Impact of the time dependent behavior of claystone on the fracture development for a drift excavated in three steps

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ANDRA (French national radioactive waste management agency) started in 2000 to build an underground research laboratory in East of France to study feasibility of deep geological repository in a claystone layer (CIGEO).
CIGEO project

- Industrial Center for Geological Disposal will have specific features:
  - Underground nuclear facility
  - Long operational life time
  - Size (length of drift, …)

- Cells will be added progressively as the operation progresses until they reach a total maximum area of about 15 km², after about 100 year
Needs in rock mechanics for CIGEO project

- Input for the performance / safety assessment calculations
  - Excavation Damaged Zone (EDZ) characterization
- Design of different elements of the repository (support of the drifts)
  - To study HM behaviour of claystone during drift and shaft excavations (short- and long-term behaviour). In situ measurements are compared with numerical modeling and useful to validate and develop HM model

How to reduce the extension of the EDZ?
Callovo Oxfordian claystone - induced fractures at the 490 m level in the direction of the major horizontal stress

- Fractures extension (shear and traction) depends on the drift orientation versus the in situ stress field
- During excavation work, fractures network are induced (mainly shear fracture 75%, extensional fracture 25%)
- Extent of shear fractures is larger than tensile fractures
Objectives of DPC (Déconfinement Préalable au creusement)

- The drift was excavated in three steps: digging of the pilot drift, wait times (around 6 months for a section) and over excavation to the final drift diameter.

- How has evolved the final EDZ extension in comparison with a drift excavated in one step?
Two processes can result in a reduction of the EDZ: creep & hydromechanical coupling (impact on the effective stress state)

- Creep will allow, at a constant strain, a decrease of the deviatoric stress
- Hydromechanical coupling with the pore pressure decrease leads to an increase of the effective mean stress

### Callovo Oxfordian claystone properties at the 490 m level

<table>
<thead>
<tr>
<th>Rock parameter</th>
<th>Ind.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk specific gravity</td>
<td>ρ</td>
<td>2.39 g/cm³</td>
</tr>
<tr>
<td>Porosity</td>
<td>n</td>
<td>16 ± 2%</td>
</tr>
<tr>
<td>Young modulus</td>
<td>E₁</td>
<td>4000 ± 1470 MPa</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td>ν</td>
<td>0.29 ± 0.05</td>
</tr>
<tr>
<td>Young modulus/E₂</td>
<td>E₂/E₁</td>
<td>1.2 to 1.5</td>
</tr>
<tr>
<td>Uniaxial compressive strength</td>
<td>UCS</td>
<td>21 ± 6.8 MPa</td>
</tr>
<tr>
<td>Hoek &amp; Brown criteria</td>
<td>S</td>
<td>0.43</td>
</tr>
<tr>
<td>m</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>UCS (MPa)</td>
<td>σₑ</td>
<td>33.5</td>
</tr>
<tr>
<td>Intrinsic permeability</td>
<td>k</td>
<td>$5 \times 10^{-20}$ m²</td>
</tr>
<tr>
<td>Water content</td>
<td>w</td>
<td>7.2 ± 1.4 %</td>
</tr>
</tbody>
</table>
Technical feasibility

- Pilot drift Ø 3.8 m
  - Excavation with BRH, increments of 1.5 m
  - Support: 10 cm fibered shotcrete and radial bolting (6-5 fiberglass, L = 2m)

- Final drift Ø 5.7 m
  - Over-excavation with BRH, increments of 1 m
  - Support: steel arches and radial bolting (12-13 bolts of 3 m)
Positions of the hydrogeological, geotechnical and geological boreholes

- Mine by experiment (equipped boreholes emplaced before the excavation) to study the HM behaviour (at short- and long-term)
- During the digging: convergence measurements, displacement measurements in boreholes
- Post excavation boreholes to characterize the fracturation and the permeabilities around the drift
Pilot & final drifts
Geological survey of the front face

- Fractures appear during the excavation (no tectonic fractures)
- Initial chevron fractures were visible during the over-excavation (oxidation traces)
Pore pressure response

- Horizontal 3,4>d>6,7 m & 2,4>D>6,1 m
- Strong HM coupling
Pore pressure response

- Vertical 4,9 > d > 6,8 m & 4,1 > D > 5,9 m
Pore pressure response (200 days after the end of the digging)

- Pore pressure gradient is coherent with previous observations
- Despite the initial stress state is nearly isotropic around the drift, the pore pressure response is anisotropic: overpressure of several MPa in the horizontal direction
Aeras of extension of shear and traction fractures

- Extensional fractures extent is larger than it is for « classical » drift
- A reactivation of the pre-excavation fractures took place
Permeability tests

- Highest hydraulic conductivities (fracture transmissivity) were observed only in the area where extensional fractures were located.
- Farther deep in the rock, hydraulic conductivities decrease from 10-10 m/s to 10-12 m/s within few meters.
Permeability tests

- Permeability measurements confirm the previous observations: it seems that the initial shear fractures could be reactivated in extension.
- The over-excavation generates an extent of the EDZ.
Preliminary conclusions

- A reactivation of the pre-excavation fractures took place and the final traction fractures extension is larger than it is for a « classical » drift.

- Over excavation generates an extent of the EDZ due to the change of aperture of the initial fractures (Highest hydraulic conductivities, fracture transmissivities, were observed only in the area where extensional fractures were located.)

- Continuation of the HM measurements will allow us to assess the long term behaviour of the drift.
Thank you for your attention