SEPTEMBER 2009

tunnels & tunneling NORTH AMERICA

NEW YORK SUBWAY: THE TUNNEL BENEATH THE TUNNELS.

Since June 2009, Herrenknecht Double Shield technology has been deployed for the first time in the USA to excavate two tunnels. Two identical machines, each with a diameter of 6.81 meters, are excavating the extension of Subway Line 7 up to the Hudson River bank in the heart of New York, beneath Manhattan's Far West Side.

On their way through slate, granite and serpentinite, the two Double Shields must cross beneath several existing tunnels, among these the Eighth Avenue Subway Lines and the three tubes of the Lincoln Tunnel, connecting Manhattan with New Jersey. The tunnel construction team is optimally prepared for this job using the Herrenknecht Double Shield technology. Meaning that one of the last gaps in the otherwise closely-knit public transport network can be closed as quick as possible. And that the New Yorkers continue to remain loyal to the their subway in the future.

NEW YORK | USA

PROJECT DATA	CONTRACTOR
S-467, S-468 **2x Double Shield TBM** Diameter: 6,810mm Cutterhead power: 2.100kW Tunnel lengths: 2,800m each Geology: slate, granite, serpentinite	S3II Tunnel Constructors (Schiavone Construction Co.; Skanska USA Civil; J.F. Shea Construction Inc.)

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Front cover

CDM provided all geotechnical services - from pre-design through design - and is executing geotechnical construction services for the Brightwater wastewater conveyance system in King County, Washington, USA. The system includes four separate large diameter tunnels, each ranging from 13ft to 19ft in diameter and from 2- to 4-miles in length.

To maximize space, the BT-1 tunnel (East contract) houses pipes for several utilities, including 48- and 66-inch influent pipes to the new wastewater treatment plant, 84-inch effluent pipe going to Puget Sound, and a 27-inch gray water effluent pipeline.

Challenging soil conditions, high groundwater pressures, and tunnels with depths greater than 300ft and lengths in excess of 20,000ft, have required extensive geotechnical and groundwater analysis during design and ongoing monitoring during construction.

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Sparring over options

This month, Washington's State Department of Transportation (WSDOT) issued a request for qualifications for the 54ft (16.5m) diameter, 9,200ft (2.8km) long, large bore tunnel replacement for Seattle's Alaskan Way Viaduct, taking the first step towards selecting a team to design and build a tunnel project that has quickly become the biggest point of contention in Seattle's current mayoral election.

Candidates Joe Mallahan, a senior T-Mobile executive, and Mike McGinn, a lawyer and former Sierra Club leader, have bitterly opposing views on the how the crumbling state highway viaduct should be replaced and have been arguing it out all summer in the local media.

McGinn has pledged to fight the tunnel tooth and nail if he gets elected - making the issue the cornerstone of his campaign. He believes a surface option would be more beneficial to the city in the long term, as it would force people to use public transport instead of sit in traffic jams and says the $920 million the city is slated to contribute to the $4.2 billion tunnel project could be better spent elsewhere - slightly ignoring the fact that this $920 million is to pay for utility relocations and a sea wall replacement.

Mallahan, quite rightly, believes that McGinn is talking complete nonsense and stands by the bored tunnel option as the only sensible and viable alternative for the city. This has gained him a lot of support from the labor unions and local business leaders, who are keen to see the work resulting from the tunnel project and also prevent the freight gridlock that would result from McGinn's surface-only alternative.

However, the voters are not entirely convinced. In a recent poll the city was pretty evenly divided on the project, with 49% for and 43% against the tunnel option. The public also previously voted against a tunnel alternative in 2007.

McGinn has been playing on this and has brought the public into the debate. Having spent most of July and August living in downtown Seattle, it became apparent just how many people were discussing the project and very few were entirely at ease with it.

> The voters are not entirely convinced. In a recent poll the city was evenly divided on the tunnel.

One of the main concerns I heard, again prompted by McGinn's campaign, was the question of who would be liable for any cost overruns resulting from the tunnel. Another issue was the general lack of understanding about how the project is being procured – how can we build a tunnel that hasn't been designed yet?

Surprisingly, for me, ground conditions were also raised. While I was writing this edition of *T&TNA* in Mexico City, I met a group of twenty-somethings from Seattle who were all very aware of the problems currently being experienced on the Brightwater Conveyance project (p14). They asked me how I could be sure the same problems wouldn't arise again with the large bore tunnel.

In truth, it is unlikely McGinn could really stop the project if he is elected, but his rhetoric has spooked city and state leaders who have begun taking steps to ensure the current plan is locked into place.

Later this month the Seattle City Council's transportation committee will vote on a formal agreement with the state Transportation Department that outlines each side's responsibilities in the project, solidifying the agreement already reached in January.

Current mayor Greg Nickels is also expected to outline a skeleton plan for how the city will finance its contribution to the project in his 2010 budget.

The point is, with so much criticism of the tunnel coming from McGinn, the public are starting to believe there may be something to his claims.

What has really surprised me is how few engineers have spoken up in this politically-driven media furore. If an election can be won or lost based on support for (or against) a tunneling project then why isn't our industry at least taking part in the debate.

We should be explaining why the right choices are being made so that when the project does move into construction it has the full backing of the public that it requires. ■`

Companies featured in this issue

No 7 Line steps up a gear

The two 22.5ft (6.8m) diameter double-shield Herrenknecht TBMs, being used to excavate the 5,900ft (1.8km) long twin running tunnels for the $2.1 billion No 7 Subway Line Extension, in Manhattan, are due to restart in late September following ground improvement works to an initial low rock cover section on each of the drives.

Construction of the No 7 Subway Line Extension has been underway since December 2007 when MTA Capital Construction gave the S3II Joint Venture, consisting of JF Shea, Skanska and Schiavone, Notice to Proceed on a $1.4 billion contract to build the project's running tunnels and associated structures. The twin hard rock TBMs were correspondingly launched in April and May (*T&TNA*, March, p6).

Of the initial 500ft (150m) of each TBM drive, 300ft (90m) required ground improvement due to low rock cover in the area. Ground freezing from the surface was selected as the preferred method, with drilling of the freeze holes, installation of the freeze pipes and the freeze operation performed by Layne Christensen Co. The freeze was maintained until excavation passed through this zone and the pre-cast lining was in place. The TBMs are now due to resume at the end of September using side dump muck cars and a series of horizontal, incline and vertical conveyors to transport tunnel muck to the surface. Approximately 4,880ft (1,485m) of each tunnel will be lined with a pre-cast concrete segmental liner manufactured by Technopref in Royersford, PA.

Right: **The TBM starter tunnel interface with the precast liner and (below) TBM trailing gear**

S3II JV's contract also includes excavation of a 100ft (30m) deep access shaft, a cross-adit and two starter/tail tunnels that are each 400ft (120m) long, the 1,200ft (365m) long 34th Street station cavern, its two access shafts and associated drifts and five cross-passages. In addition, 140ft (42m) of twin cell box structure will be constructed and the existing No 7 Line tunnel will be retrofitted, including lowering of the invert and underpinning of the existing structure.

Excavation is now complete on the 1,200ft (365m) long 34th Street Station cavern and its two shafts. The 66ft (20m) wide, 24ft (7.3m) high top heading of the cavern was excavated by drill and blast and supported with rockbolts and fiber reinforced shotcrete. The excavation was carried out via three staggered headings, each about 22ft (6.7m) wide. Cavern bench excavation was completed to a full 30ft (9m) height in two staggered headings. Concrete and waterproofing works are now ongoing.

The excavation required in the Times Square area has also been completed. The tail tracks of the existing No. 7 Line have been lowered and construction of the concrete box structure under the Port Authority Bus Terminal has begun. The chamber for the box structure will also serve as the receiving chamber for the TBMs, which with an estimated advance rate of 60-70ft (18-20m) per day are scheduled to complete by March 2010.

The 7 Line Subway is being funded by the city and managed by the MTA, it will ultimately extend west under 41st Street, from its current terminus at Times Square, and then south under 11th Avenue to the new station at 34th Street and 11th Avenue, with storage tracks continuing down to 25th Street.

When complete, the No. 7 Line Extension will serve an emerging community in Midtown West, fostering transit oriented development in one of Manhattan's most underdeveloped areas. ■

Design award for TARP's McCook

In August, the US Army Corps of Engineers (USACE) announced it has selected Black & Veatch as its designer for the McCook Reservoir Main Tunnel. The new 1,800ft (548m) long, 33ft (10m) diameter, tunnel will connect the future McCook Reservoir to Chicago's Deep Tunnel system. Black & Veatch will prepare the geotechnical baseline report and assist in development of risk management strategies for design and constructability, in addition to sequencing and procurement, schedule and budget controls.

