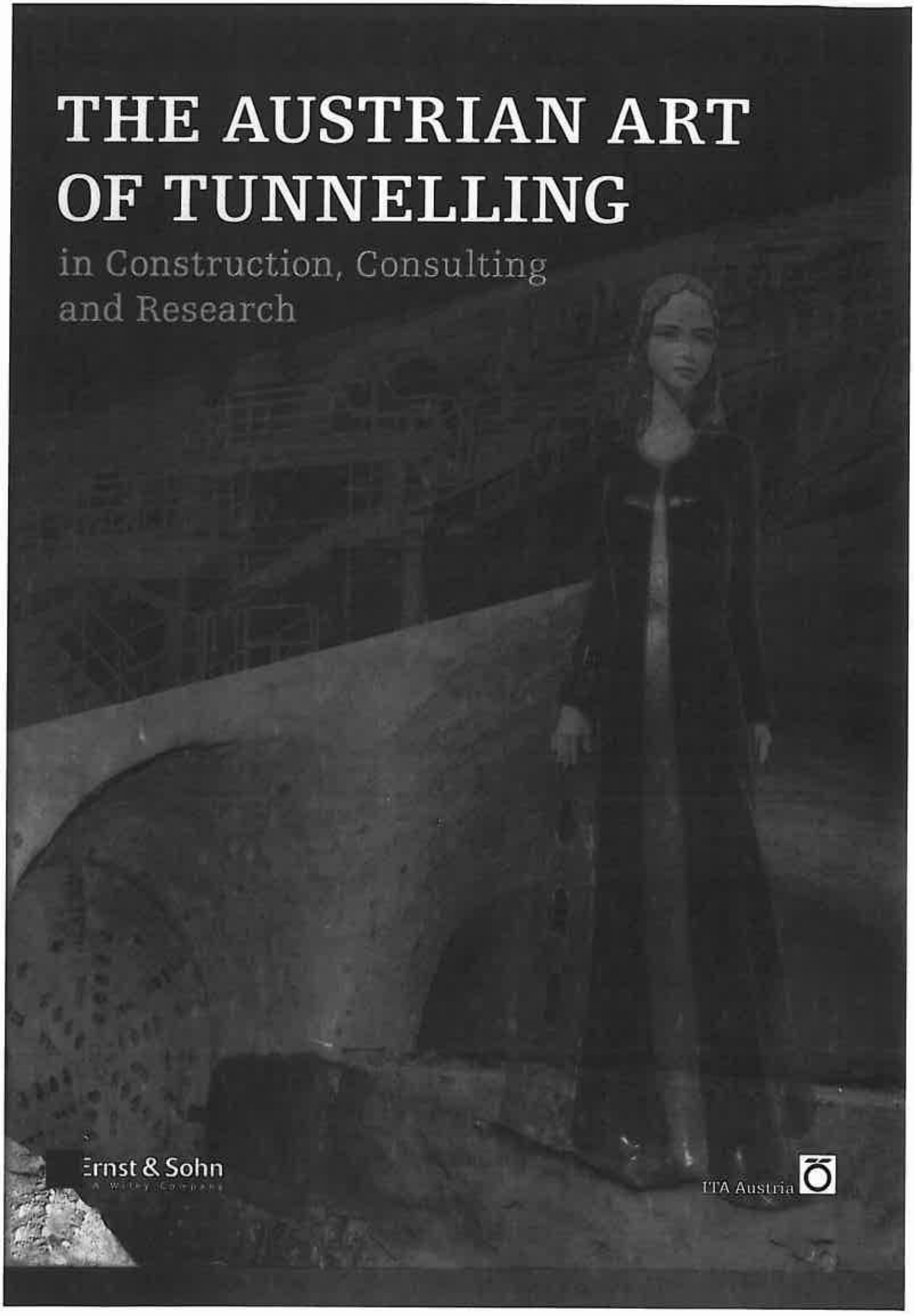
THE AUSTRIAN ART OF TUNNELLING

in Construction, Consulting and Research



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Contents

Main Activities Related to Tunnelling at Vienna University of Technology

Tunnelling as a comprehensive topic is given attention in several courses at four institutes in the Faculty of Civil Engineering at Vienna University of Technology. The study of Civil Engineering is divided into the basic bachelor course and three bottom-up master courses.

