



# Handbook of Tunnel Engineering I Structures and Methods

**Bernhard Maidl**  
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Tunnel engineering is one of the oldest, most interesting but also challenging engineering disciplines and demands not only theoretical knowledge but also practical experience in geology, geomechanics, structural design, concrete construction, machine technology, construction process technology and construction management. The two-volume „Handbuch des Tunnel- und Stollenbaus“ has been the standard reference for German-speaking tunnellers in theory and practice for 30 years. The new English edition is based on a revised and adapted version of the third German edition and reflects the latest state of knowledge. The book is published in two volumes, with the first being devoted to more practical themes of construction and construction process in drill and blast and mechanised tunnelling. Microtunnelling and ventilation are also dealt with. All chapters include practical examples.

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First Edition

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# Handbook of Tunnel Engineering

Volume I: Structures and Methods

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**B. Maidl, M. Thewes, U. Maidl**

**Handbook of Tunnel Engineering  
Volume I: Structures and Methods**

**Dedicated to My Children**

**Julia**

**Ulrich**

**Nadine**

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## Foreword to the English edition

The “black book of tunnelling” has become a standard work in German-speaking countries since its first edition in 1984. It can be found on every tunnel site and in every design office – whether contractor or consultant. Students at universities and technical colleges use it as a textbook.

For many years, colleagues from abroad have been asking me for an English edition. Now the time has come to publish the two-volume book in English. An important step was that the publisher of the first German edition, VGE, gave their permission for the publishing of the English edition by Ernst & Sohn, Berlin. Special thanks are due to Dr. *Richter* from publisher Ernst & Sohn for his successful negotiations. However, preparation of the text for the translation showed that the 3<sup>rd</sup> German edition required updating and extending. In particular, the standards and recommendations have been revised. This will all be included in a 4<sup>th</sup> German edition, which will be published soon. Changes to the standards and recommendations are given in this edition, with the references stating the latest version.

As with all books, the first English edition has also required the collaboration of colleagues. Professor Dr.-Ing. *Markus Thewes*, who has succeeded me as the holder of my former university chair, and my son, Dr.-Ing. *Ulrich Maidl*, managing director of MTC, have joined me in the team of authors. Dipl.-Ing. *Michael Griese* from MTC is the overall coordinator, assisted by Dr.-Ing. *Götz Vollmann* and Dipl.-Ing. *Anna-Lena Hammer* from the chair of Prof. *Thewes*. I thank all those involved, also the translator *David Sturge* and the employees of the publisher Ernst & Sohn in Berlin.

Bochum, in March 2013

*Bernhard Maidl*



## Foreword to the 3<sup>rd</sup> German edition

Almost 20 years after the first appearance of the Handbook of Tunnel Engineering and about 10 years after the 2<sup>nd</sup> German edition, a complete revision was necessary for the 3<sup>rd</sup> German edition. Detailed investigation only made clear what enormous developments had taken place in tunnelling.

In conventional tunnelling, progress was predominantly in the field of advance support methods such as pipe screens and jet grouting, which enabled the scope of application to be extended to include larger cross-sections and better mechanisation. Further mechanisation, particularly of muck clearance, enables parallel operation of excavation, support, muck clearance and transport in conventional tunnelling, which has also improved advance rates.

In mechanised tunnelling, an even greater leap of progress has taken place as a result of the wider experience that has come with increasing application. The traditionally established limits to the application of EPB and hydroshield machines are no longer so clear in practice. Mixshields and combishields can be used in various modes.

Particularly worth mentioning are developments of support methods installed directly behind the machine. The requirements connected with the construction of the large Alpine tunnels under the Lötschberg and the St. Gotthard have given a spur to this development.

Since the extent of the text in the chapters concerning “support methods” and “construction processes” has also increased, Chapter X “Implementation of construction projects” has been omitted. This has been integrated under other headings in Volume II. The chapter “Waterproofing and drainage” has also been included in Volume II.

As has already been the case with other books, I once again required intensive assistance from my employees for this book. Even when we could refer to the other books about shotcrete, steel fibre concrete, shield and TBM tunnelling, this still involved an enormous amount of work, for which I wish to thank all, and also the authors who worked on the former books.

Many thanks also to the many other helpers and also to those involved at the publishers.

