# TBM Excavation in Difficult Ground Conditions
## Case Studies from Turkey

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Cover: Methane Explosion in the Pressure Chamber of a Tunnel Boring Machine
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*This book is dedicated to our lovely wives*
*Ayfer Bilgin, Nurten Copur and Nurgul Balci*
*and our beloved children*
*Damlanur Bilgin, Serkan and Busra Copur and Cem Eren Balci*

## Preface

The use of tunnel boring machine (TBM) tunneling has increased considerably in the past ten years in Turkey. It is planned to excavate 200 km of tunnels in the near future in Istanbul alone, and 100 km of tunnels in other parts of Turkey. Thirty new TBMs are predicted to start working in Istanbul during 2017.

The geology of Turkey is complex, and the country is in a tectonically active region; on a broad scale, the tectonics of the region are controlled by the collision of the Arabian Plate and the Eurasian Plate. The Anatolian block is being squeezed to the west. The block is bounded to the north by the North Anatolian Fault and to the south-east by the East Anatolian Fault. The effects of these faults are seen clearly on the performance of TBMs used in these regions.

This book is written with the intention of sharing the tunneling experiences gained during several years in difficult ground and complex geology. The methane explosion in an earth pressure balance (EPB) TBM chamber, the clogging of a TBM, the need to change disc cutters to chisel cutters, the need to change CCS-type discs cutters to V-type disc cutters, excessive disc cutter consumption, the optimum selection of TBM type in complex geology, magmatic inclusions or 'dykes', the effect of blocky ground on TBM performance, the mechanism of rock rupture in front of TBMs, TBM face collapses and blockages, the effect of opening ratio in EPB-TBMs in fractured rock, squeezing of the TBM or jamming of the cutterhead, probe drilling and the use of umbrella arching ahead of TBMs are discussed within this book.

We hope that the experiences shared in this book may help project designers and practicing engineers dealing with TBM drivages in complex geology in different parts of the world.

Istanbul, June 2016

Nuh Bilgin
Hanifi Copur
Cemal Balci

## Acknowledgements

The contents of this book were discussed at some of the World Tunneling Congresses organized by the ITA, and some of the data has been published in different technical journals such as Tunneling and Underground Space Technology, Rock Mechanics and Rock Engineering and International Journal of Rock Mechanics and Mining Sciences. However, the topics in this book include more data and it has been analyzed more comprehensively. We are grateful to the organizers of the World Tunneling Congresses and cited journal authorities who gave us the chance to discuss the subject in advance.

The following contractors and state organizations have given us the opportunity to access field data and have helped in analyzing tunneling performances. Without their generous help it would have been impossible to write this book.

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Unal Akpinar
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State Hydraulic Works (DSI)
State Railway Organization (TCDD)
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## About the Authors

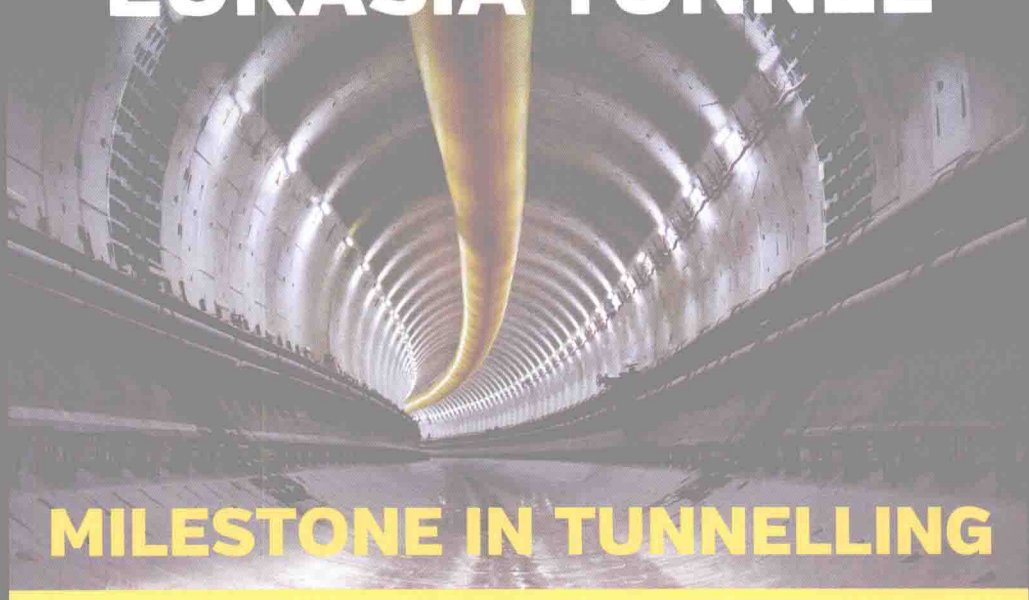
**Nuh Bilgin** graduated from the Mining Engineering Department of Istanbul Technical University, and completed his PhD studies at the University of Newcastle, UK, in 1977 in "Mechanical cutting characteristics of some medium and high strength rocks". He joined the Mining Engineering Department of Istanbul Technical University in 1978. He was appointed as a full-time professor in 1989. He spent one year in Colorado School of Mines, USA, and one year in Witwatersrand University, South Africa, as visiting professor. He has published more than one hundred papers on mechanized mining and tunneling technologies, and is currently working in ITU and is chairman of Turkish Tunneling Society.

