T&UC

TUNNELING & UNDERGROUND CONSTRUCTION

THE OFFICIAL PUBLICATION OF UCA OF SME WWW.TUCMAGAZINE.COM VOLUME 4 NO 2 JUNE 2010

Tunneling under New York Harbor

Orebody excavation using mechanical equipment

Muck removal in soft ground

Tunnel education in the United States

Special Editorial Supplement: **2010 NAT Official Showguide**

Special Editorial Section from the publisher of *Mining Engineering*

T&UC TUNNELING & UNDERGROUND CONSTRUCTION

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COVER STORY

CONTENTS — Attendees at the North American Tunneling Conference this month will have the opportunity to visit the East Side CSO Tunnel project in Portland, OR. Tunneling industry professionals from around the world will gather to hear the latest in tunneling technology and visit with the industry's key suppliers. Photo courtesy of East Side CSO Tunnel project.

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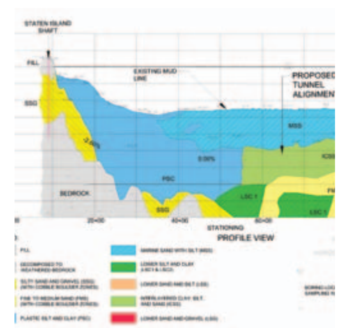
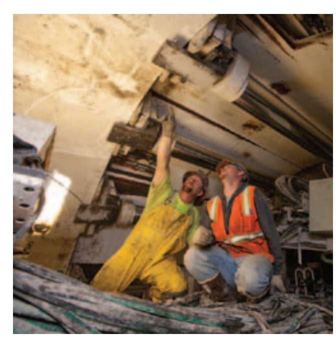




Special editorial section from the publisher of *Mining Engineering*

DEPARTMENTS

CHAIRMAN'S COLUMN

NAT will reflect strength of industry; UCA hosts sessions at SME meeting

When you are reading this article, I hope you have already made plans to attend the North American Tunnel (NAT) conference 2010 to be held in Portland, OR from June 20 to 23, 2010.

Mark Ramsey is the conference chairman. He and his committee members have put together an interesting and informative program. The theme of NAT 2010 is "Tunneling: Sustainable Infrastructure." I encourage you to arrive on Saturday, June 19, as there are some interesting programs scheduled for Sunday, June 20. There are four full-day short courses on various subjects applicable to tunnel construction and there are two workshops, one in the morning, on obtaining better tunnel industry specifications, and one in the afternoon on legal issues impacting our industry. The workshops were priced to encourage industry participation. I am co-chair of the session on obtaining better specifications. We are attempting to make it fast moving and interesting, so please, get out of bed and attend.

I encourage all attendees to buy tickets for the awards banquet on Tuesday, June 22. The awardees for Lifetime Achievement, Person of the Year and Educator of the Year are all deserving. By attending you show your appreciation of their contributions to our industry. Plus, you will be helping the scholarship fund of the UCA of SME.

I am pleased to announce that in our January 2010 executive committee meeting, we voted to fund $6,000 dollars in scholarships for 2010. Forms for making scholarship applications will soon be available. If you would like to contribute directly to the UCA of Scholarship Fund, contact Mary O'Shea at the UCA of SME, phone: 303-948-4211 e-mail: oshea@smenet.org.). This is a tax-deductable contribution. I would request that your company participate, if possible, as this is one way to assist in educating our next generation.

The North American tunnel industry remains strong as major tunnel projects were recently bid in Columbus, OH. Two SFPUC projects in San Francisco, CA were bid as were a harbor crossing utility tunnel in New York City and the Palisades Tunnel for the New Jersey Transit ARC program. The NYC Metropolitan Transit Authority (MTA) will bid two station projects in May and New Jersey Transit has released documents for the ARC program Hudson River Tunnels to the prequalified bidders, with bids due later this year. The District of Columbia Water and Sewer Authority (DC WASA) is on schedule, as the first of its four major tunnel projects has gone out for request for proposals. It should bid later this year. And three prequalified joint ventures are proceeding forward with their design build proposals for the Washington DOT Alaskan Way Tunnel project that will bid later this year.

In Canada, the Toronto Transit Commission has announced the Eglinton Line Extension project. And a new transit program is being considered for Ottawa. These and other upcoming projects are detailed in the Tunnel Demand Forecast section of this magazine (Page 24).

I recently returned from a business trip in Europe. After dealing with a disruptive volcano in Iceland for about a week, I found it very interesting to learn that Europe also has a very active tunnel market that is facing a shortage of entry-level and mid-level design and

Continued on page 30

David R. Klug,
UCA of SME Chairman

Brightwater gets new contractor

With the Brightwater sewer tunnel project in King County, WA already a year behind schedule, King County executive, Dow Constantine, announced that the project would change contractors.

The joint venture contractor, Jay Dee/Coluccio, said it could finish the Kenmore-to-Shoreline tunnel by late 2011 for $77.6 million.

Overall, the Brightwater project is more than a year behind schedule and the county has completed 16 km (10 miles) of the 21-km (13-miles) of conveyance tunneling. The treatment plant north of Woodinville is more than 70 percent complete.

The contractor currently on the job, Vinci/Parsons RCI/Frontier-Kemper (VPFK), said it would cost $98 million and take until the end of 2012 to repair a damaged tunnel boring machine (TBM) and complete the tunnel, according to the county. The machine has been idled since June 2009, the *Seattle Times* reported.

Under Constantine's planned shuffling of contractors, the Vinci group would complete the Kenmore-to-Bothell portion of the 21-km (13-mile) tunnel.

VPFK asked for additional payments for the companies' work on the central portion of the tunnel.

The company, in its written claims, repeatedly blames unforeseen circumstances such as variations in soil type for slowdowns in the tunnel drilling and the added expense of keeping it moving. It says that, before work started, the companies were given insufficient information from the county about soils and location of large rocks that slowed progress, reported *Seattlepi.com.*

Jay Dee/Coluccio, which with partner Taisei have successfully bored a tunnel from Point Wells to Ballinger Way in Shoreline, will continue eastward and excavate an additional 3 km (1.9 miles) of tunnel. Taisei has other commitments and will not participate in the new contract.