Bochum, in January 2004

*Bernhard Maidl*



## Foreword to the 2<sup>nd</sup> German edition

Many letters and comments from Germany and abroad have confirmed that the Handbook of Tunnel Engineering from 1984 has been well accepted as a textbook and also in design offices and on tunnel sites. Positive developments in tunnelling are also good news, and this has led to the call for specific planning regulations for underground structures already becoming a reality in some countries.

When the new edition was being investigated, it became clear that a great variety of technical innovations have been introduced in the last ten years, sufficient to justify a new edition. But time is limited and cannot be multiplied, so only the most important revisions have been undertaken. This includes revisions and extensions of the standards listed in the references. The sections concerning shotcrete and steel fibre shotcrete in Chapter II “Support methods” have been revised, as well as Chapters VI “Mechanised tunnelling” and VII “The driving of small cross-sections”. Chapter IV “Shotcrete tunnelling using the New Austrian Tunnelling Method” has been rewritten and renamed and also part of Chapter X “Quality assurance in tunnelling”.

For the production of the new edition, I was once again dependent on the intensive support and experience of my colleagues at the University Chair and in the consultancy. In particular, I wish to thank Dipl.-Ing. *Feyerabend* for the overall coordination, ably assisted by Dipl.-Ing. *Gipperich* and Dipl.-Ing. *Berger*.

I also have to thank *Helmut Schmidt* for the production of drawings and naturally also the publisher, for whom Dr. *Jackisch* has supported us at all times.

Bochum, in June 1994

*Bernhard Maidl*



The art of the Engineer is to avoid high ground pressure, that is not to permit it to occur, a much more difficult task than to overcome ground pressure after it has occurred.

And let us dare to resist the former with intellectual, the latter with raw material work.

Franz RŽIHA, 1874

## Foreword to the 1<sup>st</sup> German edition

*Leopold Müller*, my teacher, said with slight resignation at the 28<sup>th</sup> Geomechanics Colloquium in 1979 in Salzburg: “Experience on construction sites and at congresses gives cause to reflect on the state of development in geomechanical research related to construction in rock, but experience shows that this development is largely uncontrolled and not always coordinated with the needs of practitioners and theoretical progress. Many results of scientific research remain unknown in practice or do not become accepted, while in the other direction, the research needs of practicing engineers are not recognised satisfactorily or indeed not at all”. It remains for us as his former students to consider the reasons for this development and to attempt to divert progress to a sensible path.

On tunnel projects in recent years, the “new Austrian tunnelling method” has become very successful in construction practice. But it has still today been verified by astonishingly few calculations, and that despite many Geomechanics Colloquia. However, the opinion is becoming ever more common that tunnels should be designed and built using refined calculations and with a lot of work and paper. Refined calculations demand particularly from the consultant the mastery of model formation and the application of the results of calculations in practice on site; the responsible site manager on the other hand should be able to judge how the parameters of rock mass, support and construction process affect the results of the calculation, particularly under varying geological conditions. But how is he meant to do that when the calculation has been performed externally and the given results are scarcely understandable for him?

If we investigate the failures, losses, schedule and cost overruns in tunnelling in recent years, then the calculations do not normally turn out to have been performed too little or too roughly, and there have been plenty of expert reports. The causes are rather more inadequate studies of the ground parameters, insufficient care in the selection of a construction process, inadequate adaptability to changing geological conditions, gross construction errors in important details, lack of skilled personnel, insufficient measurements; the list could be continued. Perhaps we feel too safe and become careless having put too much



trust in too much paper. In addition, the structural design of tunnels cannot be compared to the structural verification of other engineered structures. The construction of a tunnel has more to it and thankfully most tunnellers appreciate this.

On every tunnel construction project, the correct selection of a construction process is a precondition for technical and commercial success. The factor time has not yet been considered in calculations in tunnelling, but it can only be influenced through the construction process with the various excavation processes on agreed schedules and the effect of the support. The surrounding ground belongs to the structure; the sequence of operations influences the loading on the support and the load-bearing behaviour of the rock mass. The literature of tunnelling is today aligned into specialist areas, which are often aligned with the specific activities of the chairs of university lecturers, like rock mechanics, foundation engineering, structural engineering, construction management and transport. Construction process technology should in this case be understood as a structural subject, which includes the influences of construction on the design, including the consideration of construction states. Such a systematic way of thinking has only been taught for a few years as an individual scientific subject in civil engineering; the number of publications is not yet too large.

