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Effects of temperature on 1-D consolidation characteristics of clayey soil

Effets de température sur 1-D consolidation caractéristiques de l'argile

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ABSTRACT
This paper aims at understanding the effects of temperature on consolidation and volume change behavior of the Bangkok clay due to elevated temperature. A conventional oedometer was modified and fitted with a heater and thermostat and consolidation tests were performed under controlled environment. Consolidation tests on normally consolidated specimens revealed that volume contracts upon heating. Samples during thermal unloading swelled in contrast. The effect of an elevated temperature is similar to that of primary consolidation process. However, if prolonged heat is applied (reloaded) with higher temperature, the effect of temperature increase becomes similar to that of secondary consolidation. The deformation induced during thermal loading is not fully recoverable mainly because once the soil is heated clay structures deteriorate.

RÉSUMÉ
Cet article tend à comprendre les effets de la température sur la consolidation et le comportement du changement de volume de l'argile de Bangkok à cause des températures élevées. Un oedomètre conventionnel a été modifié et doté d'un chauffage avec thermostat et des tests de consolidation ont été pratiqués dans un environnement contrôlé. Les tests de consolidation sur des spécimens consolidés normalement révèlent que le volume se contracte sous la chaleur. Des échantillons pendant le chargement thermique ont gonflé par contraste. L'effet d'une température élevée est similaire à celui du premier procédé de consolidation. Cependant, si une chaleur prolongée est appliquée (rechargée) avec une température plus élevée, l'effet de l'accroissement de température devient similaire à celui de la deuxième consolidation. La déformation induite pendant le chargement thermique n'est pas complètement récupérable, principalement parce que, lorsque le sol est chauffé les structures de l'argile se détériorent.

1 INTRODUCTION

The effects of temperature on consolidation have been major field of research for long. Terzaghi's general theory of hydrodynamic consolidation itself describes a process of water being expelled out of a soil disc. Permeability on the other hand is a function of water viscosity and hence temperature. Thus, the hydrodynamic theory of consolidation implies the basic influence of temperature on the rate of pore pressure dissipation and resultant strain. Since Terzaghi, there has been substantial research done on this field. Based on the experimental study on Penn Soil, Paaswell (1967) concluded that with a small temperature rise (of the order of 10 ^{o}C over 4 hours), the effect of temperature on strain is analogous to a secondary consolidation that represents a process of stabilization between soil and pore water at the soil water interface and particles at the minute points of contact. The increased temperature would create more of a film flow at the boundaries. For larger and sudden temperature gradient, the response of soil would be more apparent (Paaswell, 1967). It was demonstrated from the laboratory experiments that normally consolidated clays contracted upon heating (Plum and Esrig, 1969). When over consolidated clays were heated, the magnitude of volume contraction was smaller than the one recorded for normally consolidated clays (Demars and Charles, 1981).

A number of geo-engineering applications are available for which heat is a major concern. One such application could be the soft soil-improvement by underground burning of oil as reported by Beles and Stanculescu (1958). Tsuchida (1991) suggested that elevated temperature would be an effective way to cure the disturbances that occur during sampling. Booker and Savvidou (1995) developed a semi-coupled solution for consolidation of a point heat source and applied it to the problem of buried cables (heat source). The effects of temperature changes due to heat transfer from emplaced waste are also matters of great concern in nuclear waste disposal (Giraud & Rouset, 1995) and sanitary landfills (Thomas and Ferguson, 1999).

Bangkok clay is known for its high compressibility and low strength. The subsoil originates from sedimentation at the delta of the Chao-Phraya River and consists of alternate layers of sand, gravel and clay. The marine clay is the uppermost clay layer just beneath the top and weathered clay layer. The soil samples were retrieved from this soft clay (marine clay) layer from a depth of 5 m to 6 m.

2 EXPERIMENTAL INVESTIGATION

The primary objective of this research is to study the effect of elevated temperature on deformation behavior of Bangkok clay (normally consolidated). A conventional oedometer was modified and fitted with heater and thermostat as shown in Fig.1. A clay specimen of the dimension 60 mm (diameter) x 20 mm (height) was rested in an oedometer that lies in a hot water bath. A heater was fitted to a thermostat with an accuracy of $\pm$ 1 ^{o}C. An electrical propeller was also used to make the temperature of water bath homogeneous. Calibration of the equipment was required to estimate the thermal expansion of the oedometer box and the heating bath (container).

