Symposium on Energy Geotechnics
Accelerating the energy transition
3-5 October 2023, Delft, the Netherlands

Peer-reviewed Conference Contribution

A direct shear setup for studying the THM shear response of the soil-structure interface in the context of energy geostructures

Amirhossein Hashemi[1,*] and Melis Sutman[1]

[1] School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, UK
* Corresponding author: sh204@hw.ac.uk

Developing pathways for climate-resilient development involves integrating mitigation and adaptation actions, ensuring sustainable development [1]. A climate-resilient development can be achieved through the inclusion of effective mitigation approaches into development planning, reducing vulnerability, conserving ecosystems, and restoring ecosystems [1]. In this regard, energy geostructures are introduced as an effective mitigating approach, providing renewable energy while limiting the emission of greenhouse gases [2-4]. The operation of the system is closely linked to daily and seasonal cycles, which leads to cyclic temperature and water content fluctuations at the soil and the soil-structure interface [4, 5]. Thus, the study of the shear response of the soil–structure interface subjected to different thermo-hydro-mechanical (THM) conditions is of importance. Testing techniques used to study the THM behaviour of unsaturated soils require advanced laboratory equipment, as well as protocols for correcting measured data due to errors in the test conditions and apparatus calibration. This paper presents the development of a new direct shear setup to measure the non-isothermal shear strength of the partially saturated soils and soil-structure interface. The modified setup, a unique one to the authors' knowledge, enables simultaneous control of temperature, matric suction, and mechanical stress state within the soil specimens. The operational temperature range of energy geostructures (i.e., 5°C to 50) is applied through a thermal plate, developed from corrosion-resistant stainless steel with high thermal conductivity, placed at the base of the soil specimen. Matric suction (i.e., in the range of 0 to 100 kPa) is controlled using the axis-translation technique and measured using a pressure transducer connected to the back of the top cap, incorporating the HAE disk, facilitating the measurement (Figure 1) [2, 4-6]. The direct shear setup is modified to accurately measure the shear strength and deformation characteristics of soil samples under controlled laboratory conditions. The design of the device is based on previous direct shear devices but includes several improvements to enhance its accuracy and ease of use [4, 5]. The device has been tested to measure the shear response of both soils and soil-structure interfaces, and the results were compared to those obtained using conventional direct shear devices [2, 4, 7-10]. The results indicate that the new device is accurate and reliable and represents a significant advancement in the field of soil testing.

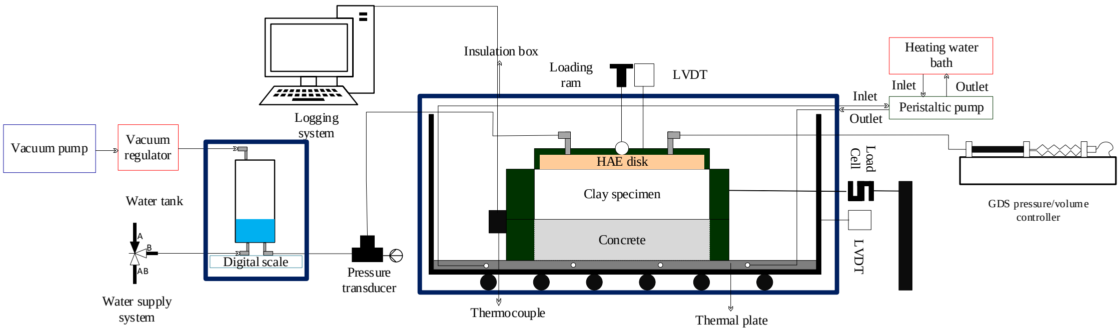

Figure 1: Schematic view of modified direct shear apparatus.

In this study, the interface is formed by kaolin clay, a temperature-sensitive clay, and concrete, a structural material widely used for energy geostructures [4, 11]. The soil samples were prepared by static compaction at 30% initial water content (ω_0) and an initial void ratio (e_0) of 1.2. Initially, all samples were inundated with distilled water at room temperature (24°C) [4, 12], followed by sequential hydraulic (i.e., matric suction, s= 0 or 70 kPa), mechanical (i.e., net normal load, σ_n=100 or 300 kPa), and thermal (i.e., temperature, T=24°C or 45°C) loading of the interface. The shearing was initiated after ensuring equilibrium criteria were met. It

