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Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment – Appendices

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Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment – Appendices

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ABSTRACT

This peer-reviewed study demonstrates that engineering properties of cover soils change while in service and that long-term engineering properties should be used as input to models employed for performance assessments. Recommendations for appropriate input are made based on the data that were collected. Increases in the saturated hydraulic conductivity, saturated volumetric water content, and the air entry suction (as characterized by van Genuchten's α parameter) occurred due to formation of soil structure, regardless of climate, cover design, or service life. Substantial changes in hydraulic conductivity were observed in some geosynthetic clay liners (GCLs) that did not hydrate completely and underwent cation exchange. Changes in geomembranes and geosynthetic drainage layers were modest or small, and computations based on antioxidant depletion rates suggest that the minimum service life of geomembranes is on the order of 50-125 yrs (the actual service life will be longer). The findings indicate that covers should be monitored to ensure that they are functioning as intended. Monitoring using pan lysimeters combined with secondary measurements collected for interpretive purposes is recommended. Future research investments should include an evaluation of remote sensing technologies for cover monitoring and analog studies to estimate properties of earthen and geosynthetic cover materials corresponding to service lives of 100s to 1000s of years.

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EXECUTIVE SUMMARY

In this peer-reviewed study, final covers at test facilities and operating waste containment facilities were exhumed to evaluate how the properties of the cover materials changed 4.0-8.9 yr after installation (6.3 yr on average). Field tests were conducted, samples were collected, laboratory testing was performed, and data analyses were conducted. The findings demonstrate that engineering properties of cover soils change while in service and that long-term engineering properties should be used as input to models employed for performance assessments. Recommendations for appropriate input are made based on the data that were collected.

Changes in hydraulic properties occurred in all cover soils evaluated due to the formation of soil structure, regardless of climate, cover design, or service life. The saturated hydraulic conductivity and the α parameter for the soil water characteristic curve (SWCC) increased, which reflects formation of larger pores due to pedogenic processes such as wet-dry and freeze-thaw cycling. Larger changes were observed for soils with lower as-built saturated hydraulic conductivity and soils with a greater proportion of clay particles in the fines fraction. Hydraulic properties of the cover soils were similar when exhumed, regardless of the as-built condition. Test scale had a significant effect on the hydraulic properties, with conditions near field-scale obtained using 0.3-m test specimens.

Substantial changes were also observed in some geosynthetic clay liners (GCLs). Analysis showed that GCLs have very low saturated hydraulic conductivity ($< 5 \times 10^{-11}$ m/s) when placed on a moist subgrade (water content > 10%) and covered with a geomembrane and cover soil soon after installation. GCLs installed under other conditions can be much more permeable. GCLs that underwent and maintained complete hydration with osmotic swell retained low hydraulic conductivity even when Na was replaced by Ca and Mg provided they did not dehydrate. GCLs that undergo osmotic swell and are covered with a geomembrane surcharged with cover soils are expected to retain low hydraulic conductivity provided the geomembrane remains intact.

Changes in geomembranes and geosynthetic drainage layers were modest or small. Analysis of antioxidants in geomembranes showed that antioxidant depletion was reasonably consistent with expectations based on first-order kinetics and laboratory-measured depletion rates. Based on antioxidant depletion, the minimum service life of geomembranes is on the order of 50-125 yrs. Actual service lives may be longer but are difficult to predict based on the limited information available today.

Because changes in the engineering properties of cover materials are commonplace, and significant in some cases, monitoring of covers should be conducted to ensure they are functioning as intended. Monitoring using pan lysimeters combined with secondary measurements collected for interpretive purposes (water content, temperature, vegetation surveys, etc.) is recommended. Future research investments should explore how remote sensing technologies can be used for cover monitoring.

This study represents a snap shot in the evolution of final covers approximately 5 to 10 yr after construction. Additional research investments are needed to more accurately and completely define very long-term properties of earthen and geosynthetic cover materials corresponding to 100s or 1000s of years. These research investments should include analog studies of natural environments where earthen and natural polymeric materials exist as well as accelerated laboratory experiments that can be used to develop predictive degradation models.

ACKNOWLEDGEMENT

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ABBREVIATIONS

Acronyms

ACAP	Alternative Cover Assessment Program
BC	bound cations
CEC	cation exchange capacity
CMH	chilled mirror hygrometer
CMP	common midpoint
D	diameter
DW	deionized water
ET	evapotranspiration
GCL	geosynthetic clay liner
GDL	geosynthetic drainage layer
GM	geomembrane
GPR	ground penetrating radar
H	depth of water in outer ring of SDRI
HDPE	high density polyethylene
H_b	height of water in bubbling tube in BH relative to base of borehole
I	infiltration rate
ICP-OES	inductively coupled plasma – optical emissions spectrometry
I_s	ionic strength
K	hydraulic conductivity
L_f	depth of the wetting front
LLDPE	linear low density polyethylene
MARV	minimum average role value
MDR	charge ratio of monovalent to divalent soluble cations
MFI	melt flow index

