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The frost penetration with the modified soil in the landfill bottom liner system

Jai-Young Lee* *Department of Environmental Engineering, The University of Seoul 130-74, Korea*
Song Lee *Department of Civil Engineering, The University of Seoul 130-743, Korea*

ABSTRACT: Many researchers have studied on the effect of freeze/thaw phenomena mainly on compacted soil samples of small diameter. Most of the experiments done so far were applied to study those effects on pavement design in civil engineering. The paper relates the freeze/thaw studies performed on large scale equipment to better simulate these effects under the existing field conditions in a landfill. A large scale (1.0 m×1.5 m×2.0 m) laboratory simulates the field depth of the bottom liner systems with the cold climate and it was also introduced many boundary conditions similar to those encountered in the landfill. As a bottom liner materials, the modified soil (mixed stabilizers, clays, cements, and clay minerals) was used instead of the natural clay. From bottom to top of this lysimeter, one can identify two layers: a) bottom liner of 30 cm; b) a stabilizer soil layer of 75 cm. As results of the performed frezee/thaw simulations, it was found out that the depth of frost penetration increased a few centimeters more with 35–40 mm/hr simulated than that performed without simulated rainfall. Then, the frost heave increased a few millimeters. Also, a few cracks appeared, but they were not severe neither significantly opened. The results showed that compacted modified soil is as much as reliable the regual compacted clay liners normally used in landfill construction, submittd to strong winter conditions.

Key words: freeze/thaw, landfill, bottom liner, rainfall, modified soils, depth of frost penetration, cracks

1. INTRODUCTION

Many researchers have studied on the effect of freeze/thaw on soils since the earliest 1920s. However, most those studies were performed on small laboratory samples and their presented lack of information about the freeze/thaw effects. Also, most of the researchers have been focused on the effect of freeze/traw on the hydraulic conductivity in soil layer. Thus, those results would have limited applications into field conditions. This study was performed by using a large scale Lysimeter (1.0 m×1.5 m×2.0 m) which would better simulate the existing field conditions (Fig. 1). In this study, the purpose of using modified soil made from a mixture of cement and stabilizer was the following: 1) to prevent a differential settlement caused by landfill, 2) to ensure the strength of vehicles load and 3) to increase the barrier function of the landfill to prevent the leachate contamination.

In this investigation, the compacted modified soil liners substituted for the compacted clay liners in the landfill bottom liner systems and these conditions were experimented two times in each different condition (Figs. 2 to 4). The liners were also covered with a protective temperature fabric (Fig. 3) and both the protective temperature fabric and Poly Vinyl Chloride (PVC) (Fig. 4) and submitted to same conditions which was possible to observe the effect of them on preventing freezing.

The cycle of the freeze/thaw was determined considering the characteristics of winter conditions in Korea; three day freezing and four day thawing situation.

As results, the depth of frost penetration in the compacted modified soil was 75 cm and there was no freezing area in the rest of two cases. Therefore, we can expect the compacted modified soil covered with the protective temperature fabric and PVC is significantly effective for preventing the frost heave of the modified soil liners.

2. LITERATURE REVIEW

When air temperatures are below freezing, frost penetrates the ground surface, causing the upward migration of soil moisture. All of the factors causing moisture migration through a frozen soil are not fully understood, but various theories attribute movement to a thermal gradient where capillary flow is in the direction from higher to lower temperatures, and to osmotic flow. Ferguson, et al. (1964) reported that water moves to a frozen zone when water in the unfrozen zone is held at low tension. Water movement to the frozen zone does not occur when the soil-water tension is greater than about 5 atm. The amount of movement may depend on the available soil/water, the temperatures of the frozen zone, the duration of freezing and the physical properties of the soil. The freezing effects on soil are primarily dependent on the soil's chemical and physical properties and moisture conditions as well as on the freezing rate.