After calibration, series of tests were conducted on clay samples with thermo-couples embedded in its center. The samples were heated and time required to reach the specified temperature (temperature of water bath) were recorded for three elevated temperatures of 40 ^{o}C, 60 ^{o}C, and 80 ^{o}C. As shown in Fig 2., within less than 10 minutes, temperature at the center of clay sample became equal to that of the water bath.

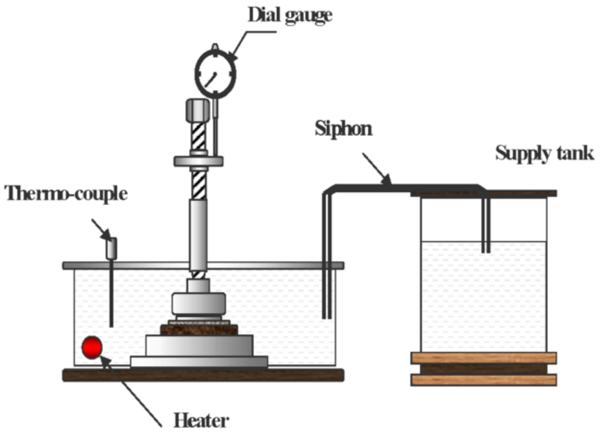

Fig. 1 Modified 1-D oedometer test

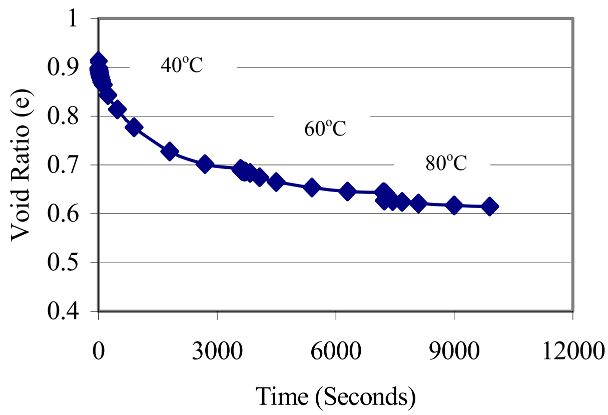

Fig. 4 Volume change during thermal loading (300 kPa)

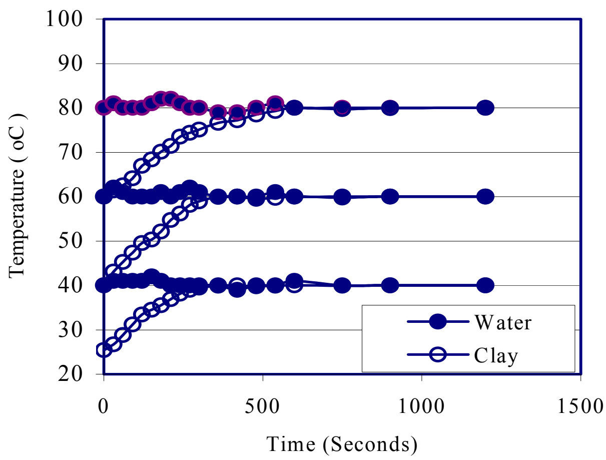

Fig. 2 Temperature build-up in specimen and water bath

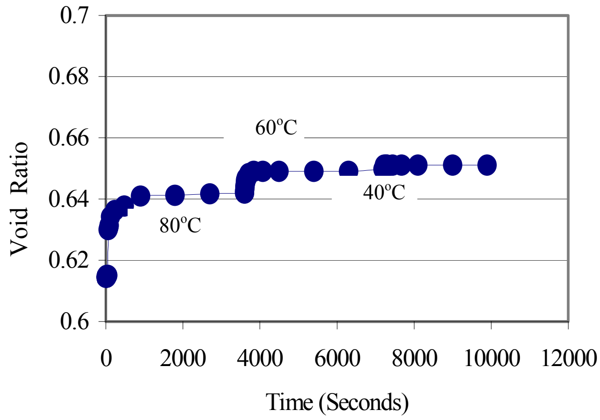

Fig. 5 Volume change during thermal unloading (Unloading under 300 kPa)

