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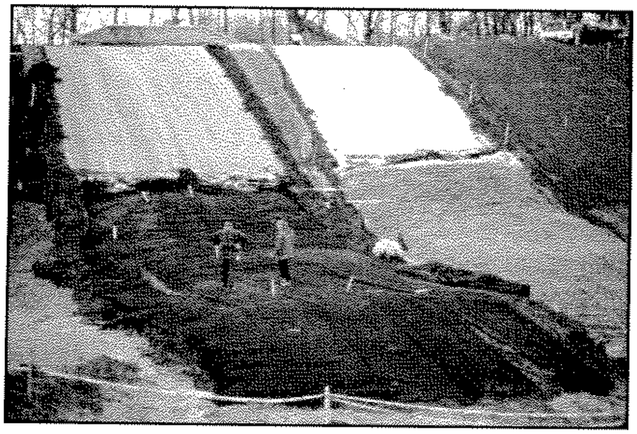
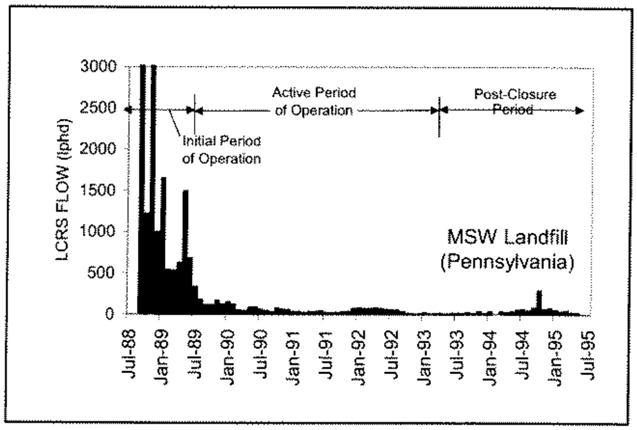
Assessment and Recommendations for Improving the Performance of Waste Containment Systems





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FOREWORD

The United States Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

This broad-based study addressed three categories of issues related to the design, construction, and performance of waste containment systems used at landfills, surface impoundments, and waste piles, and in the remediation of contaminated sites. The categories of issues, the locations in this report where each category is addressed, and the principal investigator for the study of each category are as follows:

- geosynthetic tasks are described in Chapter 2 and Appendices A and B; the principal investigator for these tasks was Professor Robert M. Koerner, P.E.;
- natural soil tasks are described in Chapters 3 and 4 and Appendices C and D; the principal investigator for these tasks was Professor David E. Daniel, P.E.; and
- field performance tasks are described in Chapter 5 and Appendices E and F; the principal investigator for these tasks was Dr. Rudolph Bonaparte, P.E.

Each portion of the report was authored by the identified principal investigator, and individuals working with the principal investigator. However, each principal investigator provided input and recommendations to the entire study and peer-reviewed and contributed to the entire report.

Geosynthetic materials (e.g., geomembranes (GMs), geotextiles (GTs), geonets (GNs), and plastic pipe) have been used as essential components of waste containment systems since at least the early 1980's. Five separate laboratory and/or analytical tasks were undertaken to address technical issues related to the use of these materials in waste containment systems. The technical issues related to geosynthetics are: (1) protection of GMs from puncture using needlepunched nonwoven GTs; (2) behavior of waves in high density polyethylene (HDPE) GMs when subjected to overburden stress; (3) plastic pipe stress-deformation behavior under high overburden stress; and (4) service life prediction of GTs and GMs. Conclusions are: (1) needlepunched nonwoven GTs can provide adequate protection of GMs against puncture by adjacent granular soils; a design methodology for GM puncture protection was developed from the results of laboratory tests and is presented; (2) temperature-induced waves (wrinkles) in GMs do not disappear when the GM is subjected to overburden stress (i.e., when the GM is covered with soil), rather the wave height decreases somewhat, the width of the wave decreases even more, and the void space beneath the wave becomes smaller; (3) waves may induce significant residual stresses in GMs, which may reduce the GM's service life; residual stresses induced in HDPE GMs by waves may be on the order of 1 to 22% of the GM's short-term yield strength; (4) if GM waves after backfilling are to be avoided, light-colored GMs can be used, GMs can be deployed and seamed without intentional slack, GMs can be covered with an overlying light colored temporary GT until backfilling occurs, and backfilling can be performed only in the coolest part of the day or even at night; (5) based on finite element modeling results, use of the Iowa State

