NEORSD

The Euclid Creek Tunnel is one of several planned storage tunnels designed to relieve overflows in the Northeast Ohio Regional Sewer District. The tunnel can hold approximately 60 million gallons of combined stormwater and wastewater. Mott MacDonald served as the lead consultant on the project.

WASHINGTON STATE DOT

The boring machine for the Alaskan Way Viaduct Replacement Program in Seattle reached more than 200 feet below grade to create a tunnel nearly 58 feet wide that carries a 1.7 mile double-deck highway. In conjunction with the Washington DOT, Mott MacDonald served as the project management assistant consultant.

BY SAMUEL GREENGARD

TUNNEL VISIONS

ADVANCES IN TUNNELING TECHNOLOGY ARE ALLOWING ENGINEERS TO BUILD WHERE THEY COULD NOT BUILD BEFORE

Engineering has always been about overcoming obstacles. In order to build a better and more functional world, humans have long constructed things to enable and simplify myriad tasks. Tunnels certainly fit this worldview. Tunnels move everything from vehicles and water to people and digital communications. Yet, today, as engineering methods improve and technology advances, tunneling is extending to places where it was not possible to build in the past: under cities, through mountain ranges, even under oceans.

The South Surrey Interceptor collects sewage from Surrey and Langley, British Columbia, Canada, and conveys it to Metro Vancouver's Annacis Island Wastewater Treatment Plant. Phase two of the interceptor project was designed by Stantec and installed by tunneling using a highly successful innovative design.

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The result is new highways, byways, subways, and passageways that are redefining transportation, waste removal, and underground infrastructure.

"Particularly in urban areas, as near surface underground real estate has been used up by existing infrastructure, tunnel solutions are being pushed deeper and through more challenging geology," says Colin Lawrence, global tunnels practice leader at Mott MacDonald. "Tunneling technology has had to meet an array of new challenges."

Computer-aided design (CAD), Building Information Modeling (BIM) software, high-tech tunnel boring machines (TBMs), and radical advances in construction materials have made it possible to tunnel farther and deeper than ever before. Furthermore, it is now possible to build tunnels in subterranean places where it was not possible in the past. As a result, a new generation of underground tunnels are taking shape.

"Tunnels are now being constructed through conditions that would not have been contemplated over 20 to 30 years ago," Lawrence says.

How do engineering firms design and build these structures, which can extend to over 30 miles and pass through challenging geological ground conditions and structures? How do firms mitigate risk during construction and build tunnels that can withstand a major earthquake or an explosion and fire inside the tunnel? How are firms using new materials to improve visibility and safety inside tunnels?

"Tunnel engineering has become a complex multidisciplinary field," says Paul Guptill, senior principal at Kleinfelder. "Today, it involves everything from geoscience to computer science and numerical modeling."

DIGGING DEEPER

Although the first human constructed tunnels appeared thousands of years ago—primarily as a way to transport water, people, and equipment—the modern era of tunneling took shape in the late 1800s. Late in the century underground construction of the New York subways began. When it commenced operation in 1904, the subway represented a new and far more advanced way to move people within a crowded city. By 1927, the Holland Tun-

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COLIN LAWRENCE
GLOBAL TUNNELS PRACTICE LEADER
MOTT MACDONALD

nel, connecting New York and New Jersey, was built. It represented a tunneling landmark. As vehicles passed under the Hudson River, 84 fans housed in four buildings changed the tunnel's air every 90 seconds.

Over the last 30 years, advances in geoscience, technology, and construction have allowed engineers to extend tunnels to places that once seemed unimaginable. For example in 1988, Japan built the 33-mile Seikan Tunnel, then the world's longest and deepest railway tunnel. It reaches a maximum depth of 787 feet beneath the surface and connects the cities of Honshu and Hokkaido. In 1994, the U.K. and France opened "The Chunnel" a $21 billion project that allowed trains to pass under the English Channel. Completed in 2019, the Alaskan Way Viaduct Replacement Program is a 2-mile tunnel that carries a 1.7-mile, double-deck highway. It is more than 200 feet beneath downtown Seattle, and is the widest in the world at nearly 58 feet. The project won the ACEC 2019 EEA Grand Conceptor Award for the year's most outstanding engineering achievement.