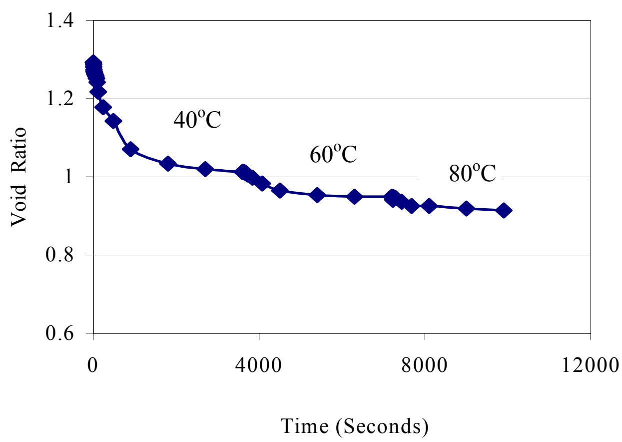

Fig. 3 Volume change during thermal loading (75 kPa-150 kPa)

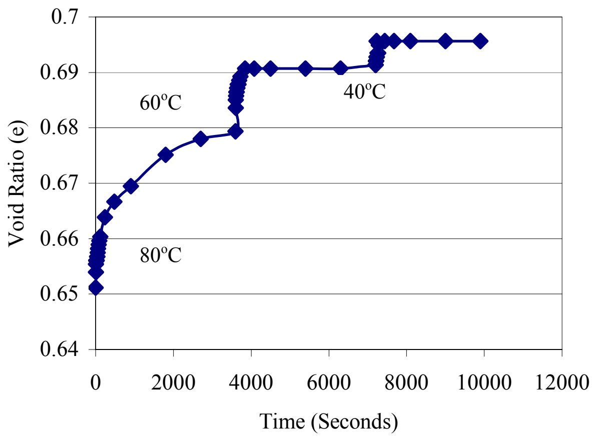

Fig. 6 Volume change during thermal unloading (Unloading from 300 kPa to 150 kPa)

3 RESULTS AND DISCUSSION

3.1 *Thermal Loading*

Figure 3 shows the progress of volume change when total stress is changed from 75 kPa to 150 kPa. The primary consolidation appears to have ceased within 15 minutes (900 seconds) of the elapsed time. After 60 minutes of heating at the temperature of 40 ^{o}C, temperature was elevated to 60 ^{o}C and the sample was heated for 60 minutes. The same procedure was followed to heat the clay sample to 80 ^{o}C. It is clearly seen from the figure that volume contraction gets reactivated each time the temperature is raised although it had nearly completed the primary consolidation stage.

Figure 4 illustrates the progress of volume change under the pressure of 300 kPa. The specimen was heated to a temperature of 40 ^{o}C at first and after 15 minutes, the temperature was increased to 60 ^{o}C and finally to 80 ^{o}C as before. As seen from the figure, volume contraction takes place each time the temperature is raised. However, the amount of contraction reduces considerably.

3.2 *Thermal Unloading*

Figure 5 illustrates the expansion behavior during thermal unloading under the pressure of 300 kPa. The expansion is instantaneous and dial gaze is difficult to read manually. Within a few seconds of lowering the temperature from 80 ^{o}C to 60 ^{o}C, the void ratio increased as much as 0.03 and stabilized at 0.645. Each time the temperature wais decreased, the expansion activated but the amount of expansion was observed less and less. When the temperature was reduced from 60 ^{o}C to 40 ^{o}C, the void ratio increased only a little (0.005). Similar trends was seen when the pressure was reduced from 150 kPa to 75 kPa (Fig. 6)

Fig.4 and Fig. 5, together, represent a complete cycle of thermal loading and unloading under 300 kPa. A comparison of these figures indicates that the initial void ratio at the onset of load application is 0.9 and after thermal loading and unloading void ratio becomes 0.65, with only 72% recovery. Thermal unloading fails to recover the changed volume back to original condition. Thermal unloading of the sample shows sudden increase in void ratio with large residual voids because of the deterioration of clay structures.

