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The High-Tech, Low-Cost World of Tunnel Building

New technology has dramatically reduced the cost—and disruption—of building tunnels under busy cities for rail, road and utility projects

By Daniel Michaels / The Wall Street Journal

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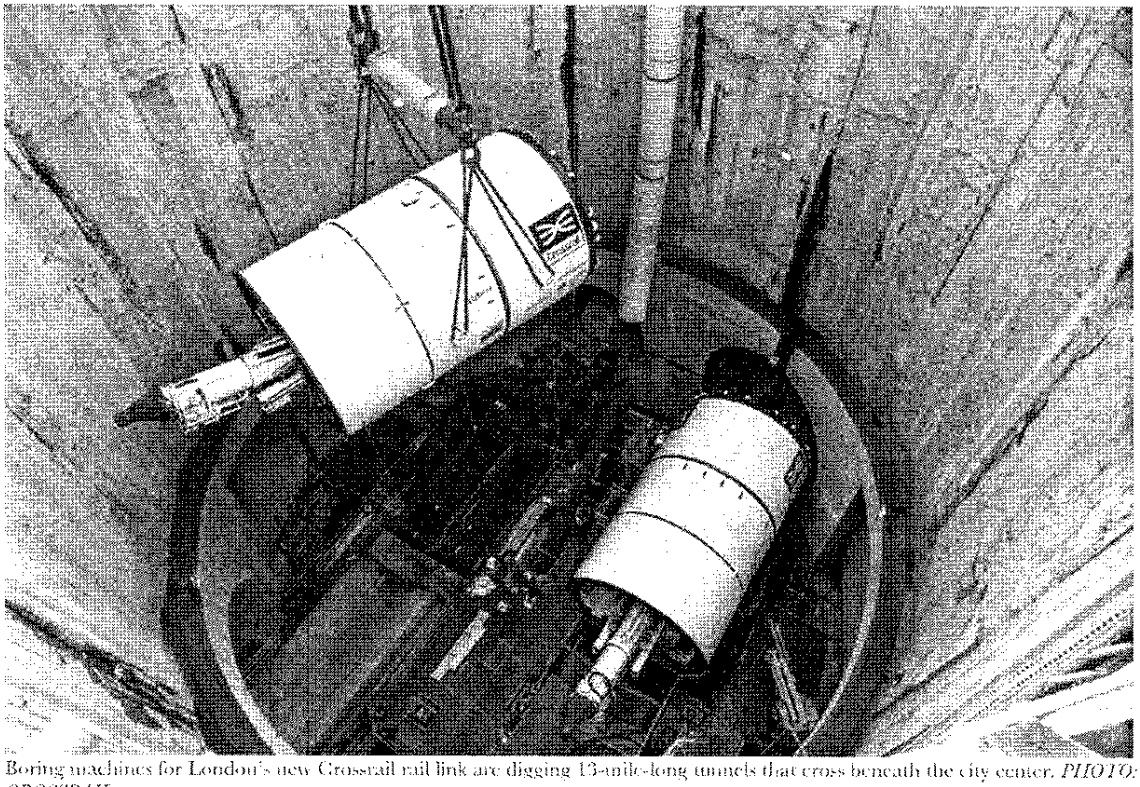

Boring machines for London's new Crossrail rail link are digging 13-mile-long tunnels that cross beneath the city center. *PHOTO: CROSSRAIL*

Cities are going down.

To manage relentless growth, urban centers are expanding underground at an unprecedented pace. But it isn't just the crush of humanity above the ground that is behind the subterranean push. It also is the result of dramatic advances in a field almost as old as civilization: tunneling.

Engineers in recent decades have developed mechanized and automated systems to chew through deep rock or muck and immediately line an excavation to prevent collapse—all without disturbing the busy city above. That means projects that once would have taken armies of men years to dig now can advance in a fraction of the time and at much lower cost.

Massive robotic worms have been burrowing rail, road and utility tunnels under New York, Singapore and London, little noticed by residents. Washington, D.C. and Indianapolis are boring vast underground cisterns to store rainwater. And Cleveland is punching narrow sewer-pipe ducts through dirt and rock without ripping open streets or lawns.

Even cities prone to seismic activity, such as Los Angeles and Istanbul, are building tunnels thanks to innovations in equipment and techniques. In the Turkish megalopolis, a new roadway under the deep Bosporus waterway includes joints that permit sections of the tunnel to move during an earthquake without structural damage.

