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Effect of leachate and freeze-thaw on the hydraulic conductivity of clayey barriers

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ABSTRACT: The effect of freeze-thaw cycles on the hydraulic conductivity (HC) of clayey barriers in water retaining structures and municipal solid waste landfills is a key issue in designing barrier systems in those structures. The effect of freeze-thaw cycles on the hydraulic conductivity of compacted clayey soil from Nazlou Region of Urmia City and a geosynthetic clay liner (GCL), and the effect of effective stress on the hydraulic conductivity change of clayey soil in freeze-thaw cycles were investigated for water and leachate. The flexible-wall triaxial hydraulic conductivity apparatus was used to measure the HC of specimens subjected to freeze-thaw. During the freezing process, ice lenses grow in the soil sample and when the ice lenses melt, a network of cracks is left and thus, the HC increases. Increasing the effective stress reduces the increased hydraulic conductivity due to freeze-thaw. The results show that on the contrary to compacted clayey soil, the application of freeze-thaw cycles do not significantly affect the HC of GCL. Interaction of clayey soil with leachate leads to a decrease in thickness of the diffuse double layer and thus, the hydraulic conductivity of clayey soil increases. Increase in hydraulic conductivity of clayey soil and GCL subjected to freeze-thaw and permeated with leachate is lower than that for water.

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1- Introduction

Compacted clayey soils and geosynthetic clay liners are often used as hydraulic barriers. In cold regions, compacted clay and geosynthetic clay liner barriers may be subjected to cycles of freeze-thaw during the winter periods [1]. Since their primary purpose is to minimize flow, low hydraulic conductivity is of paramount importance. Hence, the effect of freeze-thaw cycles on the hydraulic conductivity of compacted clayey soils and geosynthetic clay liners in water retaining structures and municipal solid waste landfills is a key issue in designing barrier systems in those structures [2].

Several investigators have conducted studies to evaluate the effect of freeze-thaw on the hydraulic conductivity of compacted clayey soil. The findings of these studies are summarized by Othman [3]. The studies involved 14 different clayey soils. The data show that increases in hydraulic conductivity as large as 1400-fold can occur as a result of freeze-thaw. Hewitt and Daniel [4] reported that the hydraulic conductivity of a GCL for water did not change after one to three freeze-thaw cycles.

In this study, the effect of freeze-thaw cycles on the hydraulic conductivity of a compacted clayey soil of Nazlou Region of Urmia City, and a geosynthetic clay liner permeated with water and leachate, and the effect of effective stress on the hydraulic conductivity change of clayey soil in freeze-thaw cycles was investigated.

2- Methodology

Compacted clay from Nazlou region of Urmia City and thermally treated needle-punched GCL with mass per unit area of 5500 g/m^2 were used in this study. Figure 1 shows the GCL used in this study. The clayey soil properties are summarized in Table 1 and the result of the XRD test on clayey soil is presented in Table 2. Soil specimens compacted

Fig. 1. GCL sample used in this study

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Table 1. Characteristics of soils used in this study

Soil type	Liquid limit (%)	Plasticity index (%)	Optimum water content (%)	Maximum dry density (kg/m^3)
CL	29	14	12	1830

Table 2. Result of XRD test on clayey soil

component	SiO_2	$CaCO_3$	Na,Ca	Clay Mineral	K
Percentage	37	24	19	13	7

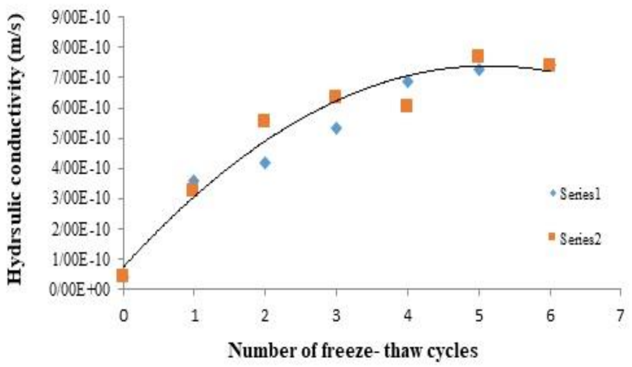

Fig. 2. Hydraulic conductivity versus number of freeze-thaw cycles for clay specimens permeated with water

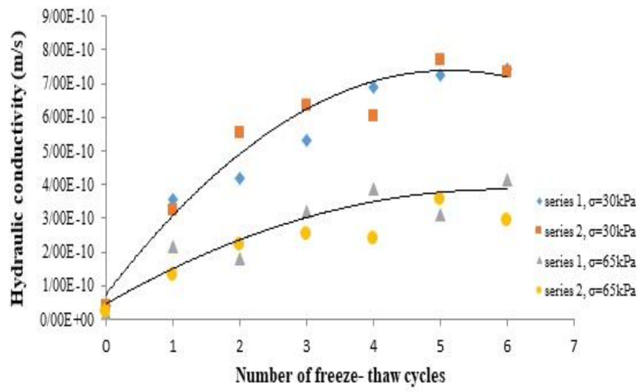

Fig. 3. Hydraulic conductivity versus the number of freeze-thaw cycles for clay specimens for two effective stresses

at water contents about 3% wet of optimum water content using standard proctor compaction. The soil specimens had a diameter of 70 mm and a height of 50 mm and the GCLs had a diameter of 70 mm.

