Imperial College London

NUMERICAL STUDY OF THE SWELLING BEHAVIOUR OF BENTONITE BUFFERS

George A. Appleby **Supervised by Dr. Katerina Tsiampousi and Prof. Lidija Zdravkovic**

Geotechnics Section, Department of Civil and Environmental Engineering, Imperial College London

1. OVERVIEW

Disposal of high level nuclear waste in deep geological repositories is considered at present to be the most viable long term waste management strategy. Current designs involve encapsulating the radioactive waste inside copper canisters and burying them hundreds of metres below ground level. Cylindrical holes will be bored into the host rock and clay blocks, approximately one metre thick, will be placed around the peripherals of the hole, leaving an annulus in the centre where the canister will be inserted. The clay blocks form an engineered barrier system known as a buffer which intends to mitigate the migration of radioactive nuclides into the surrounding biosphere.

The buffer comprises an initially partially saturated clay, such as bentonite, which has a high swelling potential when wetted. Swelling under confined conditions reduces the size of pores which fluids pass through, in turn decreasing permeability.

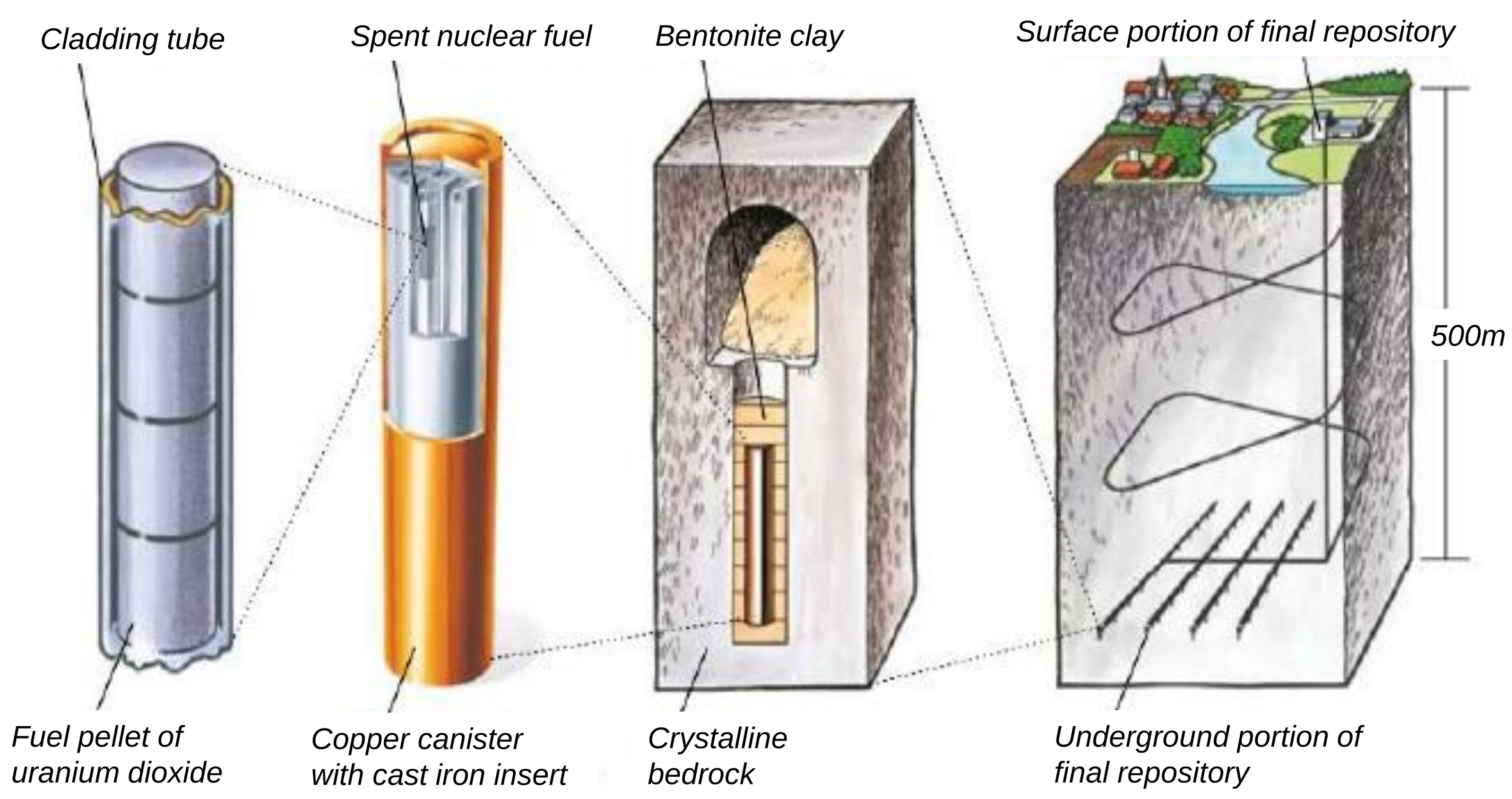


Figure 1: Disposal scheme proposed by the Swedish Nuclear Fuel and Waste Management Company (SKB) (Elfwing et al., 2013).

