Underground Research Laboratory

Prediction of the tunnels behavior during excavation in the short- and long-term based on FLAC3D simulations

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Summary

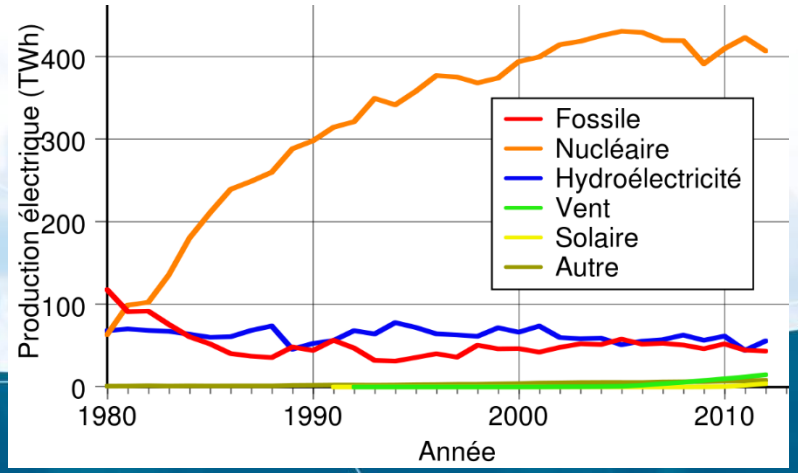
- Introduction
- Presentation of the Meuse/Haute-Marne Underground Research laboratory (URL)
- Numerical models of intersections
- Results

Nuclear Power in France

- Beginning of the Nuclear energy in France : 1950

- France derives about 75% of its electricity from nuclear energy, due to a long-standing policy based on energy security.

- Government policy is to reduce this to 50% by 2035. France is the world's largest net exporter of electricity.



Long life nuclear waste

- Given half-lifes of up to several tens of thousands years, the reference solution of the French law is to dispose of containers in a deep geological disposal facility (Cigeo).

- The licensing demand is under preparation for obtaining the authorization to create Cigeo.

- The waste will be disposed of in cells excavated to a depth of 500 meters in a stable geological environment (impermeable argillaceous rocks).

Why the Meuse/Haute-Marne Underground Research Laboratory ?

- The Meuse/Haute-Marne Underground Research Laboratory (MHM URL) was authorized by the French government in 1999 for research activities dedicated to reversible, deep geological disposal of high-level and intermediate level long life radioactive waste in a claystone formation (Callovo-Oxfordian – COx claystone)

- This formation is lying between about 420 and 550 m below the surface.

- Several major goals are supported:
  - A scientific characterization of the geological environment,
  - An understanding of excavation and operational effects on the host rock,
  - Demonstration experiments to optimize concept of the different components of Cigéo project, the deep geological repository for high level and intermediate level long life nuclear waste.

Site Geology

Approximate depth above the sea level

Surface ≈ 360 m

Possibly karst limestones
Presence of water table

310 m

Marls then limestones

200 m

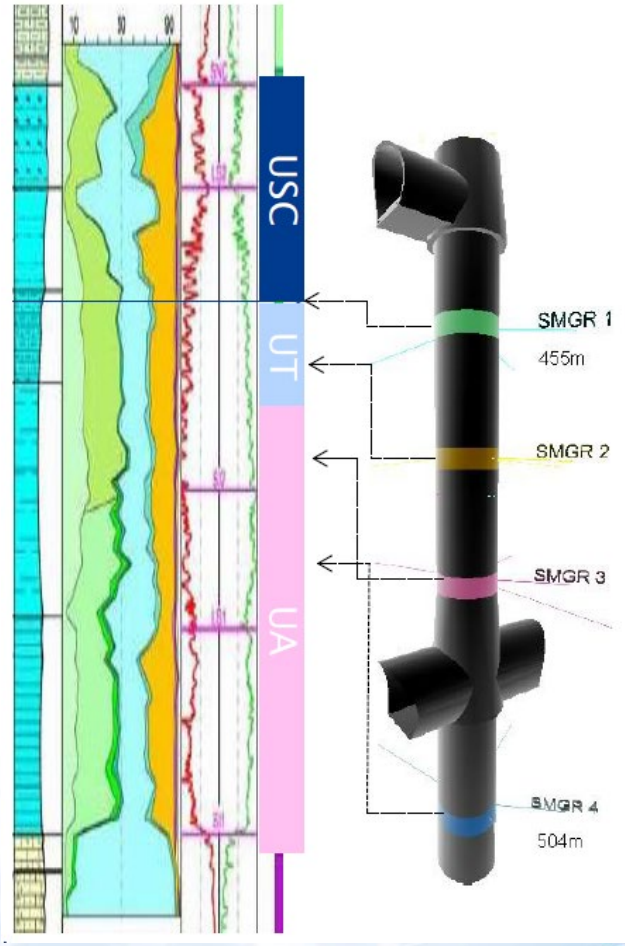
Oxfordian limestone → Different types of limestones
Groundwater presence

