Thermal Stabilization of Soft Bangkok Clay

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ABSTRACT

The presence of a thick deposit of soft clay in Thailand causes many problems for construction engineering. One of the techniques that could be used to improve the soft clay characters is thermal stabilization. The aim of this study is to investigate experimentally the thermo-hydro-mechanical behavior of the soft Bangkok clay up to 90°C. A modified oedometer and triaxial test apparatus which can handle temperature up to 100°C have been used in this study. In the range of temperatures investigated, soft Bangkok clay shows temperature induced volume changes that depend mainly on the stress history, stiffening, and higher hydraulic permeability as the temperature increases as well as apparent overconsolidation state after subjecting the normally consolidated specimen to the heating/cooling cycle. To our knowledge, this is the first study to investigate the effect of temperature on the engineering properties of soft Bangkok clay.

Temperature Induced Volumetric Strain

The temperature induced volumetric strain of soft Bangkok clay specimens is indicated in Fig. 1. The specimens were consolidated at the vertical stress of 200 kPa in oedometer condition and unloaded to different stress history (OCR=1, 2, 4, 8) before subjecting to the drained heating/cooling cycle of 25 °C to 90 °C to 25°C. In terms of volumetric strains, the normally consolidated clays contracted irreversibly and non-linearly upon heating while the highly overconsolidated specimens showed reversible expansion. The dependency of the thermally induced volume change on the stress history at constant elevated temperature is demonstrated in Fig. 2 for the specimens that had the preconsolidation pressure of 100 kPa. As the OCR value increased, the magnitude of the contraction in the volumetric strain decreased and then gradually converted to the expansion beyond a certain OCR value. More details about the modified oedometer apparatus and the testing procedure can be found in Abuel-Naga et al. (2005).

Temperature Induced Overconsolidation State

The temperature induced overconsolidation behavior of soft Bangkok clay specimens consolidated under 100 kPa after being subjected to the drained heating/cooling cycle of 25 to 90 to 25°C is shown in Fig. 3. The results show that subjecting normally consolidated specimen to heating/cooling cycle induces an apparent overconsolidation state; consequently, further loading under elastic stiffness condition will be required to reach again the yielding mode.

Figure 4 shows the temperature induced overconsolidation state of the normally consolidated specimens at different vertical stress levels of 100, 200, and 300 and different heating/cooling cycles of 25 to 50 to 25°C, 25 to 70 to 25°C, and 25 to 90 to 25°C, where the preconsolidation pressure after the heating cooling/cycle (p_cT) was normalized for the room temperature preconsolidation pressure p_c (T_o). The test results indicate that the thermally induced overconsolidation behavior is stress level independent.

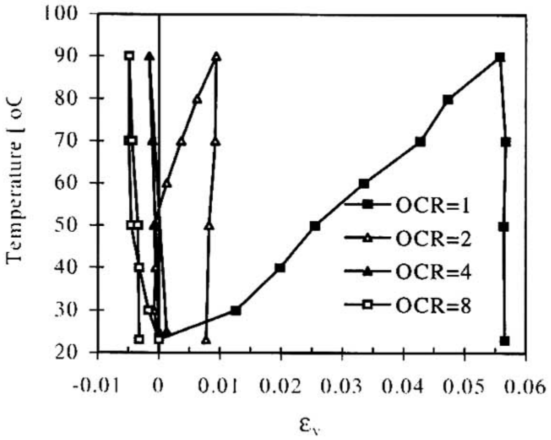

Figure. 1. Soft Bangkok clay temperature volumetric strain (p_c = 200 kPa)

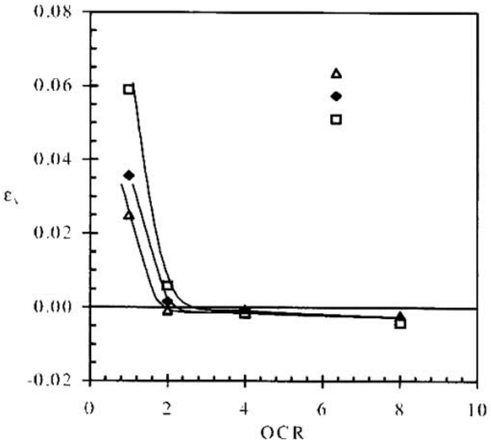

Figure. 2. Effect of OCR values on the temperature induced volumetric strain of soft Bangkok clay

Effect of Temperature on Hydraulic Permeability

The result of the constant head flexible permeameter test on the undisturbed soft Bangkok clay specimens at different temperatures and consolidation pressures was plotted in the e-log (k) plane as shown in Fig. 5, where e is the void ratio and k is the hydraulic permeability. The results indicate that the hydraulic permeability increases as the soil temperature increases.

