

Contents

1	Historical Development and Future Challenges	1
2	Basic Principles and Definitions	15
2.1	Basic Principles and Construction	16
2.1.1	Boring System	16
2.1.2	Thrust and Clamping System	17
2.1.3	Muck Removal System	18
2.1.4	Support System	18
2.2	Definitions and Terms	20
2.2.1	Tunnel Boring Machines with Full-Face Excavation	20
2.2.1.1	Gripper TBM	20
2.2.1.2	Shielded TBM	22
2.2.2	Tunnel Boring Machines for Partial Excavation	23
3	Boring Operation	25
3.1	The Boring Process	25
3.2	The Cutter Head	26
3.2.1	Shape of the Cutter Head	27
3.2.2	Clearing the Muck in the Excavation Area	29
3.2.3	Cutter Head Construction and Soil Consolidation	31
3.3	Cutting Tools	32
3.3.1	General	32
3.3.2	Working Method of Cutter Discs	33
3.3.3	Cutter Spacing	36
3.3.4	Penetration	38
3.3.5	Wear	41
3.3.6	Wear and Water	48
3.3.7	Cutter Housing	49
3.4	The Main Drive	50
3.4.1	Types of Main Drive	50
3.4.2	Main Bearing	53
3.5	Advance Rate	53
3.6	Special Types	55
3.6.1	Reamer TBMs	56
3.6.2	Bouygues System	57
3.6.3	Mobile Miner (Robbins)	58
3.6.4	Back-Cutting Technology	58
3.6.4.1	Mini-Fullfacer (Atlas Copco)	58
3.6.4.2	Continuous Miner	60
3.6.5	Shaft Sinking	61
3.6.5.1	Raise Boring	62

3.6.5.2	Blind Drilling	64
3.6.5.3	Combinations	65
4	Thrust	67
4.1	General	67
4.2	Advance with Gripper Clamping	67
4.3	Advance with a Shield TBM	72
5	Material Transport	75
5.1	Material Transport at the Machine	75
5.2	Material Transport Through the Tunnel	77
5.2.1	Rail Transport	77
5.2.1.1	Diesel or Electric Operation	79
5.2.1.2	Muck Cars	79
5.2.1.3	Loading in the Tunnel	80
5.2.1.4	Train Timetable	80
5.2.1.5	Tunnel Track	81
5.2.2	Trackless Operation	81
5.2.2.1	Transport Vehicles	82
5.2.2.2	Haul Road	82
5.2.2.3	Loading	82
5.2.3	Conveyor Transport	84
5.2.3.1	Conveyor Storage	85
5.2.3.2	Conveyor Belt Extension and Belt Operation	85
5.2.3.3	Advantages of Conveyor Transport and Innovation Potential	87
6	Backup Equipment	89
6.1	Backup Concept	89
6.2	Design Specifications	93
7	Ventilation, Dust Removal, Working Safety, Vibration	99
7.1	Ventilation	99
7.1.1	Danger	99
7.1.2	Ventilation Schemes, Ventilation Systems	99
7.2	Dust Removal	100
7.3	Occupational Safety and Safety Planning for TBM Operation	103
7.3.1	General	103
7.3.2	International Guidelines and National Regulations	104
7.3.2.1	International Guidelines	104
7.3.2.2	National Regulations	104
7.3.3	Integrated Safety Plan	106
7.3.3.1	The Safety Plan in the Environment of Management Plans	106
7.3.3.2	Safety Aims	107
7.3.3.3	Description of Dangers and Risk Analyses	107