- 80 m

Callovo-Oxfordian → **Argilites**

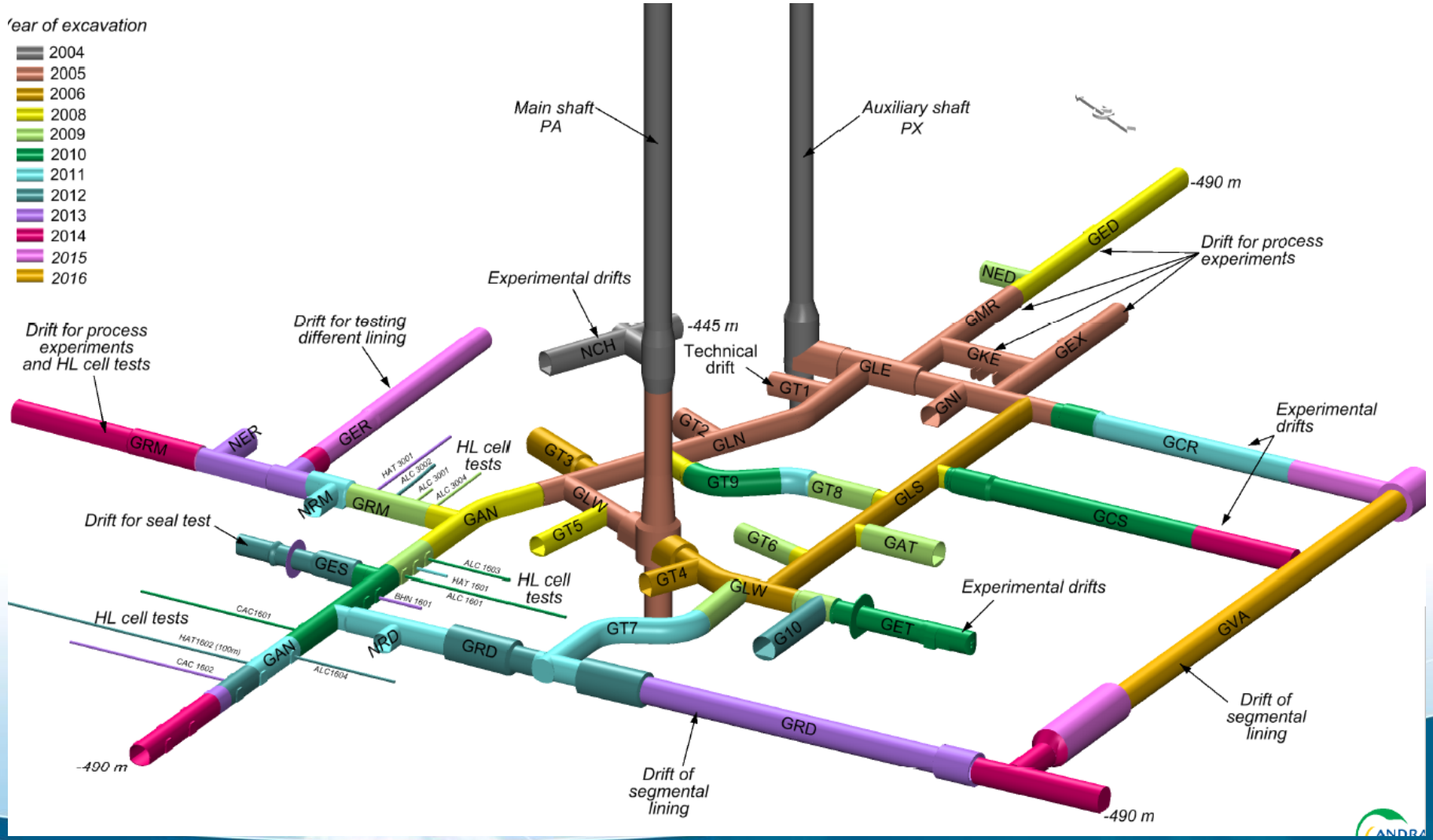
-230 m

Limestones
Presence of groundwater under pressure

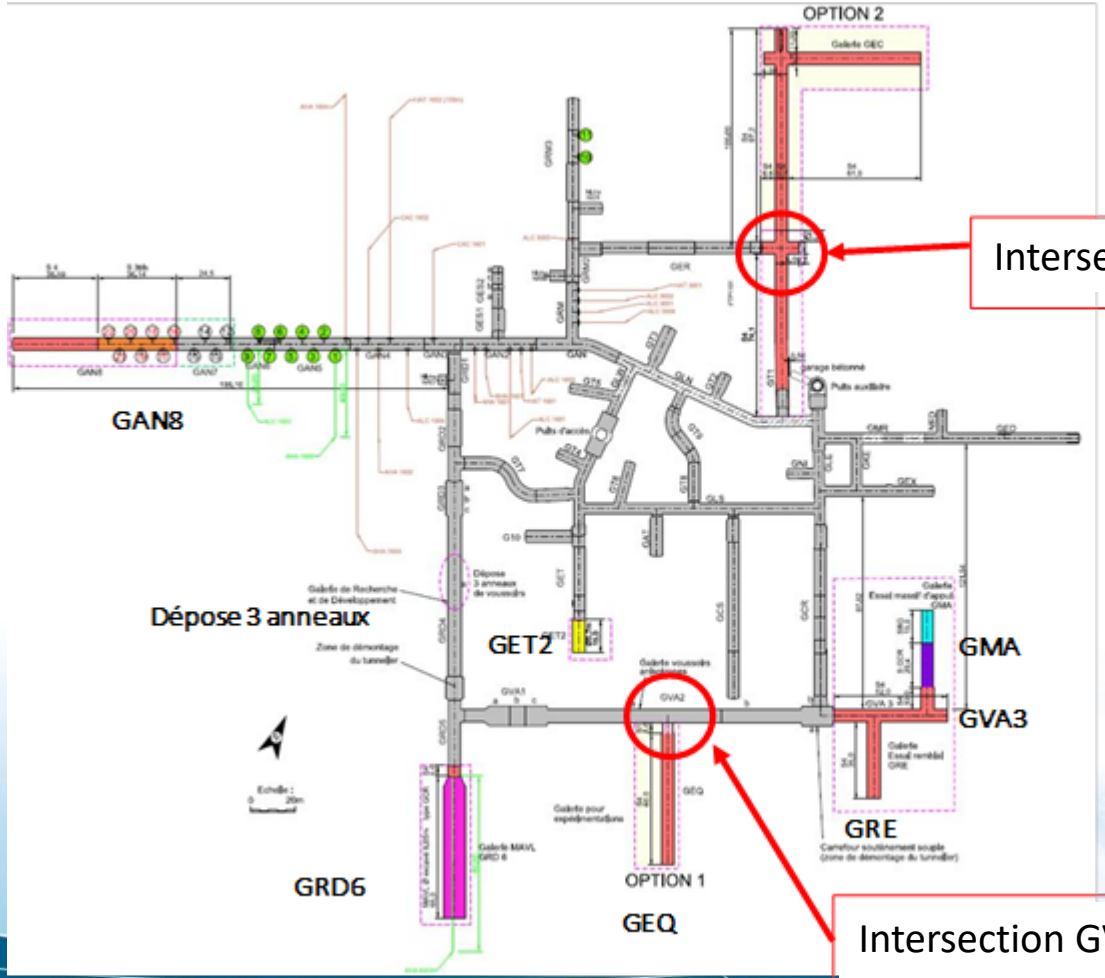


- **Nearly a linear elastic behaviour at the top of the layer (USC and UT)**
- **Elasto-visco-plastic in UA (more damaged and differed deformations)**

Meuse/Haute-Marne Underground Research Laboratory
1.5 kms of galleries



Location of URL phase 4



Intersection GT1/GER, Conventionnal tunneling

Intersection GVA2/GEQ, Mechanized tunneling

Constitutive model for the Argilites (Claystone)

- A rock constitutive model based on Souley et al. (2011), specifically developed and calibrated to reproduce the claystone behavior as observed from lab measurements.