The Brightwater project was expected to cost $1.8 billion, but problems with the deep-bore-tunneling machines could raise the price by an amount that will be determined through negotiation or litigation. ■

Brierley Associates acquires Lyman Henn

Brierley Associates announced that it has acquired Lyman Henn, a privately held company based in Denver, CO that provides specialized geotechnical, tunneling and construction services to clients in the water/wastewater and transportation industries. Financial terms were not disclosed.

Brierley Associates provides design, analysis and management consulting services for major underground construction projects throughout the country. The combined firms now have annual revenues of $8 million and 50 employees located in offices in seven states.

Lyman Henn will operate as a division of Brierley Associates. By combining Lyman Henn's capabilities with Brierley's expertise in major underground construction projects, clients across the country will have access to a broader array of tunneling/ trenchless engineering, geotechnical engineering, construction management and forensic engineering services.

"I have worked with Lyman Henn's Tracy Lyman for close to 30 years and we have the utmost respect for each other," said Gary Brierley, founder and president of Brierley Associates. "Together, we now offer the underground and geotechnical industries tremendous depth of expertise in the form of nearly two dozen tunneling, trenchless and underground engineering professionals." ■

Seli and Kawaski team up

Italian tunneling company Seli and Japanese company Kawasaki Heavy Industries have agreed to combine resources and experience on engineering, manufacturing, field service and tunnel boring machine (TBM) operation. The agreement also covers developing new technologies and servicing the operation of TBMs.

Kawasaki developed its earth pressure balance (EPB) technology more than 30 years ago, while Seli developed its double shield TBM more than 40 years ago.

The two companies' plan, through the agreement, is to increase their share in the TBM production market and be stronger in competing worldwide with the other major TBM manufacturers. ■

Las Vegas Water Authority unveils TBM for Lake Mead intake tunnel

The Southern Nevada Water Authority recently unveiled the $25-million, custom-made Herrenknecht tunnel boring machine (TBM) that will create a third raw-water intake at Lake Mead, which has dropped 33 m (110 ft) since 2000, leaving it half full.

One or both of the existing water inlets could shut down if the lake level continues to drop. The new intake will be able to draw water deeper than its counterparts at 262 m (860 ft). In March 2008, SNWA awarded a $447-million design-build contract to Vegas Tunnel Constructors LLC — a joint venture of Lombard, IL-based S.A. Healy Co. and Impreglio S.p.A. of Sesto San Giovanni, Italy.

Herrenknecht spent 17 months designing and building the 1.36-kt (1,500-st), 183-m- (600-ft-) long TBM. It was shipped disassembled in 61 heavy-duty trucks to the Port of Long Beach, CA, and transported to the Southern Nevada job site along Saddle Island's western shoreline. It took months of planning and coordination to map the route and secure the special permits.

Crews will spend four months assembling and testing the machine underground. Operation is expected to start this summer. Components will be lowered down a 9-m- (30-ft-) diameter, 183-m- (600-ft-) deep access shaft using a specially built gantry system with dual 181-t (200-st) strand jacks. The contractor will use hydraulic jacks and a rail system to slide and fasten machine components together. The machine will carve out a 4.8-km- (3-mile-) long, 6-m- (20-ft-) diameter tunnel under the lake bed. The intake will eventually channel raw Colorado River water onto the nearby treatment plant before being pumped to homes and businesses in the Las Vegas Valley.

It is the third tunneling boring machine in Nevada. The others were used years ago for a tunnel at Yucca Mountain, the site of defunct plans for a nuclear waste repository, and a water delivery tunnel through the River Mountains. The intake tunnel project has a 1,571-day schedule and is expected to be finished in July 2012. ■

Jury sides with client in Wisconsin tunnel dispute

A two-year legal battle between tunnel builder Michels Corp. and the town of Elm Grove, WI ended with a Waukesha County Circuit Court jury ruling in favor of the town, leaving Michels Corp. to pay Elm Grove $317,206. Michels Corp. will also have to absorb more than $1 million in charges on a tunneling project after a jury ruling in favor of the town, *The Daily Reporter*, a Wisconsin-based construction publication, reported.

The decision by the Waukesha County Circuit Court jury capped a two-year legal battle in which the village and Brownsville-based builder debated responsibility for delays and cost overruns on a tunneling project. The project faced delays and costs that exceeded Michels' $4.6 million bid after underground soil conditions, including boulders and loose sand, impeded the company's tunneling machine and created the risk of collapses.

Thad Nation, Michels spokesman, said the contractor's legal team is reviewing the decision. He said an appeal is unlikely. The Elm Grove tunnel, which Michels completed in September 2007, works as intended.

Elm Grove sued Michels over the project in April 2008 and Michels countersued the same year to reclaim project cost overruns for which the company paid.

The award to Elm Grove includes $209,750 in damages for missing the contractual deadline to complete the project, $54,556 for additional engineering costs the town incurred and $52,900 for the cost of maintaining the tunnel. Elm Grove village president Neil Palmer said the town withheld payments of $417,675 to Michels for work in its contract after the dispute arose over the additional project costs.

The final court award, Palmer said, is less than the $744,700 the village requested in its lawsuit.

