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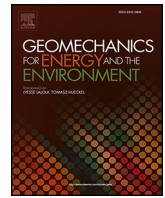
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# Geomechanics for Energy and the Environment

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## Accelerating the Energy Transition with Energy Geotechnics: editorial

### ARTICLE INFO

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It is clear that to address climate change, an energy transition which makes a large-scale use of the subsurface is needed. The subsurface will play a critical role in this transition, serving as a resource for new sources of energy production and storage, a foundation for energy infrastructure, and a repository for waste by-products from energy production (e.g., radioactive waste disposal, CO<sub>2</sub> geo-sequestration). Furthermore, there are challenges in understanding material behaviour due to complex coupled phenomena, measuring material properties and upscaling the physical phenomena to engineering scale structures. Uncertainties, heterogeneities and long timescales offer additional challenges, as does bringing technology ever closer to dense populations. This is the topic of Energy Geotechnics. In the next decade and decades, society needs to complete the energy transition, and to do so the already substantial changes need to be vastly accelerated. This brings many challenges, which academics, consultants, contractors and authorities need to address together.

This special issue brings together the latest research outcomes, drawing inspiration from selected contributions presented at the 3rd Symposium on Energy Geotechnics (SEG23), held in Delft on the 3–5 October 2023. The symposium was organised under the auspices of Technical Committee (TC) 308 (Energy Geotechnics) of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The topic of energy geotechnics has been developing for a number of decades, with ISSMGE recognising its importance in 2013 with the establishment of TC 308. The TC has about 90 members from over 40 countries, and has organised itself into 9 technical taskforces: i. High-level radioactive waste disposal, ii. Deep sea mining, iii. Energy geo-structures & storage of thermal energy in the ground, iv. Unconventional hydrocarbons, v. Energy geo-storage, vi. CO<sub>2</sub> geological storage, vii. Fundamentals of geo-energy, viii. Low-carbon geotechnical engineering, and ix. Other geotechnical activities related to energy). The flagship events of TC 308 are the symposia and conferences that are organised alternately every ~4 years, such that a major event is held every 2 years. Past events include symposia in Barcelona (2015) and

Lausanne (2018) and conferences in Kiel (2016) and La Jolla (2022), with the organisation of the next conference in Paris in 2025 well underway. For more information on the TC, see Narsilio et al.<sup>16</sup>, a contribution to this special issue.

Given both the urgency of the topic and its relative maturity, the topic of the symposium in Delft was chosen to be *Accelerating the Energy Transition with Energy Geotechnics* which put some focus on linking with industry and moving academic insights into practice. Of course, further fundamental insights are still needed, and will be for a long time to come, but it was felt that emphasis needed to be placed on making concrete contributions to the energy transition. This approach could be seen with the organising committee, with three members from academia (Philip Vardon, Anne-Catherine Dieudonné and David Smeulders), one member from a national research organisation (Ahmed Elkadi) and two from industry (Jacco Haasnoot and Siefko Slob) – supported capably by the professional conference organiser Nicole Fontein. A scientific committee augmented the work of the local organising committee, with Philip Vardon and Anne-Catherine Dieudonné joined by the chair of the past conference John McCartney and Jean-Michel Pereira. Technical tours further demonstrated the link between industry and academia. There were tours during the symposium day to the deep geothermal project that was being installed on the Delft University of Technology campus – which combines uniquely both research and commercial energy delivery. After the symposium there were tours to the Maasvlakte 2, a container port and energy hub, and to Mol where both the underground research laboratory HADES and the deep geothermal power plant Balmatt were visited.

The keynote speakers covered a cross-section of industry-academia, geographic locations, career progression and representativeness of colleagues. The speakers gave high-level inspiring lectures on the following topics, demonstrating a wealth of experience and depth of knowledge:

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- Wessel van Kesteren (Fugro, the Netherlands): Integrated geotechnical ground models in the energy transition: challenges and opportunities
- Susan Gourvenec (University of Southampton, UK): Offshore geotechnical challenges of the energy transition
- Marcelo Sanchez (Texas A&M University, USA): An experimental and numerical investigation on gas breakthrough phenomena in engineered barrier systems
- Chloé Arson (Georgia Institute of Technology, USA): Micro-macro damage and healing mechanics in halite for geostorage
- Ioannis Stefanou (Ecole Centrale Nantes, France): Transforming the underground into a huge source of renewable energies by controlling induced seismicity

To further gain insights from their experience, we asked the keynote speakers to author an opinion article, which was non-peer reviewed and published in the symposium magazine. We decided to take this approach to generate discussion on opinions, which alongside facts, are important to drive forward implementation.

In addition, a new European network for Fostering Large-scale Implementation of Energy Geostorage (FOLIAGE) was introduced and a lively discussion session between two ISSMGE TCs (TC 106 and TC 308) was held. We also were able to provide a platform for two Bright Spark lectures, who were nominated and elected by TC 308. Benjamin Cerfontaine (University of Southampton, UK) and Melis Sutman (then at Heriot-Watt University, UK) gave two extended presentations on their current and recent work, both relating to different types of foundation, silent foundations for offshore wind turbines and energy geo-structures, respectively.

