tests using principally fixed-wall permeameters. The results of these tests are presented in Figure 3, which shows the influence of moisture content on hydraulic conductivity. The influence of soil dry density is shown on Figure The values from the field hydrau conductivity tests are shown in bo figures for comparison. Laborato hydraulic conductivity tests were al conducted on samples of the liner, given in Table 2.

Conclusions

The factors that are believed influence the hydraulic conductivity compacted soil liners were divided in five groups: (1) soil type, (2) bas compaction objectives, (3) essenti choices that are necessary to meet tl basic objectives, (4) supporting elemen that are included in or subsidiary to tl essential choices, and (5) other co siderations.

The "basic objectives" that must l met for a compacted liner to have hydraulic conductivity of 1 x 10^{-7} cm p sec or less are: (1) destruction of s clods and (2) bonding between lifts.

The "essential choices" to be made achieve the "basic objectives" are (1) tl moisture content of the soil, (2) the ty and weight of the roller, (3) the thickne of each lift, (4) the size of clods befo compaction, and (5) the number passes by the roller. Soil moisture co tent is considered the most importa essential choice. The soil must be w (and therefore soft) enough for the roll to thoroughly remold both the new lift ar any loose soil at the top of the underlyir lift. The soil for the field liner constructe in this study was too dry (and therefo too strong) for the relatively light roll used to construct the liner.

The "supporting elements" of densi and degree of saturation are important achieving low hydraulic conductivity ar are useful indicators in controllir compaction in the field. But, if the "bas objectives" are not met, both factors ha little meaning.

Examinations of the dye-stained flo paths in the field liner clearly showed th the seepage was predominantly throu macrovoids between soil clods and alor the interlift boundary, not through tl finer pores between the soil particles the clods. The observations do n support the flocculated/dispersed mec anism that is frequently used to expla flow through compacted soils.

Both the sealed double ring infiltr meters and the underdrain lysimet worked well and gave results that we consistent with each other.

The laboratory hydraulic conductivi tests on laboratory compacted spe mens were poor *specific* indicators

