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겨울철 조건하의 폐기물매립지 점토층의 수분이동

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The Moisture Migration of Compacted Clay Liners in the Landfill on Winter Condition

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Abstract

The experimental investigations considered in this paper are similar in many respects to those of Lee[1], with some key differences. First, there is no layering of the soils in a heterogeneous liner. The only soil investigated is the clay component of the cover liner. This ensures that the clay is exposed to freezing and that frost propagation in the clay can be investigated separate from other processes. Second, a closed system approach to the simulation was adopted. According to Jones[2], closed-system freezing occurs when there is no source of water available beyond that originally present in the soil voids. Freezing under such conditions results in very thin or non-existent ice lenses.

One of the objectives of the experiments described in this paper was the moisture migration and the changing of moisture contents of the compacted clay liner in landfill. The closed-system was used to limit the variables in the experimental simulation to make these calculations more direct, although the final results could be applied to an open system also.

As a result, the moisture content decreased about 45% - 46% after two freeze/thaw cycles.

1. Introduction

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.[3] 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.

In 1966, Hoekstra[4)] reported on moisture movement in soils under temperature gradients in which the cold-side, below freezing, temperature was measured by g-ray. Hoekstra observed: 1) the ice phases were greatly enhanced by the amount of moisture transfer under temperature gradients; 2) the distribution of moisture content did not reach equilibrium, and the water content in the frozen soil changed continuously; 3) moisture movement in the frozen soil takes place under temperature gradients through the films of unfrozen water. Since the thickness of the unfrozen films decreases with temperature, the rate of moisture transport also decreases rapidly with decreasing temperature below 0 .

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[5)], Harlan[6)], Guymon and Luthin[7)]. Dirksen and Miller[5)] presented data dealing with the freezing process in a silty soil (highly frost-susceptible to frost heave).

Mageau and Morgenstern[8)] 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.

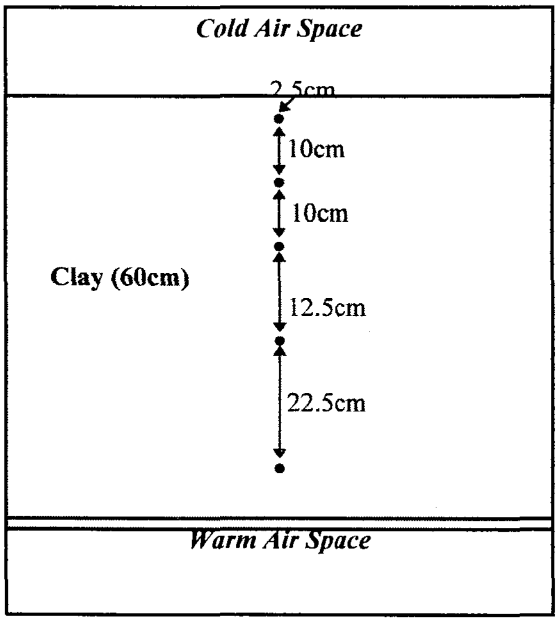
The main components of the experimental results provided in this paper include: temperature propagation, temperature gradient, moisture content fluctations.

2. Materials and Methodology

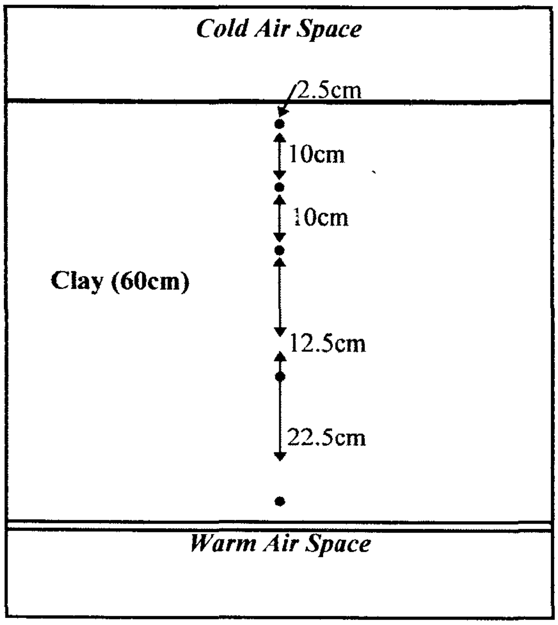
The clay liner material used in the experiments described in this paper is identical to that discussed in Lee[1)]. The simulations were completed using basically the same sequence as described in Lee[1)]. The primary difference between the present simulations and those described earlier is (1) the use of a closed-system and (2) the absence of cover soils and geosyntetics above the clay liner material. A primary objective of these simulations is determination of the thermal conductivity of the compacted clay. Such determinations are simplified using the two modifications adopted.

3. Design of the Compacted Clay Liner

The laboratory set-up illustrated in Figure 1. and 2. were subjected to an investigation of frost penetration. The investigation was repeated twice in order to check the validity of the results. Two freeze/thaw cycles were completed in each investigation. The experiment concluded with the second cycle since it was expected that the majority of frost damage would have been completed within the first two cycles. Numerous investigators (Chamberlain and Ayorinde[9)] , Zimmie et al.[10)]; Kim and Daniel[11)]; Othman[12)]), have found that most of the freeze/thaw damage in soils occurs during the first two freeze/thaw cycles.