Some reports (Logsdail and Webber, 1959; Sillanpaa, 1961; Bisal and Nielsen, 1964; Konrad, 1989) suggested that the soil type and degree of aggregation may modify the effects of freeze/thaw. According to these reports, the freeze/thaw can cause significant changes of the hydraulic

*Corresponding author: leejy@uos.ac.kr

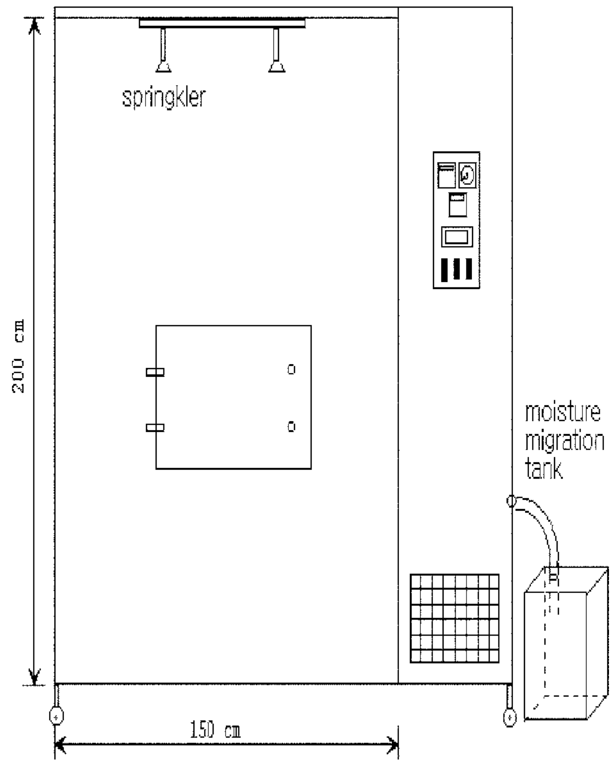

Fig. 1. The front view of Lysimeter.

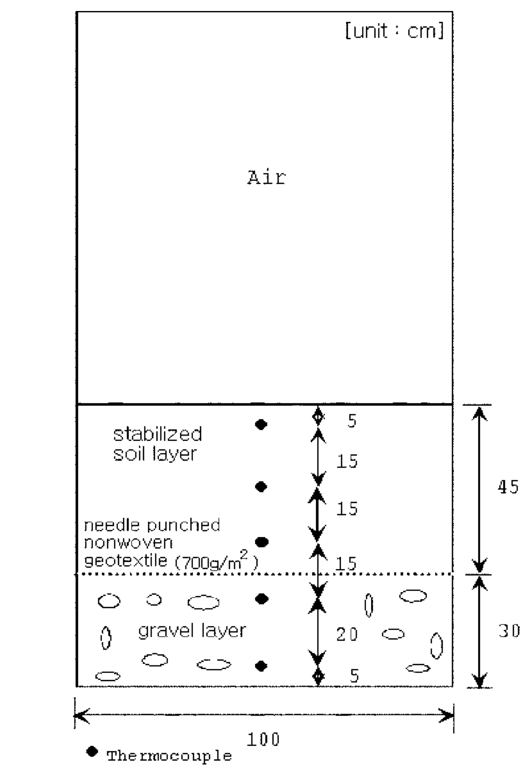

Fig. 2. The cross section of Design #1 and Design #2.

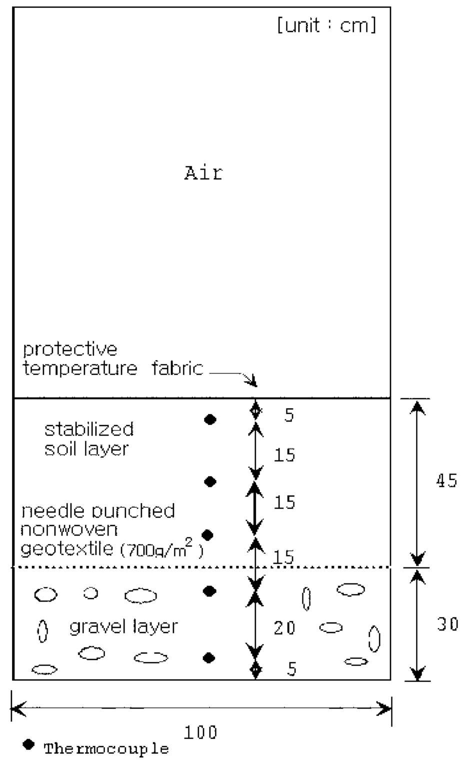

Fig. 3. The cross section of Design #3.

