



Guidelines for the Design of Shield Tunnel Lining

Working Group No. 2, International Tunnelling Association

Abstract—These guidelines, prepared by Working Group 2 (Research) of the International Tunnelling Association, are presented in three parts: Part I describes the outline of the procedure of design. Part II presents the detailed design methods. Part III provides references, including examples of design. Because the methods of designing shield tunnel linings vary, the guidelines do not recommend that priority be given to any one method. Rather, this report presents the basic concepts of shield tunnel linings, in order to provide reference and guidance in designing tunnel linings. © 2000 Published by Elsevier Science Ltd. All rights reserved.

Preface

Although these guidelines present the basic concepts of shield tunnel lining, they do not supersede relevant specifications relevant to each country and each project. The aim of the guidelines is to promote advances in the design of shield tunnels in accordance with the objectives of the International Tunnelling Association prescribed in Section II of the Statutes of the ITA (ITA 1976).

Work on the guidelines began at the meeting of ITA Working Group 2 – Research in Amsterdam in 1993. After much study, discussion and investigation, the guidelines were completed in December 1999.

The guidelines consist of three parts:

Part I outlines the shield tunnel design procedure.

Part II presents the detailed design methods.

Part III provides references, including examples of shield tunnel design.

Because there are various competent methods of designing shield tunnel linings, these guidelines give no priority to any specific method. Rather, they introduce design methods generally and widely used throughout the world.

Shield tunnels are usually excavated in soft ground rather than in rock. The parameters of linings, such as dimension and strength of material, are subject not only to ground conditions but also to construction conditions.

The practice of designing tunnel linings requires much experience, practical and theoretical knowledge. It is therefore not expected that these guidelines will cover every point of tunnel lining design, but instead will provide basic knowledge useful to design practitioners. It is hoped that this knowledge

will be continuously improved through progress in tunnelling technology.

As Vice-Animateur of ITA Working Group 2, I wish to acknowledge the important contributions of the following persons: M. Yano Leblais, who led the study as Animateur; Professor Andre Assis and Professor E. Eisenstein, who guided our study as Tutors; working group members Herr Dr. Harald Wagner, Professor Teodor Iltis, Dr. Birger Schmidt, Signor Piergiorgio Grassi, all of whom contributed greatly to the study; and members of Research and Development Committee of the Japan Tunnelling Association, chaired by Professor Toru Kondo, who prepared the draft of the guidelines.

For the International Tunnelling Association,

—YOSHINOBU HIRAO TAKANO

Vice-Animateur, ITA Working Group 2,
“Research”

Part I: Outline of Shield Tunnel Lining Design Procedure

Following the planning works for the tunnel, the lining of a shield tunnel is designed according to the following sequence, as a rule:

1. **Adherence to specification, code or standard.** The tunnel to be constructed should be designed according to the appropriate specification standard, code or standards, which are determined by the persons in charge of the project or decided by discussion between these persons and the designers.
2. **Decision on inner dimension of tunnel.** The inner diameter of the tunnel to be designed should be decided in consideration of the space that is demanded by the functions of the tunnel. This space is determined by:
 - The construction gauge and car gauge, in the case of railway tunnels;

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Tunnelling and Underground Space Technology, Vol. 15, No. 5, pp. 303–304, 2000
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Pergamon

Guidelines For Tunnel Lining Design

David J. Hatem



Guidelines For Tunnel Lining Design:

Tunnel Lining Design Guide British Tunnelling Society, Institution of Civil Engineers (Great Britain), 2004 Of geotechnical and geophysical properties 160 10 3 4 Design of tunnel linings 1 61 10 4 Instrumentation of the CTRL North Downs Tunnel 164 10 5 References 165 Appendix I Abbreviations and symbols 166 Appendix 2 Risk management 168 A21 Introduction 168 A2 2 Scope 168 A23 Risk register 169 A21 1 When to use the risk register 169 A2 32 What is it 169 A2 3 3 Assessment process 169 A2 3 4 Key steps 169 A2 3 5 Risk assessment qualitative or quantitative 171 A2 3 6 Ranking risk 175 A2 4 References 17