The project is a key component of Chicago's Tunnel and Reservoir Plan (TARP). Through TARP, the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) collects and diverts combined sewer overflows and floodwaters to temporary holding reservoirs before treatment. When completed, the tunnel will connect Chicago's Mainstream Tunnel to the planned McCook Reservoir and bolster protection of the local water supply.

In addition to the tunnel for McCook Reservoir, Black & Veatch is also leading the design for the groundwater protection system and the Thorn Creek connection tunnel, and is leading final preparations for the Thornton Reservoir. Projected construction costs for all facilities Black & Veatch is designing in conjunction with TARP are estimated to be more than $500 million. ■

PB advocates Balfour Beatty acquisition

On September 17, Kevin J Hawksworth the CEO of Parsons Brinckerhoff Inc (PB) announced that the Board of Directors of the consulting firm, which was founded in New York City in 1885, are recommending to shareholders the approval of its acquisition by London-based infrastructure firm Balfour Beatty plc (BB) for $626 million.

"We have for some time sought a strategic partner that complements the services we provide and assist us in our on-going global expansion," Hawksworth said. "The combination [of Balfour Beatty] with PB creates an organization with world-class capabilities in project development (including financing), design, management or delivery of construction services."

James L Lammie, Chairman of the Board of PB, added, "Balfour Beatty has agreed that Parsons Brinckerhoff will retain its name and organizational structure and operate as an independent but wholly-owned subsidiary. We believe this will allow us to continue to meet our clients' needs in ways they expect while expanding into new areas." Client service will be a prime focus of the combined organization with no changes in project managers, technical staff and/or executive leadership as a result of the acquisition.

The shareholders of both organizations must approve the acquisition. PB's Shareholders' Meeting will take place on October 21st. In 2008, PB had revenues of $2.34 billion and approximately 13,000 employees in over 100 offices worldwide. The publicly traded Balfour Beatty has approximately 40,000 employees and last year had revenues of approximately $15 billion.

Palomino launches

On August 18, Odebrecht Construcción y Ingeniería celebrated the launch of its 14.7ft (4.5m) diameter Herrenknecht hard rock Double Shield on a 7-mile (11.4km) section of a 42,000ft (12.8km) long headrace tunnel for the Palomino Hydroelectric Project, in the Dominican Republic.

The $364 million EPC turnkey contract for the 80MW project was awarded to Odebrecht in May 2005, by client Empresa de Generación Hidroelectrica Dominicana (EGEHID). In addition to the headrace, other major elements of the project include a 197ft (60m) high, 477ft (145.4m) wide RRC dam, a 52ft (16m) wide x 147ft (45.5m) long x 97ft (29.6m) underground powerhouse, a 6,560ft (2km) long tailrace tunnel, and numerous access adits and shaft structures.

Brazilian firm Intertechne Consultores is undertaking the design of the project, with Arup and Vigl undertaking the precast lining design for the TBM tunnel.

Drill and blast tunnel excavation for the access and tailrace tunnels first began in June 2008, and remains ongoing, with the TBM arriving on site in May this year. Following its launch from a drill and blast starter tunnel, the machine has so far advanced 1,530ft (466m), with the team expecting to reach an average production of 71ft (22m) per day.

Along the section to be excavated by TBM, the upstream 15,000ft (4.6km) will cross rocks of the Tireo formation, with cover varying from 165ft (50m) to (1,310ft) 400m. The remaining 22,300ft (6.8km), in the downstream section of the drive, will be excavated in the sedimentary rocks of the Ventura formation, with cover from 230ft (70m) to 1,970ft (600m).

"The main problem we foresee is the complexity of the geology," says Odebrecht Project Manager, Carlos Guimaraes. "We expect high levels of water inflow, possible ravelling and squeezing ground and many faults, throughout both the TBM and D&B excavations."

The current estimated finish date for the TBM drive, including disassembly and finishing works is August, 2011, with the overall project completion date is set for September 2011. ■

U Link bids

In August, bids for the second of Sound Transit's University light rail Link (U-Link) tunneling contracts, which includes 3,800ft (1,158m) of twin tunnel between Capitol Hill and the Downtown Transit Tunnel, in Seattle, again came in lower than the engineers estimate.

The lowest bid for the U230 contract was submitted by JCM U-Link JV – comprising Jay Dee, Frank Collucio Construction and Michaels Corp – and came in at $153.5 million, some %12 below the original estimate of $174.3 million. The next lowest bid, by Kenny/Shea JV, was very close at $154.1 million.

This follows the award of the first U Link tunneling contract, U220, which includes 11,400ft (3.5km) of twin tunnels from Capitol Hill to the University of Washington, in June to Traylor/Frontier-Kemper JV with a low bid of $309.2 million, 22% below the Engineer's $395.35 million estimate.

The $1.9 billion, 3.15-mile all-underground University Link line is due to open in 2016.

Powering in Portland

Despite a month's downtime this August to repair a broken stone crusher on its 25ft (7.7m) diameter Herrenknecht Mixshield TBM, Kiewit/Bilfinger Berger JV (KBB) is still powering along on Portland's $426 million East Side Combined Sewer Overflow (CSO). The fourth of the JV's six successive TBM drives is due to break-through at the end of October, marking the end of the machine's 20,340ft (6200m) northern drive to Port Centre (*T&TNA*, Sept '08, p20).

The recent machine repairs were due to the current ground conditions on the project, with large boulders of up to 4-5ft (1-1.5m) wide being encountered. "The boulders rip the picks from the cutterhead, which then get into the crusher area," explained Christof Metzger, KBB's Tunneling Manager. "They wedged the cutter arm, resulting in a build up of pressure in the cylinders, which caused quite a bit of damage."

When *T&TNA* visited the site in late-August however, the crusher repairs had already been completed and mining had begun to get back up to speed, with an advance of 45-50ft (14-15m) per day being achieved.

Breakthrough is now due in late October, following which the entire machine, including the cutterhead, will be removed from the Port Centre shaft in a single 415t lift utilizing a 700t gantry crane and transported back to the Opera Shaft site via barge. The cutterhead will be removed for refurbishment and the machine re-lowered for its southbound drive. "The time is not in taking out the TBM and transporting it, but pulling the backup through the tunnel," says Metzger. "We will have to clean 19,500ft (6km) of walkway, pipes and fixtures from the tunnel, before that can happen. Then we have to rearrange the backup the other way around."

KBB's final 8,858ft (2700m) southbound drive to the McLoughlin shaft is currently expected to start in March 2010 and with an estimated eight months of mining should be complete by November 2010, a good five months ahead of the original schedule.

Toronto boom sees eight Lovat EPBMs on order

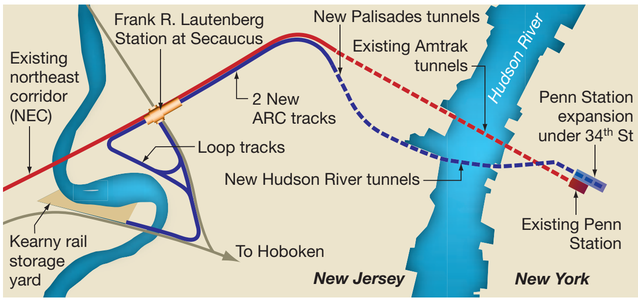
Lovat is benefiting from the current tunneling boom in its home town of Toronto, with an order of four 3.6m (11.8ft) diameter mixed face EPBMs for the Regional Municipality of York's new 15km (9.3-mile) long Southeast Collector Trunk Sewer (SeC); and a contract for four 6.13m (20.1ft) diameter mixed face EPBMs having just been signed with Toronto Transit Commission (TTC) for its 8.6km (5.4-mile) long Spadina Subway Extension. Both clients have opted to self-procure the TBMs in an effort to get a head start on the projects, which are rapidly moving towards the construction phase.

In addition to the TBMs, York Region intends to award a contract later this month for the production of the SeC Trunk Sewer's segmental tunnel liner system. Bids were received on September 1, 2009, however an official decision is still pending. Tenders for the Can$520 million tunnel will be called in early January 2010. Two contract packages will be tendered whereby contractors may bid on either contract or as a combined bid. Hatch Mott MacDonald (HMM) and Aecom are responsible for the various tunnel design elements, which also include 17 shafts ranging from 4.6m (15.1ft) to 13.2m (43.3ft) o.d.

Working to a similar procurement approach, the TTC is also currently gearing up towards tendering its two Can$300 million tunneling contracts for the Can$2.6 billion Spadina Subway Extension (*T&TNA*, March, p13) in May or June of 2010. Hatch Mott MacDonald was awarded the twin tunnel design in late 2008 and is currently leading the Spadina Link JV (HMM/Delcan/MMM) responsible for managing the delivery of the design and construction management of the project. Bids for production of the pre-cast liner are scheduled to be received by late October.