The effect of temperature on the hydraulic permeability can be attributed mainly to the effect of temperature on the soil water viscosity. Therefore, at constant soil void ratio, the ratio between the hydraulic permeability at the tested temperature k (T) and at room temperature k (T_0) can be estimated using the following equation:

$$\frac{k(T)}{k(T_o)} = \frac{\mu(T_o)\gamma_w(T)}{\mu(T)\gamma_w(T_o)}$$

where m(T) and m(T_0) are the pore water viscosity at the tested and room temperature, respectively, and g_w(T) and g_w(T_0) are the pore water unit weight at the tested and room temperature, respectively. Figure 6 shows a comparison between the measured and the predicted temperature induced increase in the hydraulic permeability of soft Bangkok clay normalized for the hydraulic conductivity value at room temperature (25°C). More details about the utilized equipment and the experimental procedures can be found in Bergado et al. (2004a).

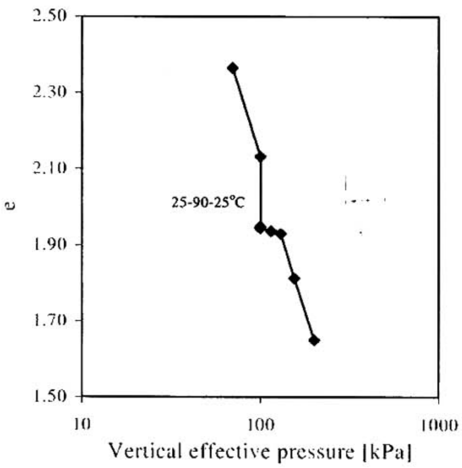

Figure. 3. Temperature induced overconsolidation state of normally consolidated soft Bangkok clay

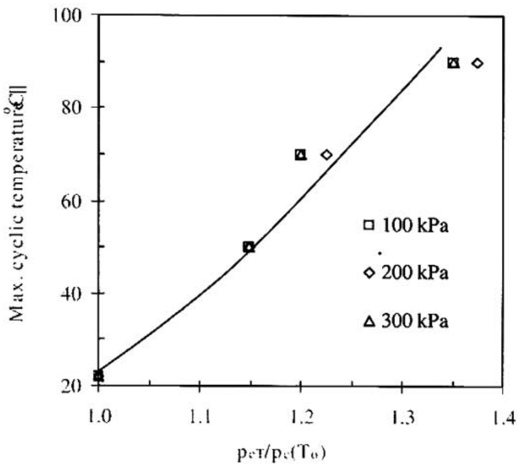

Figure. 4. Temperature induced overconsolidated state of normally consolidated soft Bangkok clay at different stress levels

Effect of Temperature on the Undrained Shear Strength

The experimental program was undertaken to study the effect of temperature on the shear stress behavior of the normally consolidated specimens at different temperature levels and histories. The preconsolidation pressure, p_{cons}, of the specimens sheared under undrained condition at different temperatures of 25, 70, and 90°C was 300 kPa while that of the specimens sheared at different temperature histories of 25 to 70 to 25°C and 25 to 90 to 25°C was 200 kPa. To make a comparison, the normalized deviatoric stress q/p_{cons} and normalized excess pore water pressure $Du/_{pcons}$, for both tests were plotted against e_a as shown in Fig. 7, where q is the deviatoric stress, e_a is the axial strain, and Du is the excess pore pressure excluding the pore pressure induced by the increase in the total mean effective stress.