After Michels encountered problems during the project, the company injected grout into the ground to prevent cave-ins and to build support structure below railroad tracks under which the tunnel passes. The contractor did the additional work without payment from the town, and all of the project subcontractors have been paid for their work, Nation said. ■

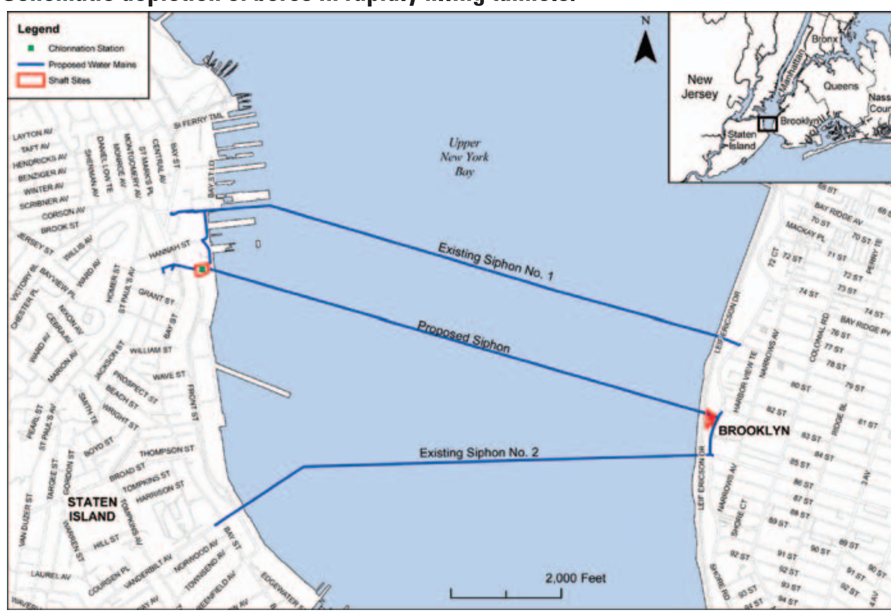
FEATURE ARTICLE

Tunneling under the gateway to New York Harbor

New York Harbor Siphon project NYC EDC/NYC DEP — The replacement of the existing water siphons between Brooklyn and Staten Island

FIG. 1

Schematic depiction of bores in rapidly filling tunnels.



The Port of New York and New Jersey is one of the most heavily used transportation arteries in the world, handling nearly 40 percent of the North Atlantic shipping trade and directly providing nearly 230,000 jobs to the local economy. In 2004, $100 billion worth of consumer goods moved through the port.

To accommodate future cargo volumes in the port, which are expected to double over the next decade and possibly quadruple in 40 years, deeper shipping channels are needed to provide access for a new generation of cargo mega-ships with drafts exceeding 13.7-m (45-ft) when loaded. Current channels within the harbor range in depths up to 13.7-m (45-ft), thus preventing carriers from using these larger ships, or requiring significant reductions in cargo to achieve lesser drafts to operate safely within the harbor.

As part of the Harbor Deepening Project, the Anchorage Channel would be deepened to 15.2 m (50 ft) below mean low water (MLW), for a length of 5,790 m (19,000 ft). The New York City Department of Environmental Protection (NYCDEP) owns, operates and maintains two existing water siphons in the harbor. Due to their shallow depth, both existing siphons must be relocated before dredging of the Anchorage Channel can be completed. Tom Costanzo, manager of capital programs for the Port Authority of New York and New Jersey (PANYNJ), says that "While the relocation of the existing siphons under the Anchorage Channel is vital to the success of the deepening program, it is also a story of cooperation among key agencies at different levels of government resulting in improvements that will benefit the people of this region greatly."

Colin Lawrence

Colin Lawrence, member UCA of SME, is senior vice president, Hatch Mott MacDonald, 475 Park Ave. South, 10th floor, New York, NY 10016-6901, e-mail colin.lawrence@hatchmott.com.

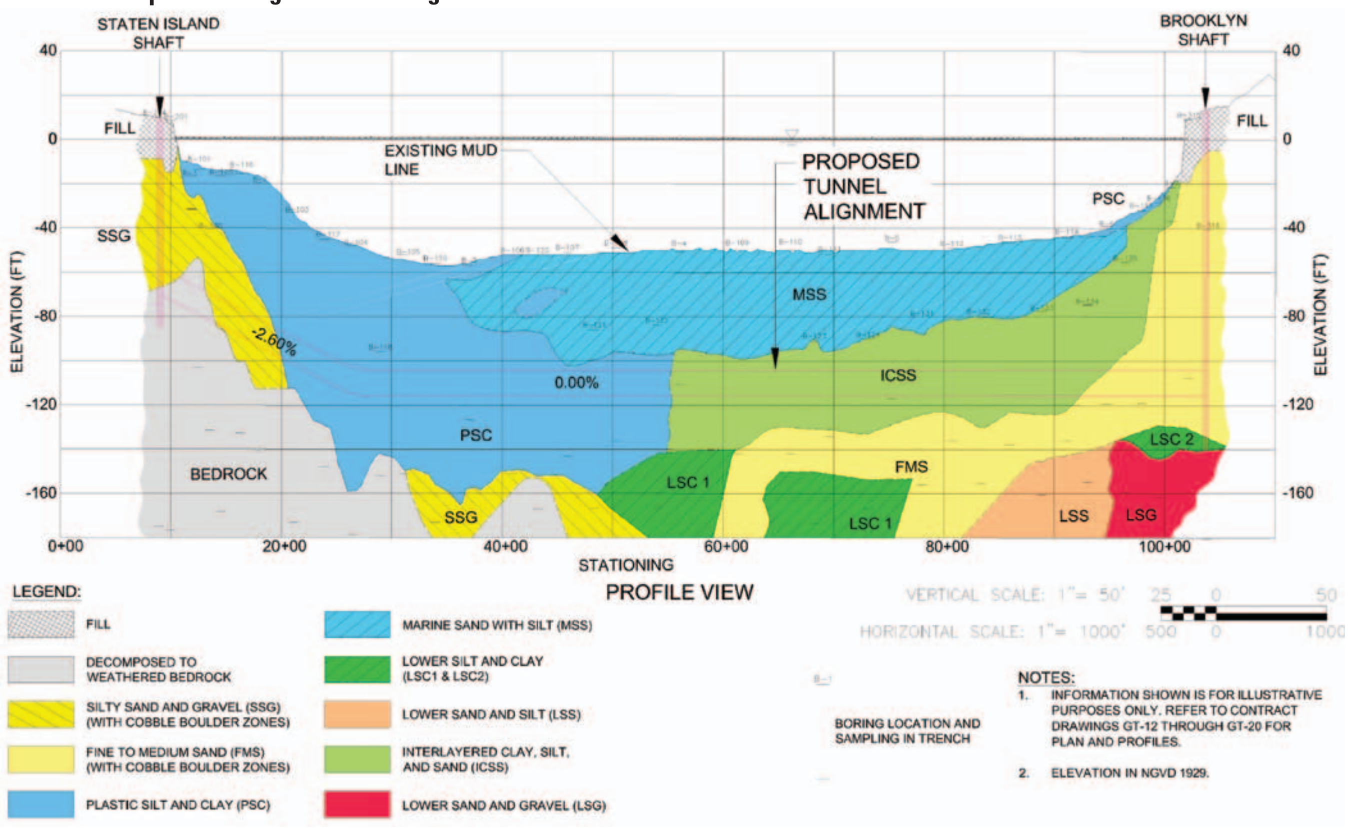
To replace the existing siphons, a new 2,877-m (9,440-linear-ft), 1.8-m (72-in.) diameter pipeline will be installed within a 3.7-m (12-ft) diameter tunnel. The location plan of the existing and proposed siphons is shown in Fig. 1. The NYCDEP has previously crossed this reach of the harbor to the north with the construction of the Richmond Tunnel in the 1960s, although at a depth of approximately 274-m (900-ft). That tunnel was excavated through rock. "Replacing the existing water siphons between Brooklyn and Staten Island will provide the necessary backup water supply to Staten Island. Maintaining the reliability and long-term sustainability of New York City's water infrastructure, and improving that infrastructure is a key goal of Mayor Bloomberg's PlaNYC," said Jim Garin, chief of project development and planning for the NYCDEP.

