Numerical analyses of the effects of tunnels construction

Maciej Ochmański

Doctoral Thesis

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NUMERICAL ANALYSES OF THE EFFECTS OF TUNNELS CONSTRUCTION

by

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Submitted to the Department of Geotechnics and Roads (SUT)
and Department of Civil and Mechanical Engineering (UCLAM)
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Abstract

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Abstract

The modern trend of urbanization tends to increasingly push infrastructure below the ground level, also thanks to the development of faster and more effective methodologies for building tunnels. As typical of geotechnical activities, the impact of tunnelling on the surrounding environment is tremendously affected by the operational procedures. However, the level of the analysis is rarely able to manage in a comprehensive and satisfactory manner, all the diverse technological factors, leaving design based on their subjective engineering judgement or rule of thumbs methodologies. Such a poor analytical basis generates a greater tendency to mitigate the negative effects of tunnelling with feedback processes, where measurement taken with sophisticated and prompt monitoring networks dictates countermeasures, following the so called "observational method".

The idea underlying the present work is that more advanced numerical modelling, capable of taking into account constructive details normally neglected or considered of minor importance, may positively integrate (but not replace !!) observation, driving designers and executors to more efficient and less problematic solutions.

Bearing this goal in mind, the presented dissertation investigates the outcomes determined by tunnels driven with different technologies, focusing on the effects of the most relevant technological factors. For this purpose, the sequence of tunnelling operations has to be rebuilt with great care and specific models need to be introduced to simulate factors such as the injection and hardening of grout, local reinforcement, excavation etc. Firstly, a review of the most frequently adopted tunnelling technologies is presented, distinguishing conventional approaches from those using advanced heading machines. Thereafter, a discussion on the experimental evidences gained from laboratory tests and from the exam of monitored cases studies is given to identify the basic mechanisms activated by tunnelling. The attention is then moved to predictive tools, performing an analytical classification of the methods available to predict ground deformation induced by tunnelling. The core of the work is numerical simulation performed with Abaqus finite element code, here applied to simulate the tunnelling mechanisms activated with two different technologies, a conventional one, making use of jet grouting canopies as provisional support, and a mechanized

one using the principle of earth pressure balance. In both cases inspiration has been taken from two real case histories, a tunnel built near Florence in Italy representative of the first type, and Earth Pressure Balance (EPB) shield driven tunnel built in Bangkok (Thailand). These examples represent the benchmarks of the performed analyses, thanks to the availability of data concerning subsoil characteristics, time construction sequence and effects at ground level, that allow to perform validation. For both cases advanced three dimensional numerical models have been created putting a great care in the technological aspects characterizing each methodology. The numerical model of the Italian tunnel, alternates face reinforcement with anchors, individual installation of jet-grouted columns forming the provisional support at the contour, excavation, insertion of temporary and final lining. Simulation of the tunnel driven with EPB shield has been carried out introducing a precise definition of the shield, face pressure, tail void injection, tunnel lining and backup trailer. Moreover, the subsoil stratification, the initial hydrodynamic conditions and also the pore pressure transient variation have been modelled with the use of the non-linear coupled soil model.

For the case of numerical simulation of conventional tunnelling, three increasingly refined and complex constitutive laws have been adopted to describe the soil behaviour analysing their influence on the obtained results. For the cemented materials, stiffness and strength time-dependency have been introduced. In particular, for the EPB tunnel a code has been implemented in Fortran language to include the irreversible strain taking place during hydration process. Willing to perform a parametric variation of the gap formed between shield and soil, and of the face pressure, a script written in a Python programming language to speed up the model generation was prepared. The complexity of both models demanded a high computational power, which has been fulfilled carrying out simulation on high-end Personal Computer (PC) and one High-Performance Computing (HPC) cluster node.

The full spectrum of results obtained with numerical simulations is discussed focusing on the consequences most relevant from the technical viewpoint, i.e. deformation of the ground level and internal forces in the structural elements, evaluating with a mechanical analysis the induced by the different tunnelling operations.

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