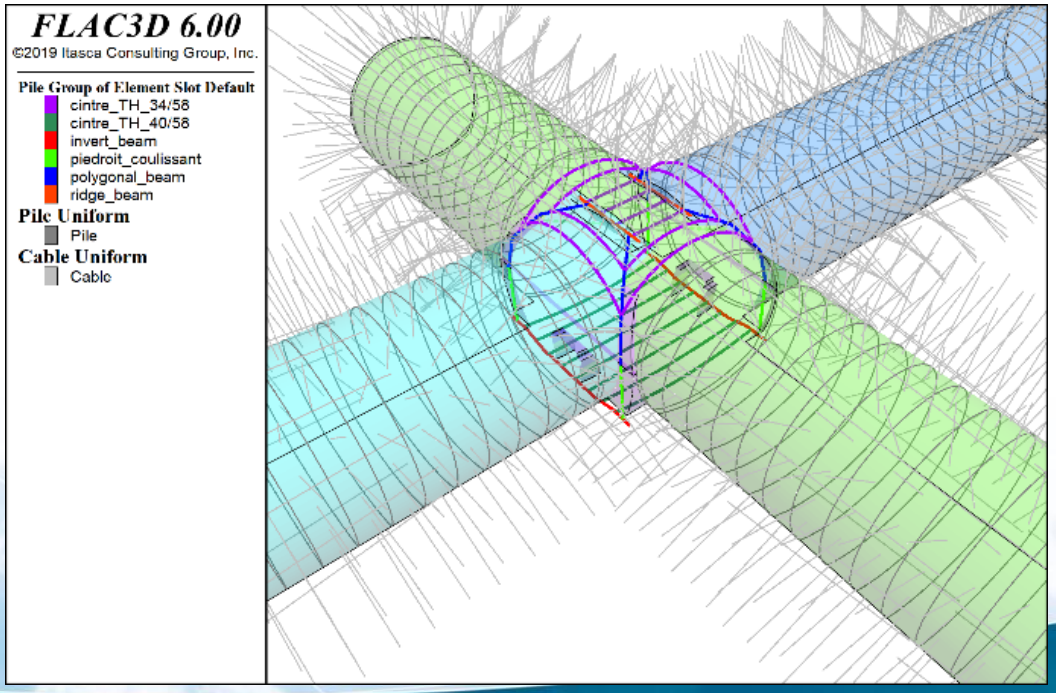
- The response of the material is represented by:
  - A hardening-softening law based on the mathematical form of the Hoek-Brown criteria,
    - Damage before peak strength (hardening),
    - The post-peak behavior is reproduced by softening,
  - A modified Lemaitre model. This reproduces time dependency, with a creep threshold and variation of the creep rate with plasticity.

Goals of the 3D numerical models

- Reproduce the real 3D excavation operations and the long-term behavior of the tunnels,
- Account for the anisotropic in situ stress state at the URL level (490 m depth) : $\sigma_v = 12.7$, $\sigma_h = 12.4$, $\sigma_H = 16.2$ MPa
- Assess the stability of the excavation and verify the support systems design.