The replacement siphon will use a pressurized face tunnel boring machine (TBM) to excavate the tunnel through the predominantly soft ground soil conditions from a launch shaft in Staten Island to a receiving shaft in Brooklyn. The tunnel will be lined with gasketted, precast concrete segments. Following completion of the tunnel drive, a welded steel pipeline will be installed and the void between the steel pipeline and the tunnel will be backfilled with grout.

The harbor siphon tunnel is scheduled to be the first tunnel built under the New York City stretch of the Hudson River or the New York Harbor in many decades. The pres-

FIG. 2

Geotechnical profile along the tunnel alignment.



surized face tunneling methodology that will be used to construct the harbor siphon will be the first application of this technique for a subaqueous crossing in New York City.

On behalf of the NYCDEP and the PANYNJ, the New York City Economic Development Corporation (NYCEDC) is managing the project. The CDM/Hatch Mott MacDonald Joint Venture (JV) was retained by the NYCEDC to perform engineering design services.

Project overview

The project comprises the following primary components:

- Bored tunnel (siphon) — 3.7-m (12-ft) nominal diameter bored tunnel to be constructed using a pressurized face TBM and lined with a precast concrete, gasketted, segmental lining system. The TBM will be launched from a shaft in Staten Island and driven a distance of approximately 2,877 m (9,440 ft), beneath the Anchorage Channel, to a receiving shaft in Brooklyn. A 1.8-m (72-in.) diameter steel transmission pipeline will be installed inside the tunnel. The design peak flow capacity is 567 M L/d (150 million gpd).
- Shafts — The Staten Island launching shaft will be located near the intersection of Front Street and Murray Hulbert Ave. on Staten Island. The Brooklyn receiving shaft will be located in Shore Road Park near the intersection of Shore Road Land and Shore Road. The shafts are to be constructed using either slurry wall or ground freezing methods.
- Trenchless crossings — Two trenchless crossings will be constructed beneath the Staten Island Railroad (SIR). The crossings are to be constructed using a microtunnel boring machine (MTBM) up to 2.1 m (84 in.) in diameter and are approximately 99 and 37 m (325 and 120 ft) in length.
- Staten Island and Brooklyn land piping — Water transmission mains constructed in open cuts to connect the new infrastructure with the existing water distribution system.
- New chlorination station — A new chlorination station is required to boost the chlorine residual in the new siphon water supply.
- Abandonment of existing siphons and metering chambers — The existing siphons and metering chambers will be abandoned in place following successful commissioning of the new siphon.

Regional geology and hydrogeology

The project site lies within the Hudson River Basin on the border between Staten Island and Brooklyn, near the confluence of the Manhattan Prong of the New England Uplift, the Newark Basin Physiographic Province and the Atlantic Coastal Plain Physiographic Province. The region is generally characterized by thick glacial sediments overlying sedimentary and metamorphic rock. The bedrock at the project site is judged to be of the Hartland/ Manhattan Schist formations. Following the glacial retreat and subsequent sea level rise, sediments including poorly graded sand, silty sand, slightly organic silt, clay and peat have been deposited in and adjacent to the New York Harbor. The surficial geology of the land sides of the proposed tunnel alignment are dominated by glacial soils overlying bedrock.

FIG. 3

Shaft footprint on the Brooklyn side of the project.

Site geology and ground water conditions

The available subsurface data gathered during the multiphase geotechnical investigation program indicated high variability in the subsurface conditions along the proposed tunnel alignment, the shaft locations and water transmission mains. The subsurface soil stratigraphy in the project vicinity (land and marine), as encountered in the geotechnical borings, can be categorized into stratigraphic units as follows:

- Fill.
- Glacial soils.
- Silty sand and gravel (SSG).
- Fine to medium sand (FMS).
- Recent marine sediments.
- Plastic silt and clay (PSC).
- Marine sand with silt (MSS).
- Interlayered clay, silt and sand (ICSS).
- Lower deposits.
- Lower silt and clay (LSC 1 and LSC 2).
- Lower sand and silt (LSS).
- Lower sand and gravel (LSG).
- Bedrock (predominantly mica schist and gneiss).