2. AIM, OBJECTIVES AND METHODOLOGY

Aim: To assess the capability of current numerical models in simulating the swelling response of a bentonite clay subject to hydration under confined conditions.

Objective 1: Calibrate the numerical model.

Objective 2: Simulate a boundary value problem.

Methodology: Numerical tools – Imperial College Finite Element Program (Potts and Zdravkovic, 1999).

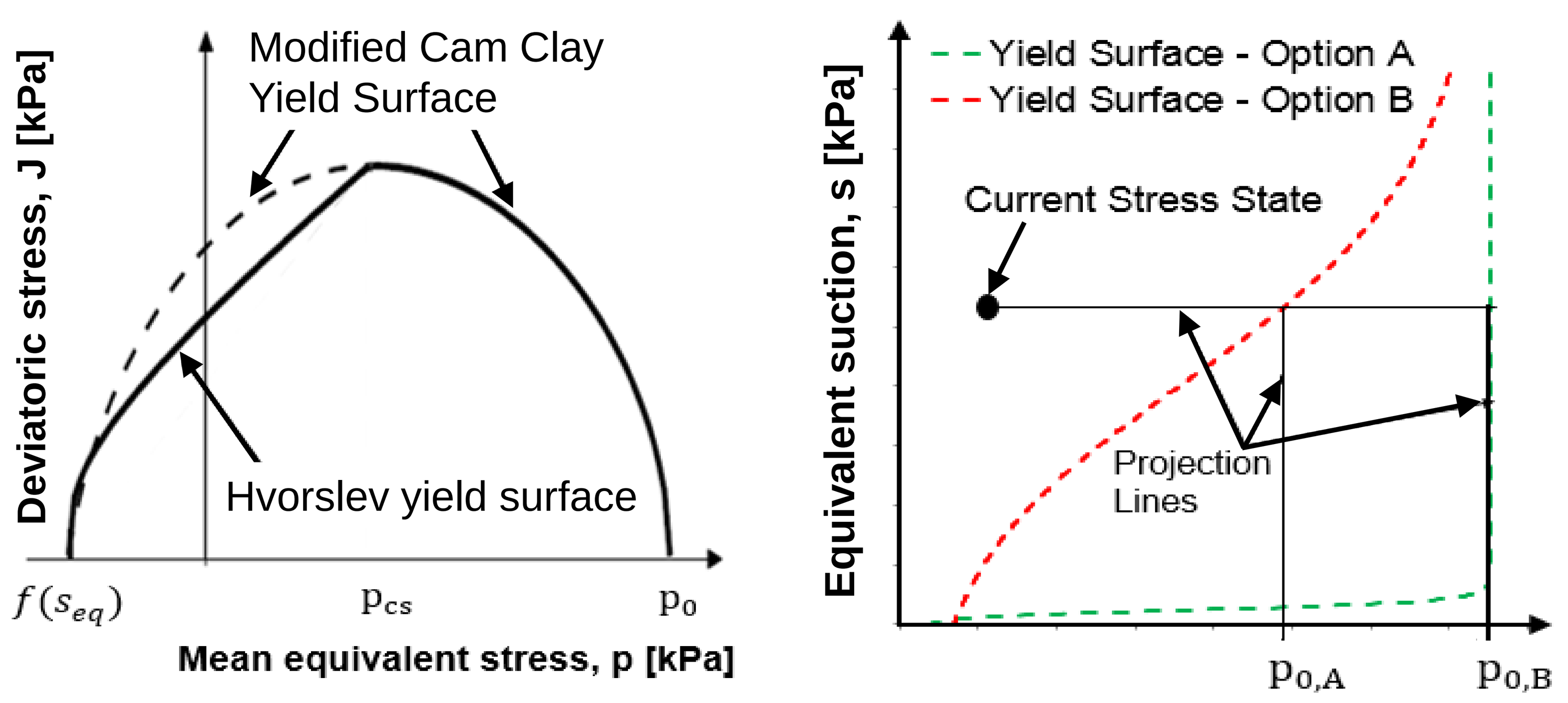
3. CALIBRATING MODEL PARAMETERS

The soil constitutive and water retention models were calibrated against laboratory tests conducted by Villar (2005).

No one set of parameters could fit all tests concurrently. In turn three different sets of parameters were defined which all gave reasonable fits to the targeted tests: *Best Fit 1, 2* and a *compromise* solution.

