Soft ground tunneling arguably remains the most challenging of underground construction operations. Until the early 1990s, the large diameter, open-face “digger shield” or “conventional shield” was still the leading method to install larger diameter tunnels in the United States, frequently with extensive dewatering and canopy grouting. Today, soft ground tunneling work is almost exclusively performed by pressurized face methods or by the New Austrian Tunneling Method (NATM), techniques at opposite ends of the ground support spectrum and requiring vastly different ground support effort.

The geotechnical methods that are being used by Moretrench Corp. and other specialty contractors in support of tunneling and tunnel-related operations are as varied as the potential subsurface conditions. The more complex and extensive the tunneling operation and the more challenging the subsurface conditions, the more likely it is that multiple geotechnical techniques will be required. The New York City Metropolitan Transit Authority’s (MTA) East Side Access Contract CQ028 (bid in late March) is a case in point.

The project includes a tunnel crossing with a recommended construction scheme consisting of a 125-ft long, 60-ft wide and 40-ft high NATM tunnel, a frozen ground canopy arch for groundwater control and temporary ground support, compensation grouting to protect the buried subway from settlement and a mechanism for heave control to limit the potential effects of freeze-generated ground heave on the existing structures.

In recent years a number of tunneling or tunnel-related projects, both large and small, owe their success to careful evaluation of the prevailing conditions and the experience of the project engineering team in designing and constructing to minimize surface impacts or reacting quickly to an unexpected condition or event.

More to the Project Than the Tunnel

Pressurized face or earth pressure balance tunnel machines provide improved earth support during tunneling and eliminate the need for dewatering and ground improvement. However, even with pressurized face techniques, ground improvement and/or dewatering may be required for the excavation of access shafts, launching or retrieving the tunneling machine, starter tunnels and cross passages. A number of geotechnical techniques are in current use.
Jet grouting is commonly used to install perimeter walls for stabilizing shaft breakouts and break-ins. Unlike construction techniques such as slurry walls, secant pile walls and soil mixed walls, which are limited to the construction of vertical walls, jet grouting can also be used for the construction of horizontal bottom seals to control groundwater inflow into a “bathtub” excavation that has no naturally impervious bottom. Jet grouting can also be used for the installation of an arch or canopy over a tunnel or completing closure around utilities or other obstructions that create “gaps” in otherwise continuous barrier walls. Thin, non-structural, jet grouted diaphragm walls installed outside of a structural element can form an effective, economical groundwater barrier. On the Lenox Avenue Subway line rehabilitation project in New York City, jet grouting provided a groundwater barrier at a difficult sand/silt interface to permit replacement of the subway invert without ground loss due to water running across the sand/silt interface.

Jet grouting can provide a high compressive strength soil-cement product in most soils. However, the technique does have certain limitations. The presence of boulders or obstructions can block the jetting penetration and the “shadow effect” can result in incomplete coverage and ungrouted inclusions. Under significant water pressure, multiple rows of interconnected jet grout columns must be used to compensate for the possibility of ungrouted inclusions. And although jet grouting can theoretically be accomplished to any depth, there is a practical depth limitation (nominally 60 ft) beyond which verticality is difficult to maintain and designed overlap of the columns therefore becomes more difficult to achieve.

Ground freezing can be effective in essentially all soil types and provides a similar, though temporary, end product to jet grouting, i.e. high compressive strength ground. The fields of application, however, differ for jet grouting and ground freezing. Freezing is well suited to deep applications, difficult ground that may not be amenable to jetting or disturbed ground that may be sensitive to mechanical action. The technique is cost-effective where both groundwater cut-off and excavation support are required.

It is recognized as an important tool for deep access or vent shaft excavation. In fact, shafts are the most common application for ground freezing. To date, this technique has been used on 10 shafts for New York’s City Water Tunnel No. 3 (TBM, October 2005) and has been applied successfully on numerous shaft construction projects across the United States for both tunneling and non-tunneling projects.

In emergency tunneling situations such as where access to the cutterhead may be necessary or when the freeze is required to be maintained for only a short time, liquid nitrogen, which promotes more rapid freeze formation, can be used as the freezing medium in lieu of brine. When a jacked pipe TBM encountered unanticipated loose, sandy embankment fill and became mired 25 ft beneath New Jersey’s Garden State Parkway, and within 35 ft of the receiving pit, an urgent response was needed to avoid damage to the roadway and retrieve the TBM. Liquid nitrogen freezing was the only viable solution in the time frame. Horizontal drilling and freezing formed a canopy of fully stabilized soil over the crown of the TBM within several days. Advancement of the tunnel continued immediately thereafter.