The geotechnical profile along the tunnel alignment is shown in Fig. 2. At the tunnel horizon, the ground water pressure will be primarily controlled by the water level within the harbor. Toward the land side portions of the alignment, the ground water head at the tunnel horizon will be greater than the hydrostatic pressures from the harbor tide level, as indicated by observation well data.

Shaft locations

The locations of the two shafts were determined based on establishing connections with the existing water distribution system, availability of suitable land, environmental impacts and a suitable site for launching and servicing of a TBM.

The NYCDEP identified a preliminary horizontal alignment for the proposed siphon. The City of New York owns a vacant site in an industrial waterfront area on Staten Island that will be used to construct the launch shaft and to stage the TBM operations. The site is adjacent to the former Navy Homeport site that is currently planned to be redeveloped as part of the Stapleton Waterfront Project.

The lack of available land on the Brooklyn side of the tunnel alignment has resulted in the receiving shaft being located within a park between the Belt Parkway and Shore Road, near Fort Hamilton High School. This park is owned and maintained by the New York City Department of Parks and Recreation (NYCDPR). The exact location of the shaft within the park has been refined in coordination with the NYCDPR to ensure that temporary and permanent impacts on the park are minimized to an acceptable level, with a number of trees requiring protection during construction. The shaft footprint is shown in Fig. 3.

Shaft design

The internal diameter of the Staten Island Launching Shaft is 8.5 m (28 ft) with the base slab approximately 26.8 m (88 ft) below existing ground level. The Brooklyn receiving shaft is 7.3 m (24 ft) internal diameter and the base slab is approximately 42.6 m (140 ft) below existing ground level. Shaft diameters were selected to accommodate water main piping and appurtenances, TBM launch at Staten Island and TBM reception at Brooklyn.

Two alternative methods of shaft construction were recommended in the preliminary engineering phase: ground freezing or slurry walls. It was decided to allow the contractor to choose which method to use to construct the shafts, with the slurry wall shaft design fully developed for the contract drawings.

Tunnel alignment

The bored tunnel will consist of a nominal 3.7-m (12-ft) excavated diameter, precast concrete, segmental lined tunnel, extending from the Staten Island shaft beneath New York Harbor to the Brooklyn shaft. A 1.8-m (72-in.) welded steel pipeline will be installed in the tunnel to convey water between Brooklyn and Staten Island. The annular void between the steel pipeline and the bored tunnel lining will be backfilled with concrete.

The tunnel alignment was selected to meet a number of construction and operational considerations, including:

Staten Island bulkhead and demolished piers. The tunnel vertical alignment near the Staten Island shaft has been located at a depth to provide clearance beneath the timber piles of both the existing bulkhead wall and the demolished Pier No. 8.

The results of the site investigation indicated that the Pier No. 8 and Pier No. 9 piles toward the harbor end of the piers were likely driven deeper than indicated on the historic drawings. As part of the risk management approach adopted on the project, the horizontal alignment was amended to avoid the plan location of the harbor end of the demolished piers.

Harbor dredging. The proposed siphon must be constructed at a depth sufficiently below the proposed channel depth of El. -50.0. The NYCDEP has also expressed an objective of constructing the proposed siphon deep enough to accommodate possible future harbor deepening programs. Based on the constraints defined for the project, the proposed siphon will be installed with the top of pipe at or below El. -75.9. This depth will be maintained across the Anchorage Channel, the Bay Ridge Channel and the Stapleton Anchorage.

Brooklyn seawall. The Belt Parkway, a six-lane highway, and the adjacent Promenade at Brooklyn are protected from the harbor by a seawall. Historic construction drawings and bathymetric data show that the seawall is founded on a relatively shallow riprap foundation placed on the previously existing mudline. The tunnel vertical alignment was set to provide sufficient cover below this structure.

Gravity drainage. The NYCDEP require the ability to drain the tunnel by pumping from one of the shafts. This necessitates a tunnel alignment that slopes to one of the shafts to allow gravity drainage of the tunnel to the shaft. The vertical alignment was developed to provide gravity drainage of the tunnel toward the Brooklyn Shaft.

Tunnel lining design

The lining rings have an internal diameter of 3.2 m (10 ft, 4 in.) and an outer diameter of 3.6 m (11 ft, 8 in.). The rings consist of four 67.5° parallelogram segments and two 45° trapezoidal segments.

Each segment is fitted with ethylene-propylene-diene monomer (EPDM) gaskets to resist water ingress into the completed tunnel. Dowels are provided at the circumferential joints, with a typical pitch of 22.5-°, and two bolts are provided at each radial joint.

The bolts, dowels and the inserts keep the gaskets compressed. The gaskets are designed for a maximum hydrostatic pressure of 9.0 bars, including gap and offset, providing a factor of safety of two in relation to the actual hydrostatic pressure.

The material properties for the segments are:

Compressive strength of concrete, fc' = 7,500 psi
Yield strength of reinforcement, fy = 75,000 psi

Access

A number of options were considered for access to the water main in the tunnel through the shafts. These options were assessed in relation to constructability, durability, access and maintenance. It was considered beneficial to provide additional space for access to the water main by installing a 2.4-m (96-in.) diameter riser pipe in the shafts. Full shaft backfill around the riser pipe was preferred by the NYCDEP after consideration of durability and long-term maintenance.

Steel water main

The required internal diameter of the steel water main through the siphon tunnel is 1.8 m (72 in.). The wall thickness required to meet to NYCDEP standards is 15.9 mm (0.625 in.). The pipes are connected by a single internal field welded lap joint, verified by magnetic particle and or dye penetrant testing.

Current status of the project

In October 2009, the NYCDEP issued a negative declaration determining that the proposed project will not have a significant effect on the environment. An environmental assessment statement was prepared by the JV to provide supporting evidence to the determination.

