Imperial College London

Department of Civil and Environmental Engineering

Geotechnics Section

Project: Effect of ground water composition on the design of a nuclear waste disposal facility

Type: Computational

Supervision: Prof. Lidija Zdravkovic (ICL), Prof. David M. Potts (ICL), Dr Jon Harrington (BGS)

Funding: EPSRC CDT in Nuclear Energy Futures and Nuclear Waste Services (NWS)

Background

Nuclear energy currently forms around 20% of UK's electricity supply and will be one of the main clean energy sources to underpin the Government's target of net zero carbon emission by 2050. The safe disposal of nuclear waste, comprising not only the newly created waste but also the existing 5 million tonnes of waste at different levels of radioactivity, is key to this strategy. The UK Government is committed to delivering a geological disposal facility (GDF) as an internationally accepted long-term solution for sustainable management of nuclear waste. This is envisaged to be one of the largest environmental projects ever undertaken, with a facility constructed 0.5 to 1 km below the ground surface and with an estimated 15-20 square kilometres footprint.

The GDF concept encompasses deposition of canisters of waste deep underground, in depositional holes excavated in a suitable geological formation. To manage the environmental risk associated with this disposal concept, the design of the disposal solution requires multiple barriers, one of which is emplaced between the canister and the host formation in the form of compacted unsaturated bentonite clay when initially installed in a deposition hole. Its purpose is to protect the canister from corrosion and to retard migration of contaminants that may leak from a failed canister. The nature of unsaturated soils is that their voids are infilled with both water and air. The function of a bentonite buffer is to become saturated during the GDF lifetime, by receiving water from the surrounding natural host environment. This process enables the bentonite to swell, promoting the sealing of any construction gaps and, ultimately, saturation and homogenisation of the buffer. The main challenge in this process is to quantify the long-term interplay between the dual porosity of compacted bentonite, comprising macro-porosity, as the void space between compacted clay aggregates, and micro-porosity, as the void space within the clay aggregates. Recent experimental research[1], in particular using Mercury Intrusion Porosimetry (MIP), has demonstrated that the initial distribution of bentonite's dual porosity depends on its initial state (stresses, dry density, suction), while the final state upon saturation can show either a single or a double porosity. Additional factors in this hydro-mechanical (HM) coupling are the temperature imposed by the energy generated in the canister, making it a thermo-hydro-mechanical (THM) process, and the composition of the ground water, which extends it to a THM-chemical process (THM-C). Most of the research conducted to date has examined the interaction of compacted bentonite with fresh water.

Proposed research and research methodology

To address the gap in knowledge of how different solutes in the ground water may affect the evolution of porosity in the bentonite barrier, advanced numerical modelling will be performed as part of this PhD research. The bespoke finite element (FE) software ICFEP[2] (Imperial College Finite Element Program) will be employed, which is a world-class computational facility for state-of-the-art modelling of geo-materials. The software has a fully coupled THM formulation for saturated[3] and unsaturated[4] soils and a dual-porosity constitutive model[5] (Imperial College Double Structure Model, ICDSM). This formulation has been successfully applied in the THM simulations of laboratory element tests and full-scale field experiments[6] conducted at temperatures of up to 100^{o}C in fresh water, as part of the Euratom BEACON project (https://www.beacon-h2020.eu/). This THM formulation is currently being extended to take account of vapour flow for the modelling of the HotBENT full-scale experiment (https://grimsel.com/gts-projects/hotbent-high-temperature-effects-on-bentonite-buffers/hotbent-introduction), in which the bentonite buffer is exposed to temperatures of up to 200^{o}C.

The THM-C development envisaged for the proposed project will be conducted in conjunction with the appropriate experimental data to characterise the behaviour of compacted bentonite exposed to different ground water composition. The data will be sourced from literature, from collaboration with the British Geological Survey (BGS, Dr Jon Harrington), from the BEACON project and at a later stage also from the HotBENT project. The project aim is to deliver a robust THM-C coupling procedure for predictive computational modelling of long-term bentonite barrier evolution, which will underpin the safe design of nuclear waste disposal facilities.

Academic requirements and experience

Essential: A first class or good 2:1 honours degree in Engineering (preferably Civil), Geo-sciences, Physical or Mathematical sciences. Excellent written and verbal communication. Willingness to collaborate with both external and internal project partners. Enthusiasm for managing environmental risks in infrastructure design. Comfortable with computational modelling.

Desirable: Mechanics (in particular of geo-materials), mathematics, coding, computer modelling and simulations with the finite element method, data analysis of laboratory and field experiments of geo-materials. A masters level degree qualification in any course with strong emphasis on soil mechanics and computational analysis would be advantageous.

How to apply

Applicants wishing to be considered for this opportunity should email their current CV to Prof. Lidija Zdravkovic (l.zdravkovic@imperial.ac.uk) in the first instance, detailing their academic record and supplying degree transcripts where appropriate. The project is conducted in conjunction with the EPSRC Centre for Doctoral Training (CDT) in Nuclear Energy Futures (https://www.imperial.ac.uk/nuclear-cdt/programme/) and applicants will be subjected to additional interviewing with the CDT management team.

Funding note

The studentship will provide funding for 4 years, including home-level fees, a UKRI minimum stipend, and a research, travel and consumables budget. It is available to UK citizens or those with the right to remain in the UK. The funding can also be used to partly support an international student. The start date of the PhD position is 1 October 2022.

References

[1] Seiphoori A, Ferrari A, Laloui L 2014. Water retention behaviour and microstructural evolution of MX-80 bentonite during wetting and drying cycle. *Geotechnique* 64 (9): 721-734.

[2] Potts DM, Zdravkovic L 1999. *Finite element analysis in geotechnical engineering: theory*. Thomas Telford Publishing, London.

[3] Cui W, Potts DM, Zdravkovic L, Gawecka KA, Taborda DMG 2018. An alternative coupled THM finite element formulation for fully saturated soils. *Computers and Geotechnics* 94: 22-30.

[4] Potts DM, Cui W, Zdravkovic L 2021. A coupled THM finite element formulation for unsaturated soils and a strategy for its nonlinear solution. *Computers and Geotechnics* 136 (104221).

[5] Ghiadistri GM 2019. *Constitutive modelling of compacted clays for applications in nuclear waste disposal*. PhD thesis, Imperial College London.

[6] Ghiadistri G.M., Potts D.M., Zdravkovic L. & Tsiampousi A. (2019). Calibration of a double structure constitutive model for unsaturated compacted soils.; *7th Int. Symp. on Deformation characteristics of geomaterials, IS-Glasgow 2019*, Glasgow, UK; E3S Web Conf. 92, 15002 https://doi.org/10.1051/e3sconf/20199215002