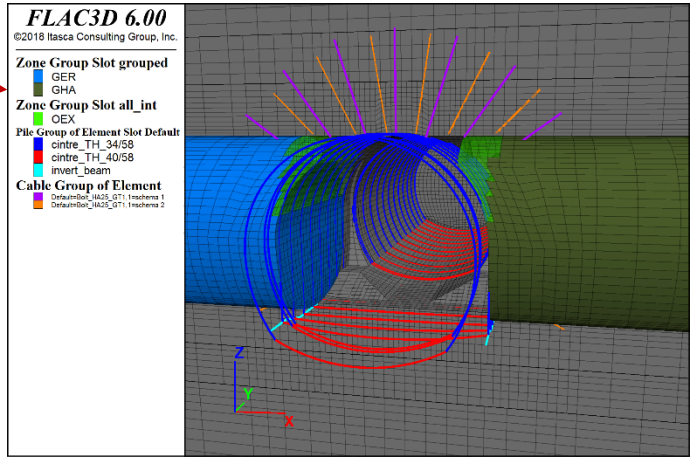
GER/GT1 intersection, Conventionnal tunneling

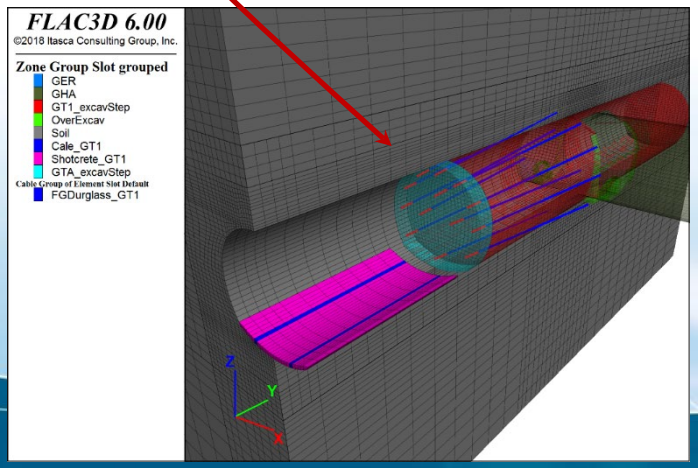
- The support system includes shotcrete layers integrating **compressible elements** to limit stress resultants, **sliding steel arches** and **bolts**.

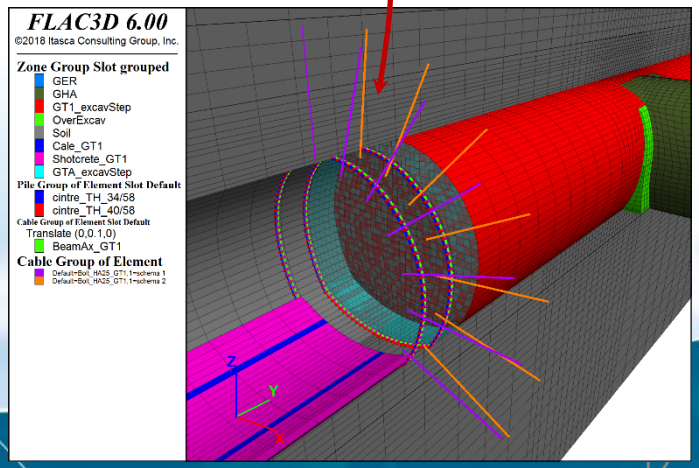


GER/GT1 intersection, Excavation steps

- Main excavation phases:
  - Excavation of GER in 1m steps
  - Installation of the steel frame at the intersection
  - Excavation of GT1 in 1m steps
- For each excavation step:
  - Excavate 1m pass, remove glass fiber bolts
  - Install support of the previous step
  - Solve to equilibrium with the Hoek-Brown model
  - Creep for 2 days with the Lemaitre model
- Creep for 20 years