The NYCEDC issued a request for qualifications for the provision of tunnel construction services on Aug. 19, 2009. NYCEDC subsequently issued an invitation for bid to qualified respondents in December 2009. Contract award and notice to proceed were anticipated to be in the second quarter of 2010. ■

FEATURE ARTICLE

In soft ground, adaptable muck removal is key

At 6 percent downgrade to a low point beneath California's Sacramento River, the Lower Northwest Interceptor Sewer was a difficult project from the outset. Project owner Sacramento County Regional Sanitation District (SRCSD) planned to excavate the V-shaped tunnel in two sections using an earth pressure balance (EPB) machine in soft ground. Muck removal, due to the steep downgrade, was a tricky proposition. "We did look at muck cars, but determined they were not the best option due to the relatively steep slope of the tunnel alignment. The safety benefits of conveyors on this job were obvious, as there were not the potential hazards associated with muck cars traveling on an incline or derailing," said Steve Norris, senior civil engineer for SRCSD.

The Upper Northwest Interceptor sewer tunnel was completed with record rates by the Traylor/Shea joint venture. It attributed the high advance rates, in part, to the continuous conveyor system.

The successful project represented one of the first instances of a conveyor system being used for a soft ground tunnel boring machine (TBM) application. Several projects in California, including a recent tunnel completed in 2009, have highlighted a growing acceptance of conveyor muck removal in a variety of ground conditions.

Conveyors offer higher system availability than more common methods, such as muck cars, as they allow for continual operation of the TBM. The design of conveyor systems must, however, take into account the differences in material between soft ground and hard rock, including belt cleaning features, sealed transfer points and other elements.

Pioneering conveyance: The Lower Northwest Interceptor Sewer (LNWI)

Sacramento's LNWI under-river tunnels were completed in 2005 by contractor Affholder Inc., offering one of the first instances of conveyor muck removal in soft ground. The project was part of a large sewer expansion project encompassing several other interceptor pipelines and tunnels, ultimately extending a total of 320 km (200 miles).

Two 610-m- (2,000-ft-) long river crossings were tunneled by a 4.59-m- (15-ft-) diameter EPB TBM at steep grades through stiff clay, silt and sand. Both tunnels were excavated to a low point beneath the Sacramento River, and then retracted back to the surface from below the riverbed. The alignment made a 'V' structure with a sharp bend in the middle.

During machine operation, a Robbins extensible fabric-belt conveyor was constructed behind the TBM and back up system. Muck was discharged from the screw conveyor into the loading hopper of the tailpiece, which then elevated the conveyor into the crown of the tunnel. "The horizontal conveyor was mounted to the top of the tunnel to allow efficient transport of precast segments to the tunnel heading. The conveyor setup in the launch shaft required that a hole be cut through the sheet piling, so the muck could be directly conveyed to a stock pile area and hauled off site by truck," said Norris. The sheet piling was extended above tunnel grade to match the height of an adjacent levee for flood protection purposes.

The Robbins continuous conveyor equipment was used on the first crossing, then removed and set up for the second tunnel section as well. "It took about three days to remove the conveyor and trailing gear out of the initial tunnel and transport it up the launch shaft. The system was easily transported by truck, as the two jobsites were less than 25 km (15 miles) apart," said Norris.

Both sections of tunnel were bored within a one year time frame. The TBM used water and foam additives for soil conditioning, which created a toothpaste-like consistency more easily transported by the conveyor. According to Nor-

Desiree Willis

Desiree Willis is technical writer with The Robbins CO. Kent, WA, e-mail willisd@robbinstbm.com.

California's Lower Northwest Interceptor tunnels used a Robbins continuous conveyor system to haul clay, silt and sand at a 6-percent upgrade with more than 90 percent system availability.

ris, downtime for the project duration was minimal: "I recall that early on some adjustments were made, and we did stop once to add an additional roll of belt. But overall, the conveyor operated at 90 percent availability or more."

Breakthrough advance rates: The Upper Northwest Interceptor Sewer (UNWI)

Within the past year, continuous conveyors have been used on several soft ground projects in the U.S. and Mexico. Sacramento's UNWI Project, completed in December 2009, used continuous conveyors to achieve weekly advances up to 210 m (689 ft). "The Robbins-supplied tunnel conveyor system performed remarkably well throughout the drive. The availability of the TBM and associated subcomponents was, in turn, very high for a tunnel heading operating 24 hours a day, five days per week," said Jeremy Theys, project manager for the Traylor/Shea JV (contractor for Sacramento's UNWI sewer project).

The project is unique in several respects — the 5.8-km- (3.6-mile-) long tunnel, driven using a 4.25-m- (13.9-ft-) diameter EPB TBM, is fairly long for soft ground projects, passes through a number of manholes and includes a tunnel liner of precast concrete segments with an imbedded PVC layer never before used in North America. The Traylor/Shea joint venture, opted for a continuous conveyor system rather than muck cars because of the tunnel length and the potential increase in efficiency when compared to muck cars.

The 5.8-km- (3.6-mile-) long conveyor system was specially designed by Robbins for varying ground conditions and water inflows. Design features included sealed transfer points and receiving hoppers. Urethane rubber was used to seal the points and minimize spillage. Additives mixed with the wet ground, such as foam and bentonite, ensured a smooth consistency of muck flow on the conveyor through changing conditions.

During TBM operation, muck was discharged from the screw conveyor onto the belt conveyor at the front of the backup system. From there, the conveyor system was elevated over top of the backup system and into the crown of the tunnel. As the conveyor traveled through radii down to 400 m (1,300 ft), Robbins' self-adjusting curve idlers transferred the load and enabled the system to run through curves. A tripper assembly, located at the opencut in the tunnel, redirected the conveyor up through the opencut at a 12° incline for discharging onto a stacker conveyor.

By machine breakthrough, the conveyor, powered by three 150-kW (200-hp) drives, had operated at more than 90 percent availability. The 210 m (689 ft) weekly advance and daily advances of up to 50.3 m (165 ft) achieved on multiple occasions are believed to be records for a soft ground TBM in the 4- to 5-m- (13- to 16-ft-) diameter range. "The use of the conveyor, in my opinion, helped the contractor to run a very efficient tunneling operation, and eliminated the slowdowns caused by waiting for muck cars," said Rigoberto Guizar, UNWI project manager for the SRCSD.