The main differences between the parameter sets was the shape of the initial yield surfaces in the $p-J$ and $p-s$ planes:

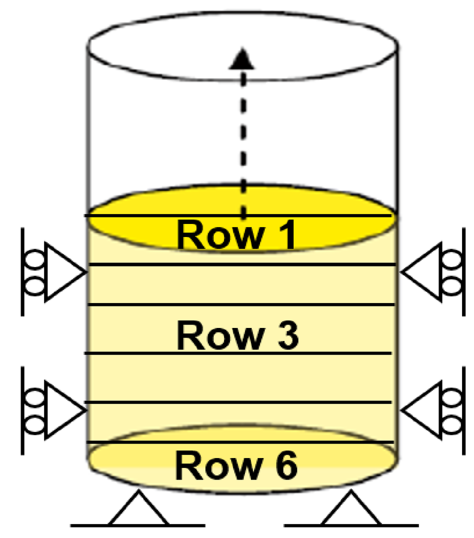
- $p-J$: with or without a Hvorslev yield surface.
- $p-s$: two distinct shapes were defined.



(Adapted from Tsiampousi (2011))

Figure 2: Different shapes adopted for the yield surfaces in the three parameter sets.

4. BOUNDARY VALUE PROBLEM



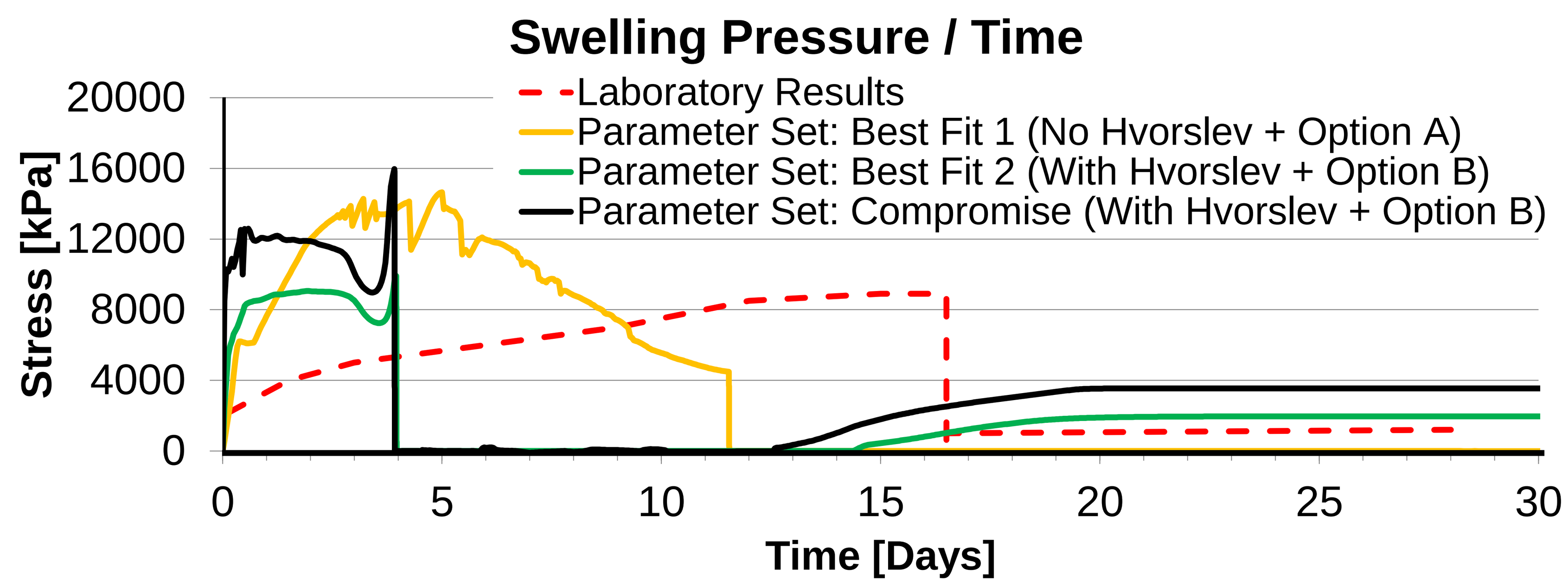
Testing and Simulation Sequence:

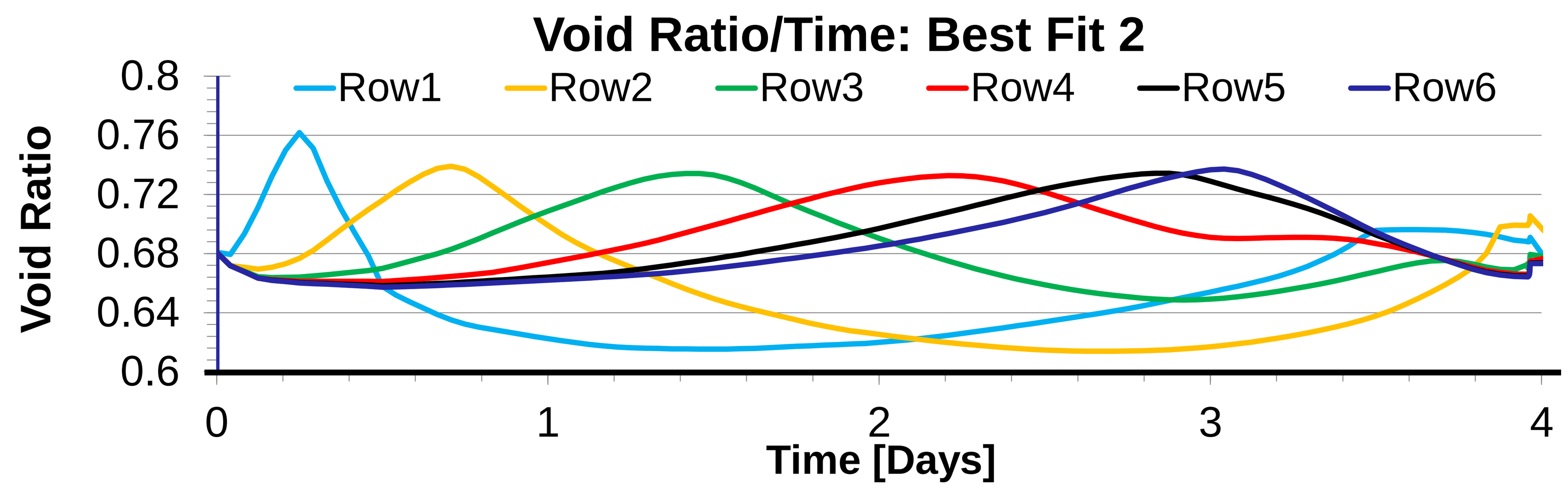
- **Step 1:** Hydrate from the top face under confined conditions.
- **Step 2:** Release the vertical confinement once the swelling pressure became constant with time and continue to hydrate the top face.
- **Step 3:** Reinstate vertical confinement once 5mm of swelling was achieved and continue to wet the top face.

Figure 3: Schematic of the simulated test (Dueck et al., 2011).

Simulated Results and Findings:

1. The simulation predicted full saturation ($S_r = 1$ & $s < s_{air}$) too early.
   Reasoning: Hydrating the clay led to an increase in swelling pressures and a reduction in suction which caused the voids to collapse; use of a 3D water retention model with a dependency on void ratio in turn meant the soil became fully saturated sooner. The soil permeability model was also inherently responsible for the advance of the saturation front.
2. The *Best_Fit_2* parameter set provided a good fit to the maximum swelling pressure.
   Reasoning: Synchronisation of the collapse and expansion of voids over the height of the specimen which formed a wave like pattern as the saturation front progressed downwards.
3. Swelling pressures after the release were only reproduced when using a Hvorslev surface.
   Reasoning: Yielding dry of critical state on a Hvorslev surface, produced larger dilative strains than yielding on the modified Cam clay ellipse.





Simulation results. "Option A and B" refers to the shape of the yield surface in the p-s plane (Figure 2). "Row" refers to the section the void ratio was evaluated at (Figure 3).

5. CONCLUSIONS

- The shape of the yield surfaces in both planes is fundamental in determining the response.
- More laboratory tests are required to accurately calibrate the model.
- The model should be further developed to incorporate microstructure affects.

REFERENCES

Dueck, A., Goudarzi, R. & Borgesson, L. (2011) Buffer Homogenisation, Status Report. Swedish Nuclear Fuel and Waste Management Co. Report number: TR-12-02.

Elfwing, M., Evins, L. Z., Gontier, M., Grahm, P., Mårtensson, P. & Tunbrant, S. (2013) SFL concept study, Main report. Swedish Nuclear Fuel and Waste Management Co. Report number: TR-13-14.

Potts, D.M. & Zdravkovic, L. (1999) Finite element analysis in geotechnical engineering – theory. London, Thomas Telford Publishing.

Tsiampousi, A. (2011) Numerical Analysis Of Slopes In Unsaturated Soils. PhD Thesis. Imperial College London, UK.

Villar, M.V. (2005) MX-80 Bentonite. Thermo-Hydro-Mechanical Characterisation Performed at CIEMAT in the Context of the Prototype Project. Informes Técnicos Ciemat, 1053.