Depending on the type of tunnel, tunnel boring machine costs can range from approximately $10,000 to $100,000 or more per linear foot

Make no mistake, planning, designing, and constructing tunnels frequently push engineering, especially geoengineering, to its limits. It requires both creative thinking and technical expertise.

"In the past, you had someone with a vision of how to build a tunnel, and they and a small group of engineers spent a whole bunch of time figuring it out," says Glen Frank, senior vice president of underground construction at Schnabel Engineering. "Today with CAD and BIM, you can experiment with different shapes, forms, and structures—and understand how to design tunnels so they work with complicated underground transit stations or other infrastructure."

Nevertheless, it may take two decades or longer for a tunnel to leap from the drawing board to reality. During that time, things change. For instance in the future, internal combustion engines could be largely replaced by electric vehicles that do not require the same heat removal and ventilation system in a tunnel.

"One thing that makes the planning task difficult is that when you have a 15- or 20-year lead time on a large transportation tunnel, by the time you actually complete building it, the

A tunnel boring machine makes breakout for the Arrowhead West Tunnel, a water supply tunnel built by Metropolitan Water District of Southern California. Mott MacDonald designed and developed probe drilling projection computer models and an early warning detection system to monitor strain on the shields of the tunnel boring machines.

MOTT MACDONALD

ventilation needs and the vehicles using the tunnels may have changed," Guptill says.

Understanding the ground conditions where the tunnel will be built is the starting point for any project. Engineers typically collect vertical boring samples at regular intervals—often 1,000 to 2,000 feet apart—and extrapolate on soil and groundwater conditions using statistical methods and computer modeling. But this does not necessarily deliver a complete picture.

"The problem is that there is no way to know exactly what is there until you get there," says Don Del Nero, vice president and tunnel and trenchless practice at Stantec. "You assume a certain advance rate, but sometimes it does not play out." Engineers may also use geospatial imagery and other data to understand earthquake faults, flooding zones, and other risks.

Of course, engineers must pay particularly close attention to tunnel curvature and grades, and other factors when designing certain tunnels, particularly those used for high-speed rail. The curvature of a tunnel or the rate of incline or decline not only impacts operational speeds and safety, but also it can become a problem if an earthquake occurs and there is fault displacement across rails or roadways underground.

"You do not want to slow trains down because the track realignment cannot accommodate the design speed, particularly if there is displacement across a fault, and the tunnel curvature and grade must be reestablished," Guptill says.