Conveyor considerations: designing for soft ground

Continuous conveyor systems were first used regularly in mining applications and have, in recent years, advanced

Clay and sand mixed with additive was conveyed using a Robbins fabric belt conveyor that emptied onto a stacker.

considerably. Computerized monitoring systems, self-adjusting curve idlers, and 20-km- (12-mile-) long steel cable belt systems are becoming commonplace on many hard rock TBM projects. However, continuous conveyor systems for soft ground tunnels have only recently been put into practice.

"The benefits of soft ground conveyor systems are very similar to those used in hard rock," said Dean Workman, vice president, Robbins. "The TBM operates at increased efficiency because it does not have to stop and wait for muck cars. The necessary ventilation can also be reduced since no locomotives are being used in the tunnel."

Minimization of startup time. The layout of conveyor systems is designed with swift setup in mind. Unlike many hard rock projects, EPB tunnels are usually relatively shallow and begin from an opencut. The use of a conveyor system setup at the surface can allow for initial use of the system at startup without having to mine a long starter tunnel.

With all components pre-assembled in place at the surface, switching from an initial muck box setup to continuous conveyor often takes a day or less — crews pull the belt onto the system to start mining. By comparison, installation of a rail muck car system can take much longer. Once mining begins, reliability and system availability of a conveyor system are typically higher. "Even in tunnels using up to five muck trains and multiple California switches, the time required to remove muck from the tunnel cannot compare to conveyor muck removal. In addition, muck cars generally require a much higher level of routine maintenance," said Workman.

Variable ground and the role of additives. Variable ground is nearly always a part of soft ground tunneling. In the course of a single project, conditions can range from weathered rock to sand to clays with changing permeability and ground water. Injection of additives through the cutterhead, such as bentonite, foam or polymer, can aid in the consolidation of muck and eliminate many of the problems associated with conveying fluidized muck. Maintenance of a smooth flow through the cutterhead and screw conveyor onto the belt conveyor system minimizes belt stoppage and material spillage. Additives also have the ability to control the fluidity of very wet ground and help solidify loose, watery material.

Water-bearing ground and control of conveyor incline. If a high amount of water-bearing ground is expected, continuous conveyor systems can be designed to minimize associated risks. Incline is kept relatively low for EPB conveyors — a maximum of about 10°, compared to 18° in hard rock tunnels. In addition, transfer points are entirely enclosed to keep material from spilling out. The enclosed points are equipped with additional belt skirting, a urethane material that seals the edges.

A 5.8-km- (3.6-mile-) long Robbins conveyor system was used at California's UNWI tunnels, resulting in both TBM and conveyor system availability of above 90 percent.

Conveyor cleaning in sticky material. Further design modifications minimize the wear of the belt and prevent stoppage due to sticky material. Primary and secondary bore scrapers clean off very heavy material, while a belt wash box installed on the surface near the main drive removes fine material from the conveyor before it cycles through the belt storage cassette. The wash box consists of water spray, which is followed by 'air knives' — pressurized jets of air that remove material from the belt without direct contact. The use of air knives eliminates the need for consumable components that come in direct contact with the belt and must be replaced after wearing down.

Forward progress

The view of soft ground conveyors in the tunneling community is improving with recent project successes. Though many equipment suppliers and contractors in the industry only recognize a difference in system availability between conveyors and muck cars in long tunnels more than 1,800 m (5,900 ft), advantages are being seen on shorter tunnel lengths as well. Despite variable geology and ground water, the use of additives can consolidate muck flow and prevent spillage on conveyor belts. Further modifications including water tight transfer points have mitigated the risk of muck loss in all but the most water-logged conditions.

"Though geology on many projects can be quite variable, ground conditions have little bearing on conveyor operation. Belt wipers and scrapers can deal with wet, sticky material as well as hard rock," said Workman. Increased safety, combined with reliability and short startup times, are making soft ground conveyor systems a competitive option that challenges the current use of muck car systems. ■

FEATURE ARTICLE

Accessing deep orebodies using mechanical excavation equipment

W. Burger, F. Delabbio and C. Frenzel

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For the development of deep, hard rock, mines fast access to the orebody is critical. In some cases the mineralized area is more than 1,500 m (5,000 ft) below surface. Excavation of shafts or declines is typically on the critical path of the project schedule. Saving time on those activities can significantly increase the net present value of the mining project.

Mechanical excavation methods are a step-change in excavation performance and labor safety compared to drill-and-blast operations. In hard rock conditions, roadheaders cannot be used effectively, so disc cutting is the first choice.

For excavation of declines, tunnel boring machines (TBM) can be used in many cases. These provide, in certain rock conditions, considerably higher production rates compared to drill-and-blast excavation.

Herrenknecht AG has developed a vertical shaft sinking machine (VSM) that is able to excavate shallow shafts in soil and medium soft rock. The ground is excavated by a roadheader boom. The muck is removed by a slurry system or a pneumatic system in combination with hoisting of skips. These machines have been applied successfully on shafts down to 100 m (300 ft). A pre-sink for a deep mine shaft has been excavated by this technology.

For deep, hard rock shafts, a new shaft boring system has been developed by Herrenknecht AG in collaboration with Rio Tinto. Based on proven technologies, the system uses a unique arrangement of existing proven technologies. The system integrates excavation, mucking, primary rock support, installation of the final lining and shaft infrastructure. This new system improves the health and safety of shaft construction. Detailed performance estimates indicate significantly higher shaft construction rates are possible compared to conventional shaft sinking methods.

Mechanical excavation

One of the options to increase the overall performance is mechanized excavation, mainly because more process steps can take place simultaneously, such as excavation and muck removal. In some cases, the installation of rock support can also be performed simultaneously.