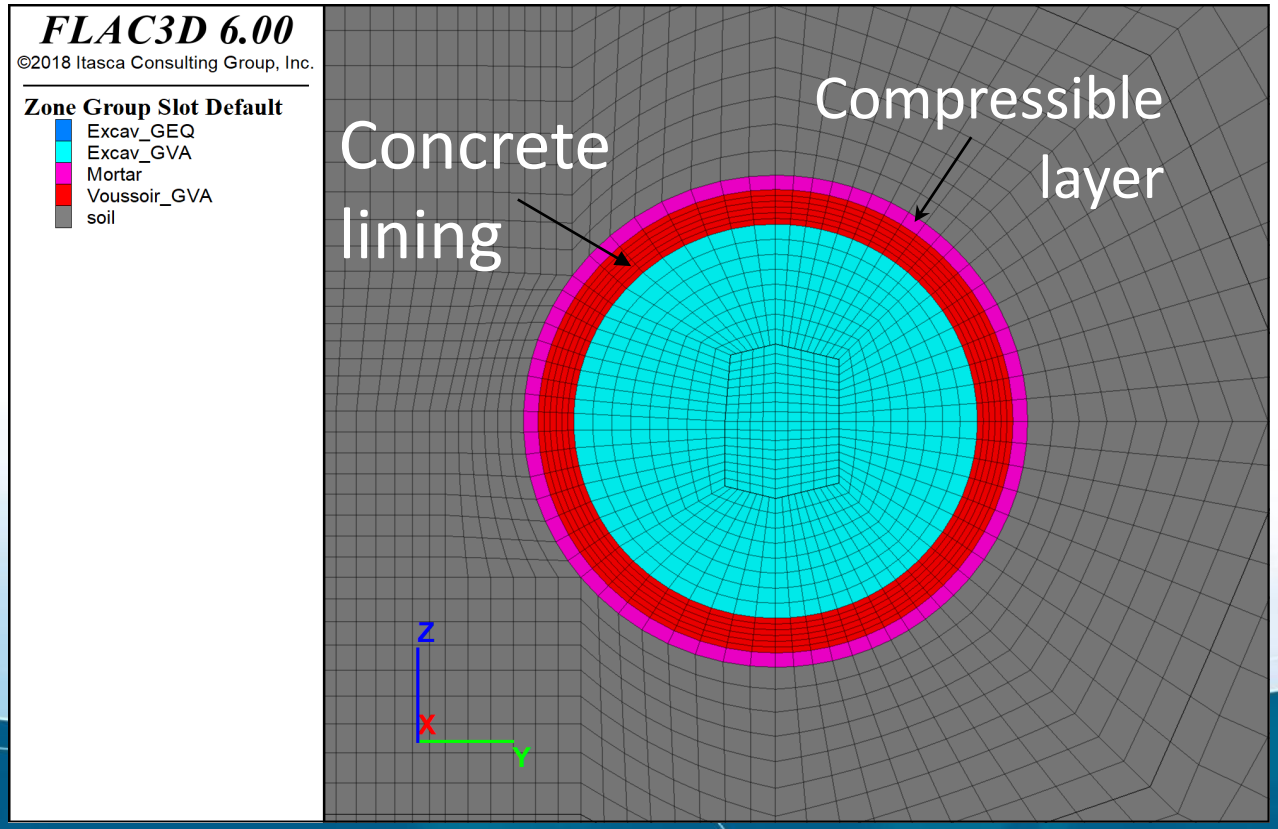






GVA2/GEQ intersection, Mechanized tunneling

- For mechanically excavated tunnels, the classical concrete lining (around 5m in diameter) is separated from the ground by a **compressible layer**.



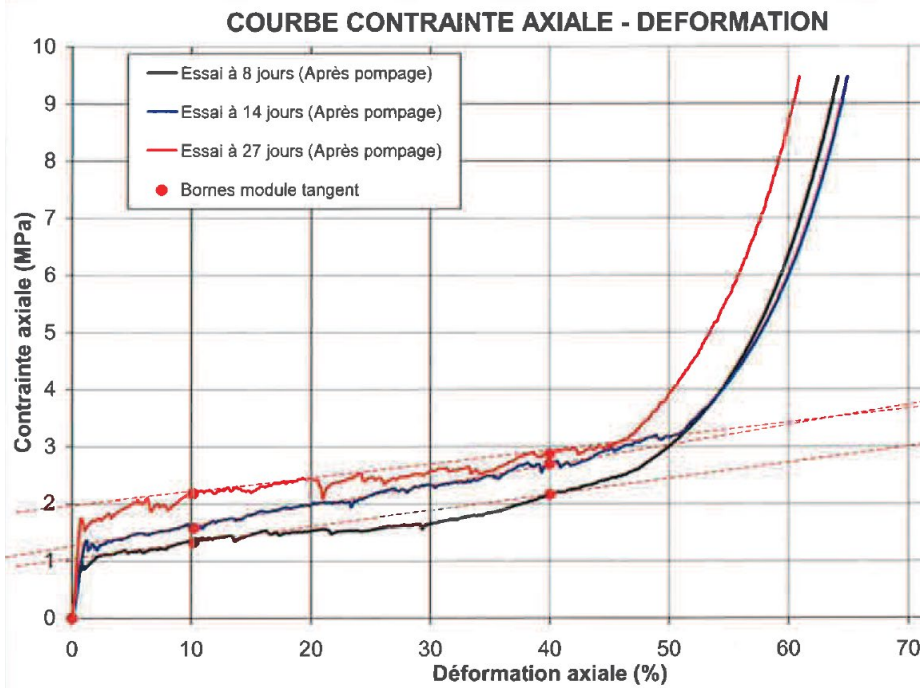
GVA2 typical section

GVA2/GEQ intersection, Compressible layer

Highly compressible mortar

Oedometer curves:

- Linear elasticity till 2 Mpa
- Plasticity threshold till 50 % of axial strain

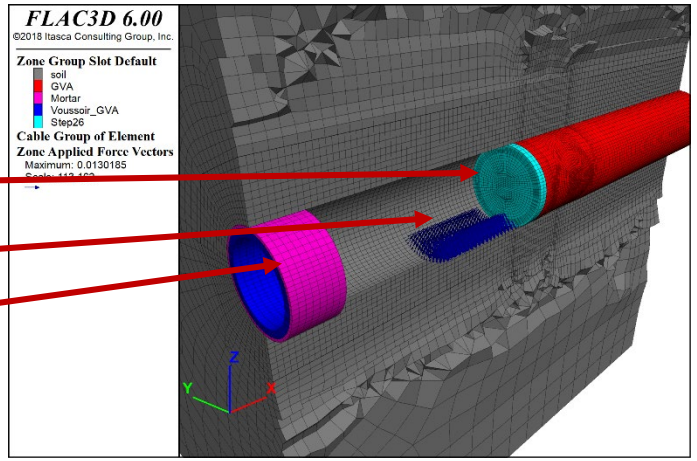


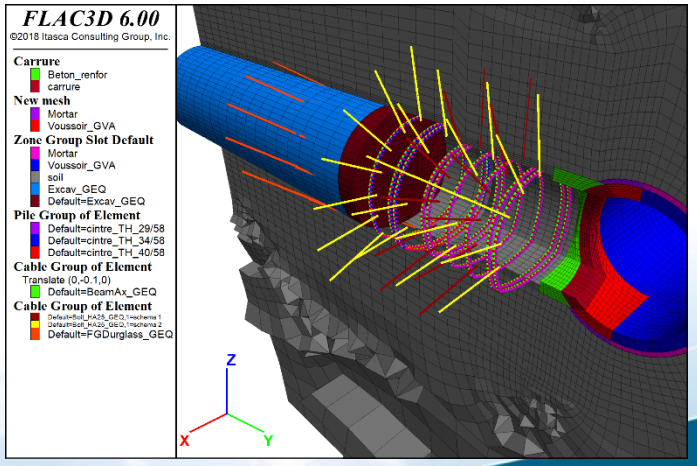
Use volumetric plasticity model:

- Infinite shear strength → infinite cohesion, null tensile strength
- Yield stress vs volumetric plastic strain ε^{pv} is time-dependent
- Calibration on the oedemeter tests
- Avoid longitudinal and orthoradial stresses → null Poisson's ratio

GVA2/GEQ intersection, Excavation steps

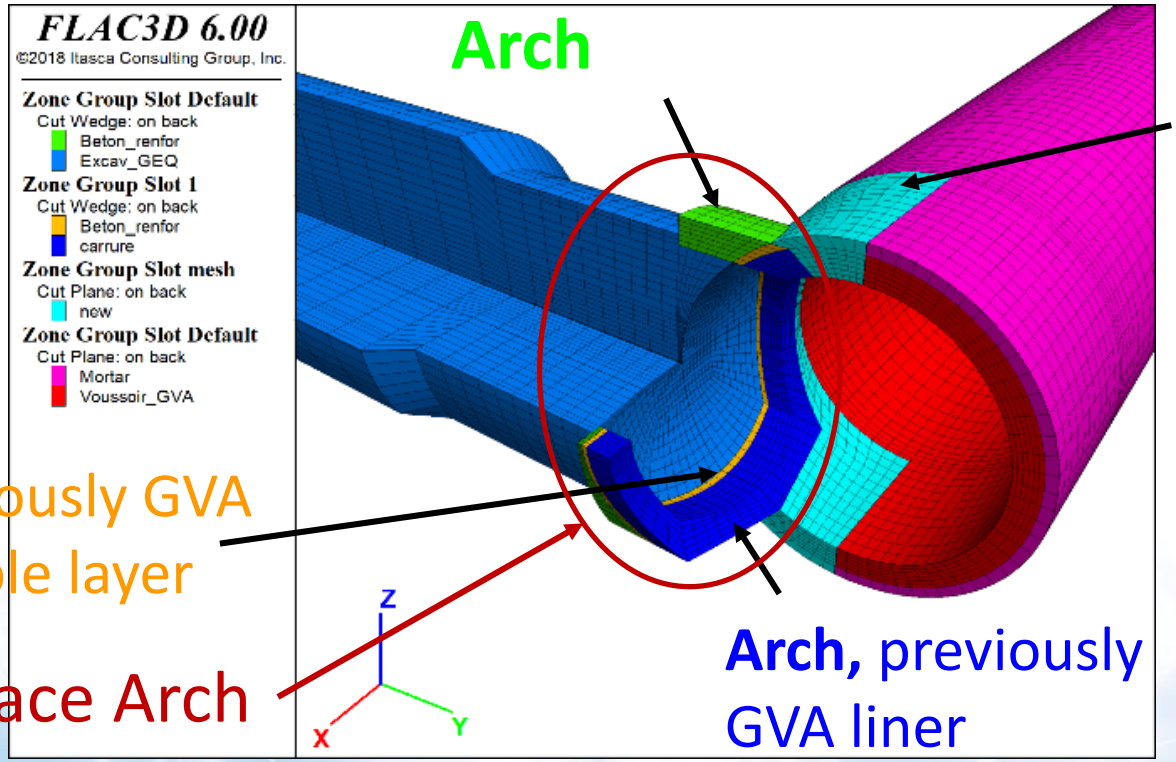
- Main excavation steps :
  - Excavation of GVA2
    - Excavate 0.8m steps
    - Apply load from the conical shield
    - Install support behind the shield (17m)
    - Solve with Hoek-Brown model
    - Creep for 1.4 days with Lemaitre model
  - Creep for 3 years
  - Installation of the concrete frame
  - Excavation of GEQ
    - Excavate 1m step, remove glass fiber bolts
    - Install support (shotcrete + bolts) for previous step
    - Solve to equilibrium with Hoek-Brown model
    - Creep for 2 days with Lemaitre model
  - Creep for 20 years