Contents		IX
7.3.3.4	Action Plan	109
7.3.4	TBM Details and Specifics Regarding Natural Gas Danger and Rock Support	110
7.3.4.1	Natural Gas Danger	110
7.3.4.2	Rock Support	111
7.4	Vibration	111
8	Additional Equipment	115
8.1	Investigation and Improvement of the Geological Conditions	115
8.2	Equipment for Rock Support	117
8.2.1	Anchor Drills	117
8.2.2	Steel Ring Equipment	118
8.2.3	Mesh Installation Equipment	118
8.2.4	Innovation Aims	119
8.3	TBM Steering	119
8.3.1	Steering the Gripper TBM with Single Bracing	119
8.3.2	Steering the Gripper TBM with X-Type Clamping	122
8.3.3	Steering a Single Shield TBM	122
8.3.4	Steering a Double Shield TBM	125
8.4	Surveying	126
8.4.1	Surveying the Position of the Tunnel Boring Machine	127
8.4.2	Forward Calculation of the TBM Route	127
9	Tunnel Support	129
9.1	General	129
9.2	Support Systems and Advance Rates	130
9.3	Systematic Support at the Machine	133
9.3.1	Steel Arch Support	133
9.3.2	Liner Plates	136
9.3.3	Segments	137
9.3.3.1	Invert Segments	137
9.3.3.2	Segmental Lining	137
9.4	Shotcrete Support	142
9.4.1	Shotcrete Support at the Machine	142
9.4.2	Shotcrete Support in the Backup Area	143
9.5	Localised Support	144
9.5.1	Anchors and Mesh	144
9.5.2	Arch Support	145
9.6	Stabilisation Ahead of the Cutter Head	146
10	Gripper TBM and Shield Machine Combinations	149
10.1	Roof Shields	149
10.2	Roof Shield and Side Steering Shoes and Cutter Head Shields	152
10.3	Walking Blade Gripper TBM	153

10.4	Full-Face Shield Machines	155
10.4.1	Developments	155
10.4.2	Special Characteristics	156
10.4.2.1	Cutter Head and Shield	157
10.4.2.2	Thrust Ring	157
10.5	Double Shields	159
10.5.1	Developments	159
10.5.2	Functional Principle	159
10.5.3	Special Cases	160
10.5.3.1	Shield and Bentonite Lubrication	160
10.5.3.2	Telescopic Shield	161
10.6	Slurry Shield Machines	163
10.6.1	Developments	163
10.6.2	Working Principle	163
10.7	Shields with Screw Conveyors	165
10.7.1	Developments	165
10.7.2	Working Principle	165
10.7.3	Machine Types	167
10.7.3.1	Open Mode (Screw Conveyor – Conveyor Belt)	167
10.7.3.2	Closed Mode (Screw Conveyor – Conveyor Belt)	167
10.7.3.3	Closed Mode (Slurry Circuit)	168
10.7.3.4	EPB Mode (Screw Conveyor – Conveyor Belt or Screw Conveyor/Slurry Pump)	169
10.7.3.5	Open Mode (Conveyor Belt)	170
10.8	Micro Machines for Hard Rock	172
10.8.1	Mini TBM	172
10.8.2	Pipe Jacking	174
10.8.2.1	Press-Boring Pipe Jacking	174
10.8.2.2	Shield Pipe Jacking	174
11	Special Processes: Combinations of TBM Drives with Shotcrete ..	177
11.1	Scope of Application	177
11.2	Construction Options	178
11.2.1	Probe Headings	178
11.2.2	Pilot Headings	180
11.2.3	Enlargement for Stations, Points or Machine Halls	181
11.3	Examples	183
11.3.1	Piora-Mulde Probe Heading	183
11.3.2	Kandertal Probe Heading	184
11.3.3	Uznaberg Pilot Heading	188
11.3.4	Enlargement at the Connecting Structure at Nidelbad Zürich–Thalwil Tunnel	190