The test results show that the deviatoric shear strength increases as the soil temperature increases even after being subjected to the heating/cooling cycle. Consequently, for the normally consolidated specimens the temperature causes a permanent increase in the undrained deviatoric shear strength. More details can be found in Bergado et al. (2004b)

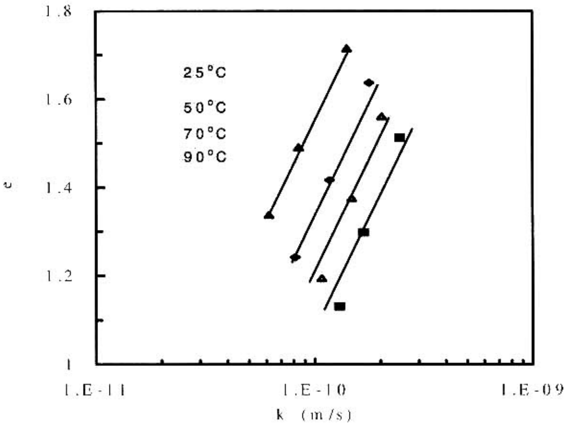

Figure. 5. Hydraulic permeability of soft Bangkok clay at different temperatures

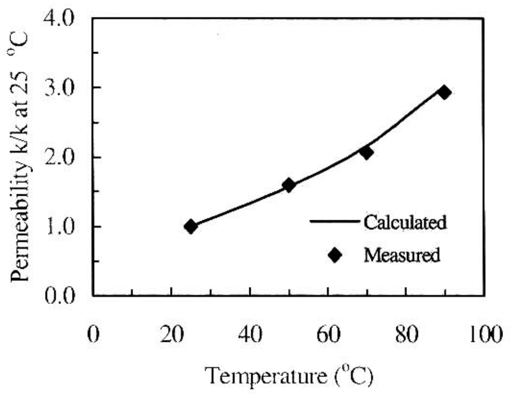

Figure. 6. Comparison between the measured and the calculated increase in the hydraulic permeability due to temperature increase

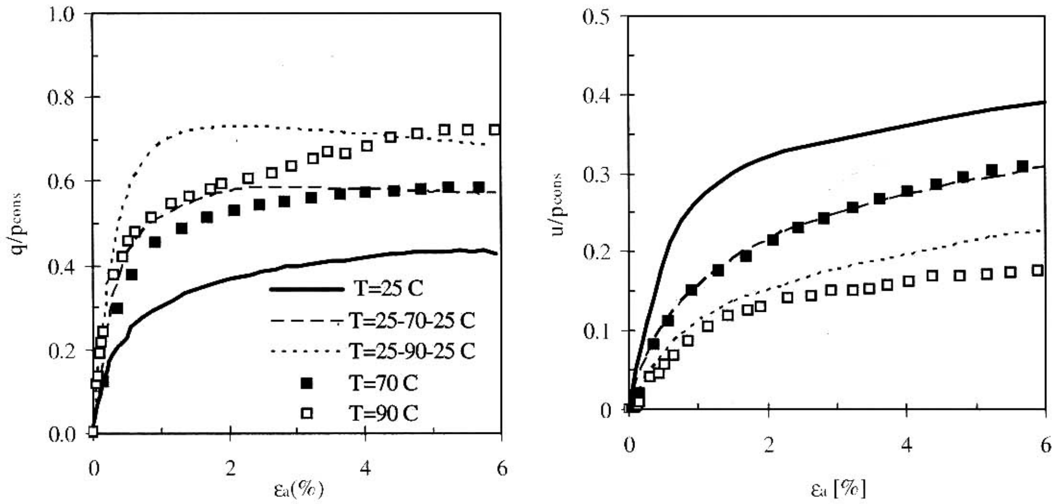

Figure 7. Undrained compression triaxial test results on normally consolidated specimen at different temperatures and temperature histories

CONCLUSIONS

The engineering properties of soft Bangkok clay at elevated temperature can be summarized as follows:

1. The thermally induced volume change depends on the stress history condition.
2. Subjecting normally consolidated clay to the heating cooling cycle induces an overconsolidation state.
3. The hydraulic permeability increases as the soil temperature increases due to the thermal evolution of the water viscosity.
4. Undrained shear strength increases as the soil temperature increases. The observed increase is considered irreversible since the shear strength after being subjected to the heating/cooling cycle is equal to the shear strength at elevated temperature.

REFERENCES

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