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原著

동결/융해에 따른 폐기물 매립지 복토층 연구

이재영

한국토지공사 토지연구원, 책임연구원

A Study of Landfill Cover Liners by Freezing/Thawing

Jai-Young Lee

Korea Land Corporation, Land Research Institute

ABSTRACT

The cover liners at municipal and hazardous waste landfill is not emphasized as much as the bottom liners. However, one of the most effective reason of landfill destroy is the cover liner failure. The cover system at municipal and hazardous waste landfills perform the following functions, at minimum: promote surface runoff, impede infiltration, protect settlement in the landfill, and provide a buffer from surface exposure of the waste.

This research was to expand the existing knowledge base of landfill cover liner behavior during period of freeze/thaw. Also, the great Lysimeter was built in the laboratory to provide as much as same condition with the field and three designs were simulated by actual cover materials. The result of simulation indicated the clay was effected by freezing/thawing. The degradation of cover liners in the frost penetration affects the physical, engineering properties of clay. these factors may consider to design and construct of the landfill. This paper provides the description of testing cover liners, experimental results and a discussion of the results of the simulation.

Key word : municipal, hazardous waste landfill, cover, bottom liners, Lysimeter, freeze/thaw, clay , frost penetration

요약문

일반 및 특정폐기물 매립지에서 복토층의 중요성은 매립지의 바닥층 만큼 강조되지는 않는 것 같다. 그러나 실제로 매립지의 파괴 원인중에 가장 커다란 영향을 미치는 것은 복토층 설치의 실패에서 온다고 볼 수 있다. 특히 복토층 기능은 우수를 지표면으로 유출증진하여 매립장 안으로 침투 억제시키며, 폐기물의 노출시 자연환경 위생

에 대하여 완충작용을 하며, 매립지의 침하 및 침강을 억제하는데 있다. 본 연구는 겨울철 동결/융해에 따른 폐기물 매립지 최종복토의 거동을 수행하였으며, 폐기물 매립지에서와 같은 조건을 부여하기 위해 거대한 Lysimeter를 설치하여 실제로 최종복토에 쓰여지는 물질로 세가지 실험을 수행하였다. 실험결과는 동결/융해에 따른 점토층의 변화를 묘사하고 있으며 또한, 매립지에서의 동결깊이에 따른 복토층의 파괴는 점토의 물리적, 공학적인 측면에 영향을 주며 이러한 영향은 매립지 설계시 고려되어야 한다고 본다. 본문은 실험에 사용되어진 복토층의 물질, 복토층의 묘사와 그들의 실험결과에 대한 결과분석 및 결론을 설명하고 있다.

주제어 : 일반 , 특정폐기물 매립지, 복토층 , 바닥층, Lysimeter, 동결/융해, 점토, 동결깊이

1. Introduction

Many researchers have reported on the effect of frost behavior on soils since the early 1920's. However, the literature does not contain much significant information on the specific problem of freezing and thawing in landfill cover systems. Most of the research devoted to cover liners specifically has focused on the effect of freeze/thaw on hydraulic conductivity in soil liners. In addition, most studies have been conducted with small samples, typically of the scale used in triaxial testing in geotechnical laboratories.

In 1929, Taber reported that pressure increases are associated with freezing due to the growth of ice crystals and that excessive heaving is to be explained by the segregation of water as it freezes. As water freezes segregation causes shrinkage cracks below the ground surface if the supply of water is limited or if the soil is very impermeable. Also, more water may become concentrated in the surface soil through ice segregation that is followed by thawing.

Many researchers also have developed mathematical models to deal with a comprehensive analysis of heat and moisture movement. Mathematical models simulating heat and moisture movement in freezing soils have been reported by Dirksen and Miller1), Harlan3), and Guymon and Luthin2). Dirksen and Miller1) presented data dealing with the freezing process in a silty soil (highly frost-susceptible to frost heave).

Mageau and Morgenstern5) presented their observations on moisture migration in frozen soils. Frozen specimens of a clayey silt have been tested under temperature gradients in both closed and open systems. They demonstrated that moisture can be moved through the unfrozen zone (film) under the effect of a temperature gradient. Finally, they concluded the frost heave rate is dominated primarily by the frozen fringe of soil between the warmest ice lens and the frozen/unfrozen interface.

Frost heave is an important consideration for landfill cover liners. When freezing temperatures develop in the soil mass, most of the pore water in the soil is also subject to freezing. There is close correlation between frost heave and ice lenses formation. That is, the amount of total ground surface frost heave has been found to equal the thickness of ice lenses existing in the soil at the heave location (McCarthy4)). However, the cover clay liner is protected by a vegetative soil layer, which is not considered in most small-scale laboratory simulations of the problem. In this investigation, the author utilized a large scale laboratory simulation allowing inclusion of the field depth of the cover systems, layered soil profiles, rainfall simulation, a cold climate, and boundary conditions similar to those encountered in the landfill.