At the **Institute for Mechanics of Materials and Structures** (IMWS) under the leadership of o.Univ.-Prof. Dipl.-Ing. Dr. techn. Dr. h.c.mult. *Herbert Mang*, Ph.D., tunnel engineering is being advanced by assessing the safety of NATM tunnel shells (i) during construction and (ii) under fire load. For this purpose, underlying physical mechanisms in shotcrete and concrete are quantified using multi-scale constitutive models, which are in turn used for Finite Element (FE) simulations of tunnel shells.

For the safety assessment of tunnel shells during construction, three-dimensional structural models of shotcrete tunnel shells are fed, in terms of boundary values, by displacement vectors measured in-situ at discrete points of the tunnel shell [1]. The underlying mixture-dependent shotcrete material behaviour is predicted from multi-scale continuum micromechanics formulations [2], [4], (Figure 1). Such hybrid analyses provide the evolution of the level of loading (i.e. the ratio of stress over strength) throughout the tunnel shell, allowing for its online monitoring.

When concrete is subjected to high-temperature loading, thermo-hydro-chemo-mechanical processes cause degradation of stiffness and strength of the linings materials, i.e. concrete and steel, and spalling of near-surface concrete layers [3], [6]. As a consequence, the load-carrying capacity of the tunnel structure is reduced. Related research work at the IMWS is based on large-scale fire experiments, (Figure 2), highlighting the concrete mix-dependent extent of spalling [3], significantly reduced by PP fibre reinforcement [6]. Permeability tests, mercury intrusion porosimetry, thermogravimetric and nanoindentation tests provide the experimental basis for structural safety assessment of tunnels under fire load by coupled thermo-hydro-chemical FE simulations [5].

Failure Mechanisms of tunnels as well as of slopes and foundations are a special field of research of the **Institute for Engineering Geology** under the leadership of o.Univ.-Prof. Dr.phil. *Ewald Tentschert*. During the last years, the "cherry pit mechanism" ("notching"; squeezing out of the side walls due to predominant vertical in-situ stresses) has been investigated, using continuum as well as discontinuum mechanics methods. Figure 3 shows a numerical model of this mechanism using the particle flow code PFC. The formation of notches in the sidewalls as well as the deformations in the roof and in the invert, being considerably smaller than those of the sidewalls, are simulated very well. The advantage of the discontinuum mechanics programme PFC is that large displacements of each particle and thus of the whole structure can be simulated, considering contacts of every particle with every other particle. These models make optimizations of the excavation sequence, of the support as well as of the monitoring system possible.

The tunnelling education on offer is included in various courses of engineering geology and deepened in the special courses "Underground Excavation Design" and "Finite-Difference-Models in Geoengineering".

Research activities at the **Institute for Soil Mechanics and Geotechnical Engineering** under the leadership of o.Univ.-Prof. Dipl.-Ing. Dr.techn. Dr.h.c.mult. *Heinz Brandl*. Tunnelling research focuses on two main topics: First is "Residual shear behaviour and progressive failure of soil or weak rock in tunnelling". The operational shear strength of soil and decomposed weathered rock depends on several factors and is not a constant parameter. Therefore, tunnel design, construction method and risk analysis should take into account the post-failure behaviour and residual strength, also comprising the tendency to progressive failure in the surrounding ground.

The second topic is "Geothermal use of tunnels". Tunnels can be used for geothermal heat extraction and storage, thus contributing to sustainable energy utilisation. Research investigates cut and cover tunnels as well as open and closed face tunnels (NATM; tunnel fittings) i.e. "thermo active traffic tunnels" ("energy tunnels"). Conventional geothermal energy can be used for heating buildings near the tunnel. Thermo-active tunnel linings, however,