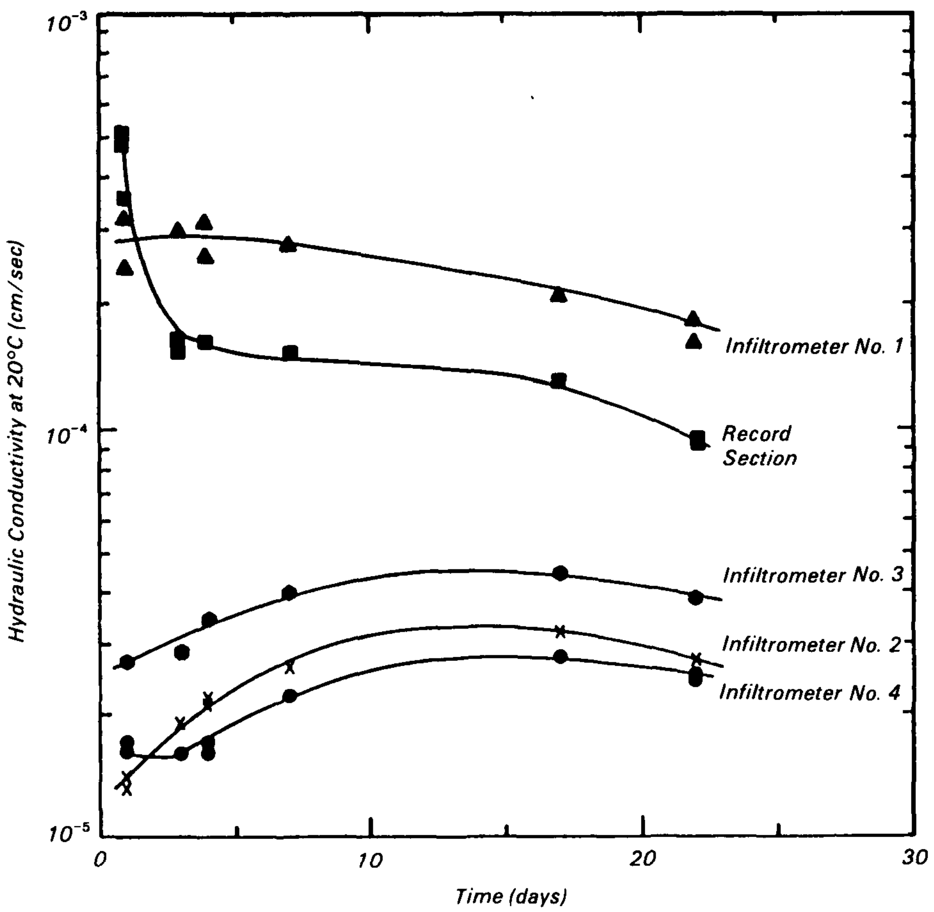


Figure 1. Field hydraulic conductivity values measured with the record section and infiltrometers.

Table 1. Summary of Laboratory Hydraulic Conductivity Testing Program for Laboratory-Compacted Soils

Type of Permeameter	Method of Compaction	Compactive Effort	Maximum Size of Clods*	Number of Tests
Flexible Wall	Impact	Std. Proctor	3/4 in.	4
Fixed Wall	Impact	Std. Proctor	3/4 in.	5
Fixed Wall	Impact	Std. Proctor	No. 4 Sieve	4
Fixed Wall	Impact	Mod. Proctor	3/4 in.	5
Fixed Wall	Kneading	Low	3/4 in.	4
Fixed Wall	Kneading	High	3/4 in.	4
Fixed Wall	Static	Low	3/4 in.	4
Fixed Wall	Static	High	3/4 in.	4

*3/4 in. = 19 mm; No. 4 Sieve = 4.8 mm

field performance. Matching *both* density and moisture content, the laboratory tests underpredict field hydraulic conductivity by about 100,000 times.

No tests on laboratory-compacted specimens predicted the performance of the liner based on correlations with density alone; in this case they underpredicted the hydraulic conductivity of the field liner by about 100 to 100,000 times, based on correlations with density. It is postulated that laboratory tests can suggest a minimum density a compacted soil must exceed to achieve a target hydraulic conductivity; however, density tests provide no information on whether a given construction procedure has produced or can produce a liner that meets the "basic objectives" that control field performance.

With respect to moisture content alone, the performance of the laboratory tests ranged from poor to good. Test specimens prepared from large clods using standard Proctor (ASTM D 698) and kneading compaction procedures showed a strong sensitivity to molding moisture content and gave hydraulic conductivities that came relatively close to matching field performance. The other procedures underpredicted field performance by as much as 1,000,000 times.

