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REVIEW
of PhD thesis by Maciej OCHMAŃSKI
on "*Numerical analyses of the effects of tunnels construction*"

1. Base of PhD thesis's review

This review of the PhD thesis of Maciej Ochmański on *"Numerical analyses of the effects of tunnels construction"* was prepared on the base of a letter of Dean of the Faculty of Civil Engineering – Prof. Jan Ślusarek – according to decision of the Board of the Faculty of Civil Engineering of March 16, 2016.

2. General characteristic of PhD thesis

This dissertation is devoted to the development of numerical procedures to simulate tunnel construction both by conventional mining and by mechanised tunnelling.

The growing demand for public transport, services, and utilities requires the construction of an increasing number of tunnels in heavily urbanised areas where ground movements due to tunnelling can transmit to structures as settlements, rotations and distortions of their foundation. These can, in turn, induce damage affecting visual appearance and aesthetics, serviceability or function, and, in the most severe cases, stability of the structures. The subject of the prediction of tunnelling effects is therefore of undeniable interest not just from the academic point of view but also for its implications for the engineering practice, as lending institutions, insurers, contractors and many tunnelling associations share the common goal of reducing the cost and risk associated with tunnelling.

2.1. Current state of knowledge in the range of PhD thesis

The ability to control displacements, caused by the changes of total stress and of ground water pressures during excavation and in the long term, is crucial to the viability of urban tunnelling in soft ground. In the last decades, significant advances in the areas of excavation design as well as construction and analysis have been achieved, both for the theoretical and technological aspects. Through numerical analysis, it is possible, at least in principle, to deal with a large variety of intervening factors, such as three dimensional geometry, construction sequences and excavation techniques, non-linearity of soil behaviour, groundwater pressure regime, soil-structure interaction, and soil improvement processes.

However, several aspects of the observed movements are not readily reproduced by numerical analysis which necessarily incorporates some form of idealisations. Much has still to be done in the area addressed by the work described in this dissertation to clarify the role played by the main construction processes in conventional tunnelling and the phenomena occurring around the TBM in mechanised tunnelling for a reliable prediction of ground movements at surface or near surface and their impact on existing structures and services.

In common practice, the effects of tunnelling are numerical analyses of mechanised tunnel excavation are carried out in a rather simplified manner. Instead of modelling in detail the phenomena that take place around the TBM, excavation is generally simulated by prescribing fictitious boundary conditions at the tunnel boundary. This approach may however fail in detecting over-excavation situations that may turn into accidents such as excessive ground settlements or even collapses, if the excavation works continue unchanged. In order to investigate soil movements due to shield tunnelling, in this dissertation, 2D and 3D numerical models were created involving realistic simulations of the construction sequences of conventional tunnelling under the protection of a jet grouted canopy and of the main phenomena occurring during operation of a typical EPB shield, such as *e.g.*, a variable support pressure on the excavation face, soil over-cut at the cutter head, shield tapering, the existence of a gap between segmental lining and soil, and tail void grouting. Parametric analyses were also carried out to establish whether simplified and less computational-time consuming numerical procedures may be adopted in the simulation of real tunnels, where other complexities may arise due to tunnel alignment, soil layering, groundwater conditions and soil-structure interaction. The developed numerical models permit to overcome the need to introduce fictitious boundary conditions at the excavation boundary and to assume given values of volume loss as an input parameter.

One of the most important idealisations in the numerical analysis of boundary value problems is the choice of an appropriate constitutive model for the soil, which, in principle, should be able to reproduce the main features of soil behaviour such as irreversibility, non-linearity and stress-history dependence. In this case several constitutive models of increasing complexity have been considered form linear elastic perfectly plastic to complex hypoplastic, with clear effects on the quality of the predictions.

2.2. Structure of PhD thesis

The thesis consists of:

- an introduction defining the objectives and scope of work, and outlining the structure of the thesis (Chapter 1);
- a review of conventional and mechanised tunnelling methods (Chapter 2);
- a review of the main available experimental evidence, both from case studies and physical models, on the effects induced by tunnelling (Chapter 3);
- a review of existing methods to predict mostly ground movements induced by tunnelling, but also, marginally, internal forces in the lining (Chapter 4);
- the detailed development of 3D and 2D numerical models to simulate conventional tunnelling under the protection of a jet-grouted canopy, loosely based on a case history of a tunnel in the northern suburbs of Firenze, for which monitoring data were available (Chapter 5);
- the detailed development of a 3D numerical model to simulate EPB mechanised tunnelling, loosely based on an EPB shield driven tunnel built in Bangkok, including the results of a sensitivity analysis carried out to assess the effects of different factors such as e.g., face pressure and gap parameter (Chapter 6);
- a set of conclusions and recommendations for further work (Chapter 7)
- two appendixes detailing the mathematical framework of the constitutive models adopted in the numerical work (Appendix A) and a Fortran code for the constitutive model of grout, originally developed by the candidate (Appendix B).