MSW	municipal solid waste
OIT	oxidation induction time
PET	potential evapotranspiration
Q	volumetric flow rate
RMD	ratio of monovalent to divalent cations in a solution
SC	soluble cations
SDRI	sealed double-ring infiltrometer
SI	swell index
SW	standard water (0.01 M $CaCl_2$)
SWCC	soil water characteristic curve
TDR	time domain reflectometry
BH	borehole permeameter
TCM	total soluble cations charge per mass
USCS	Unified Soil Classification System
USEPA	US Environmental Protection Agency

Western Symbols

Ca	calcium
Cl	chlorine
K	potassium
K_F	field-measured saturated hydraulic conductivity
K_s	saturated hydraulic conductivity
K_{sa}	as-built saturated hydraulic conductivity
K_{SDRI}	field-measured hydraulic conductivity with SDRI
K_{si}	in-service saturated hydraulic conductivity
K_{BH}	field-measured hydraulic conductivity with BH permeameter

n	shape parameter in van Genuchten's equation
n_{LS}	shape parameter in van Genuchten's equation from large-scale tests
n_{SS}	shape parameter in van Genuchten's equation from small-scale tests
n_a	shape parameter in van Genuchten's equation from as-built test section
Na	sodium
Mg	magnesium
p	p statistic from t-test
t	t statistic from t-test
X_m	mole fraction of monovalent cations

Greek Symbols

α	shape parameter in van Genuchten's equation
α_a	shape parameter in van Genuchten's equation from as-built test section
α_{LS}	shape parameter in van Genuchten's equation from large-scale tests
α_{SS}	shape parameter in van Genuchten's equation from small-scale tests
γ_{dmax}	maximum dry unit weight on compaction curve
θ	volumetric water content
θ_r	residual volumetric water content
θ_s	saturated volumetric water content
Θ	effective saturation
σ	standard deviation

APPENDIX A – EXHUMATION PHOTO GALLERY

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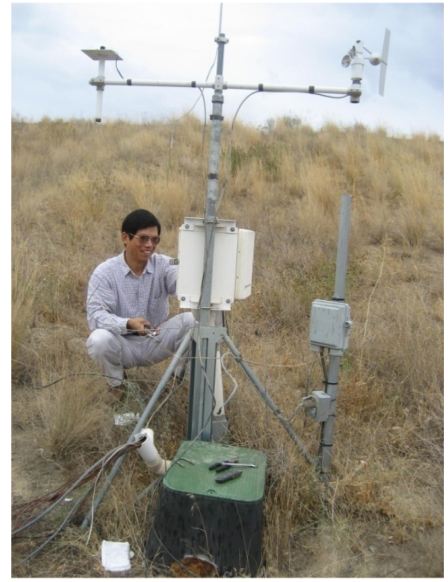

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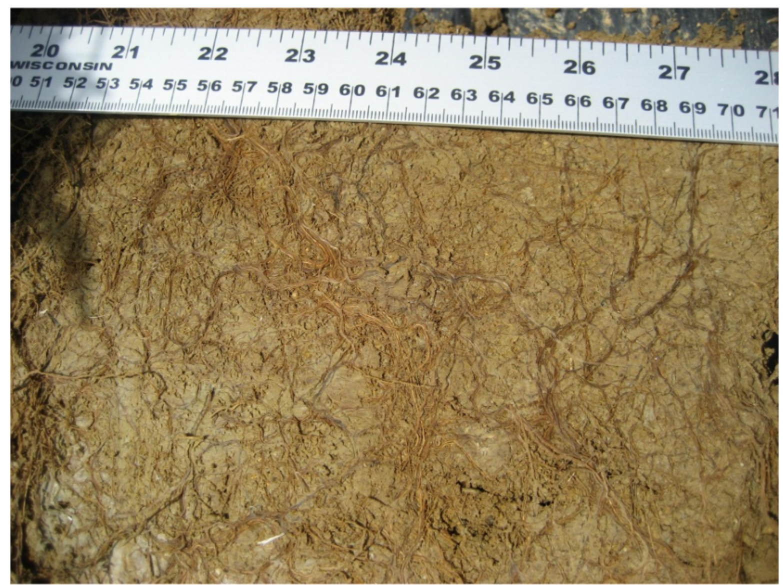