GVA2/GEQ intersection, Mechanized tunneling

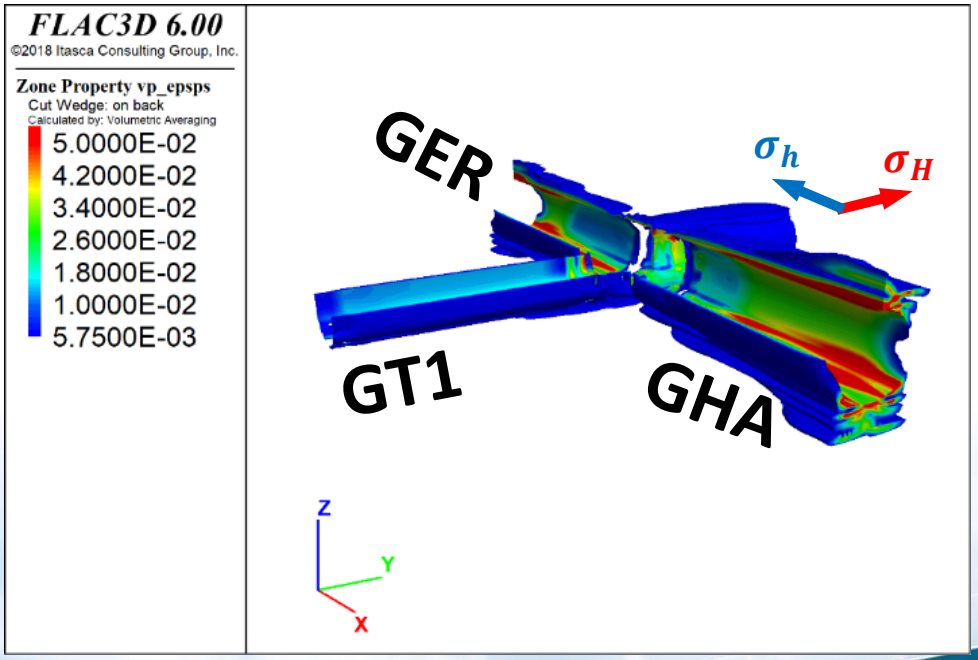
- Tunnel intersections are supported by a concrete arch:



Main results

Effect of anisotropy

- For tunnels excavated along the major horizontal stress σ_H, plasticity around the excavation is relatively isotropic (GT1),
- In the other direction (GER, GHA), plasticity develops mainly at tunnel crown and invert.



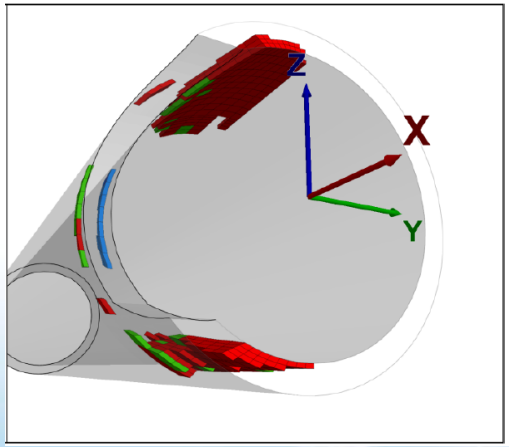
Plastic shear strain contour

GVA2-GEQ intersection: Behaviour of GVA liner and concrete arch

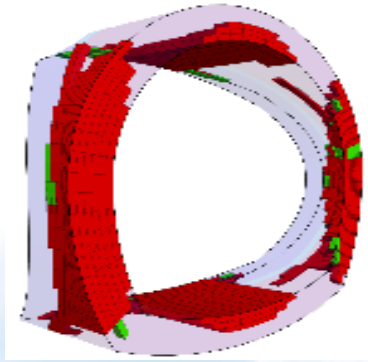
The concrete arch is not loaded directly by the argillite: a 10 cm-thick void space, filled with a very compressible mortar, surrounds the arch. Still, the arch plastifies.

