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Analysis and design methods for energy geostructures

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ABSTRACT

Based on discussions at the international workshop on "Thermoactive geotechnical systems for near-surface geothermal energy", hosted at École Polytechnique Fédérale de Lausanne (EPFL), Switzerland (http://www.olgun.cee.vt.edu/workshop/), this article attempts to provide a broad overview of the analysis methods used for evaluation of systems that use either boreholes or geo-structures for heat exchange. It identifies commonalities where knowledge transfer from the former to the latter can be made, and highlights where there are significant differences that may limit this cross-fertilisation. The article then focusses on recent developments and current understanding pertaining to the analysis of the thermo-mechanical interaction between a geostructure and the ground, and how this may be incorporated into the geotechnical design of energy geostructures.

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Nomenclature

AR	Pile length to diameter ratio
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BHE	Borehole Heat Exchanger
CTE	Coefficient of Thermal Expansion
DST	Duct Ground Heat Storage
EGS	Energy Geostructure(s)
FEA	Finite Element Analysis
GSHP	Ground Source Heat Pump
HDPE	High Density Polyethylene
MLS	Moving Line Heat Source
PHE	Pile Heat Exchanger
SBM	Superposition Borehole Model
SGE	Shallow Geothermal Energy
SPF	Seasonal Performance Factor
TBM	Tunnel Boring Machine
THM	Thermo-Hydro-Mechanical
UTES	Underground Thermal Energy Storage

Symbols

MW_{th}	Mega-Watts thermal
H	borehole depth
h	hours
$\dot{q}_b$	heat flux
r_b	borehole radius
T	Temperature (of borehole wall) at time t
T_0	Initial temperature (of borehole wall)
T_{in}	Inlet fluid temperature
T_{out}	Outlet fluid temperature
ΔT	Temperature change in pile
t	elapsed time
t_s	time to steady state
α	soil thermal diffusivity
α_T	linear coefficient of thermal expansion of pile
ε	strain
ε^e	elastic strain
ε^{th}	thermal strain
λ	ground thermal conductivity
ψ_i	variable action factors

1. Introduction

The use of the ground as a means for managing the thermal loads within buildings is a well-established technology and borehole heat exchange systems have been used for several decades, especially following the “oil shocks” of the 1970s.

Worldwide installed Ground Source Heat Pump (GSHP) capacity is estimated to have increased nearly twenty-fold between 1995 and 2010, from about 1854 MW_{th} to 35,236 MW_{th} and more than doubled from 15,384 MW_{th} in 2005 [1]. To the end of 2012, installed capacity of GSHP and Underground Thermal Energy Storage (UTES) systems in Europe, was estimated to total approximately 16,500 MW_{th} [2]. Lund et al. [1] annualise the growth in this period to a rate of about 20% and Antics et al. [2] suggest that growth within the geothermal energy sector in Europe, which is dominated by GSHP systems, was estimated to be about 30% in the two years to 2015.

While the borehole heat exchange technique is well established, continuing research and development is focussed on reducing installation costs, i.e. speed/ease of installation, improved borehole heat transfer and heat pump efficiency, and more refined models for use in design [3–5].

The GSHP and UTES installations referred to in the above figures are entirely borehole based systems; increasingly, however, designers and developers are looking to use engineering structures where heat absorber pipes are integrated within structures in contact with the ground, as the means for providing thermal exchange with the ground. These applications have been referred to variously as energy foundations, thermo-active ground structures [6], geothermal piles, heat exchanger piles and energy geostructures [7] – this latter will be used here.