Guidelines for Tunnel Lining Design ASCE Technical Council on Research. Technical Committee on Tunnel Lining Design, 1984 **Practical Guide to Rock Tunneling** Dean Brox, 2017-04-11 This Practical Guide to Rock Tunneling fills an important void in the literature for a practical guide to the design and construction of tunnels in rock. Practical Guide to Rock Tunneling takes the reader through all the critical steps of the design and construction for rock tunnels starting from geotechnical site investigations through to construction supervision. The guide provides suggestions and recommendations for practitioners on special topics of laboratory testing, durability of rock and acceptance for unlined water conveyance tunnels, overstressing or deep and long tunnels, risk based evaluation of excavation methods, contract strategies and post construction inspections. Key considerations and lessons learned from selected case projects are presented based on the author's extensive international experience of over 30 years and 1000 km of tunneling for civil hydropower and mining infrastructure including some of the most recognized projects in the world to date. Instead of revisiting all theory and concepts that can be found in other sources, this book contains the hard learned lessons from the author's experience in the field of Rock Tunneling gathered over 30 years of service. *AUA Guidelines for Backfilling and Contact Grouting of Tunnels and Shafts* Raymond W. Henn, 2003 Introduction Affects of geological conditions of grouting Structural and operations requirements of the completed facility Grouting of various lining types Grout materials Grout properties Backfill grouting Contact grouting Grouting equipment Record keeping Quality control Contract documents

The Shanghai Yangtze River Tunnel. Theory, Design and Construction R. Huang, 2008-04-04 One of the world's currently largest tunnel projects is under construction at the Yangtze River estuary, the Shanghai Yangtze River Tunnel project with its length of 8950 m and a diameter of 15.43 m. The Shanghai Yangtze River Tunnel Theory Design and Construction which was presented as a special issue at the occasion of the 6th International North American Tunneling 1988 Levent Ozdemir, 1998-01-01 Grouped into six sections, the papers in this volume address a wide range of issues on the challenges and opportunities facing underground construction and the use of underground space **The Channel Tunnel** Institution of Civil Engineers (Great Britain), 1992 Concept, reality and expectations Management of the project Tunnel design and construction Geology alignment and survey Machine driven tunnels Major Underground structures Construction planning and logistics Tunnel lining design and procurement **Frontiers of Rock Mechanics and Sustainable**

Development in the 21st Century Wang Sijing,Fu Bingjun,Li Zhonkui,2001-01-01 These proceedings contain the scientific contributions presented at the 2nd Asian Rock Mechanics Symposium ISRM 2001 2nd ARMS The theme of the symposium was Frontiers of Rock Mechanics and Sustainable Development in the 21st Century

Handbook of Precast Segmental Tunnel Lining Systems Verya Nasri,David Klug,Brian Fulcher,James A. Morrison,2024-07-31 This comprehensive handbook covers all aspects of design production and construction of precast concrete tunnel segmental lining with the best practices in the field included in one book for the first time New and current design methods and quantitative analyses are considered in line with ACI and ASTM codes as well as a full selection of global standards for the reliable design of the product and all components Also incorporated are new applications of science and technology such as new admixtures and the latest manufacturing processes and precisions such as tight dimensional controls and high repeatability cycles With detailed guidance from world leading practitioners this is the definitive international technical and practical manual on these linings forming a one stop reference for tunnel engineers and an invaluable resource for advanced students in civil mechanical and mining engineering

Tunnel Engineering Handbook Thomas R. Kuesel,Elwyn H. King,John O. Bickel,2012-12-06 The Tunnel Engineering Handbook Second Edition provides in a single convenient volume comprehensive coverage of the state of the art in the design construction and rehabilitation of tunnels It brings together essential information on all the principal classifications of tunnels including soft ground hard rock immersed tube and cut and cover with comparisons of their relative advantages and suitability The broad coverage found in the Tunnel Engineering Handbook enables engineers to address such critical questions as how tunnels are planned and laid out how the design of tunnels depends on site and ground conditions and which types of tunnels and construction methods are best suited to different conditions Written by the leading engineers in the fields this second edition features major revisions from the first including Complete updating of all chapters from the first edition Seven completely new chapters covering tunnel stabilization and lining difficult ground deep shafts water conveyance tunnels small diameter tunnels fire life safety tunnel rehabilitation and tunnel construction contracting New coverage of the modern philosophy and techniques of tunnel design and tunnel construction contracting The comprehensive coverage of the Tunnel Engineering Handbook makes it an essential resource for all practicing engineers engaged in the design of tunnels and underground construction In addition the book contains a wealth of information that government administrators and planners and transportation officials will use in the planning and management of tunnels

