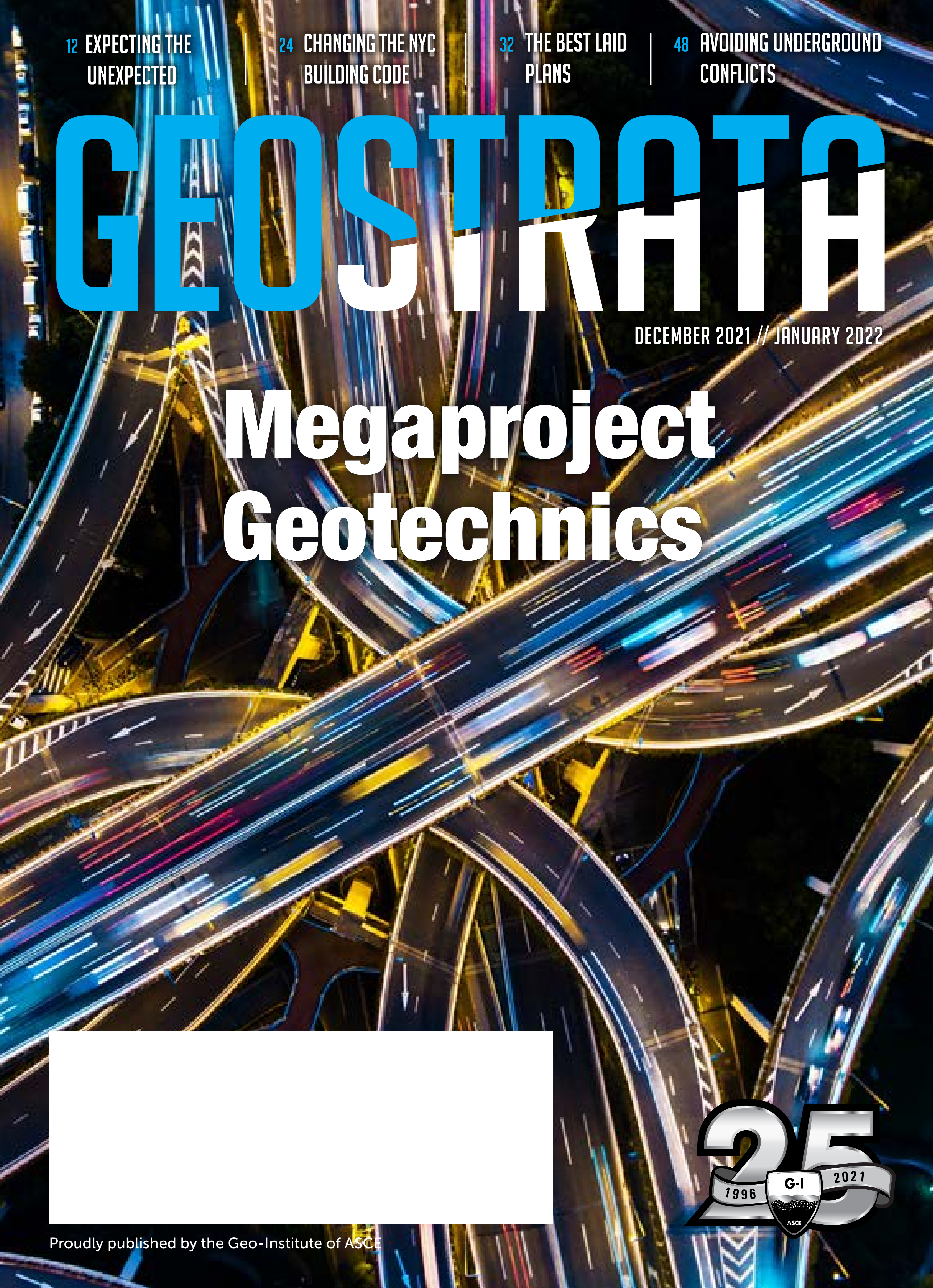

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Trenchless Goes Hybrid

Old Tricks Are Finding New Applications

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The International Society for Trenchless Technology defines trenchless technology as "Underground construction methods of utility installation, rehabilitation, inspection, location and leak detection, with minimum excavation from the surface." Today, trenchless contractor innovations and technology improvements are responding to the demand for cheaper and faster trenchless construction at a rapid pace. Innovation is expanding the range of subsurface conditions where existing equipment can achieve owner-prescribed design criteria. Business sectors with linear underground infrastructure are realizing benefits related to reduced cost, schedule, permitting conditions, and avoidance of right-of-way acquisition as a result of these technology advances and innovations in a maturing trenchless technology market. To understand the values of these advancements, some historical background on the technology offers perspective and context regarding their value.