This study was performed to evaluate the effect of the cold weather conditions on the landfill cover system. Three designs were simulated in a large tank. The liner materials were obtained from a land waste disposal site in Southeastern Michigan, approximately 30km from Detroit. These soils are used in the construction of the top and bottom liner of the landfill located in the city of Sumpter.

This paper provides the description of testing cover liners, experimental results, and a discussion of the results of the simulation. The experimental results include rainfall and leakage data, the temperature history and water balance for each design.

2. Design of the Simulated Cover Liner

Three different cover liner configurations were investigated. The three designs are shown in Figures 1-3. Design #1 corresponds to the most simplistic cover system, while design #2 includes barrier protection soil between the topsoil and clay. Of the three designs, only design #3 includes a lateral drainage layer above the clay liner to limit fluid pressures above the clay.

3. Experimental Results

3.1 Rainfall and Leakage Simulation

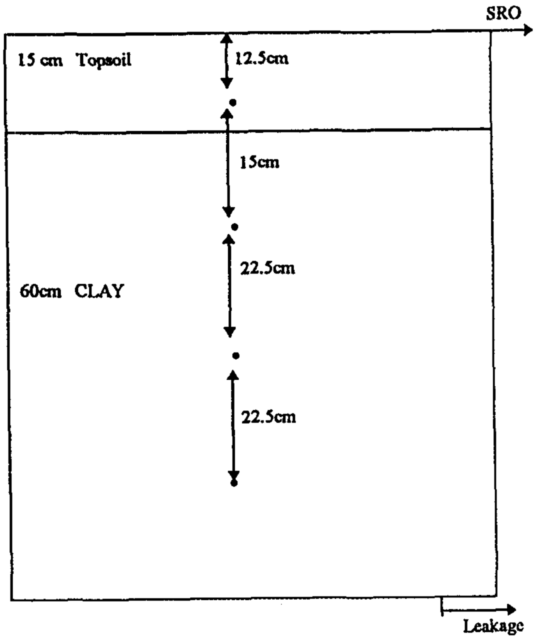

Fig. 1. Design #1 for Cover System

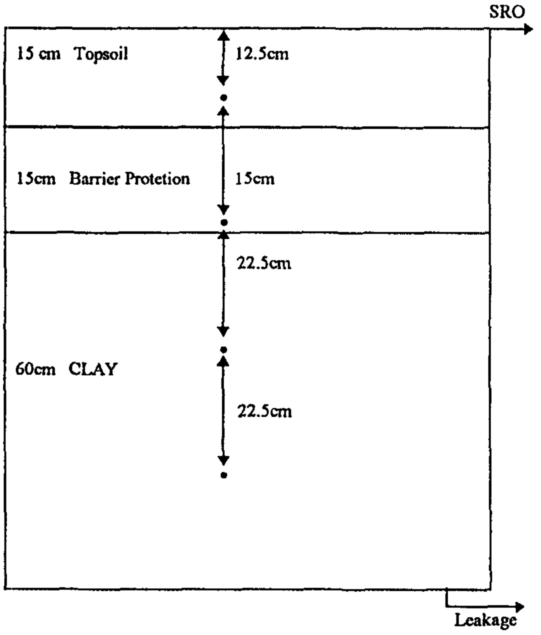

Fig. 2. Design #2 for Cover System

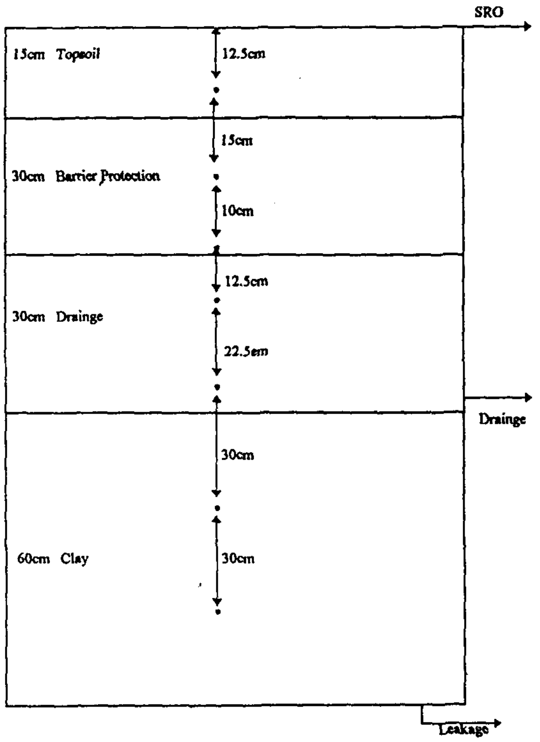

Fig. 3. Design #3 for Cover System

Four rainfall events, separated by freeze/thaw cycles, were simulated for each of the three designs. The rainfall intensity for each event was approximately equivalent to the 100-year 60 minute rainfall of southeastern Michigan.