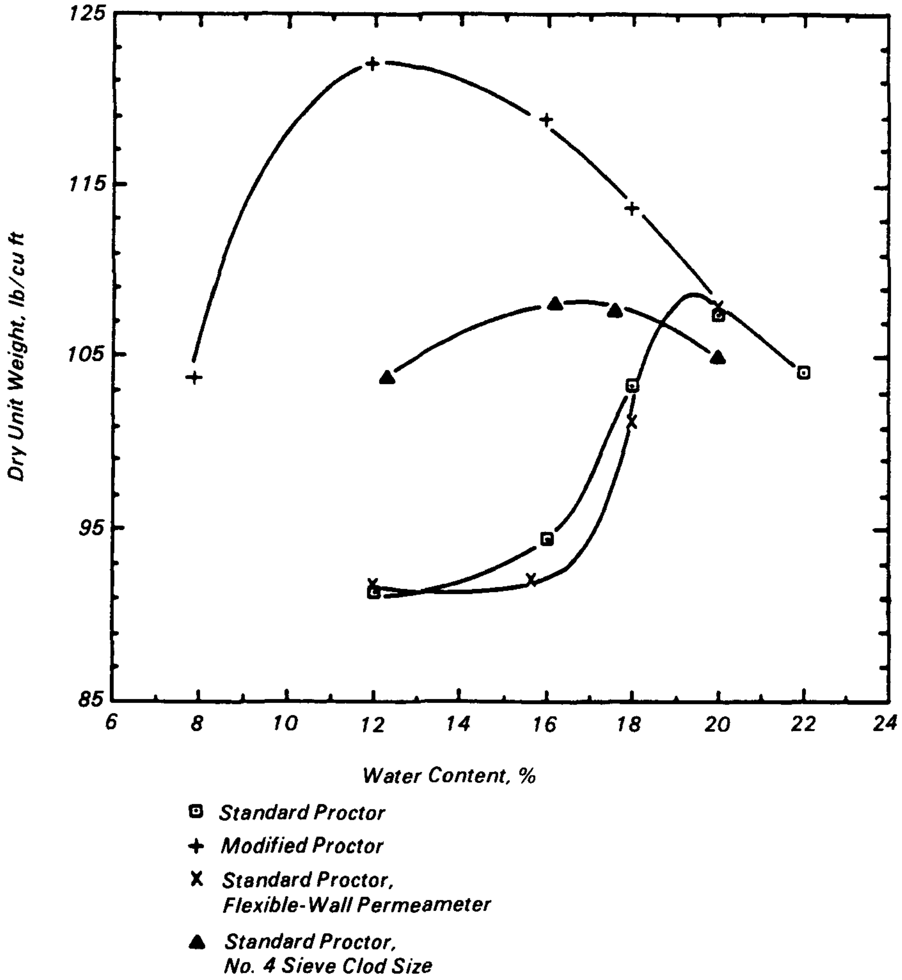
Laboratory tests on samples taken from the field liner with 3-in.-diameter (76-mm) thin-walled tubes underpredicted the hydraulic conductivity of the field liner by a factor of about 20,000 times, because: (1) the paths followed by seepage in the field had lateral dimensions larger than the laboratory specimens; (2) taking and extruding tube samples can densify unsaturated soils, which can close the voids that cause high field hydraulic conductivity, and (3) the spacing between the voids in the liner provides opportunities for them to not be represented in laboratory specimens.

Laboratory tests on hand-trimmed block samples gave results that underpredicted the hydraulic conductivity of the liner by only 2 to 10,000 times, which is better than the performance of thin-walled tube samples.

The effective porosity of the field liner was shown to be much less than the total porosity; the quantity of data collected was not sufficient to quantify the difference.

Recommendations

Further research is needed (1) to assess the performance of various types of rollers in compacting soil to achieve low hydraulic conductivity and (2) to

