PUBLICATIONS

Geotechnical Engineering in Research and Practice

WBI-PRINT 5

Edited by Prof. Dr.-Ing. W. Wittke
Beratende Ingenieure für Grundbau und Felsbau GmbH

Consulting Engineers for Foundation
Engineering and Construction in Rock Ltd.

New Austrian Tunneling Method (NATM) Stability Analysis and Design

Walter Wittke, Berndt Pierau, Claus Erichsen

translated into English by:
Jens Lüke and Johannes R. Kiehl

Translated from the German edition: Statik und Konstruktion der Spritzbetonbauweise. Geotechnik in Forschung und Praxis, WBI-PRINT 5, VGE-Verlag Glückauf GmbH, Essen 2002, ISBN 3-7739-1305-2

From the contents:

> Means of support

> Geotechnical mapping and monitoring

> Case Histories:

- Crown heading with open invert
- Crown heading with closed invert
- Sidewall adit heading
- Full-face heading
- Heading under the protection of pipe umbrellas
- Heading under the protection of jet grouting columns

Preface

Within the series "WBI-PRINT, geotechnical engineering in research and practice", volumes 4 to 7 are designed as a compendium of tunnel statics. This compendium started with the volume WBI-PRINT 4 "Stability analysis for tunnels, fundamentals", published in 1999 in German and in 2000 in English.

The present volume WBI-PRINT 5 "New Austrian Tunneling Method stability analysis and design" covers, beside fundamentals of the New Austrian Tunneling Method (NATM), case histories of realized mined tunnels designed and constructed with participation of WBI.

The selected case histories from the years 1985 to 2001 include crown headings with open and closed invert, sidewall adit headings, full-face headings and headings under the protection of pipe umbrellas and jet grouting columns.

Analyses according to the finite element method have proved to be an indispensable tool for the design of tunnels. The stability analyses for all case histories presented were carried out using the program system FEST03. In order to enable this program system to be used by our professional colleagues as well, we have been offering it for sale for some little time now.

WBI-PRINT 5 has been previously published 2002 in German as a paperback. Now the English translation is available online to provide a worldwide access to those who are interested in tunneling. It is also available on CD-ROM via WBI company.

The next volume in the series WBI-Print is dedicated to the mechanized tunneling. This volume appears as WBI-PRINT 6 in German in December 2006. Special problems of tunnel statics will be covered in WBI-PRINT 7.

I adress my special thanks to my two co-authors and directors at WBI, Dr.-Ing. B. Pierau and Dr.-Ing. C. Erichsen, who have been supporting my work substantially for many years. I am also obliged to Dr.-Ing. J. R. Kiehl for his editorial work. The translation into English was carried out by Dr.-Ing. J. Lüke as well as Dr.-Ing. J. R. Kiehl. I convey my sincere thanks to them. Further thanks are due to our secretary and design office.