"Major cities just can't function without going underground," says Joe Guertin, a retired geotechnical engineer who worked on tunnels in the U.S. for five decades, including New York subway projects in the 1970s. "Technology has changed the equation."

Urban stealth

Not all projects advance smoothly. Under Seattle, one of the world's largest tunnel-boring machines sat idle for two years until December, undergoing repairs after unexpectedly hitting metal pipes near the start of a highway dig. But Seattle's experience—which attracted a lot of attention because of the project's problems and delays—is unusual these days.

"There are tunnel-boring machines all over the world in very complex geology that never get any attention," says Michael Mooney, a professor of underground construction and tunneling at the Colorado School of Mines.

Indeed, the number of tunnel-boring machines, or TBMs, in operation has surged since 2000. Herrenknecht AG, one of the world's biggest TBM makers, says it is providing machines for as many as 100 projects annually, up from as many as 20 some 15 years ago.

"The ability to deliver a tunnel on time and on budget has changed a lot...and really pushed the industry," says Achim Kühn, a spokesman for the privately held German company, whose tunnel-boring machines can cost more than $50 million each.

Few places illustrate the progress more than New York. The metropolis was a tunneling pioneer a century ago, but financial woes after World War II ended that. Today, urgently needed rail tunnels are again advancing.

Few New Yorkers are aware of the underground work that is going on, which makes the city's top rail tunneler happy. Michael Horodniceanu, president of capital construction for the Metropolitan Transportation Authority, keeps a photograph of central Manhattan streets ripped open to build the Broadway subway line around 1900. The old construction approach, which turned the famously busy thoroughfare into a massive trench, cut off buildings and snarled traffic while the avenue was excavated and resurfaced.

Tunnelers then "weren't concerned with the impact of the construction on the surrounding area," says Mr. Horodniceanu. Today, upending lives and commerce isn't an option.

MTA projects now snake through spots with more than 100,000 people per square mile, including along Manhattan's Second Avenue and posh Park Avenue.

"The technology allows us to go and dig without people knowing we are there," Mr. Horodniceanu says.

Dramatic savings

Pioneering urban tunnels—including London's Thames Tunnel, which opened in 1843, and New York's Holland Tunnel, which opened in 1927—were dug by workers with picks and shovels. Supplying air to workers and fortifying the dig before it could collapse were constant challenges. Tunneling through hard rock required blasting that threatened the buildings above.

Machines began replacing human tunnelers in the 1950s, after American mining engineer James Robbins built a giant auger to eat through shale for a hydroelectric dam in South Dakota. The tunnel-boring machine, a cylinder with cutting wheels protruding from its circular face, dug up to 10 times as fast as traditional methods.

But most cities sit on softer ground that can collapse after excavation, like sand on a beach. Many urban tunnels must run below the water table in saturated, fluid earth. Even mild subsidence can damage pipes, rail tracks or buildings above. So during the 1970s, Japanese and German engineers learned to use water and air pressure to stabilize the ground around a borer. They developed tunnel-boring machines that could robotically install precast concrete tunnel-lining panels immediately behind the cutting face, leaving a nearly completed thoroughfare in their wake.

The savings from automation can be dramatic. Mr. Horodniceanu says the MTA recently had to manually dig a particularly difficult 120-foot tunnel at a cost of almost $1 million per foot. By contrast, tunneling 3 miles under Second Avenue with giant machines cost about $19,000 per foot, he says.

"The fact we can utilize TBMs makes a hell of a difference," he says.

Other recent advances in tunneling technology include precision guidance to thread around existing infrastructure and electronic monitors to track vibrations, which let tunnelers stop at the first hint of trouble. Advances in chemistry allow engineers to thicken loose ground or soften hard terrain.

These innovations have enabled tunneling in areas once considered impassable. Miami recently dug a traffic tunnel beneath a busy waterway by eating through a mix of saturated ground and porous coral rock that previously defied affordable excavation. The dig was "wildly successful," Prof. Mooney says.

New technologies, analytical tools and materials have "facilitated the design of tunnels under adverse conditions," says George A. Munfakh, director of geotechnical and tunneling at engineering firm WSP-Parsons Brinckerhoff. With science and technology, "the engineering and economics of urban tunneling have definitely changed."

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