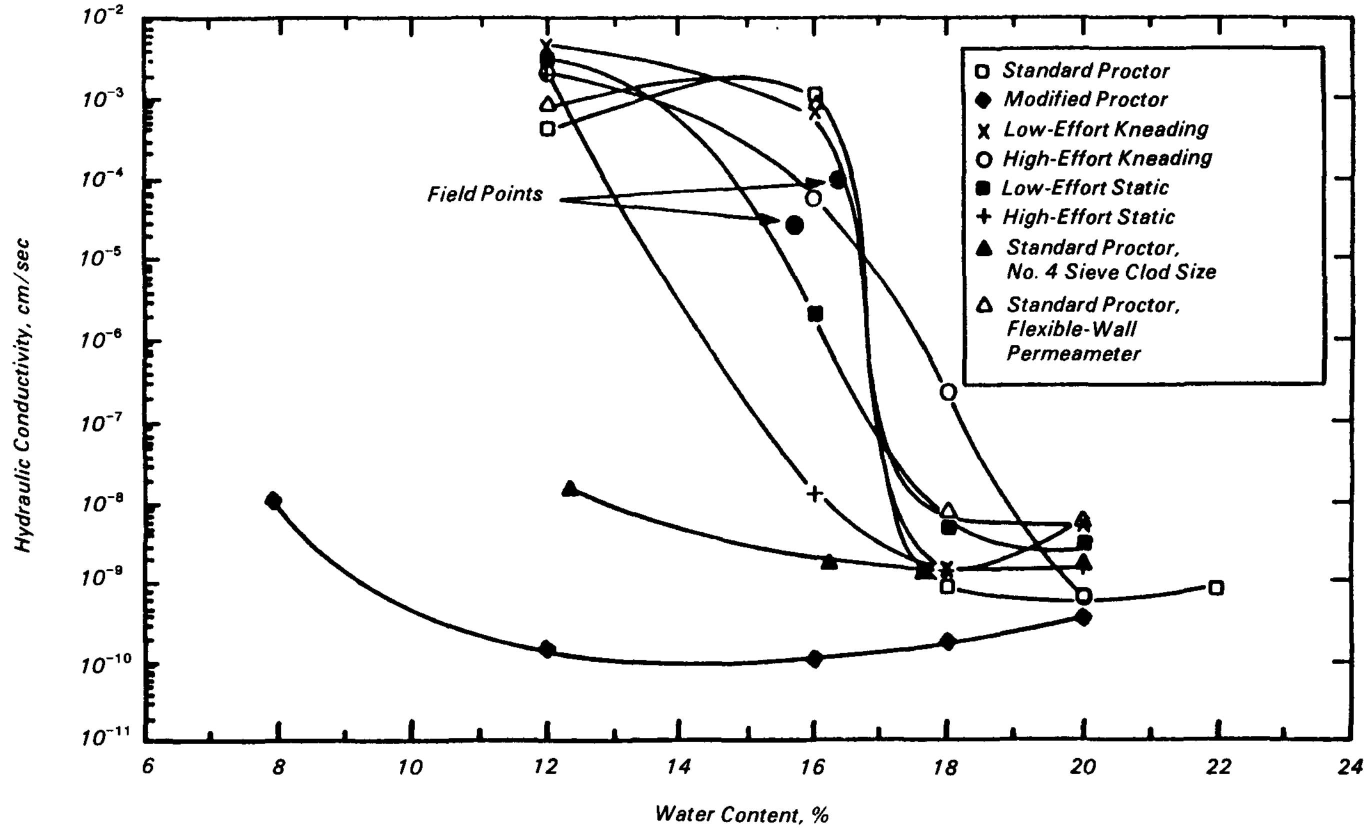


Note: 3/4-in. (19-mm) maximum clod size was used for all compacted specimens except where indicated.

Figure 2. *Compaction curves for soils compacted with impact compaction.*

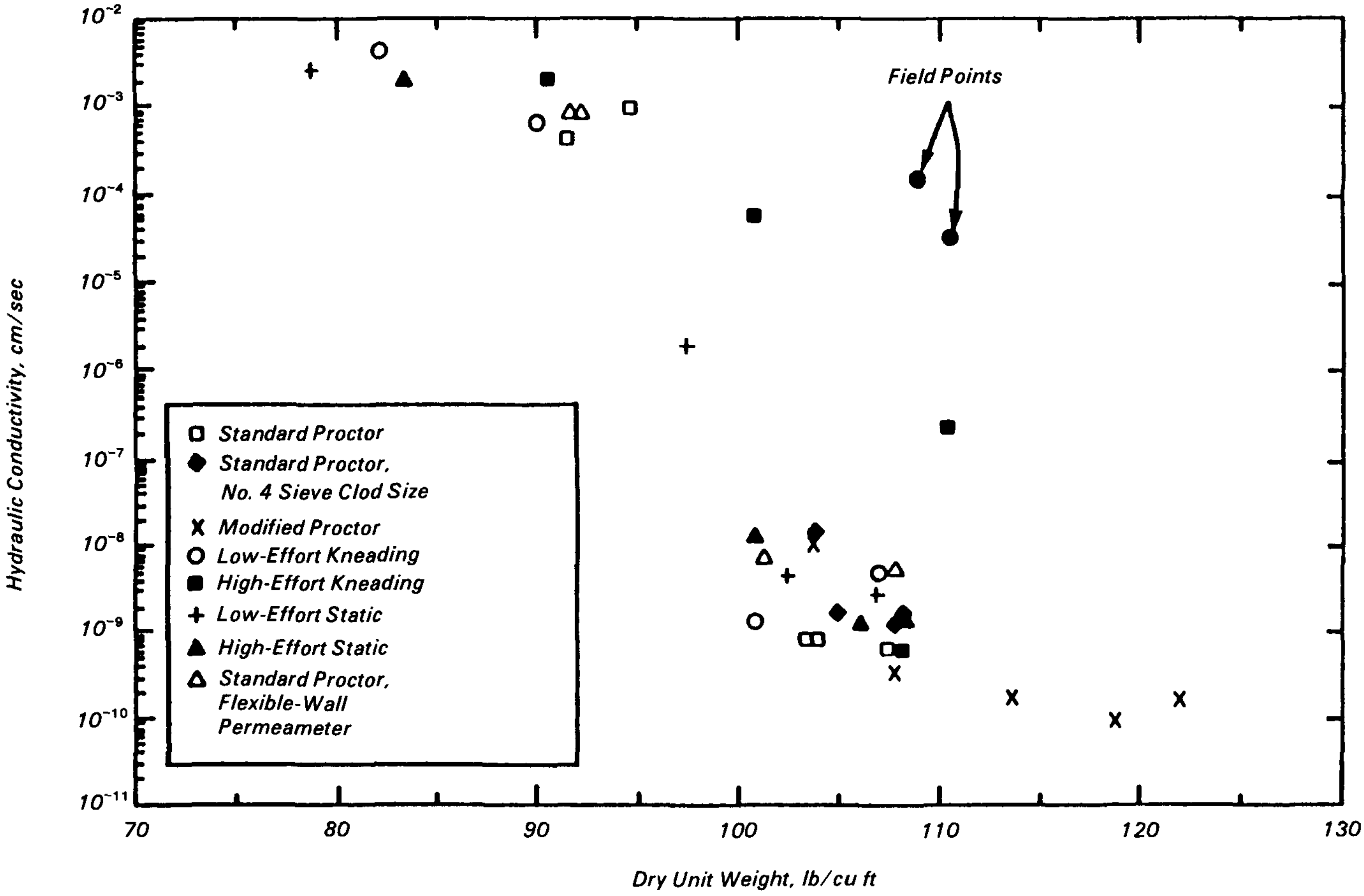
develop/assess laboratory test methods for predicting and evaluating the performance of soil liners.