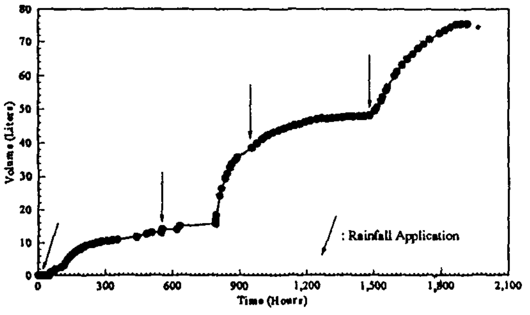

Fig. 4. Leakage for Design #1

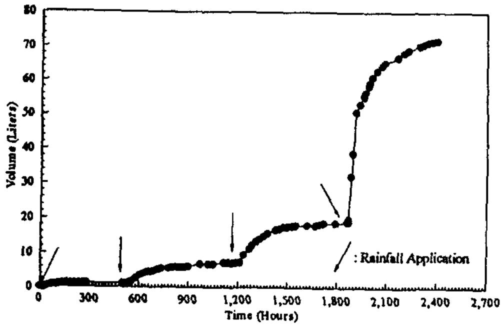

Fig. 5. Leakage for Design #2

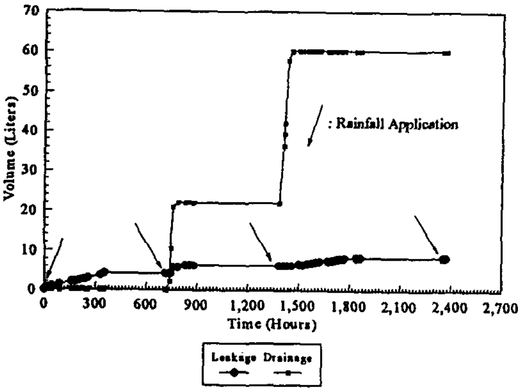

Fig. 6. Leakage and Drainage for Design #3

Figures 4 -6 display the time history of rainfall inputs and leakage outputs for each of the design.

3.2 Temperature History of Each Design

A primary focus of this project was the evaluation of temperature profiles resulting from continuous freezing periods. Thermocouples were located above the simulated cover liner and at several depths within the cover as illustrated earlier in Figures 1-3. Figures 7-9 display the temperature history for each of the three designs. The temperature profile is nearly linear. However, the top-most soils were influenced by the cold air temperature, and so the temperature of top-most soils changed frequently and dramatically, resulting in an unstable top-most soil. A stage before the first freezing in design #1 performed as a test of the refrigeration unit in the tank.

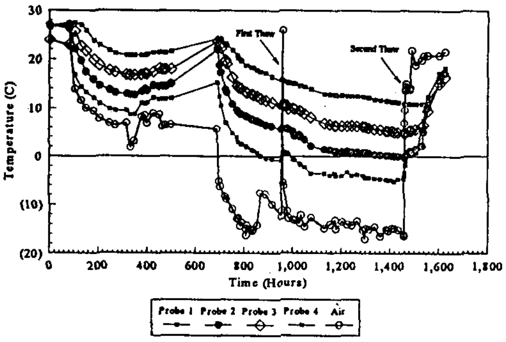

Fig. 7. Temperature History for Design #1

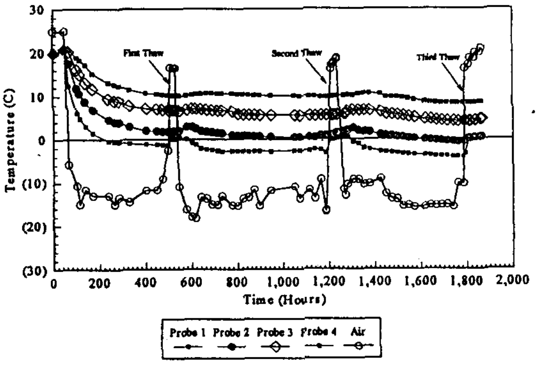

Fig. 8. Temperature History for Design #2

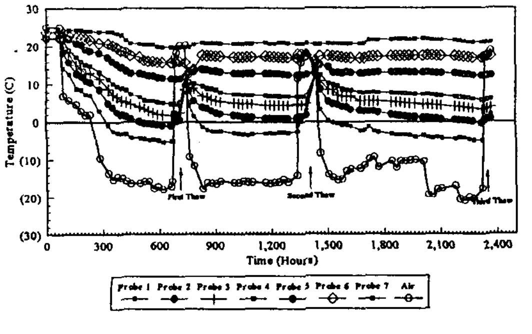

Fig. 9. Temperature History for Design #3

3.3 Moisture Contents

The moisture contents in the compacted clay liner were measured in two places for each lift placed in the tank. Moisture contents were measured before the simulation was started. Moisture contents were evaluated as the clay liner was disassembled after the completion of a simulation. Table 1 shows the moisture content measurements for each design.