Both projects will be constructed below the water table, predominantly through the region's glacial tills, as well as sand, silt and clay deposits. Some cobbles and boulders also expected. ■

Progress on the move: ARC's MTT



The $8.7 billion Access to the Region's Core (ARC) Mass Transit Tunnel, America's largest transit infrastructure project, is moving rapidly into construction with shovels in the ground on the project's first contract and bids for two major tunneling contracts to be taken later this year. Here NJ Transit provides an overview of the project

The $8.7 billion Access to the Region's Core (ARC) Mass Transit Tunnel will be a historic step forward for mobility in the increasingly congested New Jersey-New York region. The project's new 9-mile (14.5km) long twin-track line will double commuter rail capacity under the Hudson River between the two states and create a new, state-of-the-art, 2245ft (6.85m) long x 96ft (29m) wide station cavern in Midtown Manhattan.

The benefits of the project will create a new era of prosperity for the region just as the Pennsylvania Railroad did almost 100 years ago when it built the existing twin single-track rail tunnels that now form the sole heavy (commuter) rail link between New Jersey and New York.

The existing tunnels run from North Bergen, NJ, under the Hudson River to Pennsylvania Station at 33rd Street in Manhattan. The new 3.4-mile (5.47km) long, 24ft 6in (7.46m) diameter, tunnels will follow a similar, slightly more southerly route under the Hudson River, connecting to a new Penn Station Expansion under 34th Street.

The MTT has been propelled into construction thanks to a major commitment of financial, engineering, project management and other resources from NJ Transit, New Jersey's statewide mass transit agency, and the Port Authority of New York and New Jersey, a bi-state agency that operates the Holland and Lincoln tunnels, the George Washington Bridge and other major transportation facilities. The project is also strongly supported by the state governments of New York and New Jersey, as well as that of New York City. The Mass Transit Tunnel is New Jersey Governor Jon Corzine's number one transportation priority. And the tunnel has strong financial backing from the federal government, which has committed to contributing one-third of the project's cost over the life of construction.

Key infrastructure elements of project include:

- Two new 3.4-mile (5.47km) long, 24ft 6in (7.46m) diameter, single-track tunnels under the Palisades in New Jersey, the Hudson River, with continuation of these two tunnels under the west side of Manhattan
- A new 2245ft (6.85m) long x 96ft (29m) wide underground station cavern (the "Penn Station Expansion") under West 34th Street between Eighth and Sixth Avenues, adjacent to the existing Penn Station
- Five NYPSE station entrances, Americans with Disabilities Act (ADA)-compliant elevator entrances
- A new direct connection at Secaucus, NJ, between NJ Transit's Main, Bergen County and Pascack Valley lines and the Northeast Corridor (NEC) in New Jersey
- New track capacity along the NEC between Frank R. Lautenberg Station in Secaucus and the Palisades in New Jersey
- A mid-day train storage yard in Kearny, New Jersey
- One fan plant/construction access shaft in New Jersey and four fan plants/construction access shafts in Manhattan

Construction will be split into about two dozen defined-scope contracts each of which will have a relatively short duration to match specialized contractors with specific work scopes.

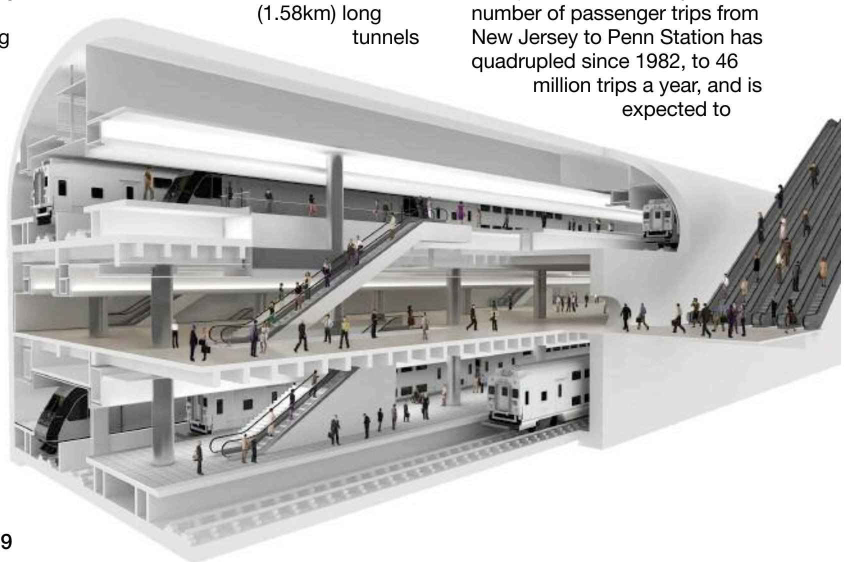
The first construction contract, a $13.6 million underpass allowing the project's new tracks to pass under Routes 1 & 9 in North Bergen, NJ, was awarded to Ferreira Construction Co Inc and broke ground in June. It is proceeding on schedule, with completion currently expected in early 2012.

Two of the project's three major tunneling segment contracts, the contract for the 5,700ft (1.73km) long tunnels under Manhattan, and the contract for the 5,200ft (1.58km) long tunnels under New Jersey's Palisades Mountain, are moving quickly through procurement and review, and are due to have bids taken late this year, with construction beginning in 2010. The third 7,400ft (2.25km) long tunneling segment contract, for the bores under the Hudson River, will go out to bid in 2010.

The major tunnel segments are being constructed on a design-build basis, an approach that capitalizes on contractor innovation while reducing build time. The pre-qualified bidders for the Palisades Tunnel section include: OHL/Tulley JV, Barnard/Judlau Contracting JV, Shea/Schiavone/Skanska JV, and ARC Constructors – a JV of SA Healy and CCA Civil/Halmer. For the Mahattan Tunnel section the pre-qualified bidders are: Barnard/Judlau Contracting JV, Shea/Schiavone/Skanska JV, and ARC Constructors.

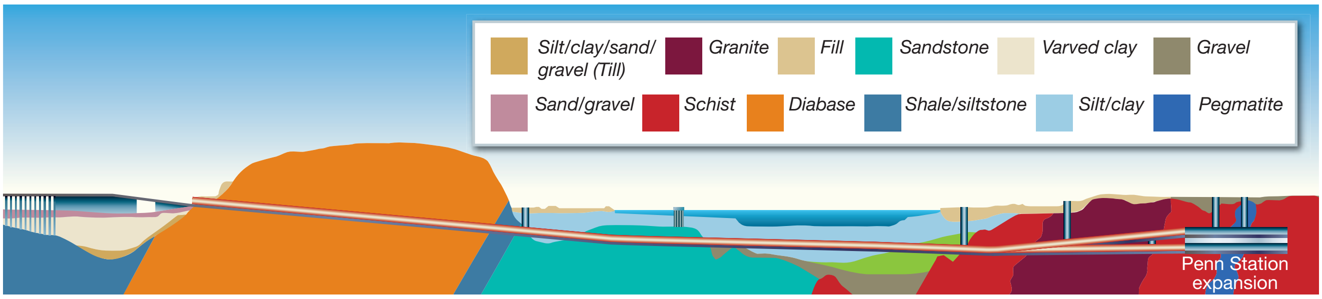
Project alignment

Like the Pennsylvania Railroad's tunnels, the ARC Mass Transit Tunnel was born of transportation necessity. The number of passenger trips from New Jersey to Penn Station has quadrupled since 1982, to 46 million trips a year, and is expected to



Above: Figure 1 – Map showing the alignment of the new Mass Transit Tunnel project

Right: Figure 2 – Artists' impression of the New York Penn Station Expansion in Manhattan



Above: **Figure 3 – Longitudinal cross section of the Matt Transit Tunnel showing predicted geology along the alignment**
Right: **Figure 4 – Artists' impression of one of the mezzanine levels in the Penn Station Expansion**
Below right: **Downtown Manhattan, where the tunnels will terminate at the Penn Station Expansion**

double again in the next 20 years. This steady growth prompted leaders at NJ Transit and the Port Authority of New York and New Jersey to make additional rail capacity a significant part of the region's long-term transportation plans.

Years of rigorous planning determined that the best route for the new line is parallel to the existing Northeast Corridor above ground from the Frank R. Lautenberg Rail Station in Secaucus, NJ, eastward to North Bergen, NJ. At that point the line will curve south and go underground in two single-track tunnels under the Palisades.