formula for predicting plastic pipe deflection under high overburden stress is reasonable; (6) polypropylene GTs are slightly more susceptible to ultraviolet (UV) light degradation than polyester GTs, and lighter weight GTs degrade faster than heavier GTs; (7) GTs that are partially degraded by UV light do not continue to degrade when covered with soil, i.e., the degradation process is not auto-catalytic; (8) buried HDPE GMs have an estimated service life that is measured in terms of at least hundreds of years; the three stages of degradation and approximate associated durations for each as obtained from the laboratory testing program described in this report are: (i) antioxidant depletion (≈ 200 years), (ii) induction (≈ 20 years), and (iii) half-life (50% degradation) of an engineering property (≈ 750 years); these durations were obtained from the extrapolation of a number of laboratory tests performed under a limited range of conditions; it is recommended that additional testing be performed under a broader range of conditions to develop additional insight into the ultimate service life of HDPE GMs, and other types of GMs as well.

Geosynthetic clay liners (GCLs) are a relatively new type of liner material, having first been used in a landfill in 1986. One of the key issues with respect to field performance of GCLs is their stability on permanent slopes, such as found on landfill final cover systems. Fourteen test plots, designed to replicate typical final cover systems for solid waste landfills, were constructed to evaluate the internal and interface shear strength of GCLs under full-scale field conditions on 2H:1V and 3H:1V slopes. Five different types of GCLs were evaluated, and performance was observed for over four years. All test plots were initially stable, but over time, as the bentonite in the GCLs became hydrated, three slides (all on 2H:1V slopes) that involved the GCLs have occurred. One slide involved an unreinforced GCL in which bentonite that was encased between two GMs unexpectedly became hydrated. The other two slides occurred at the interface between the woven GTs of the GCLs and the overlying textured HDPE GM. Conclusions are: (1) at the low normal stresses associated with landfill final cover systems, the interface shear strength is generally lower than the internal shear strength of internally-reinforced GCLs; (2) interfaces between a woven GT component of the GCL and the adjacent material should always be evaluated for stability; these interfaces may often be critical; (3) significantly higher interface shear strengths were observed when the GT component of a GCL in contact with a textured HDPE GM was a nonwoven GT, rather than a woven GT; (4) if bentonite sandwiched between two GMs has access to water (e.g., via penetrations or at exposed edges), water may spread laterally through waves or wrinkles in the GM and hydrate the bentonite over a large area; (5) if the bentonite sandwiched between two GMs does not have access to water, it was found that the bentonite did not hydrate over a large area; (6) current engineering procedures for evaluating the stability of GCLs on slopes (based on laboratory direct shear tests and limit-equilibrium methods of slope stability analysis) correctly predicted which test plots would remain stable and which would undergo sliding, thus validating current design practices; and (7) based on the experiences of this study, landfill final cover systems with 2H:1V sideslopes may be too steep to be stable with the desired factor of safety due to limitations with respect to the interface shear strengths of the currently available geosynthetic products.

To evaluate the field performance of compacted clay liners (CCLs), a database of 89 large-scale field hydraulic conductivity tests was assembled and analyzed. A separate database for 12 soil-bentonite admixed CCLs was also assembled and analyzed. In addition, case histories on the field performance of CCLs in final cover test sections were collected and evaluated. Conclusions are: (1) 25% of the 89 natural soil CCLs failed to achieve the desired large-scale hydraulic conductivity of 1×10^{-7} cm/s or less; (2) all of the 12 soil-bentonite admixed CCLs achieved a large-scale hydraulic conductivity of less than 1×10^{-7} cm/s; however, all of these CCLs contained a relatively large amount (more than 6%) of bentonite; soil-bentonite admixed CCLs will not be discussed further; (3) the single most common problem in achieving the desired low level of hydraulic conductivity in CCLs was failure to compact the soil in the zone of moisture and dry density that will yield low hydraulic conductivity; (4) the most significant control parameter of CCLs was found to be a parameter denoted "P_o", which represents the percentage of field-measured water content-density points that lie on or above the line of optimums; when P_o was high (80% to 100%) nearly all the CCLs achieved the desired field hydraulic conductivity, but when P_o was low (0 to 40%), fewer than half the CCLs achieved the desired field hydraulic conductivity; (5) practically no correlation was found between field hydraulic conductivity and frequently measured soil characterization parameters, such as plasticity index and percentage of clay, indicating that CCLs can be successfully constructed with a relatively broad range of soil materials; (6) hydraulic conductivity decreased with increasing CCL thickness, up to a thickness of about 1 m; and (7) analysis of CCLs constructed in the final cover test sections generally showed that CCLs placed without a GM overlain by soil tended to desiccate and lose their low hydraulic conductivity within a few years.

