PHD POSITION OPPORTUNITY – RESEARCH IN GEOTECHNICAL ENGINEERING – 2025

THERMO-MECHANICAL BEHAVIOUR OF GEOTHERMAL MICROTUNNELS: FULL-SCALE EXPERIMENTATION AND NUMERICAL MODELLING

Supervisors:

- **Thesis supervisor:** Hussein MROUEH (Professor, Laboratory of Civil Engineering and Geo-Environment, University of Lille, France);

Partnerships:

- **CETU:** Nicolas BERTHOZ (Head of geotechnical department, Centre for Tunnel Studies, Bron, France); contributing to the design of the prototype; member of the thesis monitoring committee
- **Bessac**, Pascal MOLINER (commercial manager), Saint-Jory, France: contributing to the construction and implementation of the experiment
- **University of Grenoble-Alpes**, Alice DI DONNA (university lecturer), Gières, France: contributing to in-situ monitoring, member of the thesis monitoring committee;
- **Université Gustave Eiffel**, Thibault BADINIER (researches associate), Champs-sur-Marne, France: contributing to in-situ monitoring, member of the thesis monitoring committee;
- **Polytechnic University of Turin**, Marco BARLA (professor), Turin, Italy: member of the thesis monitoring committee.

1 Context and project challenges

Low-enthalpy geothermal energy consist in installing tubes through which a heat transfer fluid circulates, connected to a heat pump that extracts heat from the ground in winter or injects it in summer to heat and cool adjacent buildings (Brandl, 2006). Local, clean, and renewable, this technology is perfectly aligned with current ecological transition needs and growing energy demand.

The technology has been widely applied to foundation piles (Amtya[1] *et al.*, 2012). It has more recently been applied (but not on a large scale) to tunnels (Barla[2] *et al.*, 2019; Ma[3] *et al.*, 2022), whose major advantage is that they interact with a larger soil volume, giving them greater heat exchange potential. However, the implementation of the technology is difficult due to the numerous joints between the segments that make up the structure's lining.

The proposed work involves considering the transposition of this technology to structures carried out using microtunneling machines. The main differences compared to the case of segment tunnels are: (i) a smaller

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[1] Amatya, B.L., Soga, K., Bourne-Webb, P.J., Amis, T., and Laloui, L. 2012. *Thermo-mechanical behaviour of energy piles.* Géotechnique, **62**(6): 503–519.

[2] Barla, M., Di Donna, A., and Insana, A. 2019. *A novel real-scale experimental prototype of energy tunnel.* Tunnelling and Underground Space Technology, **87**: 1–14.

[3] Ma, C., Di Donna, A., and Dias, D. 2022. *Numerical study on the thermo-hydro-mechanical behaviour of an energy tunnel in a coarse soil.* Computers and Geotechnics, **151**.

diameter (approximately 1.8 to 3.5 m), (ii) a lining made of pipes rather than segments, (iii) a thinner lining thickness, (iv) a different use leading in some cases to fluid circulation inside the pipe. These differences have an impact on the system's energy performance.

2 Methodology and objectives

In addition to the literature review required prior to any research, this thesis will rely on two complementary approaches:

- An experimental component based on the design, implementation, and operation of a full-scale experiment on a (micro)tunnel section constructed using a microtunneling machine. The measurements acquired will be compared with those available from the few existing geothermal tunnel experiments (Jenbach, Turin, London);
- A numerical component using thermo-hydraulic finite-element models. Their objective will be to identify and quantify heat transfer mechanisms as a function of hydrogeological conditions, using experimental results as support for model calibration and comparison. This model will be based on those developed on tunnels (*e.g.* Ma *et al.*,2022), while incorporating the specific characteristics of microtunnels.

The objectives of this thesis are, of course, scientific, but also technical and operational:

- <u>On the scientific side:</u> to capture the influence of the thermal properties of the soil (conductivity, permeability), hydrogeological conditions (temperature, velocity, and direction of groundwater flow), microtunnel geometry (diameter, depth), the nature of the lining pipes (thickness, constitutive material), and the fluid circulating within the tunnel (temperature, flow velocity) on the system's energy performance; This implies some enhanced numerical modelling of thermo-hydro-mechanical coupled calculations.
- <u>On the technical side:</u> to design the integration of the pipes carrying the heat transfer fluid inside the pipes by optimizing the energy efficiency of the system without compromising the mechanical performance and durability of the pipes, design the connections between pipes, define the instrumentation allowing the monitoring of the system operation, design the test program to assess the operational thermal response of the device (measurement period, duration, etc.);
- <u>On the operational / societal side:</u> to conduct a cost/benefit analysis of the contribution of this technology to address current climate challenges: quantify the additional cost of geothermal equipment, consider ways to recover the energy acquired, evaluate possible energy gains, identify preferred configurations to raise awareness among project owners.

3 Candidate's profile

The ideal candidate should possess a robust foundation in geotechnical engineering.
Undergraduate/Master students in civil engineering / geotechnical and geological engineering / geothermal engineering are particularly welcome. Experience in numerical modelling (e.g. Finite Element Analysis Comsol, Plaxis, etc.) and foundation design is beneficial, but not obligatory for this position. Proficiency in the English language is essential for the role.
Other preferred requirements:
- Proficiency in programming languages such as MATLAB, Python, or similar.
- Ability to work both independently and collaboratively in a multidisciplinary research environment.

4 Location and funding

This PhD position is fully funded by the University of Lille for the duration of the PhD program, covering stipend and tuition fees. The cost of the experiment will be covered by partners, with the support of ANR funding granted as part of the PEPR S-Pass project.

The selected candidate will be based at the Laboratory of Civil Engineering and Geo-Environment at the University of Lille (France). Day trips to CETU will be organized to facilitate the follow-up of the thesis. Their frequency will be specified but could be quarterly. Travel to the experimental prototype site provided by BESSAC company (a few weeks in total) will also be planned.

He/she will have access to state-of-the-art laboratory facilities and computational resources, as well as the opportunity to collaborate with leading experts in the field and contribute to cutting-edge research. The research environment will be supportive and stimulating, fostering personal and professional growth.

5 Application Process

Interested candidates should submit the following documents to [Hussein.mroueh@univ-lille.fr]:

1. Curriculum Vitae (CV) detailing academic qualifications, research experience, and relevant skills.
2. Official transcripts of undergraduate and graduate studies.
3. A cover letter outlining research interests, motivation for pursuing a PhD, and how their background aligns with the project objectives.
4. Contact information for at least two academic referees who can provide letters of recommendation.

Join us in advancing the knowledge frontier of energy geostructures and their performance in complex geological environments. Be part of a dynamic research team dedicated to shaping the future of sustainable energy and geotechnical engineering.