Given that TBMs are most efficient when designed to operate in one relatively consistent ground condition, the presence of an isolated section of soft ground, for example, along the alignment of a hard rock tunnel can bring the tunneling operation to a screeching halt. George Fox has been credited with saying that “[Conditions in] 200 ft of tunnel can make or break a project.” Jet grouting or ground freezing can be utilized to “homogenize” mixed ground conditions to permit the uninterrupted run of the TBM.

It has also been used to create a homogeneous horizon for microtunneling through mixed face conditions and to provide an improved bearing material for microtunnels advanced through poor soils. On the Central Artery/Tunnel project in Boston, mass freezing was used to stabilize a 39-ft high face consisting of saturated fill, peat and Boston Blue Clay for jacking of three concrete boxes, 150 to 350 ft long, beneath Amtrak right of way.

Ground freezing, like jet grouting, has certain limitations. The operation and maintenance associated with the typical ground freezing program adds an additional cost component to the overall project. Under rapidly moving groundwater conditions, difficulties in achieving closure of the freeze can be encountered, although this can be overcome with grouting techniques. In certain soils, heave can also occur due to frost action.

Dewatering, since it indisputably changes the characteristics of the ground, cannot be disregarded as a geotechnical technique and is often essential in the construction of tunnel project ancillary structures. In many cases, the best solution to a ground control situation is a combination of dewatering and a ground improvement technique.

Where groundwater lowering has potentially adverse off-site effects, groundwater treatment technologies applied to artificial recharge have totally changed the complexion of this work. Re-injection is now done effectively with minimal maintenance. The Central Artery/Tunnel in Boston, the Orme Street Combined Trunk Relief Sewer in Atlanta and the Copenhagen Metro projects are success stories of recharging of the ground to protect adjacent sensitive structures.

During tunneling in urban environments, there is often a need to protect overlapping structures from tunneling-induced ground

Even with pressurized face techniques, ground improvement and/or dewatering may be required for the excavation of access shafts
In 2006, Moretrench Corp. celebrates its 75th year since the company was officially founded in 1931. However, the original company first opened its doors for business in 1918 when founder Thomas Moore began manufacturing and leasing his proprietary conveying excavator from premises in Rockaway, N.J.

In 1925, the fledgling Moore Trench Machine Co. leased a machine to a sewer contractor in Hackensack, N.J. When the contractor became bogged down in quicksand, Moore assumed the contract and designed, built and installed the first practical wellpoint dewatering system in the United States to stabilize the quicksand. This marked the beginning of what was to become a thriving addition to his core business.

Building on his initial success, Moore continued to develop and improve his wellpoint system, finding a growing local market. By 1931, demand for his dewatering products was so great that he decided to make this his sole focus, incorporating as Moretrench Corp. Some 10 years later, Moore established a separate company, American Dewatering Corp., to subcontract the entire pumping operation. By 1944, Moretrench wellpoint systems had been used on 18 major subway projects in Brooklyn, Queens and Manhattan.

After 30 years of operation, Moretrench and American Dewatering merged in 1972 and Moretrench American Corp., the forerunner of modern-day Moretrench, was born.

Full-Service Company

During the mid-1970s, mass transit systems were being constructed across the United States. Moretrench worked coast to coast, dewatering station excavations, as well as running tunnels in Washington, D.C., Boston, Buffalo, Baltimore, Atlanta, New York and San Francisco. At the same time, the parent company created a new subsidiary, freezeWall, to pursue U.S. ground freezing opportunities.

To complement its by then well-accepted technologies, the company subsequently formed Ground/Water Treatment & Technology to cater to the emerging groundwater remediation market, and Moretrench Geotec, offering a wide range of geotechnical services for underpinning, excavation support and soil stabilization.

Path to Success

Following in Thomas Moore’s tradition of innovation, Moretrench’s path has been punctuated by a number of significant company milestones. Construction of Lock & Dam 26, just above the confluence of the Missouri and Mississippi rivers near St. Louis, involved what was by any measure one of the most ambitious dewatering projects ever to be accomplished in the United States.