North American Tunneling: 2014 Proceedings Davidson, Gregg,Howard, Alan,Jacobs, Lonnie,Pintabona, Robert,Zernich, Brett,2014-06-17 The North American Tunneling Conference is the premier forum to discuss new trends and developments in underground construction in North America With every conference the number of attendees and breadth of topics grows North American Tunneling 2014 Proceedings reflects the theme for the 2014 conference Mission Possible The authors share new theories novel innovations and the latest tools that make what once may have been perceived as impossible now possible

The authors of 128 papers share the latest case histories expertise lessons learned and real world applications from around the globe on a wide range of topics They cover the successes and failures of challenging construction projects Read about challenging design issues fresh approaches on performance future projects and industry trends as well as ground movement and support structure analysis risk and cost management rock tunnels caverns and shafts TBM technology and selection and water and wastewater conveyance

Geotechnical Aspects of Underground Construction in Soft Ground Klaas Jan Bakker,Adam Bezuijen,Wout Broere,E.A. Kwast,2013-05-23 A valuable source of reference on the current practices of analysis design and construction of tunnels and underground structures in soft ground This collection of reviewed papers covers a wide range of tunnelling practice from deep excavations in Singapore to the construction of a new metro line in Barcelona The international scope of the contributors makes this a truly comprehensive collection of work on the geotechnical aspects of soft ground excavation

Rapid Excavation and Tunneling Conference 2021 Proceedings Jarrett E. Carlson,Gregg W. Davidson,2021-06-06 Every two years industry leaders and practitioners from around the world gather at the Rapid Excavation and Tunneling Conference RETC the authoritative program for the tunneling profession to learn about the most recent advances and breakthroughs in this unique field The information presented helps professionals keep pace with the ever changing and growing tunneling industry This book includes the full text of 106 papers presented at the 2021 conference Though the tunneling industry continues to develop both technically and contractually one notable adaptation of the last two years has been the onset and management of COVID 19 The hallmarks of tunneling professionals include adaptability resiliency optimism and management of change These are traits that have been recently put to an entirely new challenge over the last year or so We have truly witnessed why what we do is deemed essential infrastructure The COVID 19 pandemic has impacted each of us personally and professionally and while times have been hard we are fortunate to work in a field that is able to meet the challenge and thrive thereafter Congratulations are in order to everyone in our industry for keeping the planning and development of projects moving forward and for maintaining safe and productive worksites in these challenging times

North American Tunneling 2022 Proceedings Paul Madsen,Matthew Crow,Louis Falco,Amanda Morgan,Kathy Murtagh,2022-06-03 Your timely source for more cost effective and less disruptive solutions to your underground infrastructure needs The North American Tunneling Conference is the premier biennial tunneling event for North America bringing together the brightest most resourceful and innovative minds in the tunneling industry It underscores the important role that the industry plans in the development of underground spaces transportation and conveyance systems and other forms of sustainable underground infrastructure With every conference the number of attendees and breadth of topics grows The authors expert and leaders in the industry share the latest case histories expertise lessons learned and real world applications from around the globe Crafted from a collection of 92 papers presented at the conference this book takes you deep inside the projects It includes sections on technology planning design and case histories

Geotechnical Aspects of Underground Construction in Soft Ground Charles W.W. Ng,H.W. Huang,G.B. Liu,2008-12-03