Liquids management data were evaluated for 187 double-lined cells at 54 landfills to better understand the field performance of landfill primary liners, leachate generation rates, and leachate chemistry. Conclusions are: (1) average monthly active-period leak detection system (LDS) flow rates for cells with HDPE GM primary liners constructed with construction quality assurance (CQA) (but without ponding tests or electrical leak location surveys) will often be less than 50 lphd, but occasionally in excess of 200 lphd; these flows are attributable primarily to liner leakage and, for cells with sand LDSs, possibly construction water; (2) average monthly active-period LDS flow rates attributable to leakage through GM/GCL primary liners constructed with CQA will often be less than 2 lphd, but occasionally in excess of 10 lphd; (3) available data suggest that average monthly active-period LDS flow rates attributable to leakage through GM/CCL and GM/GCL/CCL primary liners constructed with CQA are probably similar to those for GM/GCL primary liners constructed with CQA; (4) GM liners can achieve true hydraulic efficiencies in the 90 to 99% range, with higher efficiencies occasionally being achievable; (5) GM/GCL, GM/CCL, and GM/GCL/CCL composite liners can achieve true hydraulic efficiencies of 99% to more than 99.9%; (6) GMs should not be used alone in applications where a hydraulic efficiency above 90% must be reliably achieved, even if a thorough CQA program is employed, except perhaps in situations where electrical leak location surveys or ponding tests are used to identify GM defects and the defects are repaired; (7) GM/CCL and GM/GCL/CCL composite liners are capable of substantially preventing leachate migration over the entire period of significant leachate generation for typical landfill operations scenarios without leachate recirculation or disposal or liquid wastes of sludges; (8) leachate collection and removal system (LCRS) flow rates were highest at the beginning of cell operations and decreased as waste thickness increased and daily and intermediate covers were applied to the waste; leachate generation rates decreased on average by a factor of four within one year after closure and by one order of magnitude two to four years after closure; within nine years of closure, leachate generation rates were negligible for the landfill cells evaluated in this study; (9) municipal solid waste (MSW) cells produced, on average, less leachate than industrial solid waste (ISW) and hazardous waste (HW) cells; for cells of a given waste type, rainfall fractions were highest in the northeast and lowest in the west; the differences in leachate generation rates are a function of type of waste, geographic location, and operational practices; (10) in general, HW landfills produced the strongest leachates and coal ash landfills produced the weakest leachates; MSW ash leachate was more mineralized than MSW leachate and the other ISW leachates; (11) the solid waste regulations of the 1980s and 1990s have resulted in the improved quality of MSW and HW landfill leachates; and (12) the EPA Hydrologic Evaluation of Landfill Performance (HELP) computer model, when applied using an appropriate simulation methodology and an appropriate level of conservatism, provides a reasonable basis for designing LCRSs and sizing leachate management system components; due to the complexity and variability of landfill systems, however, the model will generally not be adequate for use in a predictive or simulation mode, unless calibration is performed using site-specific measured (not default) material properties and actual leachate generation data.

Waste containment system problems were identified at 74 modern landfill and surface impoundment facilities located throughout the U.S. The purpose of this aspect of the project was to better understand the identified problems and to develop recommendations to reduce the future occurrence of problems. Conclusions are: (1) the number of facilities with identified problems is relatively small in comparison to the total number of modern facilities nationwide; however, the search for problems was by no means exhaustive; (2) the investigation focused on landfill facilities: 94% of the identified problems described herein occurred at landfills; (3) among the landfill problems, 70% were liner system related and 30% were cover system related; however, the ratio of liner system problems to cover system problems is probably exaggerated by the fact that a number of the facilities surveyed were active and did not have a cover system; (4) based on a waste containment system component or attribute criterion, the identified problems can be grouped into the following general categories: (i) slope instability of liner systems or cover systems or excessive deformation of these systems (44%); (ii) defectively constructed liners, leachate collection and removal systems (LCRSs) or LDSs, or cover systems (29%); (iii) degraded liners, LCRSs or LDSs, or cover systems (18%); and (iv) malfunction of LCRSs or LDSs or operational problems with these systems (9%); (5) considering a principal human factor contributing to the problem criterion, the identified problems are classified as follows: (i) design (48%); (ii) construction (38%); and (iii) operation (14%); (6) the main impacts of the problems were: (i) interruption of facility construction and operation; (ii) increased maintenance; and (iii) increased costs; (7) problems detected at facilities were typically remedied before adverse environmental impacts occurred; (8) impact to groundwater or surface water was only identified at one facility, where landfill gas migrated beyond the edge of the liner system and to groundwater; (9) all of the identified problems can be prevented using available design approaches, construction materials and procedures, and operation practices; (10) although the environmental impact of problems has generally been negligible thus far, the landfill industry should do more to avoid future problems in order to: (i) reduce the potential risk of future environmental impact; (ii) reduce the potential health and safety risk to facility workers, visitors, and neighbors; (iii) increase public confidence in the performance of waste containment systems; (iv) decrease potential impacts to construction, operation, and maintenance; and (v) reduce costs associated with the investigation and repair of problems.

