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Long-term behavior of lined tunnels excavated in squeezing ground

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1 INTRODUCTION

Within the Lyon-Turin railway link project, an access gallery (SMP2) has been excavated across a Carboniferous formation to reach the base tunnel level in Saint-Martin-la-Porte (France). In this formation, tectonized productive Houiller was encountered at a depth of 300 m, which is highly stratified and fractured, consisting of schists, sandstone, and also a significant proportion of cataclastic rocks. The ground exhibited a squeezing behavior, characterized by large, time-dependent and anisotropic deformation. Several studies have been carried out on SMP2 to analyze the squeezing behavior of Houiller thanks to the intensive program of field monitoring. In the present work, numerical modeling is carried out to study the time-dependent response of SMP2. The specific tunneling and support method and the re-profiling process are carefully modeled in the computations.

2 SMP2

Conventional excavation of SMP2 was carried out in highly heterogeneous ground using various kinds section profile and support. From chainage 1325 to 1384 m of the gallery, where strong squeezing behavior was encountered, the excavation and support processes were performed in 3 stages (Bonini & Barla 2012). Initially (Stage 1), a horseshoe section profile (P7-3) was applied, with an equivalent radius of about 5.5 m. The support system consists of yielding steel ribs with sliding joints, rock anchors and a shotcrete layer. As the observed tunnel convergence was very large, the gallery was then remined to the full circular section and an innovative yielding control support system (DSM) was adopted (Stage 2). DSM support system consists of 20 cm shotcrete lining, yielding steel ribs with sliding joints and 9 highly deformable concrete (HiDCon) elements. Finally (Stage 3), a coffered concrete ring with a thickness of 80-100 cm was installed when the tunnel convergence rate was small enough (less than several mm/day).

Excavation of these sections was completed at the end of the year 2006. Extensive monitoring (e.g., tunnel convergence, ground extension around the tunnel wall, extrusion of the tunnel face etc.) was carried out in SMP2 during and after tunneling until the year 2010. Several measurements of the pressure on the final lining are available on the years 2014 and 2017, which contribute to the analysis of long-term ground response and interaction between the ground and the support system.

3 NUMERICAL MODELING

In a previous work (Tran-Manh et al. 2015), large time-dependent and anisotropic convergence of SMP2 has been analyzed. 3D numerical modeling had been performed to study the ground response in stage 1 without taking into account the support system. A numerical model combining the visco-elastic plastic constitutive law (CVISC) and the ubiquitous joint approach has been developed and implemented in *FLAC3D* (Itasca 2017). CVISC model is used to describe the time-dependent behavior of the rock mass and the ubiquitous-joint approach allows to simulate the material anisotropy by introducing weakness planes with given orientation.

In this paper, the previous studies of SMP2 are revisited and extended by modeling the full support system in a 3D numerical model and explore the long-term response of the support. The numerical code *FLAC3D* is used and the excavation and support installation process is modeled step-by-step. The calculation is performed in large-strain mode, where the coordinates of the grid-points are updated at every step. The large-strain mode allows to model the very high convergence of the tunnel wall and the re-profiling of the gallery between stage 1 and 2. The initial state of stress and the model parameters are assumed identical to the ones used in previous studies (Tran-Manh et al. 2015) and the introduced weakness planes are parallel to the tunnel axis, with an inclination of 45 degrees to the left top side of the gallery (Table 1). The high deformable concrete blocks in the DSM support are modeled by using the double-yield constitutive model, which is available in *FLAC3D* code. The 3D mesh used in the computations is shown in Figure 1.

Table1. Model parameters and initial state of stress.

Rock mass	Bulk modulus	(MPa)	542	Cohesion	(MPa)	0.63
	Shear modulus	(MPa)	250	Tension limit	(KPa)	8.5
	Kelvin shear modulus	(MPa)	250	Internal friction angle	(°)	26
	Maxwell dynamic viscosity	(GPa.day)	35	Dilation angle	(°)	0
	Kelvin viscosity	(GPa.day)	6.25			
Weakness planes	Joint cohesion	(MPa)	0.38	Joint friction angle	(°)	23
	Joint tension limit	(KPa)	8.5	Joint dilation angle	(°)	0
Initial state of stress	Horizontal stress	(MPa)	8.5	Vertical stress	(MPa)	8.5