Figure 1. Dual rod system. (Photo courtesy of Ellingson Companies.)

Early Techniques

Early civilizations recognized the need for underground conveyances in the form of tunnels to provide common water and sewer infrastructure, while avoiding disruption and optimizing use of the ground surface. The industrial age accelerated urbanization, resulting in the demand for cheaper and faster solutions for underground construction. When the method of pipe jacking was introduced, it improved the efficiency of underground construction by separating the excavation from the spoil removal and ground support. The first documented application of pipe jacking occurred in 1895, and consisted of using hydraulic jacks to push concrete pipe with hand excavation to advance concrete culverts under the Northern Pacific Railroad.

Industrial-age demand for increased water supply resulted in the development of mechanized water-well equipment in 1808, followed by auger tooling techniques along with the use of steel casing to contain the fluids and water in the 1820s and 1830s. Around 1936, trenchless contractors adapted auger excavation to pipe jacking for coal mining, and in the 1940s adapted auger mining to civil projects in dry or dewatered soils to increase production rates.

In response to the rapid expansion of transportation and communications systems following World War II, the market demanded more communication infrastructure and less interruption to existing infrastructure. In addition, increasing energy demand required pipelines to move volumes of oil and gas that far exceeded railroad transportation capacity. To meet this demand, contractors developed unguided piercing technology to install small-diameter cables across congested roads. First used in the early 1900s with pneumatic hammers, this method evolved through the development of stronger piercing tool materials during the 1950s and 1960s, in Poland and Russia, which provided a faster and more economical trenchless alternative. Further advancements in the 1970s ultimately led to present-day pipe-ramming methods, applicable to both small- and large-diameter pipes.

In 1964, a semi-steerable horizontal directional drill was invented to install power cables without surface disruption under streets for the Sacramento Municipal Utility District. The longest drive was a 1,530-ft installation below a curved street. The first successful HDD river crossing in 1971 involved the installation of a 4-in.-diameter gas pipe under the Pajaro River in the Central Coast region of California.

Sewer and water pipeline projects eventually demanded large pipe installations in unstable ground that could not be accomplished using auger boring or HDD methods. During the early 1970s, Japan responded to the need for trenchless excavation in unstable ground by developing microtunneling that borrowed slurry technology from the drilling industry to stabilize the excavation face.

Recent Innovations

Just over the last decade, the trenchless construction industry has pioneered the use of curved microtunnels, bursting methods to replace every type of pipe material,

Figure 2. **Prime P-80 drill turning dual rods. (Photo courtesy of Ellingson Companies.)**

HDD projects with lengths exceeding 12,000 ft, and a large assortment of flexible and rigid rehabilitation lining systems that can rehabilitate pipes with diameters of more than 100 in. In fact, innovation has advanced at such a rapid pace that no one person or professional group can be reasonably expected to remain current with the state of the art — but teams of trenchless professionals can provide successful projects nonetheless. Successful trenchless construction involves strong cooperation and communication among the owner, the engineer, the contractor, and the equipment manufacturer. Overall advances by the specialized team members include:

- Owner — Performance-based contracting, assignment of risks, and proper funding
- Engineer — Risk-based engineering studies, risk identification and management options, and the definition of ground conditions along the bore path
- Contractor — Current knowledge of tooling, implementation of available tooling for solving stability and excavation issues, and field implementation of means and methods with contingency options

Innovation grows from recognizing an opportunity to make money and reducing exposure to losing money on similar projects. Trenchless knowledge and capabilities have led to recent innovations as problems are identified and solutions are developed in a team environment. Opportunity thus exists for all as education and experience permeates these teams.