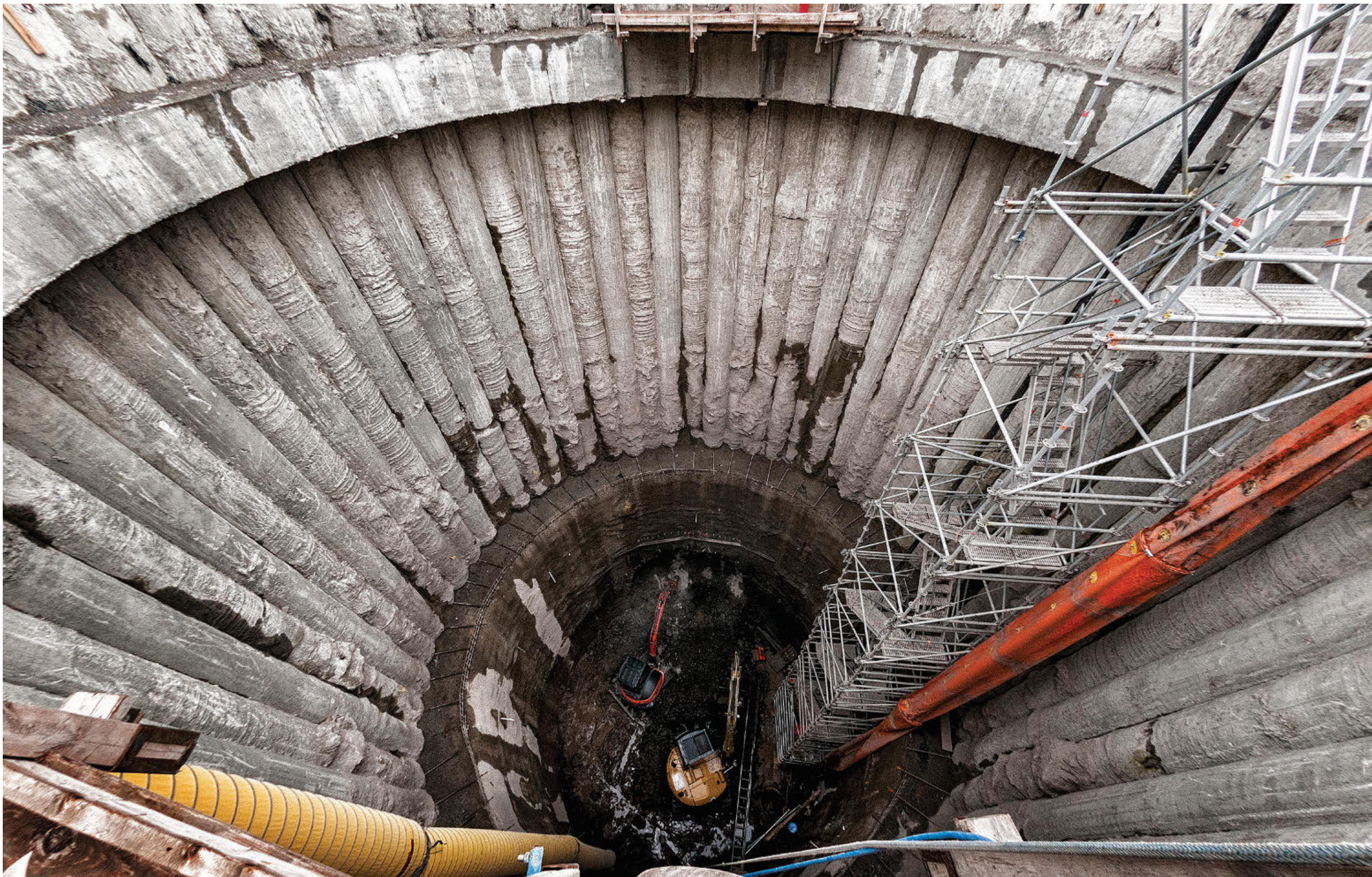
> "We have the ability to go deeper and build tunnels in harsher environments than ever before."
>
> **DON DEL NERO**
> **VICE PRESIDENT**
> **TUNNEL AND TRENCHLESS PRACTICE**
> **STANTEC**

TUNNELING IS BORING

If designing a tunnel is challenging, building it is daunting. Today's TBMs are an example of how far construction has advanced in recent years. Once operated entirely by humans, these giant pressurized machines—controlled by computers and including as many as 85 rolling steel disc cutters at the front—grind through rock, soil, and sand at a rate of up to 1,600 tons per hour. Hydraulic cylinders connected to the drill's spine propel a TBM forward at a rate of 100 feet or more per day—all the while sensing ideal boring speed and methods. As a TBM worms through a subterranean space, steel shoes typically push outward and grip the tunnel walls while retractable legs lift the giant machine slightly off the ground.

