Thermal effects on the mechanical behavior of Paris green clay–concrete interface

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1 Introduction

Energy piles are dual purpose foundation elements that are used both to transfer the building loads to the supporting soil and as heat exchangers (heating/cooling). Over the seasons, these piles are subjected to heating and cooling cycles that result in cyclic expansion and contraction. The expansion and contraction bring about the increase of vertical displacements and the modification of vertical stress on the piles. In other words, the thermomechanical behavior of the pile, the soil, and the soil-pile interface changes. Despite the increasing number of studies on energy piles in recent years, the impact of thermomechanical cycles on the behavior of soil and the soil-pile interface is still poorly documented (Yin 2021; Yin et al. 2021a).

To assess the impact of thermal cycles on the mobilization of the shear strength of the interface between energy piles and clayey soils, a series of direct shear tests on Paris green clay-concrete interfaces was performed in the laboratory using a new device adapted to thermomechanical loadings. The machine was validated and employed to perform soil-structure interface direct shear tests under various thermomechanical loadings (Vasilescu et al. 2018; Vasilescu et al. 2019; Vasilescu 2019; Yin 2021; Yin et al. 2021b). The upper part of the shear box is used to contain a green clay sample with a size of 100 mm × 100 mm × 50 mm. The bottom part is designed to hold a concrete plate having dimensions of 140 mm × 100 mm × 11 mm. The machine can carry out displacement- or load-controlled shear tests. More details about the direct shear device can be seen in Vasilescu (2019) and Yin (2021).

The soil used in this study is Romainville green clay, which was sampled from the in-situ testing site in École Nationale des Ponts et Chaussées (Parisian area, France). 92% of the green clay particles have a diameter smaller than 80 µm (Mantho 2005, Vasilescu 2019). The green clay's liquid limit (wL) and plastic limit (wL) are 95% and 31%, respectively. In the laboratory, the green clay was cut from the borehole tube and dried in an oven at a

temperature of 105°C for at least 48 hours. When preparing samples for the interface direct shear tests, the dry green clay was mixed into slurry with distilled water at 1.5 wL, then moved to a designed oedometer cell (diameter = 150 mm) to perform a preconsolidation process (see Yin (2021) and Yin et al. (2021c)). The maximum vertical stress during preconsolidation was 50 kPa. After the preconsolidation phase the sample was cut into a square shape by a trimming tool (see Yin (2021) and Yin et al. (2021c)) for the interface direct shear box. This procedure of sample preparation guarantees the fabrication of green clay specimens with homogeneous structure for the interface tests (Yin et al. 2019; Yin 2021; Yin et al. 2021c; Yin et al. 2021d; Yin et al. 2021e). A concrete plate was cut from a concrete block and used for all the interface tests. The Ra and Rmax of the concrete plate are 10.2 µm and 90.5 µm, respectively. The normalized roughness, Rn, is >90.5, therefore in this case the interface is considered as rough (Yin 2021; Di Donna et al. 2016).

The interface direct shear tests were conducted under constant vertical stresses of 50 kPa, 100 kPa and 150 kPa. The shear box was installed in a container that was full of distilled water to ensure the clay samples were saturated during the whole test. The experimental campaign of shearing was divided into two parts: (i) interface direct shear tests of reference, at 13°C (constant temperature), (ii) interface direct shear tests after 10 thermal cycles ($\Delta T = 10^\circ\text{C}$, i.e., 8°C to 18°C). The displacement-controlled shearing test was performed with a rate of 0.006 mm/min until a maximum horizontal displacement of 5 mm.

2 Results

A constant temperature of 13°C was chosen for the reference test as it reflects the soil temperature 5 m below the ground level in the Paris region (Vasilescu et al. 2018; Vasilescu et al. 2019; Vasilescu 2019). The vertical strain as a function of time and temperature during the 10 thermal cycles is presented in the Figure 1. The results confirm an accumulation of deformations during the

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thermal cycles due to the thermal consolidation process (Di Donna 2014; Idries et al. 2020; Yazdani et al. 2019).

Fig. 1: Vertical strain during 10 thermal cycles: (a) 50 kPa; (b) 100 kPa; (c) 150 kPa.

Figure 2a shows a small increase in shear strength at the normal stress of 50 kPa after the 10 thermal cycles. While at normal stress of 100 and 150 kPa, the difference between the reference and the cyclic tests is quite small. The interface friction angle reduces slightly (0.6°) after the 10 cycles, whereas the most significant thermal impact is found to be an increase of 2.6 kPa on the adhesion of the green clay-concrete interface (Figure 2b). This decreasing trend of interface friction angle is not in agreement with the results in Yazdani et al. (2019) and Idries et al. (2020). To conclude, the effect of the thermal consolidation on the shear strength is not so significant, but it increases the contact surface between the green clay and the concrete plate.

Fig. 2: Shear result comparison between the tests of 13°C and 10 thermal cycles: (a) shear stress versus horizontal displacement and (b) interface friction angle.

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