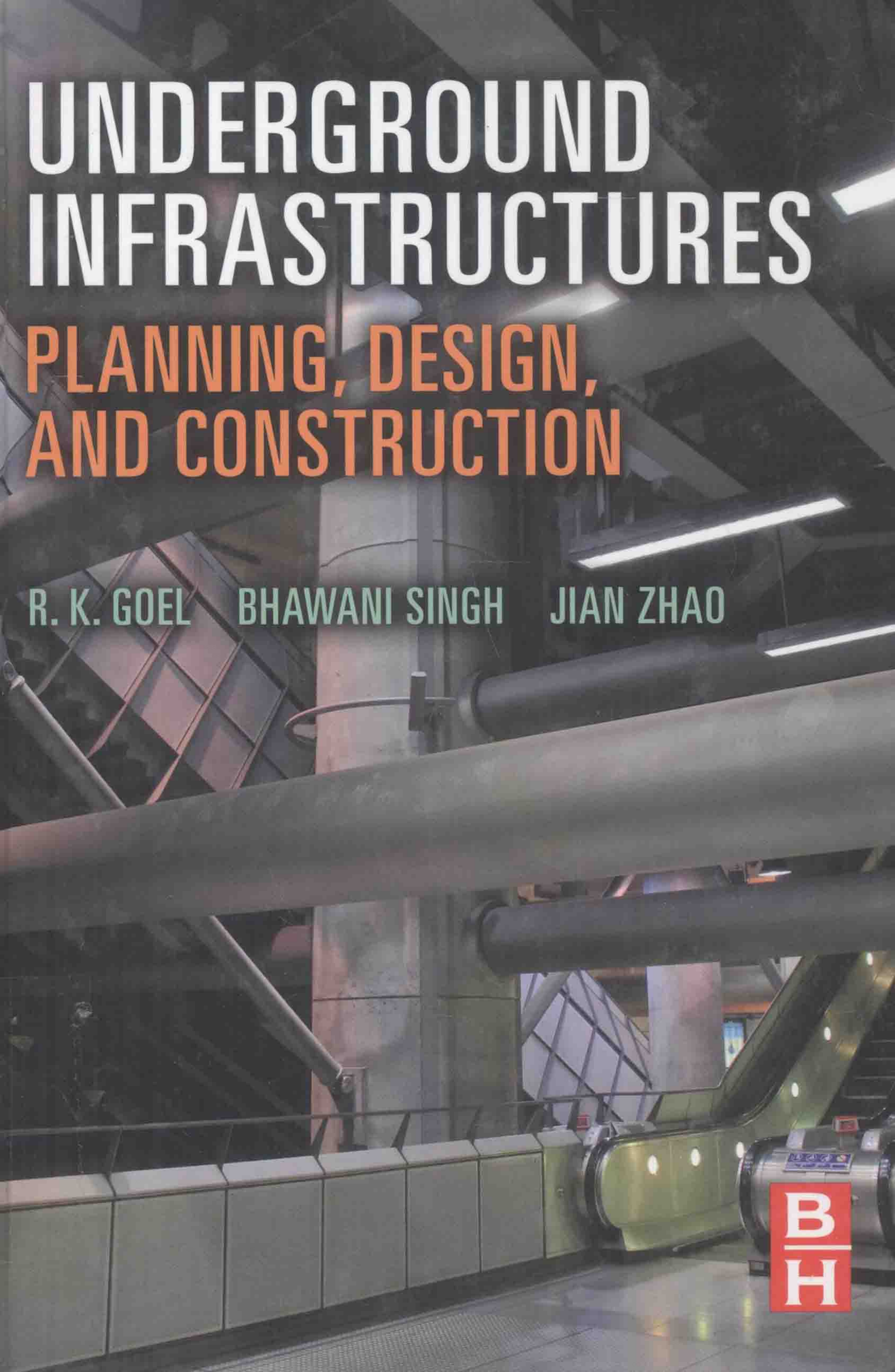
UNDERGROUND INFRASTRUCTURES

PLANNING, DESIGN, AND CONSTRUCTION

R. K. GOEL BHAWANI SINGH JIAN ZHAO



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Planning, Design, and Construction

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225 Wyman Street, Waltham, MA 02451, USA
The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK

