Intelligent realisation of ground energy

There is a need to reduce the economic cost of the energy geostructure and increase the efficiency such systems, which will also rationalise the environmental impact

HIGHER, wider, heavier: reaching the edges of architectural audaciousness yields a number of civil-engineering issues, and out of the mere structural challenges the bearing capacity of soils often comes to a limit. Then, deep foundations and large-slab engineering will necessarily be involved, and meanwhile the service state of building will call for a cost-effective, heating/cooling installation. Hence, following global trends, primary-energy consumption keeps on rising.

Among the environmentally-friendly techniques for conditioning temperature in buildings, geothermal-energy systems are of particular interest, minimising the consumption of CO_2 up to 50% for new buildings.

Heat may indeed be exchanged between a building and the soil by means of several techniques, such as pumping naturally hot groundwater from moderate to very deep soil layers. Also, fields of boreholes of heat-exchangers (probes) use specifically-designed tubes implanted within the soil next to the building.

Yet, contractors may argue that such systems, though displaying a very high energetic efficiency, imply considerable extra costs during construction and non-standard construction skills. The innovative alternative is to combine the foundation system with the heat-exchanger network by building energetic geostructures.

> **"The energetic performance of the heat-exchanger structure can be significantly reduced with respect to its real potential"**

The key factor in the sustainability of such a system is the use of some building elements that are already required for structural reasons. In addition, by using a local source of energy (the ground directly below the building), the system does not involve transporting energy and guarantees a secure and rational supply. In theory, only minor modifications in the foundation design are necessary and almost no energy supply is required. These peculiar features render the system affordable and efficient.

In that case the heat exchange is made possible by absorbing and transporting ground-thermal energy to the buildings via a fluid circulating in pipes cast in the concrete piles, walls and/or slabs. Buildings are cooled and heated with a heat pump, using available local, ground energy and natural-concrete thermal properties (see figure 1).

The efficiency of the process is optimised by seasonal operation, where heat is extracted from the soil in winter and reinjected back in the summer when it is necessary to cool the building.

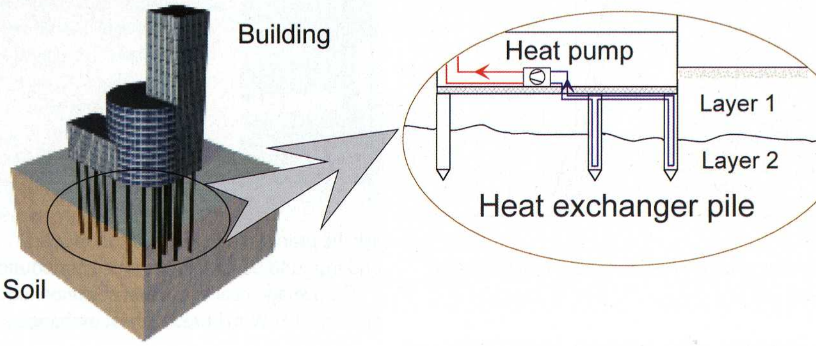

Figure 1: the elements of an installation with heat-exchanger piles, after Laloui, L, Nuth, M, Vulliet, L, 2006. 'Experimental and Numerical investigation of the behaviour of heat exchanger pile', International Journal for Analytical and Numerical Methods in Geo-mechanics, vol 30, pp 763-781, doi: 10.1002/nag.499

More than 300 constructions in Europe use thermal piles, accounting for the wide success of the principle of soil-energy storage. The knowledge of energetic dimensioning of these systems is such that custom sizing tools are already available for assessing heat-pump performance. Yet, the calculations are often based on sets of classical, geothermal earth probes in which only heat transfer is considered. Then, the method is simply applied to installations with heat-exchanger piles.

As a consequence, the energetic performance of the heat-exchanger structure can be significantly reduced with respect to its real potential. Moreover, geotechnical engineers will systematically over-estimate the dimensioning of concrete heat-exchange piles in order to err on the side of caution. Safety factors applied to the design of thermo-piles are generally twice the values used for classical piles, obviously affecting construction costs downstream.