The twin tunnels will traverse through the Palisades at an average depth of 200ft (60m) and then continue under the Hudson about 50ft (15m) under the riverbed. When the tunnels reach Manhattan they will navigate a course 100ft (30m) to 145ft (45m) below street level, traveling beneath 34th Street to Sixth Avenue. The total length of the tunnels will be 3.4 miles (5.5km) each. Cross-passages between the tunnels will be constructed at approximately 800ft (245m) intervals.

At its eastern end, the tunnel will connect with a new, modern underground cavern station, called the New York Penn Station Expansion beneath 34th Street. This facility will be adjacent to the existing station, and the new station's mezzanine will be about 150ft (45m) below street level. The new station will include a three-over-three track/platform arrangement between Eighth and Sixth Avenues, with a spacious mezzanine in the middle level.

The expansion will also feature three high-rise escalator banks, at Sixth Avenue/Broadway, Seventh and Eighth avenues. Pedestrians will be able to connect directly with 14 New York subway lines as well as the PATH system, and there will be five station entrances to the street, at key locations on Eighth Avenue and Seventh Avenues, and at Sixth Avenue/Broadway. Three separate ADA-compliant elevator station entrances will also be provided on Eighth and Seventh avenues and Sixth Avenue/Broadway.

For the first time pedestrians will be provided with direct access to key New York subway lines, including the Sixth Avenue and Broadway lines. The project has also been designed to allow the opportunity for future eastward expansion at a subsequent stage.

A joint venture of PB Americas Inc, DMJM + Harris Inc and STV Inc was engaged in mid-2006 to perform the preliminary engineering for the project. That task was completed late last year and the joint venture is now proceeding with final design.

Meanwhile, local funding for the project is committed, thanks to a pledge of $2.7 billion from New Jersey and $3 billion for the Port Authority of New York and New Jersey. The federal government has issued a $1.35 billion Early Systems Work Agreement and also indicated its intent to provide a total of $3 billion to the project over the life of construction.

Geology

Extensive studies of the geological conditions along the tunnel alignment have included borings, sample investigations, and geophysical testing. The results of these investigations show the geology varies significantly at different sections of the alignment, presenting unique challenges, from sedimentary and intrusive and extrusive igneous rocks, to metamorphic rock and post glacial estuarine deposits of soft, gray, organic silty clay and clayey silt with traces of fine sand and shells. Faults are anticipated both across and sub-parallel to the tunnel alignment in Manhattan.

Excavation methods

Tunnel excavation will be achieved using a total of three TBMs, with one hard rock TBM each for the Palisades and Manhattan segments, and a shielded mixed-face/soft ground TBM for the Hudson River segment.

The TBMs for the Hudson River work will be lowered into access shafts in Hoboken, NJ, and removed in Manhattan. The TBMs for Manhattan will be lowered and removed from an access shaft in Manhattan. The TBM for the Palisades Tunnel will be started from an access point in North Bergen, NJ.

Work will proceed on the new Penn Station Expansion cavern using conventional drill-and-blast mining methods after the Manhattan tunneling work has been completed.

Five fan plants, one in Hoboken and four in Manhattan, will also be built, along with new traction power facilities in New Jersey and at the new Penn Station Expansion in New York.

Altogether, about 1.67 million cubic yards of rock and 322,000 cubic yards of soil will be hauled away by truck, to cap a property in Kearny that will become a mid-day train storage yard.

On completion of the project, dual mode locomotives will be used to provide a transfer-free "one-seat" service on five existing NJ Transit rail lines, which currently operate a diesel service to Newark, Secaucus, or Hoboken, NJ. The number of peak hour trains that will travel between New York and New Jersey will more than double, from the current 23 to 48.

In addition to creating much needed capacity for rail passengers traveling between New Jersey and New York, the ARC Mass Transit Tunnel project will provide major economic stimulus to the metropolitan region, a particularly valuable benefit at this current time of economic weakness.

The project will create 6,000 construction and related jobs during peak construction years, and generate 44,000 permanent jobs after completion. The project will result in $4 billion in additional real personal income for New Jersey and New York.

The Mass Transit Tunnel's sweeping economic and mobility benefits will ensure the New Jersey-New York metropolitan region will remain a world-class area to live and work in the 21st Century and beyond. ■

How green is your tunnel?

Above: **Figure 1 – The sustainability triple bottom line incorporates economic growth, social responsibility, and environmental stewardship**

What exactly is sustainability and how can sustainable principles be incorporated into underground construction? Michael B Gilbert, Vice President, and Michael S Schultz, Senior Vice President, of CDM, discuss a variety of ideas

Sustainability is the buzzword we've all been hearing lately. What exactly is sustainability and how can sustainable principles be incorporated into underground projects, such as deep excavation support systems, shafts and tunnels? More importantly, should sustainable practices be integrated and what are the benefits to the tunneling industry?

The term sustainability is generally used to describe actions or activities undertaken in a manner that the needs of the present generation are met without compromising those of future generations. Therefore, in a sense, underground projects are essentially already sustainable, based on the fact that they incorporate the needs of both current and future generations, particularly in the areas of transportation and utilities, reducing pollution to the environment, the moving of goods and people, and providing water supply over great distances, etc.

However, we need to recognize that in our industry we can and must do more to explore ways of better incorporating sustainable elements into underground construction projects. The questions are - what, how, and where can we? This Viewpoint article explores a few ways we might begin to answer these questions.

The triple bottom line

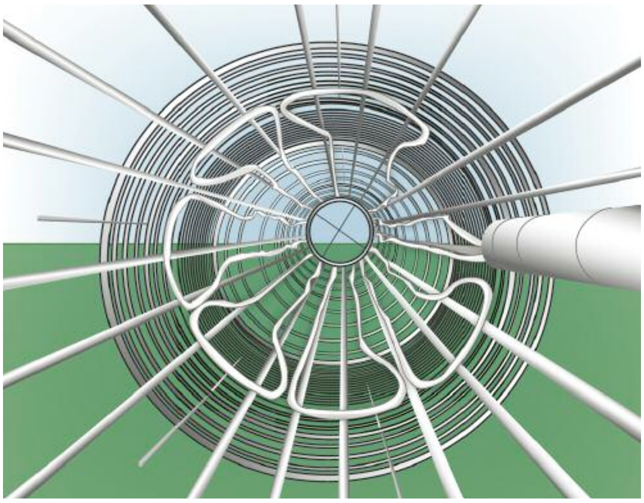
The sustainability "triple bottom line" concept is one that incorporates economic growth, social responsibility, and environmental stewardship, while recognizing the inter-related and inter-dependent relationships for any new activity people can propose (Figure 1). Advancement of one dimension at the cost of another is not the goal. The goal is to make improvements and show that those improvements added value in all three dimensions; thus achieving the triple bottom line objective.

Fortunately, projects in the underground construction industry generally already meet more than one component of the triple bottom line. In addition, we are starting to see some exciting of projects that are being taken even further. For example, in the case of infrastructure projects, combined technologies are being incorporated into designs to accomplish the sustainable goal of maximizing resources - old capped landfills are becoming public parks and recreation facilities; wastewater treatment plants are being designed to reduce energy demands by turning biogas into energy; electric transmission towers are being viewed as possible structures for wind turbines.

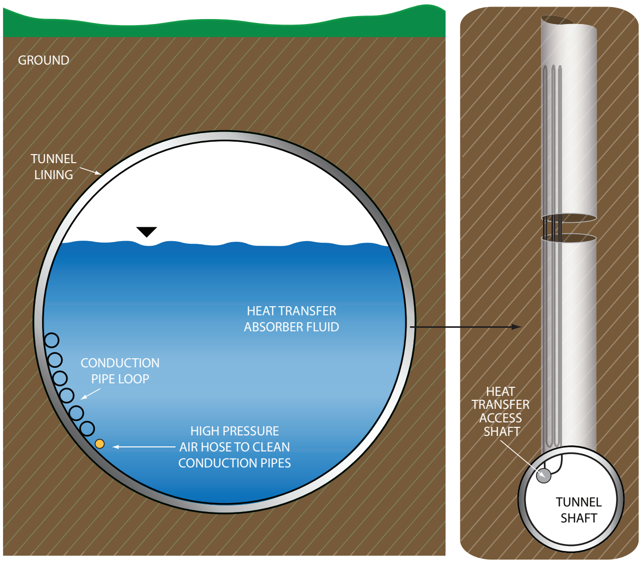
As for the underground structures we design and build, such as tunnels and pipelines, several sustainable options are being explored for multiple benefits, including:

- Geothermal heating and cooling for buildings
- Small hydropower generation in water lines
- Using heat collected in transportation tunnels to melt icy pavements at stations or roadways above
- Biogas collection in wastewater pipelines
- Multiple uses for the underground space created

Since each of these topics could be written about extensively, for this Viewpoint, we have chosen to focus primarily on incorporating geothermal heating and cooling elements and hydropower usage in tunneling.



