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Editorial

Advances in Underground Construction Help Provide Quality of Life for Modern Societies

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In a technological world that is increasingly being changed by advances at the tiniest of scales—in chemical engineering, bioengineering, computing, mechanical engineering, and other fields—it is worth examining the changes that are being made by large-scale engineering endeavors that impact the quality of life of billions of people around the world. Water distribution, sanitation, transportation, and buildings are key elements that support healthy and livable cities, which are now home to over half the world's population. Changes in cities such as new skyscrapers and freeways, along with the less pleasant side-effects of traffic congestion and pollution, are familiar to most people. However, there is also a less obvious dynamic to city growth—the trend of placing an increasing amount of supporting city infrastructure underground. Combined with increases in tunneling to allow highways and high-speed railways to overcome the historic barriers of mountains and rivers, this trend means that the world is seeing unprecedented levels of underground construction.

Underground space use and tunnels have been part of human existence since prehistoric times. Underground spaces were perhaps first used through opportunistic shelter in caves; they later became important in connection with mining for precious minerals or building materials, as well as for the first applications of city drainage systems. In addition to mining, early uses for tunneling included military and defense applications. Early excavation work was labor-intensive and slow; tunneling in soft ground was dangerous and, in fact, impossible for many types of poor ground conditions. Tunneling hard rock was limited to extremely slow methods of rock fracturing, such as thermal spalling using fire and water.

Technological leaps in underground excavation and tunneling have been dramatic over the past centuries, with rapid changes following key innovations: the use of gunpowder for rock excavation, the development of compressed air (and later hydraulic) drilling tools, the invention of the tunnel shield allowing tunneling in soft ground below the water table, the invention of the steam shovel for large-scale earth moving, and so forth. Each technological advance not only changed the speed, ease, cost, or safety of construction, but also changed the realm of application possibilities for underground solutions. Today, underground space use and tunneling are in another period of rapid development—driven by the needs of an increasingly urban society and facilitated by increasing capabilities in the design and construction of underground facilities.

Underground construction allows many elements of the critical infrastructure supporting cities to be hidden and protected below ground. Better technologies have resulted in larger and more challenging projects being placed deeper below the surface. However, with this success has come a new set of challenges: How to use the underground space beneath cities in the best manner, and how to maintain the vast array of underground assets more-or-less indefinitely without continually disturbing the surface. Historically, the use of underground space has followed a first-come-first-served approach, with little attempt being made to reserve the best geological conditions for appropriate uses, or to prioritize or rationalize the placement of utilities or transportation tunnels. Such a lack of planning forces new underground systems deeper and deeper; it also increases costs, as new systems must weave around a labyrinth of existing uses.

Although digging a hole in the ground may appear to be a basic task in some respects, it can be a most challenging endeavor, for various reasons:

(1) Designers and contractors cannot completely assess an underground region as an environment in which to build facilities before the design or start of construction. Our inability to "see" into the earth to determine the zonation of geologic media, the engineering properties of the respective zones, initial stress conditions, groundwater conditions, the presence of existing structures, and so forth, makes underground construction a physically and financially risky endeavor, and places a premium on technologies that rapidly adapt to changing ground conditions.

(2) Underground regions are composed of complex media ranging in strength from soft clays or organic materials with almost no strength to hard and abrasive rocks with strengths that are higher than most fabricated materials. In some cases, the nature of these materials can be represented adequately enough by elastic continua; however, such materials are usually anisotropic, time-dependent,

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and non-homogeneous. Some soils and rock masses behave more as a collection of discrete particles or blocks than as continua. In addition, the historical development of our infrastructure and the relationship of utilities and tunnels to new or existing building foundations result in complex assemblages of constructed facilities within an already complex medium.

(3) The soil is a moist, absorbent medium that receives pollutants from industrial processes, gases, and oils from natural formations, and takes on the legacy of previous attempts at underground waste disposal. The ground is a conducting medium that can support the establishment of corrosion cells, which may be exacerbated by stray currents from other electrical sources and electrical grounding in an urban area. Fluids carried by utility systems also have the potential to degrade and even destroy their conduits from the inside over time. These conditions, combined with the expense of the installation and repair of underground facilities, make the design of underground components for a long service life in a potentially severely corrosive environment very important.

The continuing engineering challenges that are posed by underground construction are being met with success in many complex and difficult projects. Urban underground space-planning issues are being addressed. Separate underground utilities are being combined into common utility tunnels in order to save space and provide for future maintainability. New systems for automated underground freight transport are under development.

The papers included in this special issue showcase advances in the theory and application of tunneling and underground space use from around the world. This issue particularly focuses on advances in China, with its world-leading investments in underground facilities and massive underground R&D activities. They cover a wide range of applications from rail and metro tunnels to highway tunnels and water supply tunnels plus descriptions of recent and ongoing tunnel projects that are at the forefront of current capabilities—tunnels in rock and in soil at increasing depths, record-breaking lengths of tunnels both beneath mountain ranges and under the sea. The new site investigation, design, construction, and monitoring technologies that are needed to allow these projects to happen safely and economically are described. To complete the issue, the questions about the impact of some types of tunnels on the livability and resilience of urban areas also are addressed.

These new underground endeavors represent engineering, planning, and construction on a grand scale—but hide their accomplishments underground, so that the surface remains a pleasant place to live.