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Library of Congress Cataloging-in-Publication Data
Goel, R. K., 1960-
Underground infrastructures: planning, design, and construction / R.K. Goel, Bhawani Singh, Jian Zhao.
p. cm.
ISBN 978-0-12-397168-5
1. Underground construction–Planning. 2. Underground construction–Design. 3. Underground storage–Planning. 4. Underground storage–Design. 5. Underground areas–Design and construction. I. Singh, Bhawani. II. Zhao, Jian, 1960- III. Title.
TA712.G584 2012
624.1'9–dc23
2011051741

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

For information on all Butterworth-Heinemann publications visit our Web site at *http://store.elsevier.com*

Typeset by: diacriTech, Chennai, India

Printed in the United States of America
12 13 14 15 16 17 18 10 9 8 7 6 5 4 3 2 1

Preface

Heavenly underground cities are dreams of civil and mining engineers, architects, city planners, and geologists. Everywhere people like underground metros, nearby underground malls, and underground parks in the 21st century. The usefulness of underground infrastructure in business is no less in developed and developing nations. Safety against major devastating earthquakes, landslides, cyclones, and wars is the key attraction in underground cities. Safety costs money. Hence a humble effort has been made to write this comprehensive book on "Underground Infrastructures: Planning, Design, and Construction" for city planners, civil and mining engineers, architects, military engineers, administrators, and municipal authorities. Our dear people may also like reading this simple book. The rail and road tunneling networks in weak hilly areas and mega cities are rightly regarded as engineering marvels by people. The aim of this book is to generate more creative confidence among civil, mining, and nuclear energy engineers; city and town planners; architects; geologists and geophysicists; managers; and administrators.

Earlier Bhawani Singh and R.K. Goel have published three books. The first book is on "Rock Mass Classification—A Practical Approach in Civil Engineering" in 1999. The second book is on "Software for Engineering Control of Landslide and Tunnelling Hazards" in 2002. Subsequently, the third book is on "Tunnelling in Weak Rocks" in 2006. Practicing civil and mining engineers, geologists, geophysicists, and students have enjoyed and used all these books. Everyone has boosted our morale so we have written a fourth book. We pray God that everyone enjoys reading and using this book in imagining real master plans for underground cities or infrastructure. The aforementioned three books are offered for detailed designs of underground opening systems, which are envisaged in their master plans.

The Himalayan region is vast, an amazingly beautiful creation of nature that possesses an extensive rejuvenating life support system. It is also one of the best field laboratories for learning rock mechanics, tunneling, underground space science, engineering geology, and geohazards. The research experience gained in the Himalayas is precious to the whole world.

The authors' foremost wish is to express their deep gratitude to Professor Charles Fairhurst, University of Minnesota; Professor E. Hoek, International Consulting Engineer; Dr. N. Barton, Norway; Professor J.J.K. Daemen, University of Nevada; Professor Ray Sterling, USA; Dr. E. Grimstad, NGI; Professor G.N. Pandey, University of Swansea; Professor John Hudson, UK; Professor J. Nedoma, Academy of Sciences of Czech Republic; Professor V.D. Choubey;

Professor T. Ramamurthy, IITD; Mr. B.B. Deoja, Nepal; Mr. A. Wagner, Switzerland; Professor R.N. Chowdhary, Australia; Professor S. Sakurai, Japan; Professor R. Anbalagan, IITR; Professor M. Kwasniewski, Poland; Dr. B. Singh; Professor B.B. Dhar, Dr. N.M. Raju, late Dr. A.K. Dube, Dr. J.L. Jethwa, Dr. Amalendu Sinha, CIMFR; Dr. V.M. Sharma, ATES; late Professor L.S. Srivastava; Professor Gopal Ranjan, COER; Professor P.K. Jain, IITR; Professor M.N. Viladkar, IITR; Dr. A.K. Dhawan, CSMRS; Dr. V.K. Mehrotra; Dr. H.S. Badrinath; Dr. Prabhat Kumar, CBRI; Dr. P.P. Bahuguna, ISM; Dr. Subhash Mitra, Uttarakhand Irrigation Department; Dr. Rajbal Singh, CSMRS; Professor Mahendra Singh, IITR; Professor N.K. Samadhiya, IITR; Mr. H.S. Niranjan, HBTI; and Dr. Rajesh K. Goel, ONGC, for their constant moral support and vital suggestions and for freely sharing precious field data. The authors are also grateful to the scientists and engineers of CIMFR, CSMRS, IRI Roorkee, IIT Roorkee, IIT Delhi, ATES, AIMIL, HEICO, New Delhi and to all project authorities for supporting field research and sharing data.