Volume I “Details and construction processes” puts the emphasis on construction process technology as a constructive area of tunnelling. Support materials and construction, excavation and advance processes and their directions of development are also dealt with. Some sections have been dealt with in more detail though the research work carried out at the Chair of Construction Technology, Tunnelling and Construction Management at the Institute for Structural Engineering at the Ruhr University, Bochum in the fields of shotcrete, steel fibre shotcrete and the driving of small-diameter tunnels, through my experience on the tunnels of new lines for German Railways and also through my former work into the drilling of blast holes. An extensive provision of illustrations shows numerous practical examples and the tables contain much technical data.

This handbook is based on my lectures for the specialised course “Construction process technology and operations”. I would like to thank the managing director of the publisher Verlag Glückauf GmbH, Dr.-Ing. *Rolf Helge Bachstroem*, for the encouragement to develop this handbook from my lecture notes on Underground Construction. In the course of long discussions, he advised me about the final version of the text, assisted in the selection of illustrations and tables and made constructive suggestions for many improvements as publisher and expert. I have also received valuable support from my employees at the Construction Technology, Tunnelling and Construction Management and in the consultancy. I wish to thank Oberingenieur Dr.-Ing. *Dietrich Stein*, my brother Dipl.-Ing. *Reinhold Maidl* and particularly Dipl.-Ing. *Harald Brühl* for their intensive collaboration. I thank *Agatha Eschner-Wellenkamp* for her inexhaustible industry with the writing work, and *Helmut Schmidt* and *Walter Zamiara* (publisher) for the preparation of many drawings.

Volume II will have the subtitle “Basics and auxiliary works in design and construction”; the volume should include geotechnical aspects, rock classification, stress states in the rock mass, structural verifications, monitoring instrumentation, dewatering, surveying and scheduling.