Clearly, there is room to improve this empirical

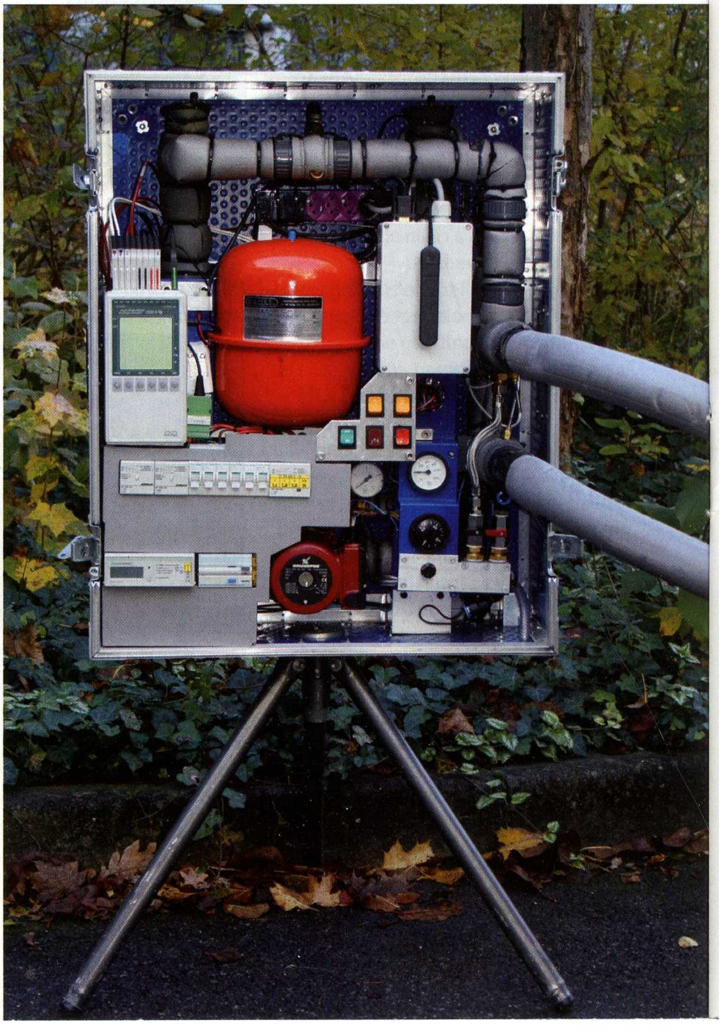

Figure 2: the EPFL-LMS in-situ thermal-response testing device, after Mattsson, N, Steinmann, G, Laloui, L., 2008. 'Advanced Compact Device for the In-situ Determination of Geothermal Characteristics of Soils', Energy and Buildings, doi: 10.1016/j.enbuild.2007.12.003

GEOTHERMAL LIVE! TALKS

Prof Laloui will present two papers at Geothermal Live! on May 1: 'Formation thermal conductivity testing' in the session at 9.05-10.30am; and 'Experimental and numerical investigations of the behaviour of a heat exchanger pile' in the session taking place 2.05-3.30pm.

design method in order to reduce the economic cost of the energetic geostructure on the one hand and increase the energetic efficiency of the system on the other, which will also rationalise the environmental impact.

As geoengineers, we are concerned by the complexity of soil materials, whose mechanical behaviour is everything but linear and reversible, and which host many multi-physics processes. The core issue to focus on here is the modification of soil mechanical behaviour upon temperature changes.

Our research activities on the heat-exchanger piles theme are then aimed at providing the correct answers to the actual questions from practitioners. By the means of *in situ* full-scale testing, modelling and developing numerical tools, we are now able to quantify the long-term effects of cyclic temperature variations on the bearing capacity of a concrete pile.

Interestingly, we can prove, for instance, that temperature increase enhances the performance of the pile and the resilience of the soil under cyclic loading (such as earthquakes).

> **"The ultimate, scientific challenge is now to provide a practical design tool that combines the energetic geostructure and building-service behaviour with the thermo-hydro-mechanical behaviour of the soil"**

We also offer our expertise out of the Ecole Polytechnique Fédérale de Lausanne laboratory (EPFL), by carrying out *in situ* thermal-response tests. Such tests provide an effective method to determine the ground-thermal properties required for the design of a geothermal-energy installation. This service is based on a unique, compact, testing device for *in situ* thermal-response testing (see figure 2).

The understanding of fundamental aspects of heat storage in soils and soil-pile interactions contributes to rationalising the design process by reducing the applied safety factors significantly. For this purpose, the development of a numerical tool, taking into account a wide range of thermo-hydro-mechanical couplings arising in soil is essential.

If the applicability of our conceptual approach to heat-exchanger structures has been demonstrated, the ultimate, scientific challenge is now to provide a practical design tool that combines the energetic geostructure and building-service behaviour (temperature and loads) with the thermo-hydro-mechanical behaviour of the soil. Once optimised from both an energetic and a mechanical viewpoint, the heat-exchanger geostructure will become one of the most intelligent and cost-effective methods to valorise the intrinsic soil energy.

Mathieu Nuth, Dr Hervé Péron and Prof Lyesse Laloui. Soil Mechanics Laboratory, Ecole Polytechnique Fédérale de Lausanne, Station 18, CH 1015 Lausanne, Switzerland. Email: Lyesse.Laloui@epfl.ch