The authors are very grateful to their families and friends for their sacrificing spirit. Without their support the writing of this book would have been very difficult.

The authors also thank A.A. Balkema, Netherlands; American Society of Civil Engineers (ASCE), Reston; Ellis Horwood, U.K.; Institution of Mining & Metallurgy, London; John Wiley & Sons, Inc., New York; Springer-Verlag, Germany; Trans Tech., Germany; Wilmington Publishing House, U.K.; Pergamon, Oxford, U.K.; Van Nostrand Reinhold, New York; Wiley Interscience, USA; Elsevier Ltd., U.K.; Bureau of Indian Standards, India; ISO for the kind permission; and all eminent professors, researchers, and scientists whose work is referred to in the book.

All engineers, architects, city planners, and geologists are requested to kindly send their precious suggestions for improving the book to the authors for future editions.

R. K. Goel
Bhawani Singh
Jian Zhao

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Chapter 1

Introduction

Life is given to us, we earn it by giving it.

Rabindranath Tagore

1.1 UNDERGROUND SPACE AND ITS REQUIREMENT

The joy of traveling through underground metros, rail, and road tunnels, especially the half-tunnels in mountains and visiting caves, cannot be described. Modern underground infrastructures are really engineering marvels of the 21st century. The space created below the ground surface is generally known as *underground space*. Underground space may either be developed by open excavation in soft strata or soil, the top of which is subsequently covered to get the space below, or created by excavation in hard strata or rock.

Underground space is available almost everywhere, which may provide the site for activities or infrastructure that are difficult or impossible to install aboveground or whose presence aboveground is unacceptable or undesirable. Another fundamental characteristic of underground space lies in the natural protection it offers to whatever is placed underground. This protection is simultaneously mechanical, thermal, acoustic, and hydraulic (i.e., watertight). It is effective not only in relation to the surface, but also within the underground space itself. Thus underground infrastructure offers great safety against all natural disasters and nuclear wars, ultraviolet rays from holes in the ozone layer, global warming, electromagnetic pollution, and massive solar storms.

Increasing population and the developing needs and aspirations of humankind for our living environment require increasing provision of space of all kinds. This has become a high priority for most "mega cities" since the closing years of the 20th century. The world's population is becoming more urbanized, at an unprecedented pace. There were 21 mega cities with populations of more than 10 million people by the year 2000, as predicted earlier; 17 of these cities were in developing countries [1]. There is a need for sustainable development that meets the need of the present generation without compromising the ability of future generations to meet their own needs.

At the same time, growing public concerns for both conservation and quality of life are rightly giving pause to unrestrained development of the cities at ground level. Provision of new urban infrastructure may either coexist or conflict with improvement of the urban environment. In each city, the balance will depend on local priorities and economic circumstances; but unquestionably, environmental considerations are now being accorded greater importance everywhere. Even skyscrapers have three- to four-storied basements.

In the aforementioned scenario, city planners, designers, and engineers have a greater responsibility to foster a better environment for living, working, and leisure activity at the ground surface and are therefore turning increasingly to the creation of space underground to accommodate new transportation, communication and utility networks, and complexes for handling, processing, and storing many kinds of goods and materials. So to stay on top, go underground.

In different countries, various facilities have been built underground. These facilities include:

- Underground parking space
- Rail and road tunnels
- Sewage treatment plants
- Garbage incineration plants
- Underground mass rapid transport systems, popularly known as "underground metro"
- Underground oil storage and supply systems (through pipelines in tunnels)
- Underground cold storage
- Hydroelectric projects with extensive use of underground caverns and tunnels

In Shanghai, China, more than 2 million m^2 of subsurface space has been developed as underground buildings for various uses since modernization in 1980. Underground supermarkets, warehouses, silos, garages, hospitals, markets, restaurants, theaters, hotels, entertainment centers, factories and workshops, culture farms, plantations, subways, and subaqueous tunnels may be found throughout the city of Shanghai [2].