Table 1. Comparison between Initial and Final Moisture Contents in the Clay of Each Design

	Design #1	Design #2	Design #3
* Initial Measurement (%)	14.2	14.4	15.2
* Final Measurement (%)	15.8	16.2	15.5

* Values shown represent an average of all measurements for each design.

4. Discussions and Conclusions

The purpose of this investigation was to provide a comparative analysis of three different landfill cover liner designs under freeze/thaw conditions. The primary basis for the comparison was the frost penetration characteristics of the liners. Therefore, the average air temperature maintained for each design was similar.

Table 2 provides a performance-based comparison of the three liner designs. Although the depth of frost penetration was similar for all designs tested, the freezing zone never propagated into the clay of Design #3 because of the additional depth of cover materials used in Design #3. A maximum depth of frost penetration in Design #3 was measured at 32*cm*. One explanation for this that Design #3 was run at the coolest average freezing period temperature, -13℃. It appeared that even had the test been performed for a much greater period of time, the clay would have remained unfrozen, with a steady state condition having been achieved. Certainly the low boundary condition is acting to limit depth of frost penetration.

Several locations of frost heave appeared with surface disruption. The frost heave was measured for each design and found to vary between 3.8*cm*-4.4*cm*.

Designs #1 and #2 were very similar in regards to the leakage performance (% of infiltration that exits system as leakage). However, design #3 had much less leakage. This was clearly attributed to the presence of the 30*cm* drainage layer employed in Design #3. The drainage layer appeared to be very effective in removing potential leakage from the system before it had an opportunity to migrate through the clay. It may also be true that the clay liner of Design #3 was more effective at "holding up" the leakage because the frost had not propagated to the clay in this design.

As shown in Table 1, moisture contents increased from 0.3% to 1.8% at three designs. Design #3 indicated much less moisture content than designs #1 and #2. It may also prove that the drainage layer appeared to be effective in removing potential leakage from the system.

Hence, Design #3 had clearly superior performance to each of the earlier designs. The performance was measured in terms of leakage through the clay barrier, frost penetration of the clay, and frost heaving. However, the depth of frost penetration in Design #2 was very minimal. Considering that the air temperatures simulated were much more severe than those typically encountered in a Michigan winter, it appears that Design #2 would be adequate for frost penetration concerns. Design #3 had superior performance for leakage. Again, however, Design #1 and #2 have only minimal percentages of the incipient rainfall exiting as leakage.

As shown in Table 4.2, the moisture increase of 223.3 liters in design #3 represents the change in moisture throughout the various layers of soil. The excess moisture, 30.0 liters, represents the quantity: (rainfall-surface runoff-leakage-evaporation-moisture increase). It is the moisture that is unaccounted for in the various components of water balance. It is a measure of the error of the experimental techniques. Therefore, the indication is that there is a water

Table 2. Performance Comparison of Three Cover Liner Designs

Characteristic	Design #1	Design #2	Design #3
Avg. air temperature(℃) during the freezing cycle	-11.6	-12.6	-13.0
Depth of frost penetration - Total(*cm*)	29.0	31.0	32.0
Depth of frost penetration - In Clay (*cm*)	13.9	1.2	None
Frost Heave after first freeze/thaw cycle(*cm*)	4.4	3.8	3.8
Water Balance(liter)			
Rainfall	1490.0	1131.7	1234.9
Surface Runoff	1107.5	760.5	904.0
Leakage	75.5	71.4	8.5
Evaporation	26.3	38.5	36.9
Drainage	-	-	62.2
Moisture Increase(liter)	280.7	261.3	223.3
Excess Moisture(liter)	18.7	5.5	30.0
Leakage as% of Infiltration (Rainfall - SRO)	19.7	19.2	2.6

balance error in design #3 of 2.4% (30.0/1234.9). The experimental approach was adopted for investigating the cover liner performance, as analytical models are generally unavailable. For example, the Stefan equation is often referred to for calculation of frost penetration in single-and multi-layer soil systems. However, because it is an analytical technique, it requires significant assumptions be made, that render it much less applicable for the cover liner problem. One such assumption is the absence of a lower boundary condition of forced temperature. Therefore, the only thermodynamic control that enters the problem is air temperature at the surface. For the landfill problem, the temperature at the interface between the cover soils and the waste may be vastly different (typically warmer) than the temperature in the atmosphere. Therefore, one would expect the Stefan formula to overpredict the depth of frost penetration. Stefan's formula predicts a frost penetration of 53*cm* as opposed to the 29*cm* observed experimentally.

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