Above: **Figure 2 - Heat pipes used as part of a pile foundation - transferring heat from soil to heat carrier fluid within an absorber**



Above: **Figure 3 – Concept of heat pipe in a CSO, where heat conduction pipes can be installed along the entire length of the tunnel to take advantage of the influent flow's constant temperature**

Geothermal heating and cooling: The basics

Geothermal energy is heat supplied from solar radiation through the ground surface and by percolation of surface water down to a "neutral zone." The advantage is that you are using a potential energy source that already exists and the costs involved come from transferring the energy so that it can be used.

This process contributes to the triple bottom line by saving money, reducing future energy requirements, reducing the emission of CO_2 and other pollutants, without adverse affect on fauna and flora. Also, while fossil fuels are limited and the costs are continually rising, there is an unlimited source of geothermal heat created from the sun's solar radiation, making this approach highly sustainable.

Subsurface structures and any ground-embedded structures such as shallow foundations, bored piles, diaphragm walls and ground slabs for cut-and-cover tunnels, tunnel linings, soil/rock anchors, and sewer systems can serve as absorber elements for ground heat exchange. The technology uses pipes installed within concrete elements or at the bottom of sewer tunnels and heat carrier fluid circulated through the system. Heat is extracted from the ground or stored in the ground for heating and cooling buildings.

This method of heat transfer has been employed for many years in both the United States and Europe, particularly in Germany. In Europe, it has been incorporated as an alternative energy solution by using the heat stored at shallow depths, less than 1,300ft (400m), as a means of heating or cooling both residential and commercial buildings. The system has been made economical by utilizing the foundation pile (energy pile) system as the heat exchanger.

The heat transfer system consists of a heat exchanger, which captures the heat from the environment, and a heat pump, which uses electrical energy to pump heat from cool locations to warmer locations. Compared to a standard natural gas furnace or traditional air conditioning system, ground source heat pump systems need only a fraction of the electricity required to operate the pump. Basically, the heat pump operates by moving or transferring heat using existing heat rather than creating it and not using energy to create energy in a different form.

Above: **A geothermal system designed to capture excess heat and use it to melt ice on train platforms**

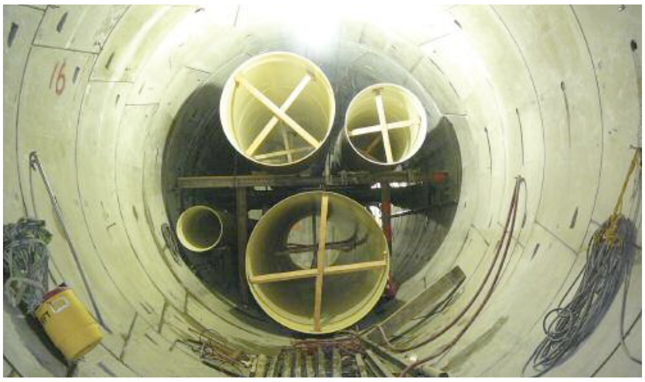
Geothermal principals applied to tunneling

Today, there are simple, reliable, and durable devices available to extract geothermal energy and geothermal systems can be combined with other sources of energy to supplement overall demands. Ground heat exchangers are both horizontal with shallow ground cover and vertical using boreholes for installation.

Such systems consist of wells for extraction/injection of groundwater and energy piles or foundation piles equipped with heat exchangers. Currently, the energy piles are the most commonly used means of transferring heat from soil to heat carrier fluid within an absorber in the energy pile (Figure 2).

Using this energy system in a tunnel would differ, as shown in Figure 3. In this example, we can take advantage of the constant temperature of the tunnel influent flow, and use the extensive length of the tunnel to install the heat conduction pipes.

Additional costs to the tunnel construction would be relatively small with the addition of the conduction pipes and/or a small separate access shaft within the working shaft of the tunnel. All of this work can be done after completion of the tunnel for minimal cost; it is out of site, environmentally safe, and non-intrusive. This method is a prime example of maximizing the opportunities available, extracting heat from one source and applying it for beneficial use in another application.



Above: **The East contract of the Brightwater conveyance tunnel in King County, Washington, where pipes for several utilities have been placed within the tunnel to maximize usage of free space**

From an engineering viewpoint, the ability to make use of what is readily available, harnessing existing technology that has already been proven, not only makes green sense, but also makes good business sense.

Many tunnels are being used - and many more conveyance systems are being investigated and designed - to convey influent to wastewater or water treatment plants. This environmental need presents one of the best opportunities to capture a sustainable energy supply and harness it for beneficial use.

Let's explore the example of a long, medium-to-large diameter combined sewer overflow (CSO) tunnel. This type of tunnel is essentially a segment of infrastructure that houses a long reservoir of near-constant temperature untreated water, which provides the potential for harnessing and exchanging heat from the liquid, similar to the premise of capturing heat from the earth. And, this constant heat source is about as close to free as we can get in today's economic environment.

This "system" is different from the foundation geothermal system where the ground acts as a relatively poor conductor and requires a large surface area to transfer the heat. CSO inflow water is a very good conductor and would be constantly moving past the heat transfer pipes. In this case, the near-constant temperature of the tunnel influent flow allows the transfer of heat without changing the temperature of the influent. In order to harness this source, engineers must establish the length, size, and location of the heat conduction pipes - similar to establishing the placement of boreholes in geothermal systems.

One possible use of this heat is to transfer it above ground and provide heat to buildings. Heat transferred from the CSO inflow water to buildings would supplement and reduce the demand for heat from other sources, particularly during winter months.

Another possible use is to transfer the heat to heating elements placed under roadways to de-ice frozen roadways. Excess heat in underground transportation facility tunnels could be used in a similar manner.

For example, in Germany, systems have been designed to capture excess heat available under sidewalks at a train station and used to melt snow and ice on train platforms. This sustainable project reduces the need for road salt, plowing, and external heat sources, reducing the carbon footprint.

The capacity of the heat exchange system is a function of the number of heat pipes placed in the tunnel and the length of these pipes to maximize the surface contact between the heat pipe and the inflow in the tunnel. For the steady state heat transfer condition the theory used to calculate the length of the heat exchange system is relatively straightforward.

However, due to the properties of sewer water versus the same parameter values of clean water, there are some complications in the details. In China, tests have indicated that the heat exchange coefficient for sewer water ranges from 580 to 800 watt per square meter degree Kelvin (W/m2K), whereas the heat exchange coefficient of clean water ranges from 500 to 10,000 W/m2K.

Low-head hydropower

Low-head hydropower has been used in the United States throughout our early history and helped generate power for the industrial revolution. Although mostly abandoned, remnants of the canal system and the "water wheel" for power generation are still visible throughout the east of the country. These "old" concepts are now being looked at in fresh ways using new technologies.

The constant or near-constant flow of water in sewer or water conveyance tunnels presents another sustainable opportunity for harnessing energy. A low-head hydroelectric turbine generator installed in the tunnel can capture the momentum of the water in motion and use it as a renewable energy source.

Similar to the energy pile or tunnel suggested above, energy from water cannot be created or destroyed; however the form that it takes can be altered. The water flow can take the form of mechanical energy and be used to turn turbine blades, and then be converted to electrical energy. This energy can be used for local power requirements or could be sold to the local electric utility as a sustainable energy source, working toward the triple bottom line goal of energy efficiency and cost savings.

In order to harness this potential energy, it must first be determined if the water flow and volume are reliable within a consistent velocity. Typically, CSO tunnel design starts with the hydraulics design, which dictates the overall plan. Only within very narrow limits is the final slope dictated by other factors (i.e. ground conditions). The slope is established to maintain a flow velocity between 3ft and 10ft (1m-3m) per second; the typical tunnel slope is 0.1 to 0.5%. The change in elevation that allows the influent water to flow produces a certain amount of energy. A CSO tunnel, at a slope of 0.002 for a length of 5 miles, with a 10 miles-per-gallon flow rate at the treatment plant can theoretically generate 67 kilowatts of power.

This system's sustainable benefits stem from the fact that the source of energy is free, it is constant, and it is out of sight. Most treatment plant CSO tunnels have a major shaft located within the limits of the treatment plant property. These shafts are usually built to accommodate the contractor's needs with regard to tunnel construction. In many cases, the shaft will then be used as part of the plant facility as a lift station or holding tank.

However, for relatively little cost, an isolated small diameter shaft can be placed inside of the main shaft to serve as access for the turbine and generator that is separated from the influent flow coming into the plant.