A publication of Royal Swedish Academy of Engineering Sciences "Going Underground" [3] is a useful document describing various uses of underground space. One outstanding example of the use of underground space is an underground ice hockey stadium with a span of 61 m, in Gjovik, Norway, built for the 1994 winter Olympic Games.

"*Out of sight, out of mind*" summarizes the advantages of creating public awareness of underground space, a remarkable resource that is still largely underdeveloped but available worldwide. The time is ripe for exploring the possibilities of developing underground space for civic utilities in mega cities. It is pertinent to give the example of the Palika Bazar, an underground market in New Delhi, India. As part of the Cannought Place shopping area, the Palika Bazar was built as a cut-and-cover subsurface structure with a beautiful garden created above it. If the Palika Bazar was on the surface, the garden space would have been lost and surface congestion would have increased immeasurably.

There is a challenge for developing countries because they have to find solutions that are effective, affordable, and locally acceptable, which can be implemented at a rate that keeps pace with the growing problems. So, more rock engineering experts are being consulted now.

1.2 HISTORY OF UNDERGROUND SPACE USE

In the primitive ages, beginning roughly three million years ago, from the time human beings first existed on earth to the Neolithic age of approximately 3000 B.C., underground space was used in the form of cave dwellings so that people could protect themselves from the threats posed by natural (primarily climatic) hazards. The world's biggest cave is 207 m high and 152 m wide in a Vietnam forest. This Hang Son Doong cave is larger than the Dear cave in Sarawak, Malaysia, which is more than 100 m high and 90 m wide. Following this period, in ancient times from roughly 3000 B.C. to A.D. 500, which spanned the civilizations of Egypt, Mesopotamia, Greece, and Rome, technology employed in the construction of tunnels progressed considerably [4].

The earliest examples of underground structures in India were in the form of dwelling pits cut into the compacted loess deposits in Kashmir around 3000 and 500 B.C. This was brought to light by the Archaeological Survey of India (ASI) during excavations in 1960. These pit houses were found to provide excellent protection against cold and severe winter weather as well as the heat of summer. They also offered protection against external attack. Dwellings dating back to 1600 B.C. were also noted at Nagarjuna Konda in Andhra Pradesh state [5].

The world's most beautiful and elaborate rock tunnels, the rock temples in Maharashtra state, cut out of the hardest rock and having a length of some kilometers, indicate early experience in underground engineering by humans. The tunnels of Ellora alone add up to 10.8 km in length. In medieval India, forts and palaces were provided with fountains, underground pathways, basement halls for storage, meeting halls, summer retreats, and water tunnels. Underground constructions in Daulatabad fort, Man Mandir in the palace of King Man Singh, and the 17 basement chambers below the famous TajMahal, are outstanding constructions of medieval kings of India [6].

The mythological story of Ramayana mentions the town of Kishkindha, which was built completely underground and thus enabled its King Bali to win all battles.

Ancient Egyptians gave utmost care to bury their dead in the underground structures, as they believed strongly in life after death. The upper level is in a rectangular shape with a flat top called "mastaba." The lower part is an underground level where the floor was covered by mortar, crushed stones, and straw. Later the idea of mastaba evolved toward the true pyramid. The pyramid contains an underground tomb structure that was built first before construction of the pyramid. These pyramids are as old as 2778 B.C. The great pyramid of Khufo at Giza in Egypt has an incline tunnel as long as 82 m in Giza rock [7].

In the area of the pyramid, ancient Egyptians were fond of underpasses below causeways leading to other pyramids. Sometimes these causeways were considered sacred paths; workers were not permitted to walk on them and therefore it was necessary to cross them by these underpasses. Another example also in the area of the pyramids is the underground drainage canals for the drainage systems in the funerary temples of Khufo and Chephern. In the courtyard of Khufo's temple, a basin of 20 by 30 feet (7×10 m) with a depth of approximately 7 feet (2 m) was cut in the rock as a collector tank from which branch canals go out; most of its length was underground. Another example from this area is the underground construction under the Sphinx and the pedestrian tunnel between the pyramids [7].