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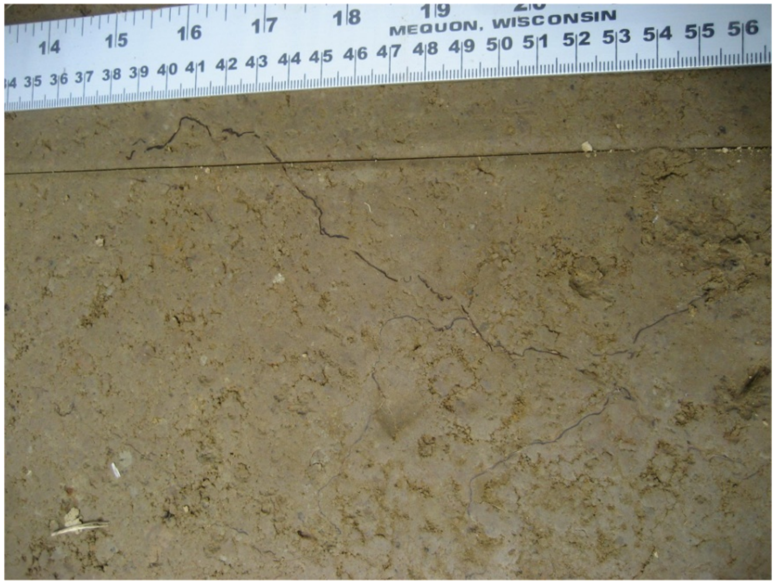

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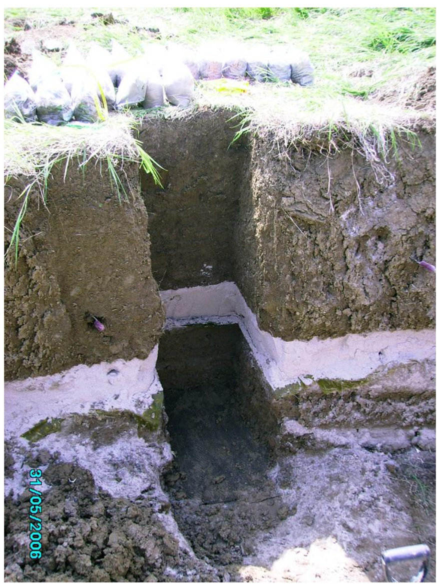

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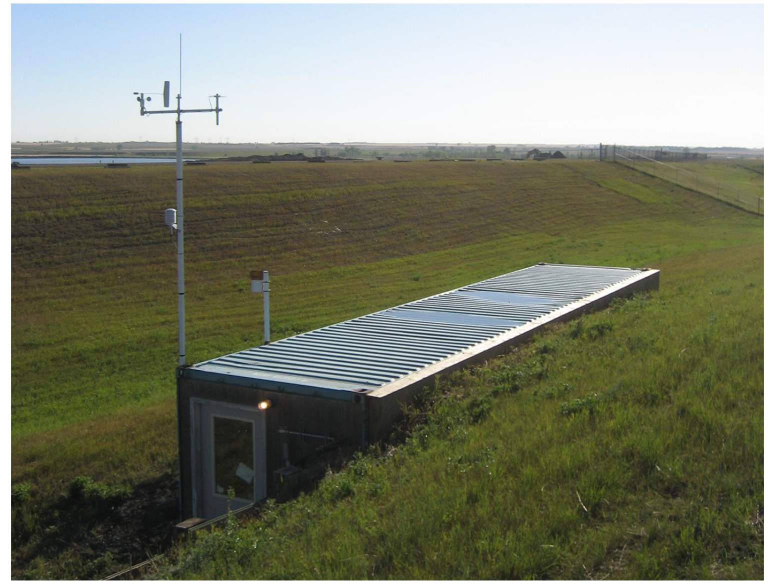

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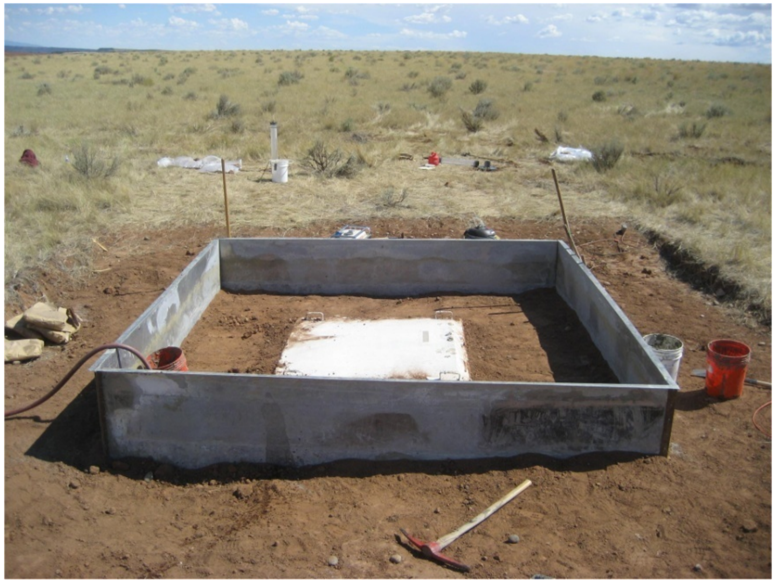

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