Maximizing space use

In terms of tunneling and deep excavation there are a wide range of elements that can be incorporated to provide sustainable solutions. Just as geothermal usage is based on the simple concept that a tunnel provides a constant temperature and sufficient space to allow for heat transfer, with proper planning and design, tunnel space can be maximized for other uses. Space is available in many tunnels simply based on the economics of tunnel construction. Rather than wasting this space, it can serve as a multi-purpose shaft.

A 1-mile (1.5km) long sewer or water conveyance tunnel will typically be excavated using some type of TBM. Two critical path issues during the construction are the ability to remove tunnel muck and get supplies to the heading.

To do this economically, the excavation will probably yield a 10ft (3m) inside diameter to move materials and keep transport off the critical path, regardless of the size of the final carrier pipe. Once that pipe is installed, the general practice is to fill the annular void with grout, but grout filling is costly and time consuming. However, installing another carrier pipe within the tunnel allows it to be used for conveyance or as a means of transferring heat.

Using all of the available space in a tunnel simply makes good environmental and business sense - it reduces the impact on the environment by not requiring additional tunnels or pipelines to be dug. This concept has been employed in King County, Washington, where the adaptable use of several utilities in the same tunnel has been implemented as part of the Brightwater tunnel project.

Final thoughts

While the concept of sustainability is novel in the world of tunneling, it is easy to see the potential for harnessing energy and maximizing the use of underground space.

Although the design challenges are different than those typically faced in the industry, these challenges are still well within the range of what has been accomplished on other projects, and could quickly become standard in the tunnel industry as well. ■

Finding solutions in Seattle

Extremely challenging soft ground conditions have been testing the limits of the TBMs excavating the Brightwater conveyance tunnel, in greater Seattle. Amanda Foley, reports on how the difficulties are currently being tackled

TBM interventions were the name of the game when *T&TNA* visited King County's 13-mile (21km) US$1.8bn Brightwater Conveyance project, in Seattle, this August. With severe wear having brought both of the 16.7ft (5.1m) diameter Herrenknecht slurry machines to a standstill on Vinci/Parsons RCI/ Frontier-Kemper JV's Central contract and all clues pointing to an obstruction in front of Jay Dee/ Coluccio/Taisei JV's 15.4ft (4.7m) diameter Lovat EPBM on the West contract, tunneling was at a complete standstill while the project teams geared up to tackle their problems head on.

Warming up out West

Following a five-month delay on the delivery, and therefore launch, of its 15.4ft (4.7m) diameter Lovat EPBM last year – due to its complex high-pressure setup, including a twin manlock in the body of the small machine (*T&TNA* Dec '08, p15) – Jay Dee/Coluccio/ Taisei (JCT) JV has achieved impressive advance rates on its eastward drive (named BT4) from Point Wells (Figure 1).

Leading up to and following a successful planned two-week maintenance stop this June, to install a California switch and re-test the high-pressure equipment on the TBM before entering the 4.5-5 bar pressures of the second half of its drive, the JV was achieving consistent advances of more than 500ft (155m) per week.

By late July, the TBM was 250ft (40m) deep and 14,000ft (4,267m) into its 21,050ft (6,415m) run to Ballinger Way, when penetration rates dropped significantly. "By the first week of August things had got very slow," says JCT's Project Manager, Greg Hauser. "We really didn't want to stop, but the muck started to get hot and we just had to, there was no other option."

Therefore, when *T&TNA* visited the site in mid-August, preparations were underway for the contract's first high-pressure intervention. "Right now our ambient pressure is 50psi [3.5 bar], so the plan is to go in next week at that – luckily we don't need tri-mix gasses or divers at that pressure – we'll open the hatch and get the area cleaned out, then we'll reduce down to 40psi [2.75 bar] and see how much water comes in," said Hauser. "We're predicting it'll be about 13 gallons [50 liters] a minute, which we can handle. If that's the case, we'll open the face doors a little to see how stable the ground is. At that stage we'll lower the pressure down as far as we can safely go."

Despite being fully prepared for the possibility, the JV had wanted to avoid the need for such a high-pressure intervention. The logistics of which became clear when General Superintendent, Tom McMann, showed *T&TNA* around the machine. Space is extremely limited under normal conditions, but in order to make room for all the compressed air equipment everything had to be stripped out. With three men locked in at a time for up to 2.5hrs decompression (for a maximum 90 minutes work), the manlocks are also extremely tight. However, training and equipment preparations for the operation were being carried out meticulously.

"We're going to do it right, we'll use all of the equipment we have and we've gone through numerous training exercises," said Hauser. "We actually have another one this afternoon, as I want to work on getting someone out of the lock, onto the DART and back up here... Just in case it ends up being me!"

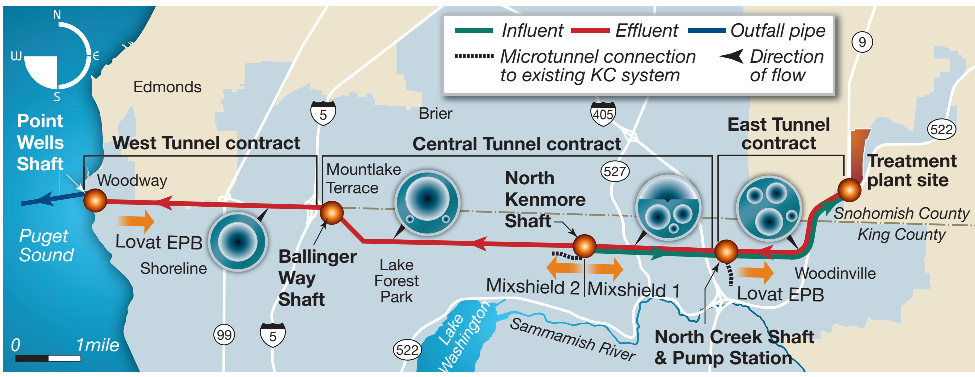
Although the JV had no idea what it would find as a result of the intervention, some pieces of wood had been found on the conveyor in the week leading up to the stop, possibly indicating a petrified log. Another prospect offered was a large boulder, or even an area of much harder ground. "We're going to be prepared for anything," said Hauser. "We just don't know what we're going to find at this stage."

Shortly before going to press, *T&TNA* contacted JCT to find out how things had developed in the following weeks. "We are still down and changing cutters," said Hauser. "We hit something very hard as many, if not most, of the cutters are worn flat at the face of the cutterhead. The inside cutters and hopefully the center cutter are mostly intact with minimal wear. So we suspect there is a very hard layer of something in the invert that hasn't risen in the tunnel face past 2-3ft below springline."

JCT was back mining by mid-September, with the first shift after restart achieving a 50ft advance.

Getting going on Cental

Shortly after resuming its 11,600ft (3.5km) eastbound BT2 drive, following a planned intervention on the 16.7ft (5.1m) diameter Herrenknecht slurry machine's cutterhead in March, the Vinci/ Parsons RCI/ Frontier-Kemper (VPFK) JV carried out a machine inspection in mid-May that revealed severe wear to the rear of the outer rim of the machine's cutterhead. The extent of the damage was such that it prompted the JV to also inspect the twin, westbound, BT-3 machine,



Top: A high-pressure intervention underway on Central's BT2 drive; Above left: Space constraints on the Lovat meant cleaning out the erector area to make room for intervention equipment; Bottom left: Figure 1 - Map of the project

Left: A lack of space within JCT's Lovat EPBM results in extremely confined airlocks and face access

revealing a similar pattern of wear, although not as extensive.

With both machines at a depth of 300ft (90m), interventions at 5-5.5 bar of pressure, using divers and Trimix gases, were required to examine and document the repairs. With working times at these pressures being a maximum of one hour, followed by five to six hours of decompression, it was a very slow process.

Even more of a challenge was formulating a plan to fix the TBMs. "The repairs involve a lot of welding," explains Anthony Pooley, Project Manager for the Jacobs-led construction management team. "Welding at high-pressure is not only dangerous and difficult, it's also not very effective. Plus a lot of the work requires pre-heating and pre-treatment of the steel, so it would have taken a lot of time."

Therefore a plan to depressurize the ground locally around the BT2 machine, using screened wells, was formulated by the Contractor's hydrologist Scott Bender, allowing the repairs to take place in low, or atmospheric, pressures.

BT-2 is currently situated under an access road to a school, which in some ways has been a blessing as it is a fairly non-residential area. With the school out for summer and plenty of surface access available, five screened dewatering wells and two monitoring wells were drilled from the surface during early-August. By the time of *T&TNA*'s visit two weeks later, VPFK had been pumping for just two days and had already drawn down the water 240ft (73m), locally depressurizing the ground around the TBM to 1.6 bar.