Contents	XI
12	Geological Investigations and Influences 195
12.1	General 195
12.2	Influences on the Boring Process 199
12.3	Influences on the Machine Clamping 202
12.4	Influences on the Rock Support 205
13	Classification for Excavation and Support 207
13.1	General and Objectives for Mechanised Tunnelling 207
13.2	Classification Systems 208
3.2.1	Classification According to Rock Properties 208
13.2.1.1	RMR System (Rock Mass Rating System) 208
13.2.1.2	Q System (Quality System) 211
13.2.2	Classification According to Cuttability and Abrasiveness 220
13.2.3	Classification According to Type, Extent and Location of the Support Work Required 222
13.3	Standards, Guidelines and Recommendations for the Classification of Mechanised Tunnelling 223
13.3.1	Classification in Germany 223
13.3.2	Classification in Austria 228
13.3.3	Classification in Switzerland 234
13.4	Classification Suggestion by the Authors 239
14	Tendering, Award, Contract 243
14.1	Procedure Examples 243
14.1.1	Procedure in Switzerland 243
14.1.1.1	General 243
14.1.1.2	Tender Evaluation 244
14.1.1.3	Quality Management 245
14.1.1.4	Assignment of Risks in the Contract 246
14.1.1.5	Geologically or Geotechnically Altered Conditions, Altered Orders, Altered Schedules 249
4.1.2	Procedure in the Netherlands 249
14.1.2.1	Tendering and Negotiation Procedure with the Botlek Tunnel as an Example 249
14.1.3	Procedure in Germany 252
14.2	Design and Geotechnical Requirements in the Tendering of a Mechanised Tunnelling as Alternative Proposal 253
14.2.1	Introduction 253
14.2.2	Examples 253
14.2.2.1	Adler Tunnel 253
14.2.2.2	Sieberg Tunnel 254
14.2.2.3	Stuttgart Airport Tunnel 255
14.2.2.4	Rennsteig Tunnel 257
14.2.2.5	Lainz Tunnel 258

14.2.3	Additional Requirements for Mechanised Tunnelling Concept in the Tender Documents	260
14.2.3.1	Geology and Hydrology	261
14.2.3.2	Design and Construction Process	261
14.2.3.3	Specification and Contract	262
14.2.4	Decisions Based on Cost	262
14.2.4.1	Design Phase and Preparation for Tendering	262
14.2.4.2	Tendering Phase	263
14.2.4.3	Construction Phase and Final Payment	263
14.2.5	Forecast	263
15	Tunnel Lining	265
15.1	General	265
15.2	Design Principles for Tunnel Linings	265
15.2.1	Single-Shell and Double-Shell Construction	265
15.2.2	Watertight and Water-Draining Forms of Construction	267
15.3	Lining with Concrete Segments	269
15.3.1	General	269
15.3.2	Construction Types	271
15.3.2.1	Block Segments with Right-Angled Plan	271
15.3.2.2	Hexagonal or Honeycomb Segments	274
15.3.2.3	Rhomboidal and Trapezoidal Segment Systems	275
15.3.2.4	Expanding Segments	276
15.3.2.5	Yielding Lining Systems	277
15.3.3	Joint Detailing	282
15.3.3.1	Longitudinal Joints	282
15.3.3.2	Ring Joints	286
15.3.4	Steel Fibre Concrete Segments	289
15.3.5	Grouting Annular Gap	290
15.3.5.1	Filling with Gravel	290
15.3.5.2	Mortar Grouting	291
15.3.6	Measures for Waterproofing Tunnels with Segment Linings	291
15.3.6.1	Sealing Bands	292
15.3.6.2	Injecting	294
15.3.7	Segment Production	295
15.3.8	Damages	296
15.3.8.1	Damage During Ring Erection	297
15.3.8.2	Damage During Excavation	297
15.3.8.3	Damage at the Shield Tail Seal	298
15.3.8.4	Damage after Leaving the Shield	298
15.3.8.5	Repair of Damage	299
15.4	Cast in-situ Linings	299
15.4.1	General	299
15.4.2	Construction	300

Contents	XIII
15.4.3	Manufacture 300
15.5	Shotcrete Layers as the Final Lining 301
15.6	Structural Investigations 302
16	Examples of Completed Tunnels 303
16.1	Tunnel Excavation with Gripper TBMs 303
16.1.1	Control and Drainage Tunnel, Ennepe Reservoir 303
16.1.2	Manapouri Underwater Tunnel, New Zealand 305
16.2	Tunnelling with Shield TBMs 313
16.2.1	San Pellegrino Tunnel, Italy 313
16.2.2	Zürich–Thalwil Twin-Track Tunnel, Section Brunau–Thalwil 317
16.3	Inclined Shaft Tunnelling with Double Shield 321
16.3.1	Cleuson–Dixence Pressure Shaft 321
References 327
Index 337