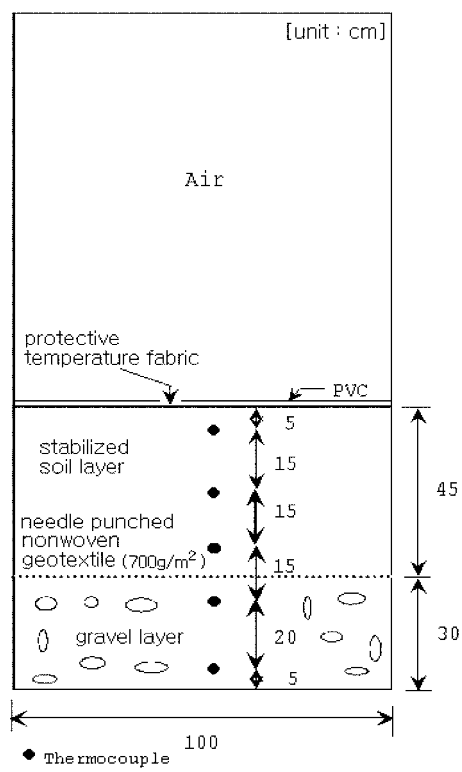

Fig. 4. The cross section of Design #4.

conductivity in soil. Furthermore, there are several recent reports documenting the influence of freeze/thaw on the performance of clay liners (Chamberlain and Ayorinde, 1991; Kim and Daniel, 1992; Benson and Othman, 1993).

In these experiments, the authors observed that freeze/thaw had an effect of increasing the permeability of compacted clay by a factor of at least two orders of magnitude.

Researchers 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 Miller (1966), Harlan (1973), Guymon and Luthin (1974). Dirksen and Miller (1966) presented data dealing with the freezing process in a silty soil (highly frost-susceptible to frost heave).

Mageau and Morgenstern (1979) 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 system. 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.

Miller and Lee (1999) showed that the response of landfill clay liners to extended periods of freezing in a large Lysimeter. They simulated three different landfill over liner designs. As the results, the frost heave was found to vary between 3.8 and 4.3 cm. Also, the depth of frost penetration was 29.2–31.7 cm.

3. EXPERIMENT

3.1. Preparation of the Modified Soil

The mixed soil in the modified soil layers was classified as a CL (inorganic clay and low plasticity) group by the Unified Soil Classification System (USCS); the specific gravity was 2.67, the moisture content was 23.2%, the percentage of soil passing through the No. 200 sieve was 93.6%, the liquid limit was 22.8% and the plasticity index was 9.3%. The mixture ratio of specimen was 90 kg of cement and 30 kg of stabilizer.

3.2. Equipment

In this study, a large-scale Lysimeter (1.0 m×1.5 m×2.0 m) was used to observe the effect of the layer on the freeze/thaw by −20 average temperature. The inside of Lysimeter was made of the aluminum steel to prevent corrosion from containments of uncertain materials. The Lysimeter was insulated to protect the heating loss from outside temperature (Fig. 1).

To simulate the modified soil layers in Lysimeter, the author layed as following; first of all, the 30–45 mm gravel was laid out 30 cm of the height and a piece of the needle punched nonwoven geotextile was placed on the top of gravel layer to separate the gravel from the modified soil. Finally, the modified soil was compacted on the needle punched nonwoven geotextile. 45 cm of the modified soil layer was compacted by optimum moisture content which was maintained as a field condition using a steel plate (31 cm×31 cm, weight: 26.2 kg).

The inside of the design system was sealed with bentonite to prevent the rainfall from leaking through the wall of Lysimeter. After compaction of the layers, the strength of compression was maintained over 5 kg/cm^2 with a portable cone device to apply to the field. Two thermocouples in the gravels stones and three thermocouples in the bottom layers were inserted to observe the depth of frost penetration. The temperature history was recorded automatically every an hour.

The temperature was measured in five different places: 5 cm, 25 cm, 40 cm, 55 cm, and 70 cm, from the bottom of Lysimeter. Also two thermocouples were installed above the modified soil layer for a cool air temperature. A springkler was installed on the ceiling to springkle about 35–40 mm/hr of rainfall intensity.

3.3. Method and Results

This study focuses on the effect of the freeze/thaw through Lysimeter under the severe winter condition. The sand cone method was performed to determine the density of the modified soil. Also a standard proctor test was performed to compare the maximum dry unit weight with the optimum moisture content.

The change of temperature in the layers was automatically recorded by the thermocouples and thermometer, so that the depth of frost penetration could be observed.

The change of the moisture content was measured before and after the freezing/thawing. Before and after each cycle, all changes were taken a picture: the surface cracking of the modified soil, the frost heave, and the condition of the bottom.