Aachen, December 2006

Walter Wittke

Contents Page

1. Introduction 1

2. Elements of the NATM 4

2.1 Shotcrete 4

2.1.1 Components and composition 4

2.1.2 Spraying methods 7

2.1.3 Early strength 11

2.1.4 Final strength 14

2.1.5 Deformability 15

2.1.6 Rebound 17

2.2 Steel sets 17

2.2.1 Basic types 17

2.2.2 Load-carrying behavior 28

2.3 Anchors 30

2.3.1 Basic types 30

2.3.2 Load-carrying behavior 36

2.4 Advance support 37

2.4.1 Spiles 37

2.4.2 Pipe umbrellas 40

2.5 Geotechnical mapping and monitoring 48

2.5.1 Mapping 48

2.5.2 Monitoring 54

3. Crown heading with open invert 67

3.1 Glockenberg Tunnel near Koblenz, Germany 67

3.1.1 Introduction 67

Contents Page

3.1.2 Structure 68

3.1.3 Ground and groundwater conditions 71

3.1.4 Excavation classes 73

3.1.5 Stability analyses 76

3.1.6 Crown heading and monitoring results 90

3.1.7 Conclusions 93

3.2 Gäubahn Tunnel in Stuttgart, Germany 94

3.2.1 Introduction 94

3.2.2 Structure 94

3.2.3 Ground and groundwater conditions 98

3.2.4 Excavation classes 99

3.2.5 Stability analyses for the design of the shotcrete support 102

3.2.6 Crown heading and monitoring results 108

3.2.7 Conclusions 110

3.3 Hellenberg Tunnel, Germany 111

3.3.1 Introduction 111

3.3.2 Structure 111

3.3.3 Ground and groundwater conditions 114

3.3.4 Excavation classes 116

3.3.5 Crown heading 119

3.3.6 Results of the crown face mapping 121

3.3.7 Stability analyses for the bench excavation 123

3.3.8 Construction and monitoring results 127

Contents Page

3.3.9 Conclusions 130

4. Crown heading with closed invert 131

4.1 Österfeld Tunnel in Stuttgart, Germany 131

4.1.1 Introduction 131

4.1.2 Structure 131

4.1.3 Ground and groundwater conditions 135

4.1.4 Fundamentals of the design 140

4.1.5 Stability analysis for the stages of construction 141

4.1.6 Excavation and support 147

4.1.7 Monitoring program and interpretation of the measuring results 151

4.1.8 Conclusions 155

4.2 Road tunnel "Elite" in Ramat Gan, Israel 156

4.2.1 Introduction 156

4.2.2 Structure 159

4.2.3 Ground and groundwater conditions 161

4.2.4 Design 164

4.2.5 Stability analyses 168

4.2.6 Construction 183

4.2.7 Monitoring 187

4.2.8 Conclusions 189

4.3 City railway tunnel to Botnang in Stuttgart, Germany 190

4.3.1 Introduction 190

4.3.2 Structure 190

Contents Page

4.3.3 Ground and groundwater conditions 190

4.3.4 Design 196

4.3.5 Stability analyses for the design of the shotcrete support 198

4.3.6 Construction 209

4.3.7 Monitoring 211

4.3.8 Conclusions 213

5. Sidewall adit heading 214

5.1 Road tunnel "Hahnerberger Straße" in Wuppertal, Germany 214

5.1.1 Introduction 214

5.1.2 Structure 215

5.1.3 Exploration 216

5.1.4 Design and construction 220

5.1.5 Stability analyses for the stages of construction 226

5.1.6 Stability analyses for the design of the interior lining 233

5.1.7 Monitoring 236

5.1.8 Conclusions 238

5.2 Limburg Tunnel, Germany 238

5.2.1 Introduction 238

5.2.2 Structure 241

5.2.3 Ground and groundwater conditions 243

5.2.4 Excavation and support 245

5.2.5 Sidewall adit excavation north 248

Inhalt Page

5.2.6 Stability analyses for sidewall adit, excavation north 253

5.2.7 Monitoring results 260

5.2.8 Conclusions 262

5.3 Niedernhausen Tunnel, Germany 262

5.3.1 Introduction 262

5.3.2 Structure 264

5.3.3 Ground and groundwater conditions 266

5.3.4 Excavation and support 267

5.3.5 Three-dimensional stability analyses 270

5.3.6 Construction 284

5.3.7 Conclusions 290

6. Full-face heading 291

6.1 Urban railway tunnel underneath the Stuttgart airport runway, Germany 291

6.1.1 Introduction 291

6.1.2 Structure 292

6.1.3 Ground and groundwater conditions 294

6.1.4 Fundamentals of the design 300

6.1.5 Excavation and support 304

6.1.6 Stability analyses for the design of the shotcrete support 307

6.1.7 Monitoring 312

6.1.8 Interpretation of the monitoring results 316

6.1.9 Conclusions 322

Contents Page

6.2 Freeway tunnel "Berg Bock" near Suhl, Germany 323

6.2.1 Introduction 323

6.2.2 Structure 323

6.2.3 Ground and groundwater conditions 328

6.2.4 Excavation and support 330

6.2.5 Stability analyses for the stages of construction and design of the shotcrete support 334

6.2.6 Stability analyses for the design of the interior lining 340

6.2.7 Monitoring 348

6.2.8 Conclusions 350

7. Heading under the protection of jet grouting columns 351

7.1 Road tunnel for the federal highway B 9 in Bonn-Bad Godesberg, Germany 351

7.1.1 Introduction 351

7.1.2 Structure 351

7.1.3 Ground and groundwater conditions 355

7.1.4 Design and construction 357

7.1.5 Stability analyses for the design of the shotcrete support 367

7.1.6 Monitoring 377

7.1.7 Conclusions 377

7.2 City railway tunnel "Killesberg-Messe" in Stuttgart, Germany 379

7.2.1 Introduction 379

7.2.2 Structure 380

Contents Page

7.2.3 Ground and groundwater conditions 382

7.2.4 Excavation and support 385

7.2.5 Stability analyses 392

7.2.6 Monitoring 400

7.2.7 Conclusions 402

8. References 404