This volume comprises a collection of four special lectures six general reports and 112 papers presented at the Sixth International Symposium of Geotechnical Aspects of Underground Construction in Soft Ground IS Shanghai held between 10 and 12 April 2008 in Shanghai China The Symposium was organised by Tongji University and the following t **Practical Tunnel Construction** Gary B. Hemphill,2012-10-05 The only modern guide to all aspects of practical tunnel construction Practical Tunnel Construction fills a void in the literature for a practical guide to tunnel construction By taking the reader through a brief introduction and history to a comprehensive discussion of how the geological factors affect tunneling the author covers the stages and technology that are common today without using complex equations Written for the individual who does not have an extensive background in tunneling but who has to make tunneling decisions the various tunneling methods are discussed to help in the determination of the appropriate method The methods discussed are hand mining drill blast Tunnel Boring Machine TBM New Austrian Tunnelling Method NATM Norwegian Method of Tunnelling NMT Roadheader Earth Pressure Balance Machine EPBM and Slurry Pressure Balance Machine SPBM This book focuses on driven tunnels This versatile handbook Offers clear and accessible coverage of the state of the art in tunnel construction Introduces the essentials of design and construction of many types of tunnels including TBM EPB Roadheader NATM drill and blast and soft ground tunneling Provides nontechnical guidance on selecting the most appropriate tunneling methods for various situations Includes a brief history of tunneling and an introduction to geotechnical considerations Discusses tunnel access shaft construction mucking methods tunnel haulage grout water handling and much more Practical Tunnel Construction is an important resource for students construction managers tunnel designers municipal engineers or engineers who are employed by government agencies or corporations that are exploring the feasibility of planning and designing or building a tunnel

Subsurface Conditions David J. Hatem,1998-01-02 Die Berufshaftpflicht ist und bleibt eines der wichtigsten Themen f r Geotechniker wenn auch nur wenig Information zu diesem Thema verf gbar ist Unterirdische Ingenieurs und Konstruktionsarbeit ist immer mit Unsicherheit verbunden Folglich ist das Haftungs und Risikomanagement f r Geotechniker ebenso wichtig wie technisches Know How Dennoch lernen die meisten erst etwas ber Risikomanagement durch eigene Erfahrungen Geotechniker geh ren zu den Berufsgruppen die die h chsten Haftpflichts tze zahlen und daher ist das Hauptthema Schadensf lle zu vermeiden Dieses Buch vermittelt Ingenieuren ein Verst ndnis ber nicht technische Aspekte des geotechnischen Ingenieurwesens Es diskutiert die Auswirkungen von Fehlern und Vers umnissen anwendbare Gesetze sowie andere Elemente die im Zusammenhang mit Schadenersatzforderungen und Streitigkeiten stehen Zusammengetragen wurde eine F lle von Informationen die bislang nur in Monographien und Fachzeitschriften zu finden waren 01 98 **Tunnels and Underground Cities. Engineering and Innovation Meet Archaeology, Architecture and Art** Daniele Peila,Giulia Viggiani,Tarcisio Celestino,2019-04-17 Tunnels and Underground Cities Engineering and Innovation meet Archaeology

Architecture and Art contains the contributions presented at the World Tunnel Congress 2019 Naples Italy 3-9 May 2019. The use of underground space is continuing to grow due to global urbanization, public demand for efficient transportation and energy saving, production and distribution. The growing need for space at ground level along with its continuous value increase and the challenges of energy saving and achieving sustainable development objectives demand greater and better use of the underground space to ensure that it supports sustainable, resilient and more liveable cities. This vision was the source of inspiration for the design of the logos of both the International ITA and Italian SIG Tunnelling Association. By placing key infrastructures underground, the black circle in the logos, it will be possible to preserve and enhance the quality of the space at ground level, the green line. In order to consider and value underground space usage together with human and social needs, engineers, architects and artists will have to learn to collaborate and develop an interdisciplinary design approach that addresses functionality, safety, aesthetics and quality of life and adaptability to future and varied functions. The 700 contributions cover a wide range of topics from more traditional subjects connected to technical challenges of design and construction of underground works with emphasis on innovation in tunneling engineering to less conventional and archetypically Italian themes such as archaeology, architecture and art. The book has the following main themes: Archaeology, Architecture and Art in underground construction, Environment, sustainability in underground construction, Geological and geotechnical knowledge and requirements for project implementation, Ground improvement in underground constructions, Innovation in underground engineering materials and equipment, Long and deep tunnels, Public communication and awareness, Risk management, contracts and financial aspects, Safety in underground construction, Strategic use of underground space for resilient cities, Urban tunnels, Tunnels and Underground Cities, Engineering and Innovation meet Archaeology. Architecture and Art is a valuable reference text for tunneling specialists, owners, engineers, architects and others involved in underground planning, design and building around the world and for academics who are interested in underground constructions and geotechnics. Urban Transportation Abstracts, 1985