To minimize the depth of frost penetration caused by the temperature change of the modified soil under the suspension of construction and prevent the cracking due to the

Table 1. The property of modified soil in the laboratory.

Type	Dry unit weight (g/cm^3)		Optimum moisture content (%)	Relative compaction (%)	Proctor test	Compaction test specification
	γ_d	$\gamma_{d\,max}$				
Modified Soil layer	1.567	1.673	22.0	93.4	Method A	ASTM D-698

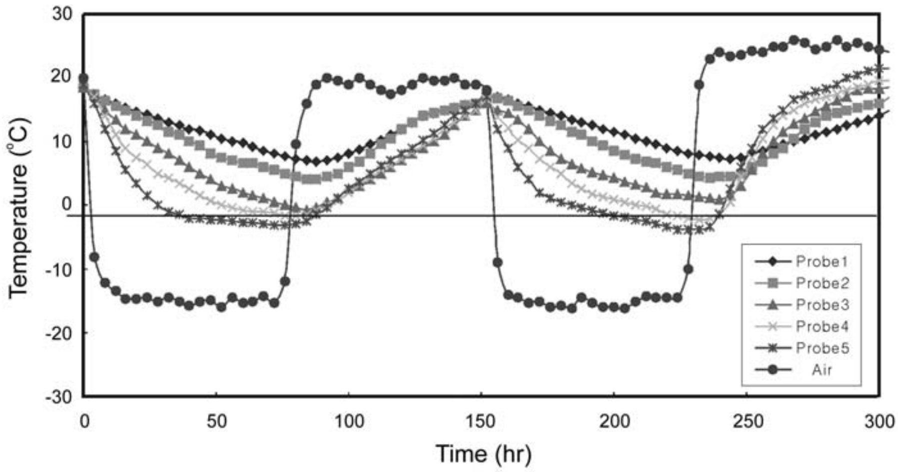

Fig. 5. The temperature history of Design #1 (modified soil layer).

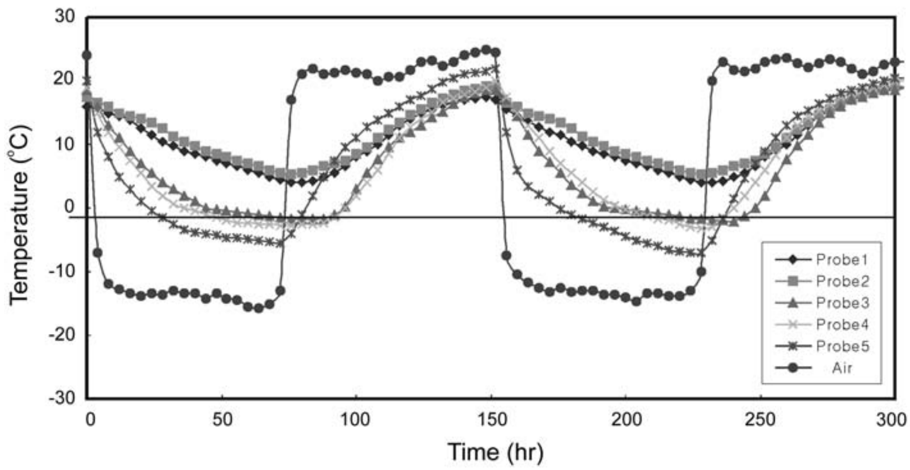

Fig. 6. The temperature history of Design #2 (modified soil layer).

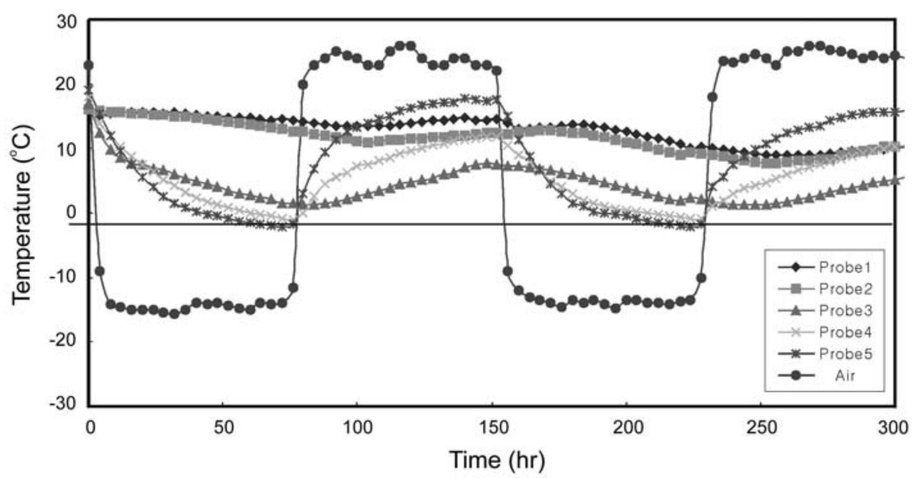

Fig. 7. The temperature history of Design #3 (modified soil layer+protective temperature fabric).