As the machine bores and removes debris, additional machines and workers install materials such as precast concrete linings, to stabilize the tunnel. Today's TBMs and earth balancing machines produce extremely smooth tunnel walls while concurrently reducing noise and vibration, which makes them highly suitable for urban

Tunnel construction for the Ottawa Combined Sewage Storage Tunnel, part of an overall River Action Plan, is aimed at enhancing the health of the Ottawa River and protecting water environment for future generations. Stantec provided overall design services on the project leading a multidiscipline team including geotechnical engineering and materials testing as well as water and wastewater.



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The Alaskan Way Viaduct Replacement Program won the ACEC 2019 EEA Grand Conceptor Award for the year's most outstanding engineering achievement

areas. Moreover, despite a cost of $50 million or more, they are able to accomplish tasks that were once impossible.

"They handle intense atmosphere, water, and ground pressures, they move through unstable sand and soil, and they operate without damaging structures above ground. They are essentially underground submarines," Frank says.

The impact of TBMs has been revolutionary. A quarter century ago, engineers frequently found themselves limited to tunneling 50 or 75 feet beneath the surface when they encountered difficult conditions. Today, they are able to descend 400 feet or more and apply materials to reinforce walls as they move through—even in sandy and wet terrain. In addition, engineers and construction crews can deploy specialized robotic boring devices and CCTV systems to build micro-tunnels where humans cannot go—sometimes in spaces as small as 2 feet in diameter. These micro-tunnels increasingly house communications cables and other infrastructure that would be costly and complicated to place above ground.

These advances in equipment and technology allow engineers to build tunnels faster, safer, and better than any point in the past. Although overall costs continue to rise for tunneling projects, and cost overruns are a nagging problem, the equipment and methods used today are driving significant advances—and, at least in some cases, curbing even higher costs. Depending on the type of tunnel, TBM costs can range from approximately $10,000 to $100,000 or more per linear foot.

"TBM tunneling costs have a very wide range that is dependent on many variables, such as geology, intended use, diameter, length, logistical constraints, and location," Lawrence says.

Not surprisingly, the materials used to build tunnels have also advanced. "Today, we have many lightweight but highly effective construction materials at our disposal," says Dave Krywiak, principal, tunneling and trenchless specialist at Stantec. These include waterproof linings that construction crews spray on walls, the use of lightweight metallic fibers that replace steel rebar and retard fires, and specialized gasket seal technology that better withstands moisture and pressure. In addition, the use of LED lighting has improved visibility during construction and, in the case of transportation tunnels, enhanced visibility for motorists passing through tunnels after they are opened.

"LED lighting improves visibility and lowers energy and maintenance costs," says Nicholas DeNichilo, president and CEO at Mott MacDonald.

DESIGNS ON THE FUTURE

Today's tunnels are nothing short of engineering masterpieces, but designers, engineers, and technologists are exploring ideas for constructing even more advanced tunnels in the decades ahead.

"Because of the increasing complexity and cost surrounding the construction of infrastructure on the surface—and the lack of space to build new roads and infrastructure—many cities are now considering or planning projects that incorporate tunnel construction," Lawrence says. "It is now possible to dig deeper and costs are at a point where it is an extremely attractive option for certain situations."

This includes tunneling under mountain ranges and oceans. For instance, when the Brenner Base Tunnel is completed in 2028, the 39-mile rail tunnel will reach a maximum depth of 5,200 feet and extend from near Innsbruck, Austria, to Fortezza, Italy. The tunnel is expected to reduce travel time between these two points from two hours down to less than an hour. Other proposals include building a transatlantic tunnel from New York City to London—with vehicles that reach speeds as great as 5,000 mph using hyperloop or maglev technologies.

Tunnels present some of the most complex challenges in engineering. But as long as there are obstacles to bypass—mountain ranges, rivers, urban areas, and more—engineers will continue designing these remarkable structures.

"We have the ability to go deeper and build tunnels in harsher environments than ever before," Del Nero says. ■

***Samuel Greengard** is a technology writer based in West Linn, Oregon.*