Innovation can occur when a project team encounters costs that exceed the perceived gains. Perceived high costs are often associated with a lack of team knowledge regarding variable ground conditions at a particular project location, hampering the ability to estimate tooling and production rates. The range of properties posed by hard rock and loose silty sand can impact daily production rates by a factor of up to 100, even when conditions are known. Trenchless operating cost per day is relatively predictable and constant, but based on a review of hundreds of HDD projects by the American Gas Association, an advance rate of 10 ft per day can be expected in hard rock, while soft, stable ground may result in rates of 1,000 ft per day. The resultant cost range significantly increases when conditions are unexpected and both tooling and production require delays and modification.

Figure 3. **Pilot tube installed with an Akkerman head. (Photo courtesy of Ellingson Companies.)**

Trenchless failures provide opportunities for innovation, often arising from a failure to reasonably delineate common ground layers and predict tooling to common ground interaction. "Common ground" is defined as having similar reactions to the excavation process. For example, silty sand and sandy silt react in a similar manner during excavation. In addition, groundwater, clay content, permeability, density, and compression or dilation during shear can all affect material behavior during excavation. Therefore, a portion of the trenchless design should include interaction stability analyses of each common ground condition anticipated along a bore path.

Owners and engineers have achieved realistic, and sometimes lower, pricing and improved schedules by using performance-based specifications that include fair change condition clauses for distributing risk among the project participants. Owners understand that contractors provide more competitive prices for projects with understandable risks that can be controlled. For example, an arbitrary and unnecessarily restrictive owner-specified pipe grade can have significant impacts on contractor equipment selection and production rate. Specifying the use of equipment requires knowledge of the ground reaction to that equipment.

Contractors and manufacturers' innovations in tooling and in means and methods have expanded the range of subsurface conditions that specific tools can economically mine. For example, guided pipe ramming has captured auger boring work; steering tools on auger boring casing allows earlier and less aggressive steering, and thus requires accuracy to capture pilot tube tunneling work; and pilot tube tunneling with auger boring equipment in soil or rock provides accurate and precise casing placement, thus capturing grade line microtunneling work.

Innovation in Action

Examples of recent innovations or application of new tooling addressing common issues are cited in the following examples.

Case 1 — Gas Transmission

HDD was required to install 3,000 ft of 10-in.-diameter steel pipe for a gas transmission line. Future construction required permanent cuts of up to 15 ft and fills of up to 20 ft for a canal crossing the pipe alignment. The subsurface conditions consisted of relatively level, very soft silty clay to a depth of 50 ft, underlain by dense sand and gravel. Even with correction to N_{60} standard blow counts, the clay layer was classified as very soft. The design drill path placed the pipe invert well into the underlying sand and gravel.

The contractor's risk evaluation showed that the very soft soils along the vertical curves did not have sufficient strength to laterally restrain the drill rods under the high thrust loads required to drill through the underlying dense granular soils. Additionally, drilling the dense soils required the use of a mud motor and relatively high drill-fluid flow rates. High-volume drill fluids need to return to the drill entry through the bore; however, the required high annular pressure increases the risk for fluid loss. Having extensive experience with similar subsurface conditions, the contractor predicted that the bore path would not remain stable, possibly resulting in the need to abandon the bore path.

Given these constraints, the project posed two critical construction issues — prevention of drill-fluid loss and adequate lateral support of the drilling rod. Part of the contractor's solution involved raising the drill path to stay in the very soft clay layer, thereby reducing thrust requirements, and using an innovative dual-rod drilling system to laterally support the drill rods (Figure 1). Nevertheless, calculations still indicated that there was insufficient cover to prevent drill fluid loss, but more importantly, they predicted that the bore path would not remain stable during drilling, even when completely filled with heavy drill fluid.

These concerns were addressed by employing a higher thrust-capacity drill rig (Figure 2) with significant drill-fluid volume reduction, using just enough fluid to lubricate the hole. While this measure resulted in no drill-fluid circulation for removal of cuttings, the rapid hole collapse would have prevented reliable drill fluid return and likely would have resulted in uncontrolled fluid loss. This style of HDD operation is called "displacement drilling" and has been successfully used for many small-diameter installations at very shallow depths. Instead of controlling fluid pressure to prevent fluid loss, the flow rate and volume are controlled to prevent buildup of sufficient volume in any portion of the hole to avoid reaching the ground surface. Space for the pipe is made by displacing material into

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the formation instead of removing it. The product pipe is pulled through the conditioned soil using rig power and a sufficiently strong pipe to survive the tension applied to it. This innovative technique and tooling resulted in a successful and swift product installation.