**Hanifi Copur** graduated from the Mining Engineering Department of Istanbul Technical University, and completed his PhD on rock cutting mechanics and mechanical excavation of mines and tunnels at the Colorado School of Mines in 1999. He worked as a research engineer at the Earth Mechanics Institute of the Colorado School Mines between 1995 and 1999, and has been working as an academician in the Mining Engineering Department of the Istanbul Technical University since 1999, and currently works in the same department. He has written many national and international scientific and industrial research reports and publications on mechanical mining and tunneling. He is a board member of the Turkish Tunneling Society.

**Cemal Balci** graduated from the Mining Engineering Department of Istanbul Technical University, and in 2004, received his PhD after completing his thesis on "Comparison of small and full-scale rock cutting tests to select mechanized excavation machines" at the Mining Engineering Department of Istanbul Technical University, Mine Mechanization and Technology Division. He worked with the research group of the Earth Mechanics Institute, Colorado School of Mines, between 2001 and 2004 as a researcher. He has published numerous papers on mechanized mining and tunneling technologies and has worked on many national and international implementation and research projects. He is currently working as full-time professor in ITU and is a board member of the Turkish Tunneling Society.

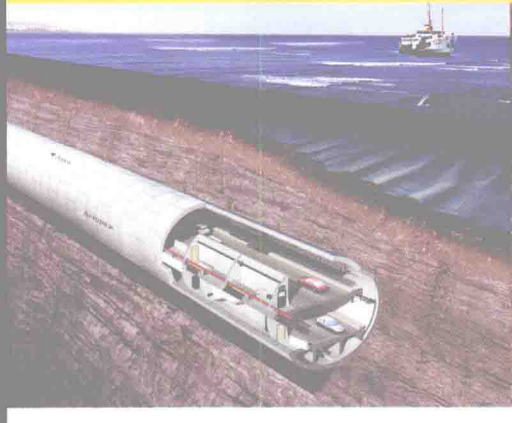
İSTANBUL

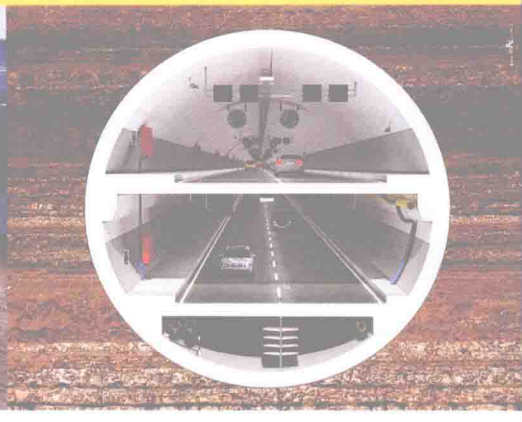
# EURASIA TUNNEL



## MILESTONE IN TUNNELLING

**TBM EXCAVATION DIAMETER: 13,7 m | FACE PRESSURE: 11 Bars | DEEPEST POINT: 106,4 m**





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## Table of contents

# 1 Introduction

*A man who carries a cat by the tail learns something he can learn in no other way.*

*~Mark Twain*

This book is written with the intention of sharing the experiences gained in difficult ground conditions with TBMs in Turkey.

Turkey is in a tectonically active region; at a large scale, the tectonics of the region are controlled by the collision of the Arabian Plate and the Eurasian Plate. The Anatolian block is being squeezed to the west. The block is bounded to the north by the North Anatolian Fault and to the south-east by the East Anatolian Fault. The effects of North and East Anatolian Faults on TBM performances in Kargi energy tunnel, Dogancay energy tunnel, Nurdagi railway tunnel and Uluabat energy tunnels are explained in detail giving the causes, effects and precautions to be taken in order to eliminate the problems created by two large sets of faults. Some information is also given about the most difficult tunnels (Ayas and Bolu) that have ever been excavated by drill and blast method.