GVA

Plasticity

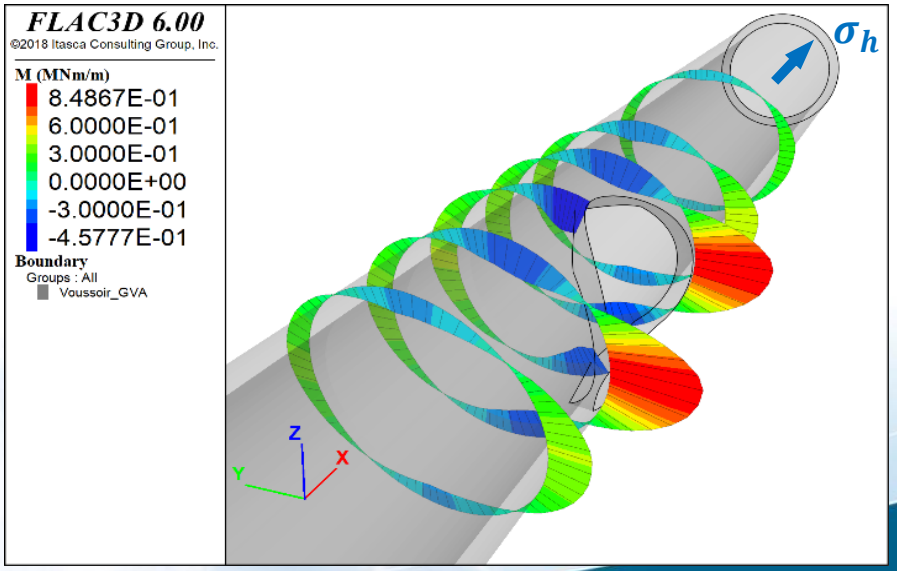


In liner

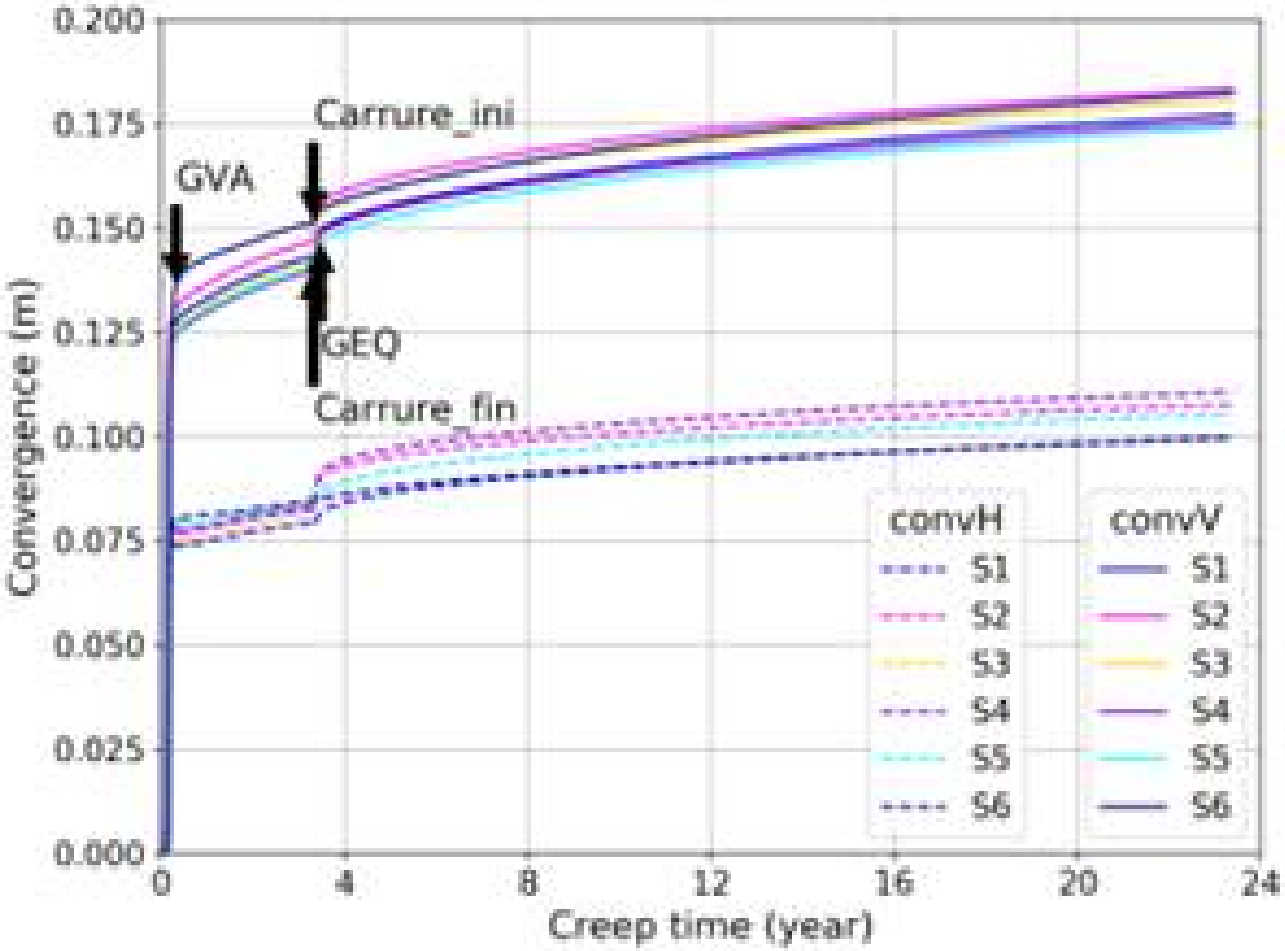


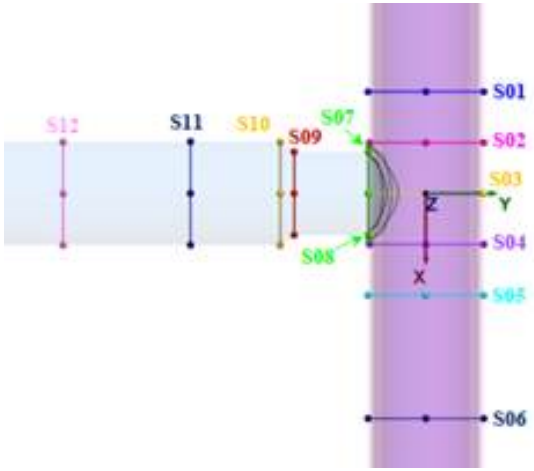
in arch

Bending moments



Convergence results of GVA2-GEQ intersection





Concluding remarks

- Anisotropy:
  - Isotropic plasticity and convergence for tunnels excavated in the σ_H direction (GT1, GEQ)
  - Larger plasticity extension and convergences on crown and invert for tunnel in σ_h direction (GER, GHA, GVA).
- Concrete arch:
  - No interaction with the claystone due to 10-cm compressible mortar,
  - Some limited plastifications at the intersection.

- Recommandations :
  - Specific instrumentation for the purpose of verifying that the thresholds (vigilance and alert during design and execution) are not exceeded,
  - In case of, the general risk management plan provides specific compensatory measures (intensification of measures, reinforcement works, adaptation of work procedures) to mitigate this risk

Thanks for your attention