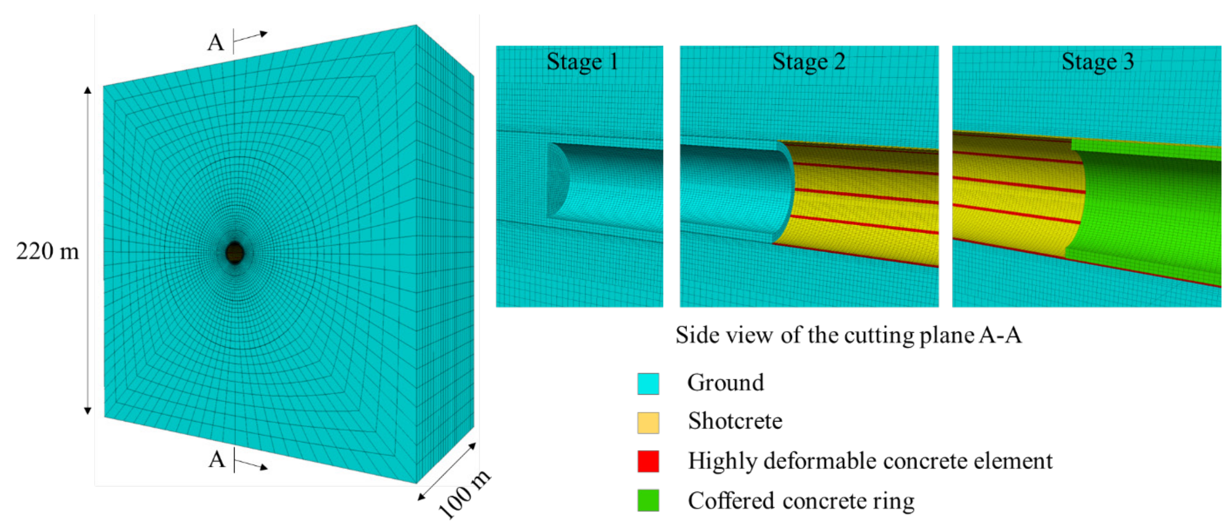

Figure 1. Mesh of the numerical model.

4 RESULTS AND DISCUSSION

A typical result of the numerical simulation is shown in the following. Strong anisotropic and time-dependent convergence of the tunnel wall is obtained. The displacement field after 6 months (i.e., at the end of Stage 1) is shown in Figure 2a. As expected, maximum ground convergence is obtained in the direction perpendicular to the weakness planes. In order to simulate re-profiling and installation of the DSM support system (Stage 2), rezoning process was performed in the computations. More HiDCon elements were installed in the upper part of the DSM support than in the lower part which leads to larger displacements in the upper part of the lining (Fig. 2b). The displacements of the HiDCon elements are larger than in the surrounding shotcrete layer. The displacement field in the DSM support is quite different from that in the ground, as the HiDCon elements break the symmetry of the ground/support system.

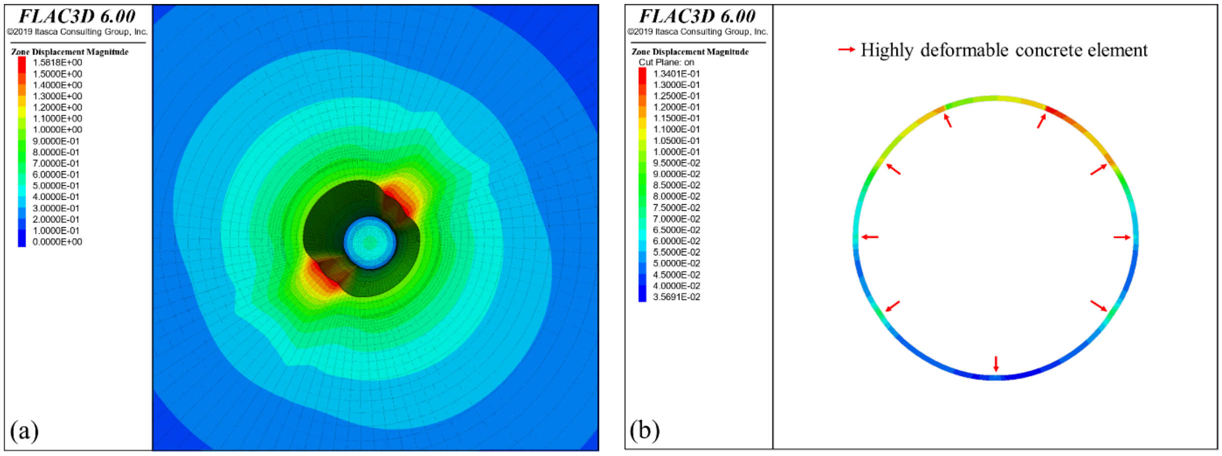

Figure 2. Displacement field of (a) the surrounding ground at the end of 183 days (Stage 1), (b) the DSM support 70 days after installation (Stage 2). Units are in meters.

5 CONCLUSIONS

CVISC constitutive law and the ubiquitous-joint approach permit to describe the time-dependent and anisotropic behavior of squeezing rock masses as encountered during the excavation of SMP2 gallery. The different excavation stages, the re-profiling process and the specific support system are simulated by using the *FLAC3D* code. Preliminary results correctly reproduce the strong convergence observed during the excavation of the tunnel and the response of the temporary DSM support with HiDCon blocks. This study will be extended to the modelling of the installation of the final concrete shell in order to validate the proposed model by comparison with field measurements. Then the model will be applied to simulate the response of the base tunnel excavated at 650 m depth.

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