ACRONYMS AND ABBREVIATIONS

ALCD	Alternative Landfill Cover Demonstration
ALR	action leakage rate
AOS	apparent opening size (of geotextile)
ARAR	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
AZ	acceptable zone
BAT	commercial term for a type of porous probe
BNA	base neutral extractable
BOD	biological oxygen demand
BTEX	benzene, toluene, ethylbenzene, and xylenes
BuRec	U.S. Bureau of Reclamation
C&DW	construction and demolition waste
CAT	Caterpillar construction equipment
CCL	compacted clay liner
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (aka Superfund Act)
CFR	U.S. Code of Federal Regulations
CH	soil classification symbol for a high plasticity clay soil
CL	soil classification symbol for a low plasticity clay soil
COD	chemical oxygen demand
CQA	construction quality assurance
CQC	construction quality control
CSPE	chlorosulfonated polyethylene
DSC	differential scanning calorimeter
EPA	U.S. Environmental Protection Agency
EPDM	ethylene propylene diene monomer
ET	evapotranspiration
FDEP	Florida Department of Environmental Protection
FEM	finite element model
fPP	flexible polypropylene

FOS	filtration opening size (of geotextile)
FS	factor of safety
GC	geocomposite
GCL	geosynthetic clay liner
GDL	geocomposite drainage layer
GEC	geosynthetic erosion control (material)
GM	GM
GN	geonet
GT	geotextile
HDPE	high density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance (computer program)
HLR	high level radioactive (waste)
HP-OIT	high-pressure oxidative induction time
HSWA	Hazardous and Solid Waste Amendments
H/W	height/width ratio (of GM waves)
HW	hazardous waste
ISW	industrial solid waste
k	hydraulic conductivity
k_{field}	hydraulic conductivity measured in the field
k_{lab}	hydraulic conductivity measured in the laboratory
LCRS	leachate collection and removal system
LDLPE	low density linear polyethylene
LDR	land disposal restrictions
LDS	leak detection system
LL	liquid limit
LLDPE	linear low density polyethylene
LLRM	low level radioactive mixed (waste)
LLR	low level radioactive (waste)
LMDPE	linear medium density polyethylene
lphd	liters/hectare/day (1.0 lphd = 9.35 gallon/acre/day (gpad))
LYS	lysimeter

MCL	maximum containment level
MF	modification factor
MP	modified Proctor (compaction test)
MSW	municipal solid waste
NCP	National Contingency Plan
NE	northeast
NW	nonwoven (geotextile)
OD	outside diameter
OH	original height (of GM waves)
OIT	oxidative induction time
OWC	optimum water content
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-p-dioxins
PCDF	polychlorinated dibenzo-furans
PE	polyethylene
PET	polyester
PI	plasticity index
PP	polypropylene
PPL	priority pollutant list
PVC	polyvinyl chloride
QA	quality assurance
RC	relative compaction
RCRA	Resource Conservation and Recovery Act
RF	reduction factor
RP	reduced Proctor (compaction test)
SARA	Superfund Amendments and Reauthorization Act
SC	soil classification symbol for a sandy clay
SDR	standard dimension ratio (of pipe)
SDRI	sealed double ring infiltrometer
SE	southeast
SMCL	secondary maximum containment level

SP	standard Proctor (compaction test)
Std-OIT	standard oxidative induction time
SVOC	semivolatile organic compound
TCLP	toxicity characteristics leaching procedure
TDS	total dissolved solids
TOC	total organic carbon
TSB	two-stage borehole test
TSCA	Toxic Substances Control Act
TSDF	treatment, storage and disposal facility
TSS	total suspended solids
UMTRCA	Uranium Mill Tailings Radiation Control Act
UV	ultraviolet
VFPE	very flexible polyethylene (includes LLDPE, LDLPE and VLDPE)
VLDPE	very low density polyethylene
VOC	volatile organic compound
W	west