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Thermally induced shear displacement of sand-concrete interface under different stress levels

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Energy geostructures are modern technologies developed to exploit shallow geothermal energy. Their installation has recently increased rapidly throughout the world. Their use is devoted to the heating and cooling of buildings, and their operation can induce thermal cycles at the soil-structure interface in the range of 5–40 °C [1]. In addition, their activation would produce thermally-induced stress and strain in structure. Over the last few decades, several full-scale tests have been performed to study the geotechnical aspects of energy piles [2,3]. The main results show that the thermal operations may slightly influence the mechanical performance of the energy pile by increasing the additional thermal compressive stresses and changing the pile axial strain. Numerical studies [4,5] concluded that the temperature increment can lead to thermal expansion of the pile, causing its uplift and the generation of negative shear forces at the pile–soil interface near the pile head. Considering that the thermal operation of energy geostructures leads to temperature change along the piles as well as in the neighbouring soil due to the heat exchange phenomenon, many researchers have investigated the temperature effects on the behaviour of soil and soil–structure interface [6,7,8,9]. Others investigated thermally induced soil deformation using modified triaxial or oedometric apparatuses allowing temperature control [10,11,12]. These results show expansive deformation of coarse-grained soils upon heating and contractive deformation upon cooling for all relative densities. A modified geothermal direct shear box (MGSB) developed at Gustave Eiffel University [13] was used to investigate the effects of temperature cycles on soil–concrete interface. The preliminary results showed that the sand expands upon heating and contract upon cooling. An accumulated contraction and shear displacement were observed after each thermal cycle. However, these preliminary results should be carefully re-analysed since the device was not fully calibrated under various thermo-mechanical loads.

In this study, the MGSB was utilized after its calibration [13], to investigate the thermally induced vertical and lateral displacements of sand–structure interface. It consists of two half-shear boxes with dimensions of 200 mm x 200 mm x 80 mm. A Peltier module was used to heat and cool water connected to a pipe embedded in the concrete plate, which was used to simulate the pile surface. Normal and shear stresses were applied to represent the geostatic stress of soil and pile load, respectively. Four linear variable differential transformers (LVDTs) were placed in contact with the lower and the upper boxes of the device to measure the shear displacement. One LVDT was placed at the top of the box to measure the vertical displacement of soil. To prevent heat losses, the system was insulated using an insulating foam. Two series of test were performed. The four tests of the first series were conducted on dense (D) sand and the three tests of the second series were on loose (L) sand, with relative densities of about 90% and 30%, respectively. For each density, three normal stress levels were tested: 25, 50 and 100 kPa. For each normal stress, a shear stress equal to 40% of normal stress (45% of the shear strength) was applied. Test D_50 was repeated because of technical problems that happened during the first test. After samples preparation, two phases were carried out. The first phase corresponds to the

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application of normal and shear stresses. Regarding the second phase, 20 thermal cycles were applied, varying the soil temperature between 14 °C and 32 °C.

The mechanical results showed a good agreement compared to standard direct shear tests. The thermo-mechanical results showed that the succession of soil expansion and contraction upon heating and cooling respectively lead to an accumulated irreversible contraction and continuous shearing displacement after each thermal cycle with different magnitudes, depending on the soil density and stress level. In addition, the rate of these incremental irreversible displacements decreases when the cycle number increases. Moreover, the increase in the stress levels will lead to an increase in the accumulated lateral displacement after 20 cycles, and this increment is significant in loose sand compared to dense sand under the same mechanical conditions. Overall, the thermally induced sand-concrete interface displacements are affected by stress level and strongly depend on the sand density. The thermally induced settlement may be critical in the case of floating energy piles under high mechanical load, and greater than 45% may lead to greater in the case of loose soil would be greater than 0.3 mm. Finally, this study suggests that using a homogeneous stress design method for energy geostructures may adversely affect the design.