Preparations for a similar operation at BT-3 are now under-way. However, despite being in a clayey zone, which should require less dewatering than BT2's sandy gravels, the location of BT-3 is slightly more complicated, in that it is currently under a much more built up area. "The drilling for BT3 will take a lot more community outreach and careful management of noise," explained Pooley. "But these boreholes are a classic example of of the collaborative approach that Contractor and County have adopted to resolve the situation. The County has a huge amount of experience in dealing with regulatory agencies and community relations and that allows the Contractor to focus on getting the work done. Everyone is taking the lead on the things that they are best at and, so far, its working very well."

The BT-2 drive is currently 65% complete, with 4,020ft (1,225m) remaining, while BT-3 is about 49% complete, with 10,340ft (3,150m) yet to be driven. The current schedule has BT2 starting up again at the beginning of October and BT3 re-starting in December – subject to the repairs.

IPS and East

Under the original design, a key scheduling challenge on the project was for BT2 to break through into a permanent shaft called the the "Influent/Portal Structure", located at North Creek, in a 60-day window this summer. The completion of the shaft and the subsequent testing and start-up of the entire treatment plant and tunnel system required the breakthrough of BT2 first.

Therefore changes to the structural design and piping layout of the shaft have now been made in order to mitigate the delays. By adding an additional internal wall, to isolate the breakthrough area, the shaft can be largely completed and clean water circulation testing and start-up of the system can proceed independently of BT-2.

While this strategy still leaves the need to complete the Central tunnels as an ongoing issue, it constitutes a significant cost and schedule risk reduction for the other elements of the system and for the program as a whole.

Elsewhere, pipe installation is ongoing on the East tunnel (BT-1), which was completed by Kenny/Shea/Traylor JV in November 2008 (*T&TNA* Dec '08, p15). Three of the tunnel's four steel carrier pipes – a 48in and a 66in influent force main and a 27in reclaimed water pipe – have now been fitted by the JV, with the last 84in effluent pipeline currently being installed using a custom made carrier system.

The contract is not on the critical path and therefore the primary focus at present is on quality and safety rather than schedule. With a requirement for zero pipe floatation in the finished tunnel, cellular concrete backfilling of the 14,050ft (4,282m) tunnel this winter will be the final challenge for the East contract, with backfill trials due to commence shortly. ■

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Slick tunnel snakes under Sacramento

EPB excavation of a wastewater tunnel with a novel lining system is currently underway in Sacramento. Desiree Willis, of The Robbins Company, explains

Sacramento's new Upper Northwest Interceptor (UNWI) is currently being constructed using a novel tunnel lining technique never before used in the US. The 3.6-mile long (5.8km) tunnel is being lined with PVC-coated segments, which have a low frictional coefficient, particularly when wet.

The design for the wastewater tunnel was selected to minimize deterioration by corrosive sewer gases, and eliminate the need for carrier pipe. Workers clean water from the invert and heat-weld strips of PVC between rings as the project's 14ft (4.25m) diameter Robbins EPB advances. By the time the tunnel is completed, crews will have performed over 62 miles (100km) of welds, creating a seamless inner liner.

The project takes tunneling operations below streets, a canal, and wildlife habitat for the area's endangered Giant Garter Snake. Careful planning has so far made this challenging project a success.

Clean water in California

When completed, the UNWI system will relieve existing interceptor systems in the area by conveying up to 560 million liters of wastewater per day to the New Natomas Pump Station (Figure 1). From here, wastewater will be sent to a regional treatment plant in Elk Grove.

The entire project, for the Sacramento Regional County Sanitation District (SRCSD) includes nine sections, totaling more than 8.6-miles (30km) of sewer, the majority of which were completed by the end of 2008. A Joint Venture of Traylor and Shea is currently excavating the remaining sections (1 and 2) as one contract, which comprises 19,500ft (3.6 miles or 5.8km) of 12ft (3.6m) i.d. tunnel, plus 20 drilled manhole shafts and a long rectangular working shaft.

The JV was awarded the $97.3 million contract after submitting the lowest of six bids in July 2007. URS designed the contract and Hatch Mott MacDonald is managing construction.

EPB design

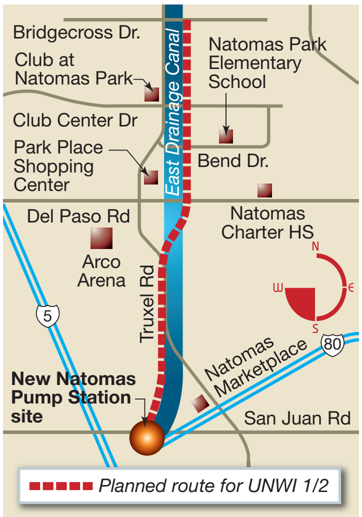
During the design of sections 1 and 2, SRCSD developed a business case evaluation (BCE) comparing tunnel construction methods including open cut, pipe jacking, two-pass tunneling and TBM tunneling. The BCE concluded TBM tunneling provided the best combination of cost, efficiency, and minimum impact to the community and environment.

"Our project alignment is in an urban area with a high ground-water table. It parallels and crosses the East Drainage Canal as well, which is considered a corridor for special status species. We needed a construction method that would minimize disruption to both residents and sensitive habitat," said Rigoberto Guizar, UNWI 1 & 2 Project Manager for the SRCSD.

Prior to the start of tunneling on January 15, 2009, a total of 49 exploratory boreholes were drilled along the alignment, which sits in the generally flat alluvial plain of the southern Sacramento Valley. Samples indicated layers of clay and sand, with no boulders expected. Below the spring line, the tunnel profile lies mostly in sand, while the upper portion of the tunnel face is in clay. The invert ranges from 22ft to 45ft (7-14m) below the surface, with groundwater present throughout. "The ground indicated the tunnel would be best suited to excavation with an EPB type TBM," said Guizar.

The 14ft (4.25m) diameter Robbins EPB Traylor/Shea selected for the project has a spoke-type cutterhead with wear-resistant plates to operate effectively in abrasive ground, while a bentonite foam injection system allows for stabilization of the face and smooth muck flow. Muck exits the mixing chamber via a 1.6ft (500mm) diameter shaft-type screw conveyor.

Two-component back-fill grout is used to further stabilize ground behind segments and reduce the risk of surface subsidence, a concern as some tunnel sections have cover as low as 9ft (3m) beneath existing utilities. The back-fill grout fills the annulus between completed segment rings and the surrounding soil. Two separate liquids are mixed and injected as completed rings exit the tail shield. By remaining viscous, the mixture can be pumped utilizing a standard concrete pump rather than the high-pressure pumps needed with one-liquid concrete fills. Reducing the pump pressure lowers the chance of disturbing the surrounding soils.



Above: **Map of Traylor/Shea's UNWI tunnel contract, in Sacramento**

To tackle the tunnel's curves (down to a 400m radius below the east drainage canal), EPB utilizes active articulation, rather than the passive system. The process makes use of articulation cylinders between the front and rear shields to steer the machine independently of the thrust cylinders, eliminating the problem of ring deformation and allowing for sharper curves.

Though the combination segment with PVC liner provides clear benefits, it also poses a challenge - the liner is somewhat delicate, and the surface can easily be damaged. To address

Left: **The tunnel utilizes a PVC liner never before used in the US**
Right: **The 14ft (4.25m) diameter Robbins EPB is more than 50% through its 3.6-mile (5.8km) drive**

Above left: **Two-component back-filling (square window in the tail shield at the top of the photo) reduces risk of subsidence;** Below left: **Twenty manholes are used for EPB inspection during tunneling**

this problem, Robbins designed the back-up system to avoid contact with the segments after erection. The entire system advances on rails, rather than rollers, to reduce pressure points that could damage the PVC.

Segment installation structures were designed to place no more than the maximum contact pressure of 3.4MPa on the PVC sheet. The segment feeder directly behind the erector is suspended from telescopic tow bars, which extend and retract with every TBM stroke. The segment hoist that places segments onto the feeder is also specialized. The unit is articulated using knuckle joints and inclined on a twin rail system to allow for tunnel curves without damaging segments.

Other modifications to the back-up include a low-inclination TBM belt conveyor, designed to prevent any fallback of muck with thin consistency. Additional work platforms allow safe access to the conveyor, segment magazine and to weld together the PVC liner.

For muck removal, Traylor/Shea chose a continuous conveyor system rather than muck cars. The 3.6-mile long (5.8km) long conveyor has been specifically designed for varying ground conditions and water inflows. Special features include sealed transfer points and receiving hoppers. The fabric belt system includes a 150kW main drive and two 150kW booster drives running at a capacity of 227 metric tons per hour. As the conveyor travels through radii down to 400m, patented self-adjusting curve idlers transfer the load and enable the system to run through curves.