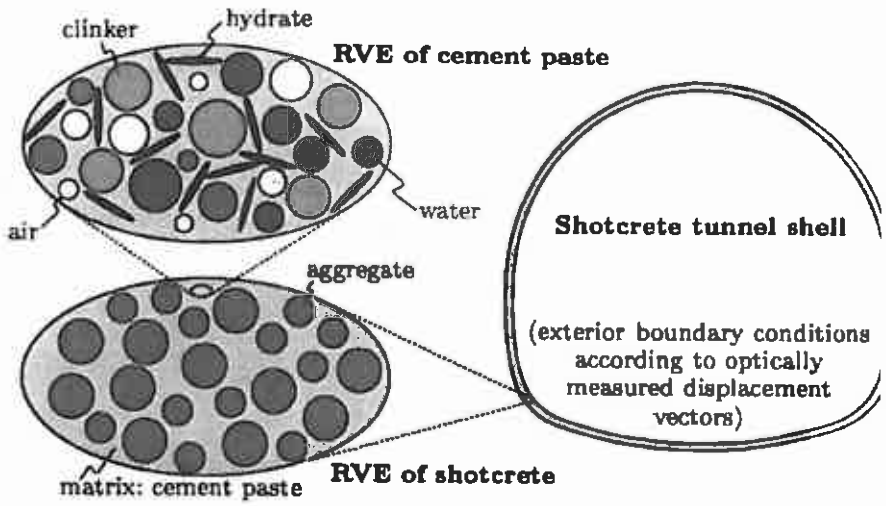

Fig. 1. Representative volume elements (RVEs) of shotcrete (two-step homogenization scheme) [2,3]; used for hybrid analyses of tunnel shells [1]

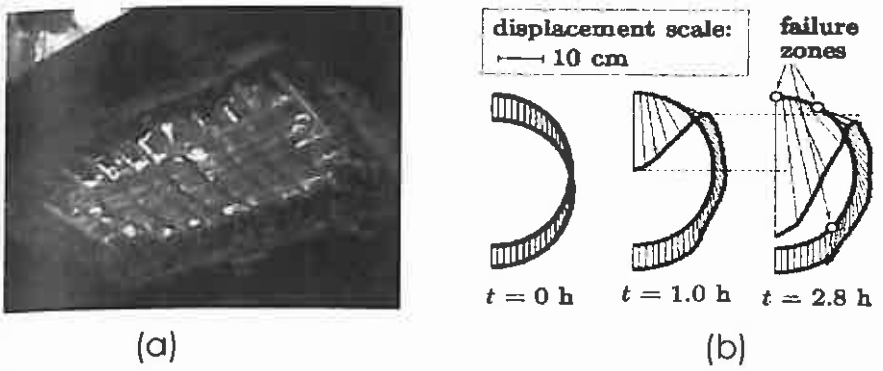

Fig. 2. (a) Large-scale fire experiments [3]; and (b) displacement pattern obtained from structural safety assessment of a tunnel under fire load [5]

enable heat extraction from the ground via absorber pipes that carry a heat carrier fluid. Seasonal operation makes cooling during summer possible by using the ground for heat storage. Meanwhile all metro stations of the new Vienna Metro extension U2 are supplied with geothermal energy from earth-contact structures for both heating and cooling purposes. This is the first application of "energy metro stations" worldwide. Finally, wells for groundwater lowering along near-surface tunnels can be also used for geothermal heat extraction/storage. These "energy wells" have proved successful in Vienna for temporary and permanent purposes. The benefits of thermo-active earth contact structures are being investigated further; they are certainly a great potential (and need) for innovative, environmentally friendly systems.

The tunnelling education on offer is included in the courses for "Ground Engineering and Soil Mechanics" and "Rock Engineering".

The **Institute of Interdisciplinary Construction Process Management** under the leadership of o.Univ.-Prof. Dipl.-Ing. Dr.techn. *Hans Georg Jodl* consists of three chairs for construction technology (*Jodl*), construction economy (*Kropik*) and construction planning (*Achammer*). The main research activities in tunnelling are focusing on contractual problems, site organisation and economical as well as technical optimisation. The evaluation, assessment and management of the tunnel construction process have become a major topic of tunnel engineering research within the chair of construction technology as a powerful partner of industry. Drafting of expert reports for the guidelines "Segmental Lining" and "Tunnelling Shield Machines" as well as "Concrete Use in Tunnels" are current intensive contributions.

The chair of construction technology offers basic tunnelling topics in the bachelor lecture "Construction Technology". In the continuing master course "Construction Industry and Geotechnics", tunnelling education is deepened in the lectures "Tunnel Construction Technology" including tutorial and the lecture "Design of Infrastructure Tunnels". Research students often produce their special diploma thesis on tunnelling topics with the overall goal of promoting the increased use of underground space for infrastructure facilities, which will be carried out in close cooperation with the Austrian tunnelling industry.