Case 2 — Urban Sewer in Wetlands and Highway

An urban gradeline sewer required the installation of a 12-in.-diameter PVC pipe crossing approximately 378 ft under wetlands and a major four-lane highway. Limited workspace at the site prevented pre-assembly of the pipe. The installation depth was 25 ft with a 0.5 percent vertical alignment. The subsurface conditions consisted of loose saturated silty sand to silty clay with uncorrected SPT N-values in the range of 3 to 4 blows per ft. The soils were deposited by marine, glacial-fluvial processes, so the soil profile was variable and contained pockets of clean material. The original design called for steel casing to be installed by auger boring or slurry tunneling between two watertight work shafts, including external dewatering systems, but no dewatering was permitted under the highway.

The project bids were higher than the municipality could afford, and rebidding would have violated the court-ordered construction schedule. A work-around solution was devised to engage the apparent low bidder in a design-build contract and to rely on contractor innovation to lower costs while maintaining the necessary program schedule. For this type of construction contract to be successful, team cooperation is critical.

The contractor's risk assessment identified several areas of concern. First, the required gradeline accuracy suggested using a microtunnel to meet the slope tolerance, but the project's funding was insufficient for an auger bore or for a more expensive micro-tunnel alternative. Additionally, there was a high risk that the weight of the microtunnel equipment would sink into the very soft soil. The solution was to first install a 5-in.-diameter steel pilot-tube pipe to achieve the required precision and accuracy and to provide ground stability data that was obtained when the pilot tube was advanced (Figure 3). Then a single pass string, consisting of 100 ft of 24-in.-diameter steel casing, followed by 42-in.-diameter steel casing, was attached to the pilot tube. Each step-up in diameter consisted of an open structural adapter welded into the string (Figure 4). Thrust would be provided by a 14-in.-diameter pneumatic hammer that could be increased to a 24-in.-diameter pneumatic hammer if needed. Augers would only be used when necessary, to lighten the casing by removing spoils. Telescoping casing provided for lighter tooling to manage construction settlement. Pneumatic hammers provided the potential to

Figure 4. **Welding an adapter to accommodate a transition between 24-in.- and 42-in.-diameter casings. (Photo courtesy of Engineers Construction, Inc.)**

Figure 5. **Taurus pipe ram driving a section of 24-in.-diameter casing. (Photo courtesy of Engineers Construction Inc.)**

accelerate the construction and offer reduced cost.

Should the hammer run out of power, the contingency plan was to cut out the adapter between the 24-in.- and 42-in.-diameter casings, and then drive a heavy wall, 24-in.-diameter casing the remainder of the distance to better transmit energy to the cutting head. The 12-in.-diameter PVC pipe could then be assembled by cartridge methods into the casing using spacers to achieve the required grade. The resulting annulus would be filled with grout to secure the alignment and to fill voids to prevent settlement of the overlying highway.

During construction, the initial pilot tube lost grade when it encountered very loose, saturated fine sand and silt. Fortunately, the small-diameter assembly allowed for removal and successful reinstallation on line and grade and within the same corridor path. As the subsequent casing drive progressed, an unexpected pocket of clean, saturated fine sand was encountered, which stopped the advance. Hammer vibration on the stalled casing caused the saturated fine sand to flow into the 48-in.-diameter casing through the adapter, causing a sinkhole between the drive shaft and the highway. The contractor converted the sinkhole to a dewatered shaft, removed the adapter, installed heavy wall 24-in.-diameter casing as called for in the contingency plan, and successfully completed the installation (Figure 5).

Progress Continues

Trenchless construction has and always will demand a combination of art and skill, but subsurface conditions and their reaction to excavation are not always easy to predict. Significant innovations in trenchless construction have evolved to tackle these challenges, but there remains much to be learned by all stakeholders. Residual risk will always be present, but there's room for improvement with innovative contracting in a team environment, with all parties listening and contributing. A contractor's experience and ability to adapt tooling and processes to address unexpected conditions can be effective when given the opportunity to participate as a project team member. Letting contractors select the means and methods based on project-specific and meaningful subsurface information, along with adequate funding and a project-team focus, will benefit owners, contractors, and manufacturers, and stimulate new, cost-effective innovations. GS

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