frost heave or the dry shrinkage, the protective fabric covered the modified soil layer and PVC was added on the protective fabric(Design #4) to compare each depth of frost penetration.

The artificial rainfall was springkled on the layers with the rainfall intensity, 35–40 mm/hr.

4. CONCLUSIONS AND DISCUSSIONS

The Design #1 and Design #2 with the modified soil showed 36–40 cm of the frost penetration through the whole layer. However, the modified soil with the protective fabric and PVC(Design #3 and Design #4) measured 15–

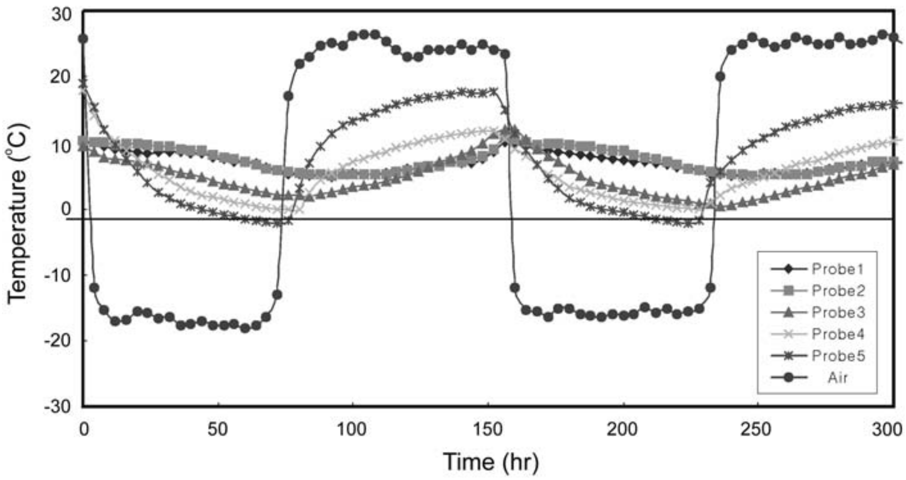

Fig. 8. The temperature history of Design #4 (modified soil layer +protective temperature fabric+PVC).

Table 2. The result of the freeze/thaw.

	Modified soil layer (MSL)				MSL and Protective fabric		MSL+PVC+Protective fabric	
	Design 1		Design 2*		Design 3		Design 4*	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2
Cool air temperature (°C)	−17	−17	−17	−17	−17	−17	−17	−17
Frost penetration (cm)	38	36	40	40	22	22	15	15
Crack view L(cm), W(mm)	×	×	L : 1−2 W : 1	L : 2−3 W : 1	L : 3−4 W : 12	L : 3−4 W: 12	L : 3−4 W: 12	L : 3−4 W: 12
Frost heave (mm)	×	×	2−3	2−3	3−4	3−4	4−5	4−5

*: artificial rainfall (Intensity: 35−40 mm/hr)
L: length
W: width

22 cm of the frost penetration because of the effect of keeping warm. Peculiarly, despite the rainfall condition, the frost penetration has penetrated shallowly through the whole modified soil layer. These facts indicate that the protective fabric and PVC reduce the moisture migration significantly.

Except for the Design #1, all the others showed the cracking (length: 2–4 cm, width: 1–2 mm) because the change of moisture content due to the freeze/thaw phenomena and the destruction of the modified soil morphology, which has occurred. The growth of ice lenses due to the migration of moisture causes the surface cracking of the modified soil layer, so that the volume increases and then the frost heave occurs. The modified soil layer has little problem of the cracking or the frost heave and the degree of the cracking is less than that of the compacted clay layer (Lee, 1994). Therefore, it can be surmised that the compacted modified soil is as much as the compacted clay liners, under winter conditions to prevent freeze/thaw effects. Also, whenever we maintain the compacted modified soil in winter, to minimize the destruction of the modified soil liner, that should be kept warm.

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