Hans Georg Jodl

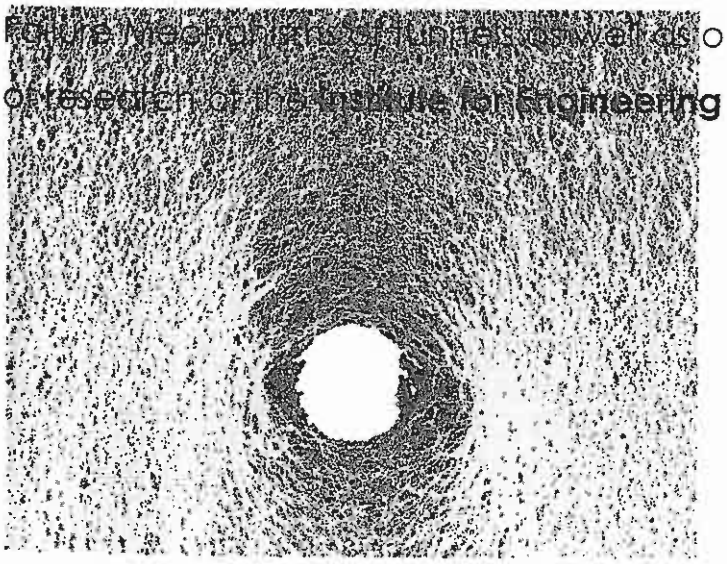

Fig. 3. Formation of "cherry pits" ("notches") in the sidewalls of a tunnel modelled by PFC

References

[1] *C. Hellmich, J. Macht,* and *H. A. Mang*: Ein hybrides Verfahren zur Bestimmung der Auslastung von Spritzbetonschalen. Felsbau 17: 422–425, 2000.

[2] *C. Hellmich* and *H. A. Mang*: Shotcrete elasticity revisited in the framework of continuum micromechanics: from submicron to meter level. Journal of Materials in Civil Engineering (ASCE), 17(3): 246–256, 2005.

[3] *W. Kusterle, W. Lindlbauer, G. Hampejs, A. Heel, P.-F. Donauer, M. Zeiml, W. Brunnsteiner, R. Dietze, W. Hermann, H. Viechtbauer, M. Schreiner, R. Vierthaler, H. Stadlober, H. Winter, J. Lemmerer,* and *E. Kammeringer*: Brandbeständigkeit von Faser-, Stahl- und Spannbeton. *Technical Report 544 ("Straßenforschung")*, Austrian Federal Ministry of Transportation, Infrastructure and Technology, Vienna, 2004.

[4] *B. Pichler, C. Hellmich,* and *J. Eberhardsteiner*: Spherical and acicular representation of hydrates in a micromechanical model for cement paste – prediction of early-age elasticity and strength. Acta Mechanica, in press (2008).

[5] *M. Zeiml, R. Lackner, F. Pesavento,* and *B. A. Schrefler*: Thermo-hydro-chemical couplings considered in safety assessment of shallow tunnels subjected to fire load. Fire Safety Journal 43(2): 83–95, 2008.

[6] *M. Zeiml, D. Leithner, R. Lackner,* and *H. A. Mang*: How do polypropylene fibers improve the spalling behavior of in-situ concrete? Cement and Concrete Research 36(5): 929–942, 2006.

Austrian tunnel engineering is highly developed and has an excellent reputation worldwide in all areas including design, execution, innovative developments and training. The Austrian Art of Tunnelling aims to document the current state of the art. Short articles present current construction sites in Austria and abroad, their special features and the chosen solutions. In addition, internationally experienced consulting engineers discuss the design challenges for selected, particularly demanding projects. The book is rounded off by a clearly arranged overview of relevant technical/scientific organisations, associations and universities.

The Austrian Art of Tunnelling is published by ITA Austria, Vienna, an umbrella organisation formed by five technical/scientific associations – Austrian Society for Geomechanics (ÖGG), Austrian Tunnel Assoiation (ATA), Austrian Society of Concrete- and Construction Technology (ÖVBB), Austrian Association for Research on Road, Rail and Transport (FSV), Austrian Society for Engineers and Architects (ÖIAV) – that represents Austrian interests in the International Tunnelling Association.