Note: * = Thermocouple
Figure 1. Design for The Compacted Clay Liner



Note: * = Thermocouple
Figure 2. Design for The Compacted Clay Liner

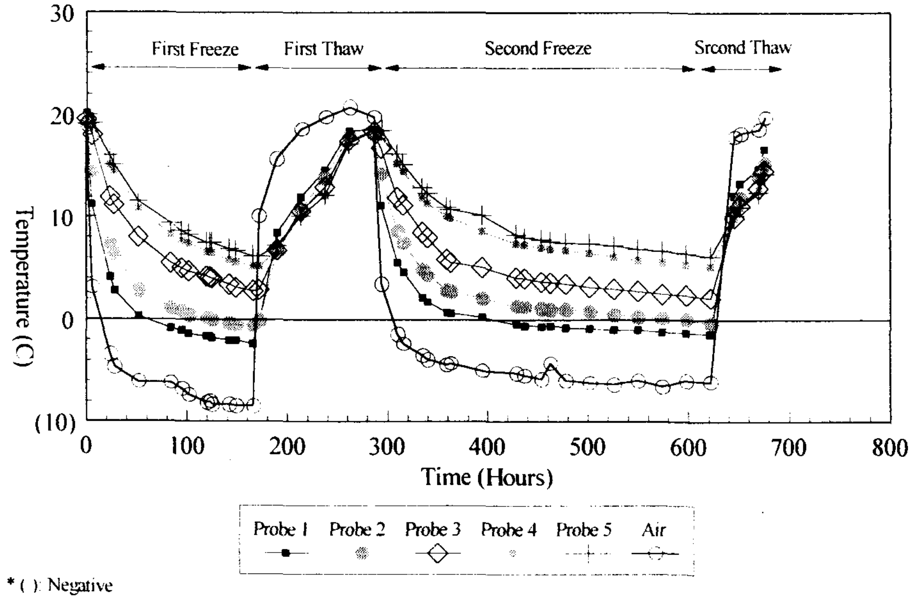
4. Experimental Results

Because this simulation was completed as a closed-system, there was no rainfall simulation and no leakage outputs to report on. However, moisture that evaporates from the soil condenses on the coils of the refrigeration unit.

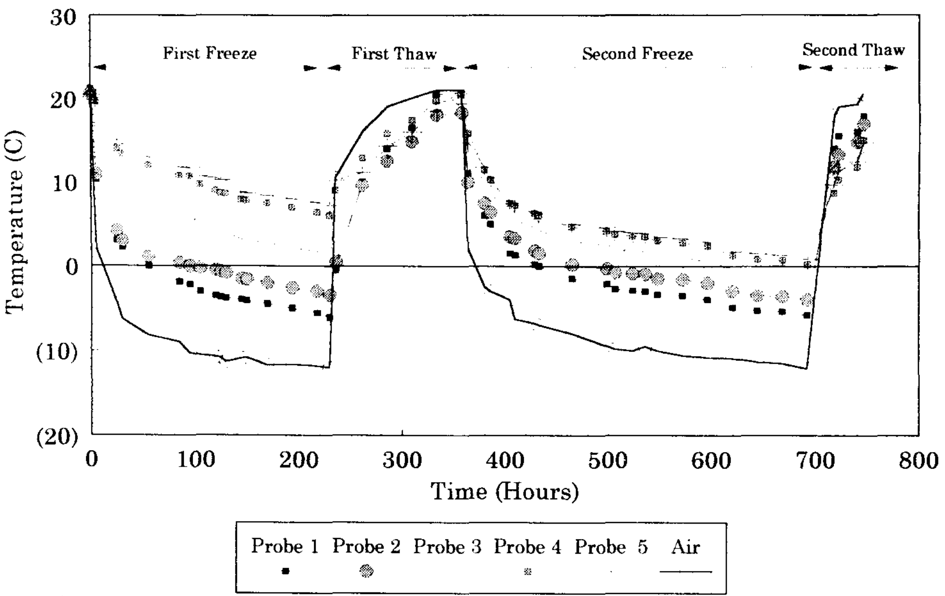
The temperature gradient shows almost a linear slope at selected times (Figure 3). However, the top-most soils were influenced by the cold air temperature, and so the temperature of top-most soils changed frequently and dramatically, resulting in an unstable top-most soil.

In order to evaluate the fluctuation of moisture contents, and assess moisture migration moisture contents were measured at critical stages of the experimental process. The initial moisture content was measured at two locations for each lift of the liner. A second measurement of moisture content in the cover lift was completed after the first freeze/thaw cycle was completed. The final moisture content measurements were taken following the second freeze/thaw cycle.

The initial moisture content was calculated from an average of the measurements taken from the top lift of the liner to allow comparison with second and final measurement. The moisture content decreased from 13.4% to 7.4% for simulation #1 and from 12.6% to 6.9% for simulation #2 after two freeze/thaw cycles.



a) Simulation #1



* ( ): Negative

b) Simulation #2

Figure 3. Temperature History for Each Liner

5. Discussions and Conclusions

According to the findings of several investigators (Wong and Haug[13]; Chamberlain and Ayorinde[4]; Zimmie et al. [5]; Kim and Daniel[6]; Othman[7]), most of the freeze/thaw damage in soils occurs during the first two freeze/thaw cycles. Hence, the observed decrease in moisture contents during freeze/thaw may be the cause of the change in soil structure, hydraulic conductivity and the propagation of cracks in frozen soil.

Moisture contents decreased during each freeze/thaw cycle. This suggests that the shrinkage cracks observed in this simulation were caused by the loss of water on freezing. The moisture content decreased about 45% - 46% after two freeze/thaw cycles. This compares well with Dirksen and Miller[9] who observed a moisture content decrease of approximately 50% at the end of closed-system freezing experiments.

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