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Numerical back-analysis of the southern Toulon tunnel measurements: A comparison of 3D and 2D approaches

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ABSTRACT

Full-face excavation associated with ground reinforcement is a common technique to build large tunnels in soft rock or hard soil. The phenomenon of the interaction between the excavation process, the reinforcements and the ground reaction is a three-dimensional (3D) problem. Currently, software and hardware developments provide the option of a numerical analysis of a 3D tunnel excavation within a reasonable calculation time; however, two-dimensional calculations based on the simplified convergence–confinement method are still the most common approach of engineers in current projects during the design phase.

This study presents the numerical back-analysis of a monitoring section setup in the southern Toulon tunnel in France. The primary goal of this study was to investigate and compare the ability of the two numerical approaches (i.e., 2D and 3D) to reproduce the real behaviour of the tunnel measured in situ. The 3D calculation correctly simulates the in situ data, confirming that this tool can represent the complexity of a tunnel excavation. Fitting the 2D calculations onto the 3D results also enabled the determination of the stress release values corresponding to the real excavation process adopted in the Toulon project. This analysis produces two-dimensional numerical results that are globally satisfactory, considering the ground displacement.

1. Introduction

The excavation of a tunnel is a three-dimensional problem, particularly in the zone of the tunnel face; the nature of this problem was clearly demonstrated by Barla and Barla (2004) based on the analysis of the stress path around the tunnel face. Three-dimensional numerical modelling is therefore necessary to study this phenomenon in all its complexity (Mollon et al., 2011). With this approach, the tunnel geometry, the initial stress state (even if anisotropic), the tunnelling method and the phasing of the work can all be considered. Currently, software and hardware developments allow for the use of this tool in underground projects; however, the two-dimensional modelling approach is still the most common tool in the current practice of tunnel projects' design calculations due to its reduced calculation time and relative simplicity. Among the different possibilities of 2D simulations, the most commonly used is a two-dimensional analysis in a cross-section with in-plane deformations combined with the convergence–confinement method (Panet, 1995). In this case, the validity of the results is based on the correct choice of the stress release coefficient λ.

Karakus (2007) compared the 2D simulation results with the settlement profile in the transverse section recorded during the construction of the Heathrow Express tunnel in London and showed that the best fit with the in situ measurements is obtained with the convergence–confinement method. This method was also tested by Svoboda and Mašín (2010), who compared it with a full three-dimensional numerical approach. The stress release coefficient λ was determined by fitting the 2D calculation settlements onto the 3D settlements. The study showed that this method produce a surface settlement profile that agreed with the one obtained using a 3D approach.

However, different authors have also highlighted the limitations of the 2D convergence–confinement approach. Möller and Vermeer (2008) simulated the excavation of a tunnel in Stuttgart and concluded that it is necessary to use two different stress release coefficients λ depending on whether the goal is to estimate the ground settlements or the stresses in the supports. This problem is observed because the 2D simulation cannot represent the complex three-dimensional phenomenon of support loading, particularly near the tunnel face. Conversely, the 3D approach obtains satisfactory results for both the settlements and the support stresses (Galli et al., 2004; Möller and Vermeer, 2005, 2006; Yeo et al., 2009); that method can also eliminate the stress release variable, which is somewhat arbitrarily chosen in the case of complex construction methods.

In addition, for a full-face tunnel excavation with ground reinforcements (i.e., face bolts, umbrella pipes, forepoling, etc.) only a 3D model can correctly simulate the behaviour of the inclusions.

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Conversely, a homogenisation approach can overestimate the positive effects of the reinforcements (Volkmann et al., 2006; Eclaircy-Caudron et al., 2006; Dias et al., 2002; Dias, 2011).

In this study, the southern Toulon tunnel in France is investigated. Thanks to an extensive monitoring section that was installed during the construction of the tunnel, important data was obtained and subsequently used for numerical back-analysis (Janin, 2012). The abilities of the 3D and 2D approaches to reproduce the real measurements in situ have been tested and compared.

2. Southern Toulon tunnel

The southern Toulon tunnel connects motorways A50 and A57 from Nice to Marseille, France and is parallel to the previously built northern tunnel, constructed from 1994 to 2000. The southern tunnel is an urban shallow tunnel that is 1820 m long and has an average opening section of 120 m^2 with a height of 11.2 m and a width of 12.7 m; it was excavated in difficult heterogeneous soils. The construction process was based on the so-called “ADECO-RS” method developed by Lunardi (2008). The work sequences and the amount of pre-reinforcement were continuously adapted to the overburden, the soil conditions and the measured settlements.

