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Effect of Temperature on the Permeability and Time-Dependent Change in Thermal Volume of Bentonite Clay During the Heating-Cooling Cycle

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Abstract : The thermal effect on soil properties induces significant variations in hydraulic conductivity, which is attributable to temperature-dependent transitions in soil properties. With the elevation of temperature, there can be a notable increase in intrinsic permeability due to the degeneration of bound water molecules into a free state facilitated by thermal energy input. Conversely, thermal consolidation may cause a reduction in intrinsic permeability as soil particles undergo densification. This thermal response of soil permeability exhibits pronounced heterogeneity across different soil types. Furthermore, this temperature-induced disruption of the bound water within clay matrices can enhance the mineral-to-mineral contact, initiating irreversible deformation within the clay structure. This indicates that when soil undergoes heating-cooling cycles, plastic strain can develop, which needs to be investigated for every soil type to understand the thermo-hydro mechanical behavior of clay properly. This research aims to study the effect of the heating-cooling cycle on the intrinsic permeability and time-dependent evaluation of thermal volume change of sodium Bentonite clay. A temperature-controlled triaxial permeameter cell is used in this study. The selected temperature is 20° C, 40° C, 40° C and 80° C. The hydraulic conductivity of Bentonite clay under 100 kPa confining stresses was measured. Hydraulic conductivity analysis was performed on a saturated sample for a void ratio e = 0.9, corresponding to a dry density of 1.2 Mg/m3. Different hydraulic gradients were applied between the top and bottom of the sample to obtain a measurable flow through the sample. The hydraulic gradient used for the experiment was 4000. The diameter and thickness of the sample are 101. 6 mm, and 25.4 mm, respectively. Both for heating and cooling, the hydraulic conductivity at each temperature is measured after the flow reaches the steady state condition to make sure the volume change due to thermal loading is stabilized. Thus, soil specimens were kept at a constant temperature during both the heating and cooling phases for at least 10-18 days to facilitate the equilibration of hydraulic transients. To assess the influence of temperature-induced volume changes of Bentonite clay, the evaluation of void ratio change during this time period has been monitored. It is observed that the intrinsic permeability increases by 30-40% during the heating cycle. The permeability during the cooling cycle is 10-12% lower compared to the permeability observed during the heating cycle at a particular temperature. This reduction in permeability implies a change in soil fabric due to the thermal effect. An initial increase followed by a rapid decrease in void ratio was observed, representing the occurrence of possible osmotic swelling phenomena followed by thermal consolidation. It has been observed that after a complete heating-cooling cycle, there is a significant change in the void ratio compared to the initial void ratio of the sample. The results obtained suggest that Bentonite clay's microstructure can change subject to a complete heating-cooling process, which regulates macro behavior such as the permeability of Bentonite clay.

Keywords : bentonite, permeability, temperature, thermal volume change
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