During the symposium, 24 themed technical sessions were held, covering a plethora of topics related to energy geotechnics. Open access peer-reviewed extended abstracts of each of the 145 oral presentations are found here: <https://proceedings.open.tudelft.nl/seg23/>. From these presentations, the session chairs recommended talks that they considered suitable for extending into full length technical papers, and those authors were approached for this special issue. In addition, to ensure presentation of the most up to date and interesting information an open call to authors present at the symposium was made. All contributions were thoroughly peer reviewed, and this special issue is the result of that process. We would like to thank the reviewers and session chairs for their contributions.

A 'sister' special issue was launched in *Tunnelling and Underground Space Technology*, entitled Emerging Technologies for a Sustainable Underground Space: Accelerating the Energy Transition and Adaptation to Climate Change<sup>17</sup>, which focused more on planning and the explicit link to climate change, but as is expected for two special issues arising from the same symposium there is some overlap in focus. The topic of both special issues recognises the 'need to get it done', and that energy geotechnics has the potential to make a high impact on climate mitigation.

The contributions sit at the cutting edge of current developments. Two contributions took a wide view of energy geotechnics, Gourvenec<sup>9</sup>, based on her keynote presentation, analyses the geotechnical challenges in offshore wind and in addition presents the wider context, both challenges in the societal, regulatory and environmental challenges, and the impact of inaction. Narsilio et al<sup>17</sup>. takes a different approach, reporting and extending the results of the animated panel discussion between two TCs of the ISSMGE. TC 308 'energy geotechnics' (the TC responsible for the symposium) considers an applied topic, with TC 106 'unsaturated soils' being a TC which focuses on fundamental understanding, with the paper focusing on the nexus between them.

The other contributions can be categorised by their application. Several contributions focus on the implementation of shallow geothermal or geo-structure systems, in particular on:

- (i) new systems: road solar collectors<sup>8</sup> which also includes novel model development in the development of surrogate models, bridge deck de-icing<sup>11</sup> and energy quay walls<sup>7</sup>
- (ii) field testing, leading to insights relevant for optimising design: choices in connecting energy piles in series and parallel energy pile<sup>5</sup>, characterisation of effects of thermal cycles under different mechanical loads<sup>20</sup>, and testing of new site characterisation methods, i.e. thermal response tests<sup>6</sup>
- (iii) impact of climate change scenarios on energy geo-structures, in this case energy diaphragm walls<sup>15</sup>

Another set of contributions relate to deep resource extraction and fracture flow behaviour, with combined experimental / numerical work relating to permeability changes in fractured rock<sup>18,19</sup>, a constitutive modelling approach using a state-of-the-art model in the analysis of data on materials suitable for caprocks<sup>3</sup> and a new approach for modelling coupled thermo-hydro-mechanical processes in fractured reservoirs<sup>4</sup>. Saifullin et al<sup>21</sup>. addressed two key problems, one the creation of surrogate/proxy models to substantially reduce computational time and the structural incorporation of measured data in model calibration via data assimilation. A highly novel concept, based on one of the keynote presentations, is a simulated approach to control seismicity using control theory and measurements, whereby it is proposed to control fluxes in injection wells in response to live measurements to control seismicity<sup>10</sup>.

The last category is the material behaviour of geo-materials in response to thermo-hydro-chemo-mechanical impulses, which is an ongoing topic relevant for the whole range of energy geotechnics topics. Many contributions relate to the disposal or containment of wastes and fluids, with a particular focus on radioactive waste disposal. Buffer materials are investigated, with examination of hydration under high temperatures<sup>14,2</sup>, the impact of groundwater flow on the erosion of buffer materials<sup>13</sup>, and the impact on chemistry on the mechanical behaviour<sup>1</sup>. As well as in deep resource extraction where coupled hydraulic-mechanical fracture and fracturing behaviour are of importance, this topic is also of importance in the containment of wastes, where a contribution on the modelling of desiccation fracturing is included, where continuum and discontinuum approaches are combined<sup>12</sup>.

Within the categories above, approaches include the identification of needs, conceptual developments, field testing and new numerical model development. This illustrates the range of needs in energy geotechnics, but also the vibrant community that exists and comes together in the international symposia and conferences organised by TC 308.

We hope that you find this special issue informative and inspiring, and look forward to further meetings of the community in the next conferences and symposia.

#### CRediT authorship contribution statement

**Guillermo Narsilio:** Writing – review & editing. **David Smeulders:** Writing – review & editing. **Jean-Michel Pereira:** Conceptualization, Writing – review & editing. **John S. McCartney:** Writing – review & editing. **Anne-Catherine Dieudonné:** Conceptualization, Writing – review & editing. **Philip J. Vardon:** Conceptualization, Writing – original draft.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

No data was used for the research described in the article.

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