In addition to the regular settlement measurements, a specific monitoring zone was setup to improve the understanding of the ground response and to collect precise data for validating numerical simulations.

3. Presentation of the extensive monitoring section

The monitoring section was situated in the “Alexandre I” garden on the west side of Toulon at the excavation progress or chainage PM 882. In this zone, the cover depth was approximately 25 m.

3.1. Geology

Based on borehole investigations, a geological profile of the section has been drawn and is shown in Fig. 1. The investigations showed a global horizontal geological stratigraphy and an important degree of alteration of the phyllitic bedrock. The average ground properties of the different strata were formulated in detail in the design phase and are reproduced in Table 1 and Section 4.1.

3.2. Monitoring

Fig. 1 shows the instrumentation setup in the analysed section. The monitoring from the surface was composed of one vertical extensometer that was located 2 m from the tunnel axis, two deep inclinometers on both sides of the tunnel and three surface target

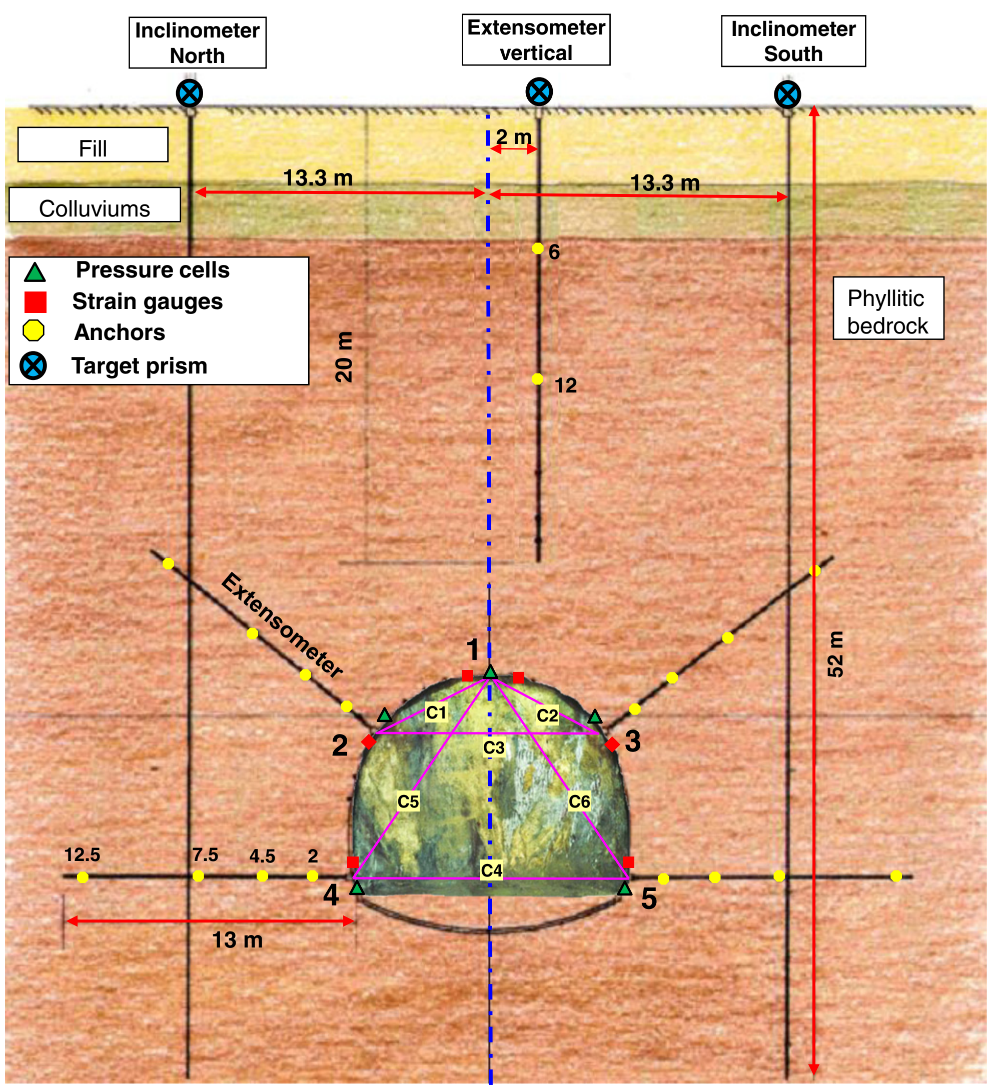

Fig. 1. Geological section and instruments.