The full report was submitted in fulfillment of Contract No. 68-03-3250 by McClelland Engineers under the sponsorship of the U.S. Environmental Protection Agency.



Note: 3/4-in. (19-mm) maximum clod size and fixed-wall permeameters were used for all specimens except where indicated.

Figure 3. *Hydraulic conductivity versus molding water content for all soils compacted in the laboratory, plus field points.*



Note: 3/4-in. (19-mm) maximum clod size and fixed-wall permeameters were used for all specimens except where indicated.

Figure 4. Hydraulic conductivity versus dry unit weight for all soils compacted in the laboratory, plus field points.

Table 2. Hydraulic Conductivities Measured on Field-Compacted Soil

Location of Sample	Sample Number	Type of Sampler	Initial Water Content (%)	Initial Dry Unit Weight (lb/cu ft)*	k (cm/sec)
Lower Lift	5	Thin-Walled Tube	16.1	113.2	5.0×10^{-9}
Lower Lift	6	Thin-Walled Tube	16.7	115.3	3.0×10^{-9}
Upper Lift	1	Thin-Walled Tube	15.3	113.9	2.0×10^{-9}
Upper Lift	2	Thin-Walled Tube	17.5	113.2	6.3×10^{-10}
Lift Interface**	-	Thin-Walled Tube	16.4	103.7	1.2×10^{-7}
Lower Lift	-	Block	25.2	87.4	7.5×10^{-5}
Upper Lift	-	Block	25.2	91.1	1.1×10^{-8}

*100.0 lb/cu ft = 15.71 kN/cu m.
**Test specimen trimmed for the equivalent of horizontal flow.
All specimens from the liner cell compacted with the roller in the vibratory mode.

Bill R. Elsbury and Gregory A. Sraders are with McClelland Engineers, Inc., Houston, TX 76244; David C. Anderson, James A. Rehage, and Joseph A. Sai are with K. W. Brown & Associates, College Station, TX 77840; and David E. Daniel is with the University of Texas, Austin, TX 78712.

Jonathan G. Herrmann is the EPA Project Officer (see below).

The complete report, entitled "Field and Laboratory Testing of a Compacted Soil Liner," (Order No. PB 89-125 942/AS; Cost: $21.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

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