In June 1992, 5 large man-carved rock caverns were unearthed by four local farmers after they pumped water out of five small pools in their village near the town of Longyou in the Zhejiang Province of China. Subsequently, 19 other caverns were found nearby. These caverns were excavated in Fenghuang Hill, a small hill that is 3 km north in Longyou County. The hill has elevations between 39 and 69 m above mean sea level. The Longyou rock caverns are a group of large ancient underground caverns. They were carved manually in pelitic siltstone in the Quxian Formation of the Upper Cretaceous. They have the following five characteristics: more than 2000 years old, man carved, large spanned, near the ground surface, and medium to hard surrounding rock. This discovery attracted the attention of many specialists from China, Japan, Poland, Singapore, and the United States [8].

There are 23 known large-scale underground cities in the Cappadocia region in Turkey. The underground cities were connected by hidden passages to houses in the region. Hundreds of rooms in the underground cities were connected to each other with long passages and labyrinth-like tunnels. The corridors were made long, low, and narrow to restrict the movement of intruders. Shafts (usually connected with the lowest floor of the underground cities) were used for both ventilation and communication inside the underground cities. Although some researchers claim that the underground settlements were connected to each other with tunnels, conclusive evidence to support this idea has not yet been found [9].

New hydropower projects are being taken up involving construction of more than 1000-km length tunnels with sizes varying from 2.5 to 14 m diameter to add 16,500 MW of hydropower by the end of 11th 5-year plan in India. After the success of the metro rail project in Delhi with state-of-the-art technology, construction of a metro rail project is planned in various cities, including Mumbai, Bangalore, Hyderabad, Lucknow, Pune, Chandigarh, and Howrah-Kolkata. The Indian Railways is constructing the most challenging Jammu–Udhampur–Srinagar–Baramulla railway line in the difficult Himalayan terrain of Jammu and Kashmir State, and there are 42 tunnels with a total length of 107.96 km in the Katra-Quazigund section (142 km). The Konkan Railway Corporation Limited (KRCL) has constructed a 760-km Konkan railway line with 92 tunnels with a total length of 83.6 km. The Border Roads Organisation has planned a prestigious and challenging highway tunnel with a length of 8.9 km under the 3978-m high Rohtang pass on Manali-Leh road, and construction of the tunnel is to start shortly [10]. Six-story underground parks are under construction in New Delhi and are planned in many cities. The government of India is planning a 497-km-long rail link between Bilaspur-Manali and Leh in Himalaya. China is building 5000-km-long rail lines in Himalaya for rapid development there. Interesting case histories of construction are presented extensively in The Master Builder (Vol. 8, No. 8, Sept. 2006, India).

The basic difference in these historical underground spaces and present-day spaces, however, is that those in the past were built or created out of an interest to do something new and creative. However, today underground space is required for sustainable development and for providing better lifestyles to people.

1.3 UNDERGROUND SPACE FOR SUSTAINABLE DEVELOPMENT

When the United Nations was established in 1945, 90% of the world's population lived in rural areas [11]. With time and migration of people toward cities in search of jobs and better lifestyles, the populations of cities grew many fold. Already a billion of these new urban residents live in health- and life-threatening situations, with hundreds of millions living in absolute poverty. At least 250 million people have no access to safe piped water. Four hundred million people lack sanitation.

Ninety percent of the population growth will be in developing countries; 90% of that will be in urban areas. In effect, every year we are witnessing the birth of 20 new cities the size of Washington, DC, or, put another way, more people will be packed into the cities of the developing world in the 21st century than were alive on the entire planet in 1996 [11]. This global trend of migration toward mega cities is the consequence of rapid growth and sometimes destructive wars that face both rural and urban populations the world over.

Most of these huge cities will be located in developing nations with limited financial resources. Will these cities become ecological and human disasters or can they be designed to evolve as healthy, desirable places to live? Planners are beginning to develop planning tools for future mega cities surrounded by sustainable regions, which in turn would be linked to other regions as part of a global economic network. Each region would import resources such as clean water, energy, raw materials, and finished products. Most cities would be surrounded by rural areas that would provide agricultural and other locally generated products. These sustainable regions in turn would export products and services.