3- Results and Discussion

3- 1- Effect of number of freeze-thaw cycles on the hydraulic conductivity

The changes of hydraulic conductivity of compacted clayey soil sample are plotted versus the number of freeze-thaw cycles in Figure 2. Figure 2 shows that the hydraulic conductivity of the compacted clayey sample increased about one order of magnitude after one cycle of freeze-thaw. The hydraulic conductivity increased as the number of freeze-thaw cycles increased but ceased to increase after about three cycles and remained constant after 5 cycles.

3- 2- Effect of effective stress on the hydraulic conductivity change of compacted clay

In Figure 3, the hydraulic conductivity of clay specimens was plotted versus the number of freeze-thaw cycles for two effective stresses of 30 kPa and 65 kPa. Figure 3 shows that the hydraulic conductivity of specimens subjected to freeze-thaw cycles with effective stress of 65 kPa is less than the hydraulic conductivity of the specimens with effective stress of 30 kPa.

3- 3- 3.3 Effect of number of freeze-thaw cycles on the hydraulic conductivity of GCLs

GCL sample used in this study, subjected to 0, 1, 3, 5, 8 and 12 freeze-thaw cycles. For the GCL specimen not subjected to freeze-thaw, the hydraulic conductivity of 2×10-11 m/s was obtained and for the specimen that was subjected to 12 freeze-thaw cycles, the hydraulic conductivity of 2.57×10-11 m/s was obtained. Thus, there was a small increase (about 35%) in the hydraulic conductivity of the GCL specimen subjected to 12 freeze-thaw cycles relative to the GCL specimen with zero freeze-thaw cycles. The results show that on the contrary to compacted clayey soil, the application of freeze-thaw cycles do not significantly affect the hydraulic conductivity of GCL.

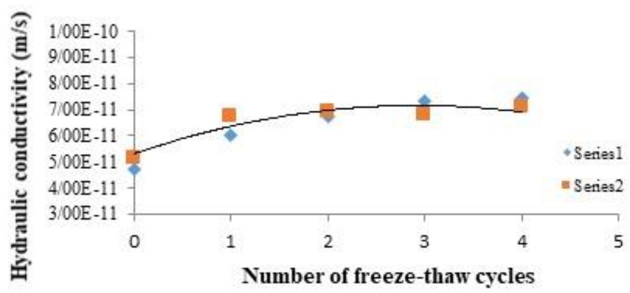

Fig. 4. Hydraulic conductivity versus the number of freeze-thaw cycles for clay specimens permeated with leachate

3- 4- Effect of number of freeze-thaw cycles on the hydraulic conductivity of compacted clayey soil permeated with leachate

After saturation with leachate, clay samples were subjected to freeze-thaw cycles and permeated with leachate. The changes of hydraulic conductivity of compacted clayey soil sample are plotted versus the number of freeze-thaw cycles in Figure 4. As shown in Figure 4, there was a small increase (about 50%) in the hydraulic conductivity of the clay specimen subjected to 3 freeze-thaw cycles relative to the clay specimen with zero freeze-thaw cycles. Thus the effect of freeze-thaw cycles on the clay samples that permeated with leachate is less than that of permeated with water.

3- 5- Effect of number of freeze-thaw cycles on the hydraulic conductivity of GCLs permeated with leachate

After saturation with leachate, GCL samples were subjected to 0, 1, 3, 5 and 8 freeze-thaw cycles. There was a small increase (about 10%) in the hydraulic conductivity of the GCL specimen subjected to 8 freeze-thaw cycles relative to the GCL specimen with zero freeze-thaw cycles.

4- Conclusions

The effect of freeze-thaw cycles on the hydraulic conductivity of compacted clay and geosynthetic clay liner (GCL), permeated with water and leachate, and the effect of effective stress on the hydraulic conductivity change of clayey soil in freeze-thaw cycles were investigated. Results are summarized as follows:

The hydraulic conductivity of compacted clay samples increased about one order of magnitude after one cycle of freeze-thaw. The hydraulic conductivity increased as the number of freeze-thaw cycles increased, but ceased to increase after about three cycles and remained constant after 5 cycles. The hydraulic conductivity of clay specimens that were subjected to freeze-thaw cycles with higher effective stress is less than the hydraulic conductivity of the specimens with lesser effective stress. There was a small increase (about 35%) in the hydraulic conductivity of the GCL specimen subjected to 12 freeze-thaw cycles relative to the GCL specimen with zero freeze-thaw cycles. There was a small increase (about 50%) in the hydraulic conductivity of the clay specimen subjected to 3 freeze-thaw cycles relative to the clay specimen with zero freeze-thaw cycles. There was a small increase (about 10%) in the hydraulic conductivity of the GCL specimen subjected to 8 freeze-thaw cycles relative to the GCL specimen with zero freeze-thaw cycles.

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