

Table of contents

Preface	VII
Acknowledgements	IX
About the Authors	XI
1 Introduction	1
2 Geology of Turkey and Istanbul, expected problems, some cuttability characteristics of the rocks	3
2.1 Introduction.....	3
2.2 Geology of Turkey.....	3
2.3 Geology of Istanbul.....	4
2.4 TBM performance in different projects in Istanbul	6
2.5 Description of geological formations in Istanbul, physical and mechanical properties.....	8
2.5.1 The stratigraphy of Istanbul and description of geologic formations.....	8
2.5.2 Typical frequency of RQD and GSI in the geological formations in Istanbul.....	16
2.5.3 Physical and mechanical properties of rocks taken from different geological formations.....	28
2.5.4 Schmidt hammer tests carried out in station tunnels in Uskudar-Umraniye metro line.....	37
2.6 Full-scale linear rock cutting tests with disc cutters in rock samples collected from different projects in Istanbul	40
2.6.1 Description of laboratory full-scale linear rock cutting test	41
2.6.2 Testing methodology and test results	43
2.6.3 Comparison of laboratory full-scale linear rock cutting test results with in-situ cutter performance – the effect of rock discontinuities	52
2.7 Conclusions.....	68
References	70
3 Difficult ground conditions dictating selection of TBM type in Istanbul	73
3.1 Introduction.....	73
3.2 Case study of open TBM in complex geology (1989), in Baltalimani tunnel: Why open type TBM failed	73
3.2.1 Collapse between chainage 0+920 and 0+935 km	78
3.2.2 Collapse between chainage 0+965 and 0+982 km	79
3.2.3 Collapse between chainage 1+148 and 1+155 km	80
3.2.4 Collapse between chainage 1+220 and 1+235 km	80
3.3 Double shield TBM in the Istanbul–Moda collector tunnel, 1989/90	80
3.4 Double shield TBM working without precast segment, difficulties in difficult ground: Tuzla-Dragos tunnel in Istanbul.....	80
3.5 Difficulties in using slurry TBMs in complicated geology, Marmaray tunnel project	84

3.6	Difficulties in single-shield TBM working in open mode in complex geology: An example from Kadikoy–Kartal metro tunnel.....	86
3.7	Eurasia tunnel excavated by a large diameter slurry TBM	88
3.8	Conclusions.....	88
	References	90
4	Difficult ground conditions affecting performance of EPB-TBMs	91
4.1	Introduction.....	91
4.2	Factors affecting performance of EPB-TBMs.....	92
4.3	Performance prediction of EPM TBMs in difficult ground conditions.....	93
4.3.1	A model to predict the performance of EPB-TBMs in difficult ground conditions	94
4.3.2	Estimation of optimum specific energy from full-scale laboratory cutting experiments.....	95
4.3.3	Estimation of optimum field specific energy	95
4.3.4	Estimation of machine utilization time	98
4.3.5	Numerical example to estimate daily advance rate of an EPB-TBM	99
4.3.6	Comparison of predicted and realized EPB-TBM performance values	100
4.3.7	Verification and modification of the model for silty-clay and sand in the Mahmutbey–Mecidiyekoy metro tunnels.....	103
4.4	Conclusions.....	106
	References	107
5	Selection of cutter type for difficult ground conditions	109
5.1	Introduction.....	109
5.2	Comparative studies of different type of cutters for Tuzla–Dragos tunnel in Istanbul – test procedure and results.....	109
5.2.1	Efficiency of chisel cutters as against disc cutters.....	111
5.3	The inefficient use of tungsten carbide studded disc cutters in the Marmaray–Istanbul project	114
5.4	Conclusions.....	115
	References	116
6	Effects of North and East Anatolian Faults on TBM performances	117
6.1	Introduction.....	117
6.2	Kargi tunnel	117
6.3	Gerede tunnel	118
6.4	Dogancay energy tunnel.....	120
6.5	Nurdagi railway tunnel	122
6.6	Uluabat energy tunnel	123
6.7	Tunnels excavated by drill and blast methods.....	126
6.7.1	Ayas Tunnel: the most difficult tunnel in Turkey affected by North Anatolian Fault	126
6.7.2	Bolu tunnel.....	127
6.8	Conclusions.....	127

References	128
7 Effect of blocky ground on TBM performance and the mechanism of rock rupture	129
7.1 Introduction.....	129
7.2 Mechanism of rock rupture and face collapse in front of the TBM in the Kozyatagi–Kadikoy metro tunnels in Istanbul.....	131
7.2.1 Kozyatagi and Kadikoy metro tunnels and problems related to blocky ground.....	131
7.2.2 Mechanism of rock rupture and face collapse in front of the TBM.....	134
7.2.3 Other factors affecting the efficiency of tunnel excavation on the Kozyatagi–Kadikoy metro line	138
7.3 Conclusions.....	140
References	141
8 Effects of transition zones, dykes, fault zones and rock discontinuities on TBM performance	143
8.1 Introduction.....	143
8.2 Beykoz sewerage tunnel.....	143
8.2.1 Description of the project	143
8.2.2 Geology of the area.....	144
8.2.3 Description of the TBM	146
8.2.4 Effect of rock formation on chip formation and machine utilization time	147
8.2.5 Effect of dykes on tunnel face collapse and TBM blockage.....	149
8.2.6 Effect of transition zones on TBM performance	150
8.2.7 Effect of fault zones on TBM performance.....	152
8.3 Kartal–Kadikoy metro tunnels, methodology of understanding critical zones	153
8.3.1 Geology and physical and mechanical properties of rocks	154
8.3.2 Mechanism of face collapse and TBM blockages	155
8.3.3 Change of TBM performance in problematic areas	161
8.4 Conclusions.....	163
References	165
9 Squeezing grounds and their effects on TBM performance	167
9.1 Introduction.....	167
9.2 Basic works carried out on squeezing ground	167
9.3 Uluabat tunnel	168
9.3.1 Description of the project	168
9.3.2 Geology of the project area	169
9.3.3 Description of the TBM used and the general performance	171
9.3.4 Effect of TBM waiting time on squeezing	176
9.3.5 Effect of bentonite application on TBM squeezing	178
9.3.6 Conclusions.....	179
9.4 Kargi Tunnel	179
9.4.1 Squeezing of the cutterhead and related problems	179

