Three-dimensional simulation of the desaturation and resaturation of a hypothetical repository in a deep clay formation

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Background and Scope

General Framework

- Deep indurated clay formation as a potential host rock
- Underground structures:
  - ➔ Access and ventilation shafts
  - ➔ Access, emplacement, ventilation and construction drifts
- Backfill materials: concrete, sand/bentonite mixtures, bentonite
- Wastes Types:
  - ➔ B-waste: low to medium level, long-lived waste in long and large diameter emplacement tunnel),
  - ➔ C-waste: high level, long-lived waste (short emplacement tunnel)

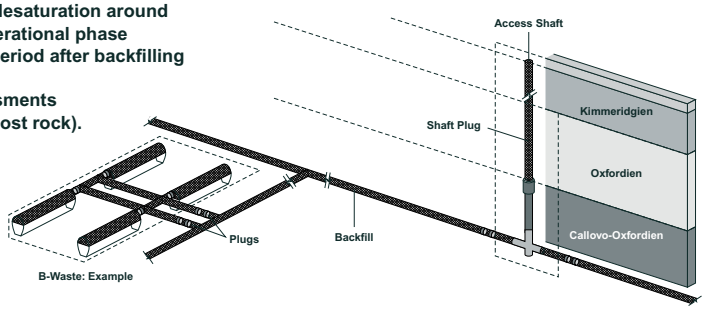
Scope of the 3D numerical simulations

Assess the impact of 3D structure on the desaturation and resaturation process:

- determination of the extent of the desaturation around the drifts and shafts during the operational phase
- determination of the resaturation period after backfilling

➔ Major importance for safety assessments (release of radionuclides into the host rock).

Schematic view of the hypothetical repository



Physical Processes and Conceptualisation

Ventilation

Ventilation of the repository during the construction of the drifts, the waste emplacement and the backfilling phases:

- Progressive lowering of the pore pressure within the host rock
- Progressive desaturation of the host rock (suction effect of the ventilation, i.e. drying

Resaturation

Start: 2 years after excavation for emplacement drifts, after 50 years for access drifts and shafts

End: after complete resaturation of the host rock and the backfilling materials, the pressure in the water phase slowly equilibrates towards the hydrostatic conditions

Mathematical Conceptualisation

- Equivalent porous medium and viscous and capillary driven unsaturated water flow.
- Air is infinitely mobile, no friction resistance
  - ➔ generalized Darcy's equation, Richards equation for unsaturated flow

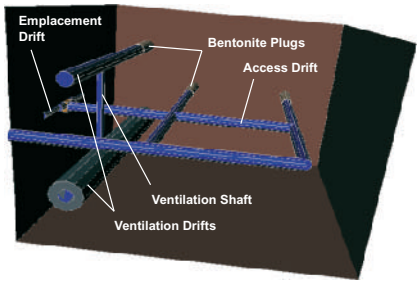
- Unsaturated zone hydraulic properties for each type of material:
  - ➔ Bentonite: buffer material at the emplacement drifts and for the plugs
  - ➔ Concrete: cladding of the drifts
  - ➔ Sand/bentonite mixture: backfilling material in access and ventilation drifts and shafts.
  - ➔ Host rock: indurated clay.

Material Parameters

Material	K [m/s]	S [m^{-1}]	Porosity [-]	Residual Water Saturation [-]	Initial Water Saturation [-]	Air Entry Pressure [Pa]	Van Genuchten Coefficient n [-]
Undisturbed host rock (clay)	10^{-13}	$4.4 \cdot 10^{-6}$	0.14	0.15	1	$1.54 \cdot 10^{7}$	1.49
Disturbed host rock	10^{-11}	$4.4 \cdot 10^{-6}$	0.14	0.15	1	$1.54 \cdot 10^{7}$	1.49
Concrete	10^{-11}	10^{-6}	0.15	0.00	1	$2.00 \cdot 10^{6}$	1.54
Bentonite plugs	10^{-11}	$6.4 \cdot 10^{-3}$	0.35	0.00	0.7	$1.80 \cdot 10^{7}$	1.61
Compacted clay (shafts)	10^{-9}	$6.4 \cdot 10^{-3}$	0.30	0.01	0.7	$1.54 \cdot 10^{7}$	1.49
Sand/clay (drifts)	10^{-6}	$5.7 \cdot 10^{-5}$	0.43	0.08	0.7	$2.00 \cdot 10^{3}$	1.55

3D Numerical Investigations: An example

3D-structure for C-waste at the entrance of the disposal area

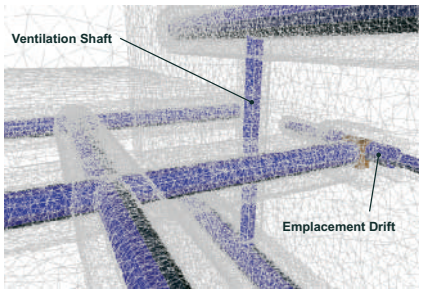


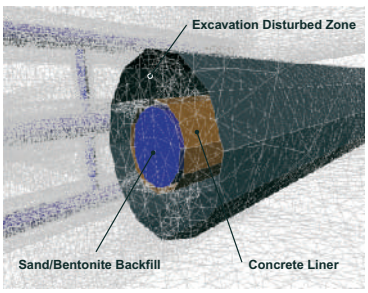
Tools

- 3D-Meshing: Mesh Automatic Generator for Integrated Complex Structures MAGICS
- Unsaturated flow computations: NAMMU- Finite Element code

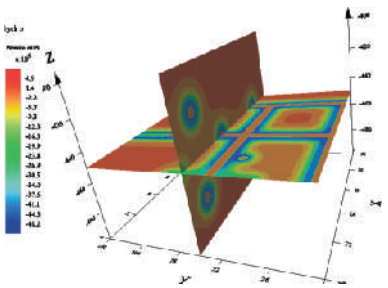
Meshing and Results

- Significant interference between the impacts of the drifts and shafts occurs during the operational phase
- Resaturation process is slow: no full saturation was achieved after 8'500 years.

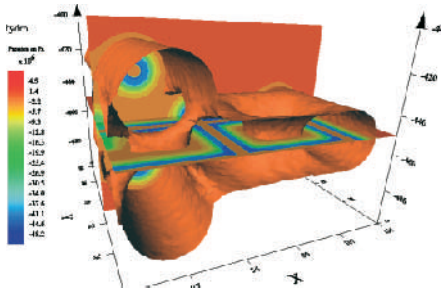




- Tetrahedral or hexahedral elements, based on a constraint Delaunay mesh refinement technique.
- Optimally sized mesh was obtained by using a nested approach based on linear tetrahedral elements.
- 800'000 tetrahedral elements (roughly 150'000 nodes)



Cross-sections through the structure: Pressure distribution at 100 years desaturation time.



Cross-sections through the structure: Pressure distribution and atmospheric isosurface (P) at 100 years desaturation time.

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