Subgrades for the three large excavations were kept dry 86 ft below high river stage while pumping as much as 100,000 gpm from multi-stage wellpoint systems. More recently, mass ground freezing aided jacking of three box tunnels for Boston’s Big Dig.

Moretrench returned to the World Trade Center in 2001 (after dewatering the area adjacent to PATH tubes for foundation excavation in 1968) and lowered the water level outside the damaged foundation to help stabilize the slurry walls as debris removal progressed.

While Moretrench has certainly changed over the years, one element has remained the same. “We are first and foremost, problem solvers,” says CEO John Donohoe. “We are committed to finding the right solution for every client ... and we look forward to doing that for many years to come.”

In 1930, Moretrench demonstrated the use of wellpoints at the Atlantic City road show.

Real-time, computerized structural monitoring, precise control of grout parameters and synchronized grout injection are critical components of successful compensation grouting, allowing re-injection as required to limit settlement to specified values. Compensation grouting has proven effective on several notable international subway tunneling projects, including the U.K.’s Jubilee Line Extension and Puerto Rico’s Tren Urbano project. The technique can also be used with open excavations to protect adjacent structures.

Structural slurry wall (diaphragm wall) construction is a mature technique that can provide a lateral groundwater cutoff, particularly in situations where conventional dewatering is not permitted. It is also an effective method of excavation support where minimizing ground movement is important. Secant pile walls can be effective for support of excavation. In Hillsborough County, Fla., this technique was used to facilitate excavation of a 40-ft diameter launch shaft and a 24-ft diameter retrieval shaft to depths of 70 ft for jacking of a new water supply tunnel.

Stand-up Time Is Not a Thing of the Past

When used in soft ground, NATM tunneling requires the soils to be cohesive (or improved) in order to reduce the risk of ground loss and maintain stability. Adequate dewatering is very critical because of the effects of water on fine grained soils and the fact that the operation relies on a relatively long “stand-up” time for the soil. Flowing ground or ground with short stand-up time is not amenable to NATM tunneling without ground improvement and/or dewatering.

Permeation grouting has been used extensively in conjunction with open face digger shield tunneling to increase the stand-up time of soils at the tunnel loss and ensuing settlement. Pioneered on the Baltimore subway, low slump compaction grout, injected through pre-placed steel pipes as the TBM passed beneath, was effective in densifying the soils to control surface settlement and thus protect overlying structures. Conceptually, this application of compaction grouting is similar to what we refer to these days as compensation grouting. Compensation grouting, as it is generally practiced today, is the injection of fluid grout through tube-a-manchette pipes to hydrofracture and create a controlled heave of soil between the ongoing tunnel excavation and the overlying foundations in anticipation of, and in response to, ground movement.
face to allow mining to take place without significant ground loss at the face or to create an arch of stabilized soil above the tunnel alignment in order to protect overlying structures from settlement. As NATM methods are coming into more common practice in the United States, their application is being stretched to more varied ground conditions, often requiring the soil stand-up time to be increased by ground improvement techniques such as permeation grouting.

Vertical drilling for grout injection is, of course, the more economical approach. However, where this is not possible due to below ground obstructions or surface access restrictions, horizontal drilling can be utilized. Long bore horizontal directional drilling in conjunction with permeation grouting for NATM tunneling was successfully accomplished on a portion of Washington, D.C.’s subway system mined beneath a historic cemetery through challenging subsurface conditions (TBM, April 2000). Shorter “barrel vault” pipe spiles were grouted in place with ultratine cement in combination with extensive dewatering to facilitate NATM tunneling on Seattle’s Beacon Hill Project. A jet grout canopy was also installed at Beacon Hill to provide overhead support for mining of the station platform.

The biggest concern with permeation grouting, similar to jet grouting, remains its use in situations where groundwater control is required, but the ground may not be 100 percent amenable to permeation. Where the greatest assurance of groundwater cut-off and ground support are required, ground freezing can be utilized in conjunction with NATM tunneling and was accomplished successfully on the Russia Wharf Project on the Central Artery.

As tunneling methods have advanced, so has the range of geotechnical methods applicable to tunneling and tunnel-related activities. The appropriate geotechnical program can positively impact scheduling and cost. However, these are highly specialized techniques, and the desired positive impact is contingent on the quality of the design and the execution of the work. The services of an experienced geotechnical contractor is therefore vital.