3. Evaluation of PhD research

The results arising from the thesis are of publishable quality as demonstrated by the fact that two journal papers, one conference paper and several short communications to technical meetings have already arisen from the work discussed in Chapters 5 and 6, which represent the core of this dissertation.

The physical format of the dissertation and the quality of figures is very good; the quality of the English language requires some small improvement in places.

4. Detailed and discussion remarks

Some of the general statements of **Chapter 1** are rather thought provoking and may be explored during oral discussion.

The subject matter of **Chapter 2** is not always organised in a very convincing way. Some topics, with many important implications, such as dewatering, are introduced in a matter of few lines. They should either be dropped altogether, because not particularly relevant to the following of the work or expanded significantly.

In **Chapter 3** the examined effects relate mostly to failure in sandy soils. Some recent and less recent results of physical models are missing. No clear distinction is made between 1*g* and N*g* physical models nor the role played by scaling laws when performing physical modelling discussed. Some relevant details of reported experimental work are missing rendering the information not fully comprehensible.

In **Chapter 4**, sometimes it is not very clear whether one is referring to model or observation and whether it is real data or centrifuge data. A large number of empirical equations for the prediction of tunnelling induced displacements at surface and subsurface is presented by several Authors: in some cases reported equations are the same (see e.g., Peck, 1969, and Clough and Schmidt, 1981: the second equation is the same as the first with $n = 0.8$). Also the attention devoted to numerical methods is possibly not adequate to the importance that these have in the following developments. It is true that many results from the literature are quoted closer to where they are effectively used (e.g., the work by Meschke and co-workers on face support pressures), but other studies, such as e.g., ALE modelling of shield advancement are not covered at all.

Chapter 5 is a very detailed and convincing study of conventional tunnelling making use of jet grouted canopies as provisional support. Here the presentation of the case history would have benefitted from an overlap of the actual soil profile with the section through the tunnel. Also some plots of normalised stiffness and normalised displacement are not very convincing and need discussion. Adoption of increasingly complex constitutive models for the soil affects the predictions, but, as the mathematical structure and the physical meaning of the relevant parameters of the models are different, the problem arises of the selection of appropriate parameters to render the comparisons meaningful, by selecting appropriate and representative strain levels for the boundary value problem under examination.

Other than reference to literature recommendations, some parametric studies to assess the effects of mesh dimension and refinement in both Chapter 5 and **Chapter 6** may have been useful to ascertain whether the chosen mesh is sufficient or, conversely is over extended/refined. In this chapter the numerical predictions are checked solely against empirical predictions. The reader is left to wonder whether some of the results, such as the compute value of volume loss ($V_L = 0.8\%$), although certainly realistic, relate at all with field observations. Also, the large number of results and their interpretation will require oral discussion.

The concluding remarks in **Chapter 7** may have been more focused. The Author warns that "sometimes there is an optimal level of accuracy (complexity?) for the computational model beyond which complexity becomes unnecessary or even harmful". It will be interesting to discuss whether the level of complexity introduced in the analyses presented in the work is too low, adequate or too high, and in which respect. Also, the problem of parameter identification, in the face of a real geotechnical investigation, should be addressed. Another interesting point for discussion may be at what stage of the design process is such an analysis required (or is this just meant to "understand" the physics?)

Summary and conclusions

The work is an interesting application of advanced numerical tools to the analysis of a relevant and complex geotechnical boundary value problem. The numerical procedures developed as part of this thesis are at least state-of-the-art, and in some instances they represent an advancement of the state-of-the-art. I will provide the Author with a detailed list of small changes, including the correction of typos, minor inconsistencies, and small improvements to the English language, but am otherwise satisfied that the work has the quality, originality and breadth to fulfil the requirements of a PhD dissertation.

I confirm that the PhD thesis of Maciej Ochmański on *"Numerical analyses of the effects of tunnels construction"* satisfies the requirements of the Act about scientific degrees and scientific titles and degrees in the field of art (Dz. U. Nr 65, poz. 595, ze zm. w Dz. U. z 2005 r. Nr 164, poz. 1365 oraz w Dz. U. z 2011 r. Nr 84, poz. 455) of 14th March 2003 and its subsequent amendments.

In conclusion, I support the acceptance of the Candidate's dissertation and grant permission to Mr. Maciej Ochmański to conduct public discussion over his dissertation.

In faith,

Giulia Viggiani

(Giulia Viggiani)