Tunnel muck is discharged from the conveyor into a holding bin at the surface and then trucked to a soil remediation project nearby, where it is being used as fill. "The use of the conveyor, in my opinion, has helped the contractor to run a very efficient tunneling operation, and has eliminated the slowdowns caused by waiting for muck cars," said Guizar.

Environment

Protected habitat surrounds the tunnel route, including territory for Burrowing Owls and the endangered Giant Garter Snake. Due to the presence of these special status species, all surface construction must proceed according to the Natomas Basin Habitat Conservation Plan, which specifies no ground disturbance other than tunneling can occur between October and May (the hibernating and breeding seasons). This restricted period meant a narrow window of five months existed in which to build 20 access manholes along the alignment. The manholes, installed every 1000ft (305m), will be used for maintenance once the system goes online.

Traylor/Shea and Hayward Baker began construction of the manholes in May 2008. Cased blind auger shaft drilling was used, which consists of a drilled pilot hole that is then reamed to the required 11ft (3.4m) diameter. Corrugated Metal Pipe (CMP) casing is placed in the holes and concrete is used to fill the annulus around the casing as well as the bottom of the shaft. All shafts were completed within the 2008 construction season at depths ranging from 19.5 to 42ft (6m-13m), though crews had to re-locate one manhole due to a nesting pair of Burrowing Owls.

Jet grout blocks were installed at each shaft to reduce permeability and increase the strength of the soils. Each block is 19.5ft tall x 19.5ft wide x 21ft deep (6m x 6m x 6.5m). The EPB will bore through each of these grout blocks during tunnel construction.

Surface subsidence is a concern in some areas of the tunnel route. The tunnel alignment forms an 'S' beneath the East Drainage Canal and crosses a number of buried utilities. "Jet grouting is also used underneath utilities, forming a sort of underground bridge to prevent disturbance by tunneling," said Todd Chandler, Field Engineer for Traylor/Shea. The tunnel has on average about 30ft (9m) of cover, while utilities beneath Truxel Road, a main thoroughfare that parallels much of the alignment, are about 14.5ft to 16.5ft deep (5m-6m).

Noise levels are also of concern with a limit set to 90dB. Near residential areas recommended noise levels are further reduced to below 75dB. Acoustic blankets are set up around work areas at the manholes and other methods of monitoring are being used as well. "We install remote microphones at sensitive locations along the alignment. If noise is above the pre-determined level, it triggers a mechanism that auto-records the sound," said Ken Hicks, Environmental Site Supervisor for consultant Kroner Environmental Services Inc. The sounds can later be played back for identification purposes.

Swift excavation

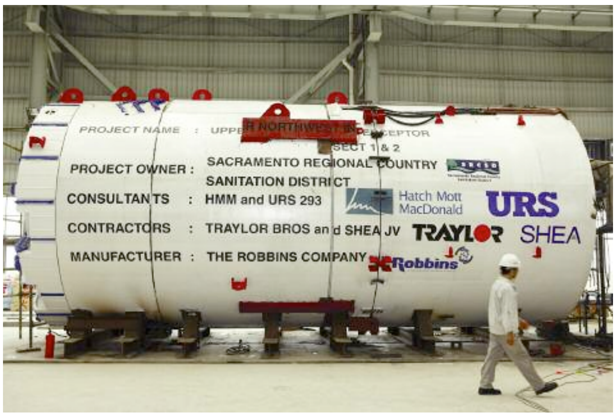
Crews are currently boring five days per week in three 8-hour shifts. As of late July 2009, the machine had advanced 8,766ft (2,672m), nearly 50% of the total drive length. Advance rates have so far topped out at 150ft (46m) in 24 hrs and 640ft (195m) per week.

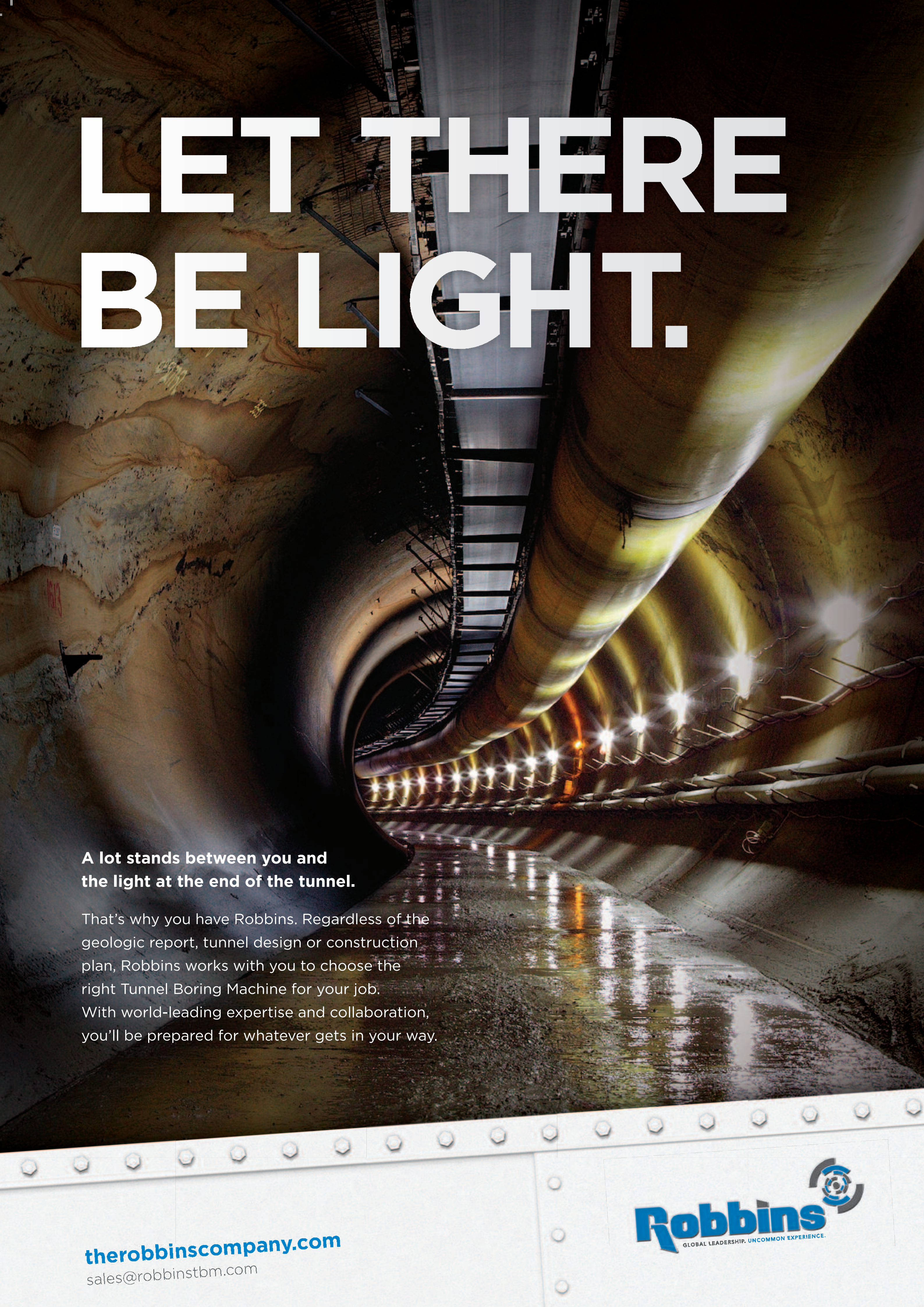
As the machine advances, crews install the rings in a 5+1 arrangement. Circumferential joints between rings are heat-sealed using 4-inch (100mm) wide PVC strips, while radial joints between segments are sealed using 1-inch (25mm) strips. The 9-inch (230mm) thick concrete segments are cast at a plant in Stockton by Traylor/Shea Precast. A 0.6-inch (1.75mm) thick sheet of PVC is placed in the segment form and concrete is cast on top. Each segment requires six to eight minutes to complete.

Every 1000ft (305m), the machine passes one of the 20 pre-excavated manholes. These are utilized to perform cutter inspections and changes without the need for compressed air.

To date the ground has been as expected and no boulders have been encountered. All tunneling is currently on schedule, for a January 2010 breakthrough, with the pipeline due to start operation in November of next year. ■

Below left: **Precast segments with PVC liner are being used to prevent corrosion;** Below right: **The Robbins EPB has active articulation to tackle 1,300ft (400m) radius curves without segment deformation**

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