DOI: https://doi.org/10.59490/seg23.2023.504

was necessary to limit the shearing rate to 0.005mm/min and the thermal loading rate to 3°C/hr to maintain the drained condition [4, 13]. Additionally, the vertical displacements associated with hydraulic load were subjected to an equilibrium criterion of 0.025%/day strain rate [14]. As presented in Table 1, the results revealed that the apparent interface friction angle was not significantly affected by matric suction at varying temperatures, but a slight decrease has been observed upon heating at all matric suctions. The apparent adhesion increased in response to temperature increase/decrease, with a decreasing rate as suction increased, while the interface desaturation led to higher apparent adhesion at all temperatures, corresponding to peak and residual values. In interfaces subjected to identical normal stress and temperature but different matric suction values, the shear stress-shear displacement curves showed greater peak stress with increasing matric suction. Furthermore, despite the same net normal stress and matric suction, higher temperatures resulted in slightly lower peak shear stress and less contractive volume change behaviour at the interface. Non-isothermal volumetric behaviour and soil dilatancy play a significant role in governing the THM shear response of the interface [15].

Table 1: Shear strength parameters of clay-concrete interface (c_a: apparent adhesion; φ: apparent interface friction angle; s: matric suction)

Temperature (°C)	Fully saturated (s=00 kPa)				Partially saturated (s=70 kPa)			
	Residual state		Peak state		Residual state		Peak state	
	c_a (kPa)	φ (°)	c_a (kPa)	φ (°)	c_a (kPa)	φ (°)	c_a (kPa)	φ (°)
8	14	16	10	21	26	16	24	22
24	12	16	8	21	25	16	23	22
45	14	14	11	19	27	14	24	20

Contributor statement

Amirhossein Hashemi: Conceptualization; Methodology; Formal analysis; Data Curation; Writing - Original Draft, Review & Editing
Melis Sutman: Conceptualization; Methodology; Writing - Review & Editing; Supervision

Acknowledgments

The authors acknowledge the assistance of Alastair Macfarlane in the set-up of the shear box device.

References

[1] IPCC, Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama eds]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844., 2022.

[2] Di Donna, A., A. Ferrari, and L. Laloui, Experimental investigations of the soil–concrete interface: physical mechanisms, cyclic mobilization, and behaviour at different temperatures. Canadian Geotechnical Journal, 2016. **53**(4): p. 659-672.

[3] Laloui, L. and M. Sutman, Experimental investigation of energy piles: From laboratory to field testing. Geomechanics for Energy and the Environment, 2020: p. 100214.

[4] Hashemi, A., M. Sutman, and H. Abuel-Naga, Thermo-Mechanical Response of Kaolin Clay-Concrete Interface in the Context of Energy Geostructures. Canadian Geotechnical Journal, 2022.

[5] Gallage, C. and T. Uchimura, Direct shear testing on unsaturated silty soils to investigate the effects of drying and wetting on shear strength parameters at low suction. Journal of Geotechnical and Geoenvironmental Engineering, 2016. **142**(3): p. 04015081.

[6] Fu, Z., Thermo-Hydro-Mechanical Effects on the Behaviour of Unsaturated Soil-Structure Interfaces and the Numerical Analysis of Energy Piles. 2017, Université d'Ottawa/University of Ottawa.

[7] Hamid, T.B. and G.A. Miller, Shear strength of unsaturated soil interfaces. Canadian Geotechnical Journal, 2009. **46**(5): p. 595-606.

[8] Borana, L., et al., Direct shear testing study of the interface behavior between steel plate and compacted completely decomposed granite under different vertical stresses and suctions. Journal of Engineering Mechanics, 2018. **144**(1): p. 04017148.

[9] Hassanikhah, A., G. Miller, and K. Hatami, Laboratory investigation of unsaturated clayey soil-geomembrane interface behavior. Geosynthetics International, 2020: p. 1-15.

[10] Maghsoodi, S., O. Cuisinier, and F. Masrouri, Thermal effects on mechanical behaviour of soil–structure interface. Canadian geotechnical journal, 2020. **57**(1): p. 32-47.

[11] Soga, K. and Y. Rui, Energy geostructures, in Advances in ground-source heat pump systems. 2016, Elsevier. p. 185-221.

[12] Ravera, E., M. Sutman, and L. Laloui, Cyclic thermomechanical response of fine-grained soil-concrete interface for energy piles applications. Canadian Geotechnical Journal, 2020(ja).

[13] Cekerevac, C. and L. Laloui, Experimental study of thermal effects on the mechanical behaviour of a clay. International journal for numerical and analytical methods in geomechanics, 2004. **28**(3): p. 209-228.

[14] Romero, E., A. Gens, and A. Lloret, Temperature effects on the hydraulic behaviour of an unsaturated clay, in Unsaturated soil concepts and their application in geotechnical practice. 2001, Springer. p. 311-332.

[15] Hashemi, A., M. Sutman, and G.M. Medero, A review on the thermo-hydro-mechanical response of soil–structure interface for energy geostructures applications. Geomechanics for Energy and the Environment, 2023: p. 100439.