We believe that the Selimpasa and Silvan tunnels also provide unique experience since one suffered a methane explosion in the EPB chamber and the other hit a natural gas reservoir completely destroying a TBM and its related accessories.

The clogging of a TBM, as is encountered in clay-containing ground, has extensive consequences for the construction process and can severely affect the performance of the machine, increasing the torque, thrust and specific energy and lowering the advance rates with the extra cleaning efforts needed. Chapter 10 is written with the intention of clarifying the subject by giving three examples of tunneling projects in Turkey: Suruc Tunnel plus Selimpasa and Zeytinburnu Ayvalidere, two wastewater tunnels that were studied in detail in this respect. Experimental studies performed in the soil conditioning laboratory indicated that regular application of foam selected by the contractor was adequate to solve the sticking and clogging problems in Selimpasa, while an anti-clay agent different from the one selected by the contractor was suggested for Zeytinburnu. The representatives in the two cases applied the laboratory results in the field. The field measurements validated the experimental studies and the net advance rates of the EPB-TBMs increased at least 1.3 to 1.5 times and the stoppages due to clogging problems were reduced to normal ranges.

One of the most difficult tunnels ever opened in Istanbul was Beykoz sewerage tunnel, which encountered a complex geology. The need to change disc cutters to chisel cutters, CCS-type discs cutters to V-type disc cutters, excessive disc cutter consumption and TBM squeezing problems were also experienced in this tunnel.

Istanbul has a very complex geology, and in the near future the majority of TBM tunneling projects of Turkey are planned to be carried out in this fast-growing city. Bearing in mind this reality, the main objective of Chapter 3 is to show how the optimum selection of TBM type for Istanbul, has gradually changed from open type TBM (Baltalimani Tunnel), to double shield TBM (Moda-Tuzla Tunnel), to slurry type TBM

*TBM Excavation in Difficult Ground Conditions. Case Studies from Turkey.* First Edition. Nuh Bilgin, Hanifi Copur, Cemal Balci.

(Marmaray tunnels) and finally to EPB-TBMs over the past 25 years. This gradually progressing selection based on the complex geology of Istanbul is a typical example to the concept of 'learning costs'. A model of the performance prediction of EPB-TBMs is also given based on experiences and data collected in several metro tunnels as Uskudar–Cekmekoy and Mahmutbey–Mecidiyekoy metro tunnels.

As already explained, Turkey is widely affected by two major fault systems, the North Anatolian and East Anatolian Faults. These two fault systems and magmatic inclusions 'dykes', fracture the host rock creating problematic blocky ground for TBM excavations. This problem is explained in Chapter 7 which is aimed to explain the effect of blocky ground on TBM performance and the mechanism of rock rupture in front of the TBM. Typical examples are given from Kozyatagi–Kadikoy Metro tunnels.

The causes and effects of TBM blockages are explained for Kadikoy–Kozyatagi metro tunnels. Eleven different TBM face collapses and blockages which have occurred in very complex geology within the Kadikoy–Kozyatagi Metro tunnels are analyzed considering TBM parameters such as opening ratio, working modes and geological parameters. It is determined that the TBM excavation parameters fluctuate while approaching the collapse regions, and these parameters show an increasing or decreasing trend in-site 'during collapse' region and it is concluded that this trend is a good indicator of face collapses, which will serve as a guide to foresee critical areas in front of TBM.

Squeezing of TBM or jamming the cutterhead is a nightmare for tunnel engineers, since it affects machine utilization time and realization of the project scheduled time. The salvation (rescue) of a jammed cutterhead can considerably reduce the mean advance rate. This problem was studied for Kargi, Uluabat and Dogancay tunnels, where the causes and effects of TBM squeezing are discussed with respect to remedial works needed for these three tunnels.

Cutter consumption is one of the most important cost items in mechanized tunneling due to replacement costs, cutting efficiency (penetration rate reduction with worn tools), and also man-hours spent on replacement. Yamanli II HEPP Tunnel, Buyukcekmece wastewater tunnel, Beykoz sewerage tunnel and Uskudar–Umraniye–Cekmekoy–Sancaktepe Metro Tunnels are detailed in this respect in Chapter 12.

Probe drilling ahead of a TBM is a time-consuming and tedious operation. If it is not interpreted correctly, it can give misleading results in complex geology. The research study summarized in this book shows that for correct interpretation of the drilling data, muck from the excavated area should be collected continuously for petrographic identification and strength tests. Two typical examples are Melen water tunnel and the Kargi Project. The experience gained in the umbrella arch in front of the TBM in the Kargi Project is also shared within this book.