Fibre-reinforced concrete: From design to structural applications FIB - Féd. Int. du Béton, 2016. The FRC 2014 Workshop Fibre Reinforced Concrete from Design to Structural Applications was the first ACI fib joint technical event. The Workshop held at Polytechnique Montreal, Canada, on July 24th and 25th, 2014, was attended by 116 participants from 25 countries and 4 continents. The first international FRC workshop was held in Bergamo, Italy, in 2004. At that time, the lack of specific building codes and standards was identified as the main inhibitor to the application of this technology in engineering practice. Ten years after Bergamo, many of the objectives identified at that time have been achieved. The use of fibre reinforced concrete (FRC) for designing structural members in bending and shear has recently been addressed in the fib Model Code 2010. Steel fibre reinforced concrete (SFRC) has also been used structurally in several building and bridge projects in Europe and North America. SFRC has been widely used in segmental tunnel linings all over the world. Members of ACI 544 and fib TG 4.1 have

been involved in writing code based specifications for the design of FRC structural members More than fifty papers were presented at the Workshop from which forty four were selected for this joint ACI fib publication The papers are organised in the document under six themes Design guidelines and specifications Material properties for design Behaviour and design of beams and columns Behaviour and design of slabs and other structures Behaviour and design of foundations and underground components and finally Applications in structure and underground construction projects

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Table of Contents Guidelines For Tunnel Lining Design

1. Understanding the eBook Guidelines For Tunnel Lining Design
 - The Rise of Digital Reading Guidelines For Tunnel Lining Design
 - Advantages of eBooks Over Traditional Books
2. Identifying Guidelines For Tunnel Lining Design
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Guidelines For Tunnel Lining Design
 - User-Friendly Interface
4. Exploring eBook Recommendations from Guidelines For Tunnel Lining Design
 - Personalized Recommendations
 - Guidelines For Tunnel Lining Design User Reviews and Ratings
 - Guidelines For Tunnel Lining Design and Bestseller Lists

5. Accessing Guidelines For Tunnel Lining Design Free and Paid eBooks
 - Guidelines For Tunnel Lining Design Public Domain eBooks
 - Guidelines For Tunnel Lining Design eBook Subscription Services
 - Guidelines For Tunnel Lining Design Budget-Friendly Options
6. Navigating Guidelines For Tunnel Lining Design eBook Formats
 - ePub, PDF, MOBI, and More
 - Guidelines For Tunnel Lining Design Compatibility with Devices
 - Guidelines For Tunnel Lining Design Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Guidelines For Tunnel Lining Design
 - Highlighting and Note-Taking Guidelines For Tunnel Lining Design
 - Interactive Elements Guidelines For Tunnel Lining Design
8. Staying Engaged with Guidelines For Tunnel Lining Design
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Guidelines For Tunnel Lining Design
9. Balancing eBooks and Physical Books Guidelines For Tunnel Lining Design
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Guidelines For Tunnel Lining Design
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Guidelines For Tunnel Lining Design
 - Setting Reading Goals Guidelines For Tunnel Lining Design
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Guidelines For Tunnel Lining Design
 - Fact-Checking eBook Content of Guidelines For Tunnel Lining Design
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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web jul 6 2016 one easy way to measure your cadence for running is to count the times your feet hit the ground in 60 seconds cadence can also be defined as the number of steps one foot takes per minute for example in polar running watches and other products a cadence of 180 steps per minute is shown as 90

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web jun 12 2017 running cadence or leg turnover is defined as the total number of revolutions per minute rpm or number of full cycles taken within a minute by the pair of feet measured by the number of times that your feet strike the ground per minute while running ground contact time cadence is usually calculated by counting the number of

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web mar 14 2023 forcing a high cadence is a questionable strategy for improving performance and as we've seen cadence is largely determined by how fast we run having said that most of us naturally select a cadence lower than the optimum and would benefit from retraining to a higher step rate

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web over the past few years studies have emerged that highlight the role of cadence to correct common running related injuries rris as little as a five percent increase in step rate while keeping running velocity constant has been shown to reduce shock absorption at the level of the knee by 20 percent additionally increasing cadence by 10

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web oct 17 2023 recreational runners tend to have a cadence between 150 to 180 strides per minute spm faster runners as we've seen often have a higher cadence for example eliud kipchoge the marathon world record holder is known to achieve a cadence of 190 200spm in general 170 180spm is considered a great running cadence

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