3.3 *Long term thermal loading-unloading*

A number of soil samples were retrieved from a greater depth of 14 m to 15 m depth to study long-term thermal behavior of the clay. This marine clay is characterized by the presence of higher percentage of sand (20%) and silt (30%). The initial void ratio for this clay was 1.5. The heating experiment was prolonged to study the thermal behavior of this clay under normal pressure of 150 kPa and 300 kPa. The results are presented as change in void ratio versus the time. Fig. 7 presents results from heating of clay (70^{o}C) and subsequent cooling down to room temperature (35^{o}C) under 150 kPa normal pressure. As expected, volume contraction takes place due to heating, which stabilizes after 6 hours of heating. When the source temperature was cut off, the sample expands and recovers deformation partially. Similar experimental procedure under high normal pressure (300 kPa), showed continued deformation even after the temperature was cut off. This could be because the amount of expansion of the solid skeleton is less than the one caused by the high normal pressure under which the specimen is still undergoing the volume compression. However, as the temperature further drops, swelling of the specimen was noticed after 800 mins (Fig. 8).

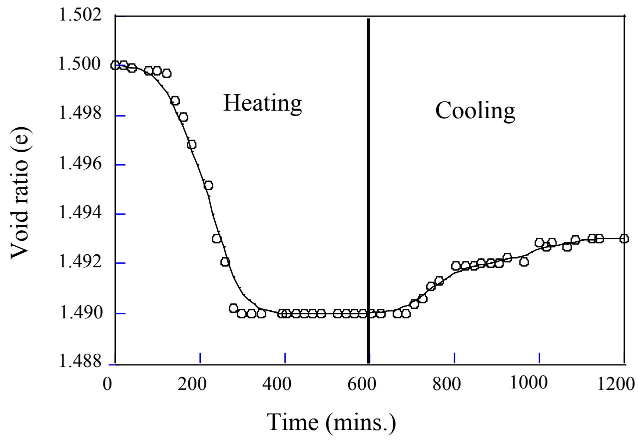

Fig. 7 Results from Heating of Clay (80^{o}C) and subsequent cooling down to room temperature (35^{o}C) under 150 kPa normal pressure.

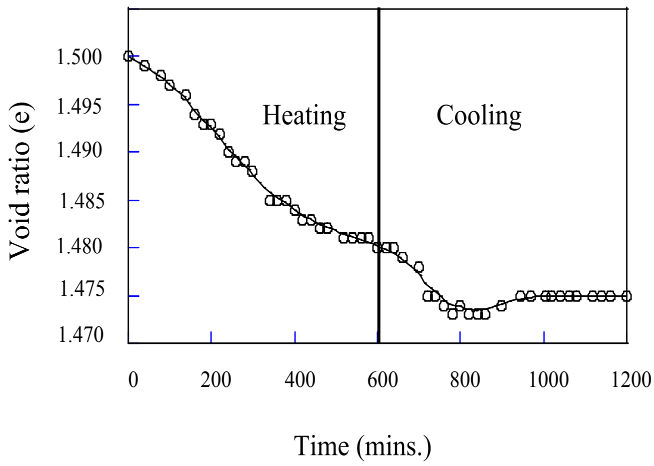

Fig. 8 Results from Heating of Clay (70^{o}C) and subsequent cooling down to room temperature (35^{o}C) under 300 kPa normal pressure.

4 CONCLUSIONS

The effect of an elevated temperature on consolidation characteristics of Bangkok clay was studied under controlled environment. It was revealed that initial heating of normally consolidated specimen resembles primary consolidation process. The rate of seepage accelerates. To understand this process, interaction of clay particles and pore-water needs to be addressed. Whereas the viscosity of water decreases upon heating, flow through pore spaces increases causing the volume contraction. However, if prolonged heat is applied with higher temperature, the effect of temperature increase becomes similar to that of secondary consolidation. Thermal unloading of the sample shows sudden increase in void ratio with large residual voids because of the deterioration of clay structures.

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