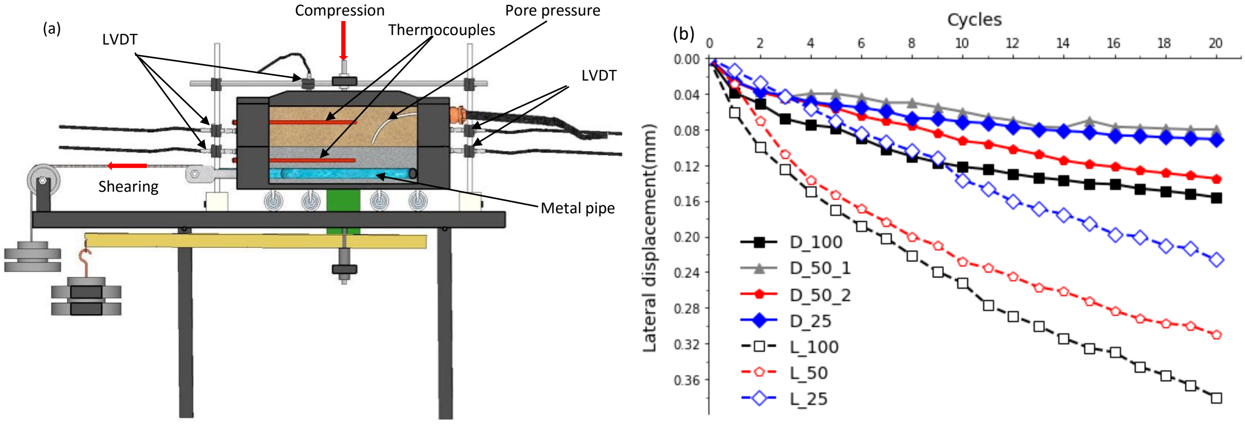

Figure 1: (a) Experimental setup; (b) Thermally induced lateral displacements versus cycle numbers over 20 thermal cycles.

References

[1] H. Brandl (2006) Energy foundations and other thermo-active ground structures. *Géotechnique*, 56(2):81-122.
[2] L. Laloui, M. Nuth, L. Vulliet. (2006) Experimental and numerical investigations of the behaviour of a heat exchanger pile. *International Journal For Numerical And Analytical Methods In Geomechanics*.;30(8):763-81.
[3] P. J. Bourne-Webb, B. Amatya, K. Soga, T. Amis, C. Davidson, P. Payne. (2009) Energy pile test at Lambeth College, London: geotechnical and thermodynamic aspects of pile response to heat cycles. *Géotechnique*, 59(3): 237-248.
[4] A. Vieira. J.R. Maranha. (2017) Thermoplastic analysis of a thermoactive pile in a normally consolidated clay. *International Journal of Geomechanics*. 1;17(1):04016030.
[5] N. Yavari, A.M. Tang, J.M. Pereira, G. Hassen. (2014) A simple method for numerical modelling of mechanical behaviour of an energy pile. *Géotechnique Letters*, 4(2):119-24.
[6] A. Di Donna, A. Ferrari, L. Laloui. (2016) Experimental investigations of the soil–concrete interface: physical mechanisms, cyclic mobilization, and behaviour at different temperatures. *Canadian Geotechnical Journal*, 53(4):659-72.
[7] N. Yavari, AM.Tang, J.M. Pereira, G. Hassen,. (2016) Effect of temperature on the shear strength of soils and the soil–structure interface. *Canadian Geotechnical Journal*, 53(7), pp.1186-1194.
[8] S. Xiao, MT. Suleiman, R. Elzeiny, C. Naito, S. Neti, M. Al-Khawaja. (2018) Effect of temperature and radial displacement cycles on soil–concrete interface properties using modified thermal borehole shear test. *Journal of Geotechnical and Geoenvironmental Engineering*, 144(7):04018036.
[9] Y. Guo, A. Golchin, MA. Hicks, S. Liu, G. Zhang, P.J. Vardon. (2023) Experimental investigation of soil–structure interface behaviour under monotonic and cyclic thermal loading. *Acta Geotechnica*, 29:1-24.
[10] Ng, C.W., Wai, S. H. Wang, C. Zhou. (2016) Volume change behaviour of saturated sand under thermal cycles." *Géotechnique Letters*, 6(2):124-31.
[11] Y. Pan, J.B. Coulibaly, A.F. Rotta Loria. (2020) Thermally induced deformation of coarse-grained soils under nearly zero vertical stress. *Géotechnique Letters*, 10(4):486-91.
[12] J. Sittidumrong, A. Jotisankasa, K. Chantawarangul (2019) Effect of thermal cycles on volumetric behaviour of Bangkok sand. *Geomechanics for Energy and the Environment*, 20:100127.
[13] T. Badinier, M. Kheireddine, J.de Sauvage, F. Szymkiewicz, (2022) Essais de cisaillement de fondation géothermique : boîte de cisaillement innovante: In *11èmes journées nationales de géotechnique et de géologie de l'ingénieur*.