Experimental studies on thermal response and thermal consolidation of soft clays

Kazuki Yamaguchi

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1. Background and objectives

New geosystems using unused heat is a novel challenge and are being actively studied mainly in Western countries. One of such new geosystems is vertical drain method with heating the ground. Ground improvement of soft clay using vertical drains can accelerate settlemenet before construction works and can be sophisticated with the help of heating the ground, because the consolidation of clay can be promoted at higher temperatures. This method is expected to be applied in coastal areas, but the effect of salinity of soil pore water on consolidation behavior of clay has not been studied. In this study, to clarify this point, consolidation test was performed on specimens prepared with two electrolyte solution under different temperatures. A pilot-scale ground heating test with the help of the solar hot-water system was conducted to evaluate the feasibility of ground heating.

2. Materials and methodologies

Kaolin clay (liquid limit of 77.0% and plastic limit of 30.2%) and Kasaoka clay (ditto, 58.5% and 24.6%) were used in the consolidation test, and kaolin clay was used in the pilot-scale test. In the consolidation test, solutions for $CaCO_3$ saturation condition (A) and artificial seawater condition (B) were used for water content regulation of each clay. A cylindrical saturated specimen with ϕ10 cm and H 5.0 cm was filled in a cell, and the cell was immersed in a water tank where water of 17°C, 35°C, or 50°C was circulated.

In the pilot-scale heating test, a 150-cm-sided cubic tank with heat insulating material on its inner wall was used. Clay in the tank was radially heated by circulating hot water through three U-shaped vertical pipes as shown in Figure 1. Thermocouples were installed at 4 depths of G.L.−10, 60, 110, and 140 cm at the point of Figure 1. The test was conducted in summer (2019/08/21–2019/09/30) and winter (2019/11/19–2019/12/17).

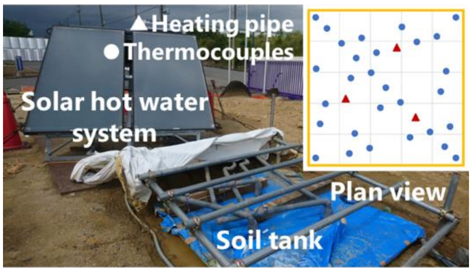

Figure 1 Overview of the pilot-scale test

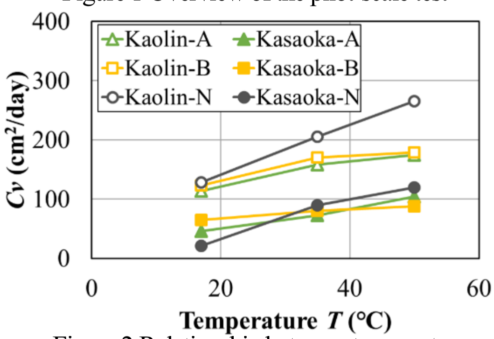

Figure 2 Relationship between temperature and consolidation coefficient

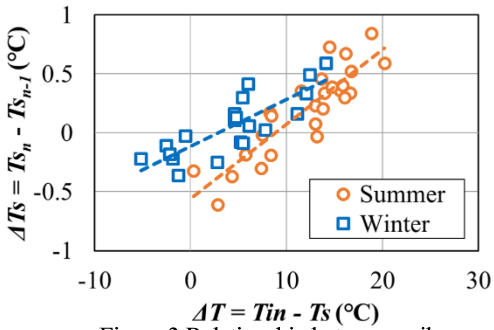

Figure 3 Relationship between soil temperature and heating pipe temperature

3. Main achievements

1) The consolidation coefficient—an index representing consolidation rate— (c_v) showed an increasing trend with increasing temperature under all conditions (Figure 2). In Cases A and B, increasing rates were smaller than that of distilled water case (N). Except the 17°C case of Kasaoka clay, this value was smaller than that of Case N.
2) The fact that c_v values in Cases A and B were smaller than that of Case N implies that the salinity in clay decays consolidation more significantly at higher temperatures.
3) The soil tank temperature *Ts* heated by the solar hot water system became almost steady in about two weeks. The increment of temperature was +8.3°C in summer and +5.0°C in winter.
4) From Figure 3, the heating effect can be expected when the heating pipe temperature *Tin* is 8.8°C higher in summer and 2.8°C in winter than the soil tank temperature *Ts*.