9.4.2	Effect of Q values on squeezing of TBM	184
9.4.3	Discussions and conclusions on TBM swelling in Kargi project.....	185
References		186
10	Clogging of the TBM cutterhead	189
10.1	Introduction.....	189
10.2	What is clogging of a TBM cutterhead and what are the clogging materials?.....	189
10.3	Testing clogging effects of the ground.....	189
10.4	Mitigation programs to eliminate clogging.....	191
10.5	Clogging of TBMs in Turkish projects	192
10.5.1	Suruc Project	192
10.5.2	Selimpasa sewerage tunnel in Istanbul	196
10.5.3	Zeytinburnu Ayvalidere-2 wastewater tunnel project	201
10.6	Conclusions.....	207
References		208
11	Effect of high strength rocks on TBM performance	211
11.1	Introduction.....	211
11.2	Beykoz sewerage tunnel, replacing CCS disc cutters with V-type disc cutters to overcome undesirable limits of penetration for a maximum limit of TBM thrust.....	211
11.3	Nurdagi tunnel, full-scale cutting tests to obtain optimum TBM design parameters in very high strength and abrasive rock formation	213
11.4	Beylerbeyi-Kucuksu wastewater tunnel, TBM performance in high strength rock formation	216
11.5	Tuzla-Akfirat wastewater tunnel, TBM performance in high strength rocks.....	221
11.6	Conclusions.....	222
References		223
12	Effect of high abrasivity on TBM performance	225
12.1	Introduction.....	225
12.2	Determination of the abrasivity	229
12.3	Empirical prediction methods for disc cutter consumption	232
12.3.1	Colorado School of Mines (CSM) model for CCS type 17-inch single-disc cutters	232
12.3.2	Norwegian Institute of Technology (NTNU) model.....	233
12.3.3	Maidl et al. (2008) model for CCS type 17-inch single-disc cutters	238
12.3.4	Frenzel (2011) model for CCS type 17-inch single-disc cutters	238
12.3.5	Gumus et al. (2016) model for CCS type 12-inch monoblock double-disc cutters of an EPB-TBM	238
12.4	Examples of cutter consumptions on TBMs in Turkey	239
12.4.1	Tuzla-Akfirat wastewater project in Istanbul	240
12.4.2	Yamanli II HEPP project in Adana.....	250
12.4.3	Beykoz wastewater project in Istanbul.....	260

12.4.4	Buyukcekmece wastewater tunnel in Istanbul	262
12.4.5	Uskudar–Umraniye–Cekmekoy–Sancaktepe metro tunnel in Istanbul	264
12.5	Conclusions	269
	References	271
13	Effect of methane and other gases on TBM performance	273
13.1	Properties of methane	273
13.2	Selimpasa wastewater tunnel, methane explosion in the pressure chamber of an EPB-TBM	275
13.2.1	Introduction to the Selimpasa wastewater project	275
13.2.2	Occurrence and causes of methane explosion in the Selimpasa wastewater tunnel	278
13.2.3	Consequences of methane explosion in the Selimpasa wastewater tunnel	279
13.2.4	Precautions against methane and excavation performance in the Selimpasa wastewater tunnel	280
13.3	Gas flaming in the Silvan irrigation tunnel	284
13.4	More gas-related accident examples for mechanized tunneling	287
13.5	Conclusions	290
	References	291
14	Probe drilling ahead of TBMs in difficult ground conditions	293
14.1	Introduction	293
14.2	General information on probe drilling and previous experiences in different countries	293
14.3	Melen water tunnel excavated under the Bosphorus in Istanbul	295
14.4	Methodology of predicting weak zones ahead in the Melen water tunnel	297
14.4.1	Data analysis and results	300
14.5	Kargi energy tunnel	308
14.5.1	General information on the Kargi project	308
14.5.2	Probe drilling operations	309
14.5.3	Analysis of probe drilling data in the Kargi project	309
14.6	Conclusions	316
	References	318
15	Application of umbrella arch in the Kargi project	321
15.1	Introduction	321
15.2	General concept of umbrella arch and worldwide application	321
15.3	Methodology of using umbrella arch in the Kargi project	322
15.4	Criteria used for umbrella arch in the Kargi project and the results	325
15.5	Conclusions	330
	References	331
16	Index	333