Bochum, in January 1984

*Bernhard Maidl*





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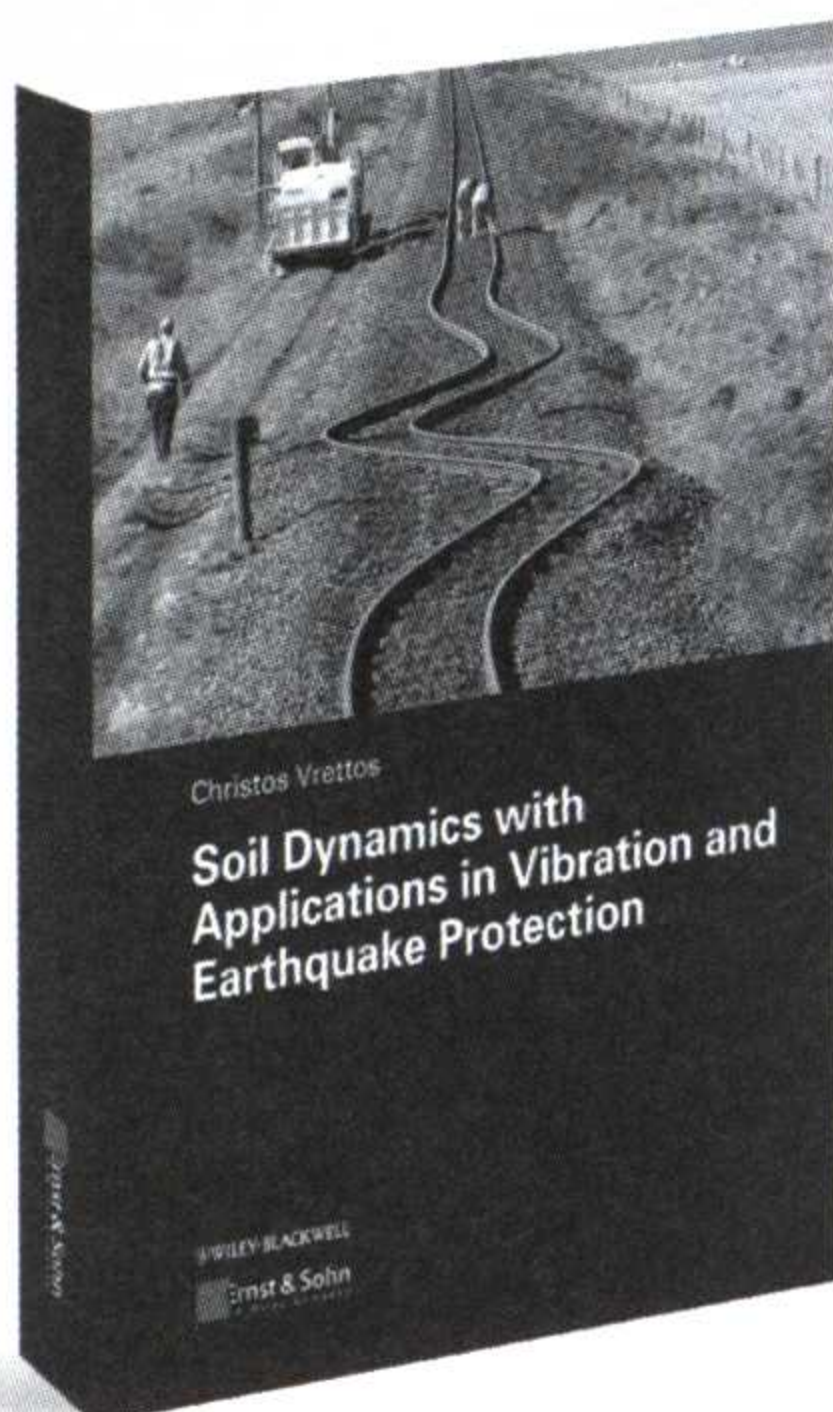
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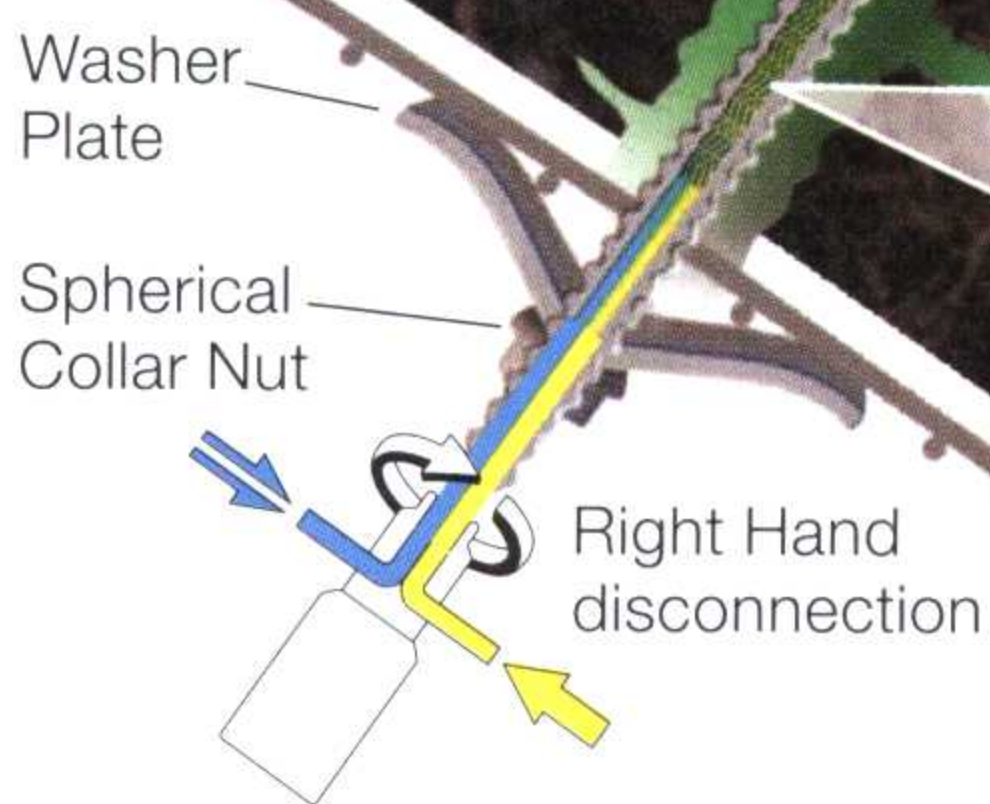
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