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Underground Research Laboratory of Bure – Prediction of tunnel behavior during excavation in the short- and long-term based on *FLAC3D* simulations

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1 INTRODUCTION

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 long-lived radioactive waste in a claystone formation (Callovo-Oxfordian – COx claystone) 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, as well as 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.

In the framework of the extension of the existing laboratory architecture, several 3D numerical simulations of the excavation operations and the long-time behavior of the tunnels have been performed to assess the stability of the excavation and verify the chosen support systems. For conventional excavated tunnels, the supporting system includes shotcrete layers integrating compressible elements to limit stress resultants, sliding steel arches and bolts. For mechanically excavated tunnels, segmental concrete linings are separated from the ground by a compressible layer. Tunnel intersections are supported by a concrete arch for the case of segmental lining (Fig. 1a), or a steel frame (Fig. 1b).

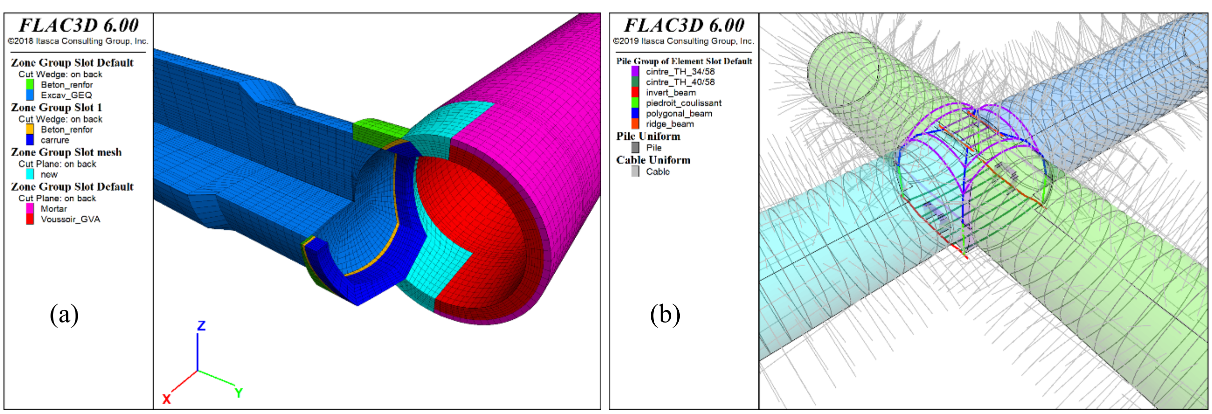

Figure 1. Concrete segmental lined intersection GVA-GEQ (a); Steel frame supported intersection GT1-GHA-GER (b).

The models are developed using the Itasca code *FLAC3D* (Itasca 2017) and a rock constitutive law based on the approach proposed by Souley et al. (2011), specifically developed and calibrated to reproduce the claystone behavior as observed from laboratory experimental measurements. The instantaneous response of the material is represented by a hardening-softening Hoek-Brown law, where damage before peak strength is simulated by hardening in the framework of plasticity theory, while post-peak behavior is classically reproduced by softening. Time dependent behavior is produced using a modified Lemaitre model, including a creep threshold and variation of the creep rate with plasticity.

2 RESULTS AND DISCUSSION

The claystone in situ stress state at URL level (490 m depth) is anisotropic (Wileveau et al. 2007). The value of $\sigma_v = 12.7$, $\sigma_h = 12.4$, $\sigma_H = 16.2$ MPa have been used in the calculation. Different behaviors are thus observed depending on the excavation direction. For tunnels excavated in the major horizontal stress σ_H, plasticity around excavation is relatively isotropic, while in the minor horizontal stress σ_h such as the GVA (Fig. 2a), GER and GHA tunnels (Fig. 2b), plasticity is mainly developed at tunnel crown and invert. This anisotropy in GER and GHA is less pronounced around the intersection with GT1, the latter being excavated before and having altered the initial anisotropic stress state.

As consequence of this anisotropy, GVA segmental liners are more compressed in the vertical direction than in the horizontal one, resulting in positive bending moment (outer fibers under tension) on sides, and negative one on top and bottom. Around GER and GHA, top bolts are more loaded than lateral ones.

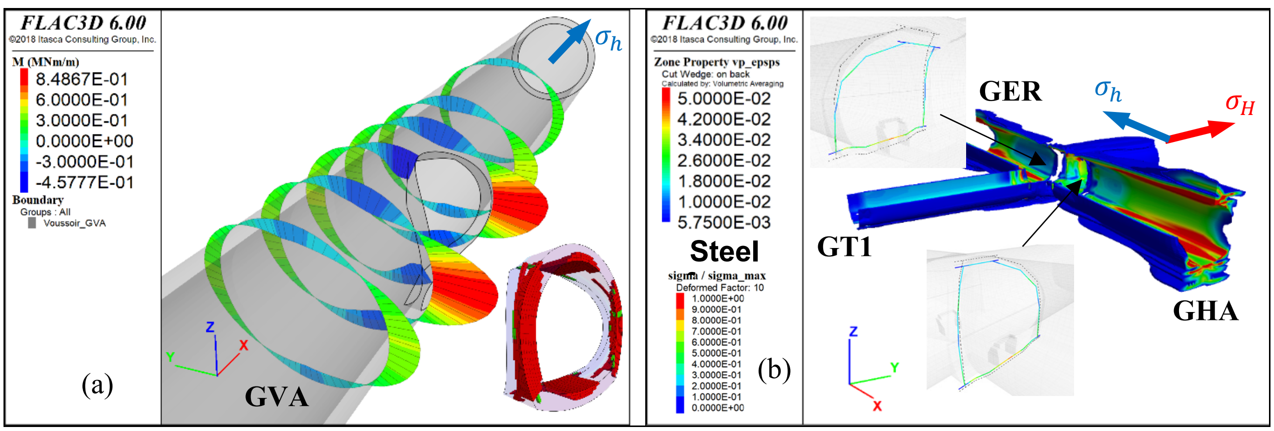

Figure 2. Long-term (20 years) results: Bending moment in segmental lining and plasticity in concrete arch at the intersection GVA-GEQ (a); Soil plastic shear strain and steel frame stress level around GT1-GHA-GER intersection (b).

The maximal stress on steel frame for the GT1-GER-GHA intersection are verified to be smaller than the elastic limit (Fig. 2b). The concrete arch for the GVA-GEQ intersection is considerable plastified (Fig. 2a) because of a void space 10 cm-thick surrounding the arch and filled with compressible material. This material limits the deformation of the arch whereas connected segmental linings are highly loaded and deformed by the claystone creep, particularly in vertical direction because of the developed plastic region. As a result, tensile plasticity is developed on inner fibers on crown and invert, and on front fibers on both sides of the concrete arch.

REFERENCES

Itasca Consulting Group, Inc. 2017. *FLAC3D – Fast Lagrangian Analysis of Continua in 3 Dimensions, Ver. 6.0*. Minneapolis: Itasca.

Souley, M., Armand, G., Su, K. & Ghoreychi, M. 2011. Modelling of the viscoplastic behaviour including damage for deep argillaceous rocks. *Physics and Chemistry of the Earth* 36: 1949-59.

Wileveau, Y., Cornet, F.H., Desroches, J. & Bluming, P. 2007. Complete in situ stress determination at the Bure laboratory site. *Physics and Chemistry of the Earth*, Parts A/B/C 32 (8-14), 866–878.