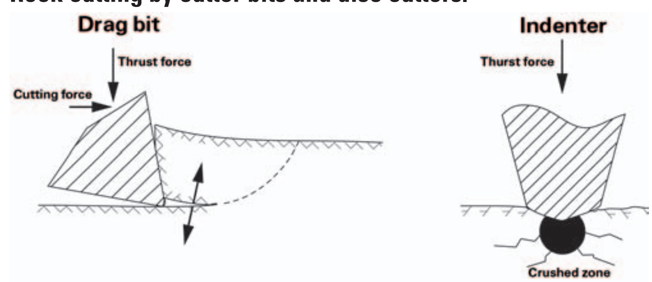
Two main types of mechanical excavation tools are used today:

- Cutter bits (or picks).
- Disc cutters.

The cutting methods are depicted in Fig. 1. Cutter bits act with high impact loads under a low angle to the rock surface, while disc cutters typically operate by rolling over the surface and penetrating the rock in a perpendicular direction.

FIG. 1

Rock cutting by cutter bits and disc cutters.



It should be noted that the advantages of cutter bits are lower cutting forces and more flexible cutting kinematics that lead to comparably small and lightweight equipment suitable for a more flexible excavation geometry.

Once the rock strength exceeds the range of 100-120 MPa, unconfined compressive strength rock excavation with cutter bits becomes increasingly infeasible due to low penetration rates and high bit consumption. Disc cutters are able to excavate rock with a compressive strength of more than 300 MPa but require significantly higher cutting forces, which lead to heavier and less mobile equipment. To achieve high excavation rates, disc cutters are usually employed on rotary full-face TBMs.

Vertical shaft machine

For mechanized excavation of shallow shafts in water-bearing soils, the VSM has been developed and presented by Suhm (Suhm, 2006). This technology is based on a roadheader boom with a cutter drum equipped with cutter bits or soft-ground chisels. A typical setup is shown in Fig. 2.

The roadheader boom is attached to a main frame that can be equipped with gripper pads to stabilize and support the machine. The whole machine is designed to operate in submerged conditions, remotely controlled from the surface.

Two options are available for rock support:

- Pre-cast concrete segments (segmental lining).
- Rock bolts, wire mesh or sprayed concrete.

The segments are erected on the surface and the whole lining is lowered as the shaft is sunk. That is the usual option for softground conditions. In stable to poor soft rock conditions rock bolting, installation of wire mesh and shotcreting can be performed from special designed working platforms with permanently installed rock drills and shotcreting equipment (Fig. 3).

The VSM technology has been used on a number of projects in soil and soft rock conditions with rock strengths of up to 120 MPa. A slurry circuit is used for soft soil below ground water level and a pilot hole for dry conditions.

Up to now, this method has been used predominantly in civil construction such as deep shafts for sewage tunnels. Currently, a VSM rig is used to excavate the presink for a deep mine shaft. The VSM technology is used to substitute the usual solutions of consolidation by grouting or ground freezing methods as well as the use of the slurry wall method. The VSM method can save time and decrease risks that come along with ground cementation, ground freezing shaft sinking methods or increased alignment difficulties for very deep slurry wall shafts.

A vacuum suction system with exchangeable skips is under development. This will enable the VSM system to excavate blind shafts to depths greater than 100 m (330 ft). In addition, alternative partial face cutting systems are under evaluation to increase the maximum rock strength that can be excavated.

Shaft boring system

The shaft boring system (SBS) is a development for mechanized excavation of deep vertical blind shafts in hard rock conditions. The semi-full-face sequential excavation process is based on the use of a rotating cutting wheel excavating the full shaft diameter in a two-stage process for one complete stroke (Fig. 4).

The excavation process is divided into two steps:

- Trench excavation to a depth of one stroke with the cutting wheel rotating around its horizontal axis and being pushed downward in the shaft direction.
- Excavation of the entire bench (face) area by slewing the rotating cutting wheel 180° around the shaft vertical axis.

The SBS machinery consists of three major areas of equipment and operation, which are (starting from the bottom):

- Shaft boring machine with excavation, muck transport and gripping system as well as equipment for primary rock support and probe drilling.
- Primary platform decks for SBS supply infrastructure and power packs.
- Secondary platform decks for final lining installation, muck handling and services extension.

The SBS machine itself can be separated into the main functional areas (starting from the bottom):

- Excavation chamber with cutting wheel, cutting wheel drive assembly, mechanical machine support structure, shotcrete and probe drilling equipment (No. 1 in Fig. 4).

FIG. 2

Core components of a vertical shaft machine.

- Adjustable front support with slew bearing/drive assembly cutting wheel support and dust shield (No. 2 in Fig. 4).
- Regular rock support area for rock bolts (No. 3 in Fig. 4).
- SBS mainframe with gripper carrier, gripper system and lowering/thrust cylinders (No. 4 in Fig. 4).
- Rear alignment system (secondary gripper).
- Muck handling system (No. 5 in Fig. 4).

The cutting wheel circumference and periphery of both sides is equipped with appropriate cutting tools and muck buckets to excavate the rock and remove the cuttings while rotating. Excavation and muck removal is a continuous process. The cuttings are guided along internal muck channels and discharged by gravity onto a center-arranged secondary conveying system.

All reaction forces of the excavation process are transferred into the shaft walls by grippers arranged in the rear. During the gripper reset operation after each excavation cycle, the machine can be adjusted along its vertical axis for alignment control.

A full mining cycle consists of the following steps, once SBS is reset:

- Trench excavation (plunging).
- Bench excavation (slewing).
- Extend SBS support legs.
- Retract and reset main gripper system.
- Adjust SBS vertical alignment with rear gripper system.
- Activate main gripper system.

FIG. 3

Work stage of VSM for installation of rock support.

In case the SBS support legs cannot provide sufficient safety due to weak rock conditions in the bench, the front support, in combination with the rear gripper system, can also secure the SBS during reset of the main gripper system.

Cutting wheel and excavation process

The cutting wheel has a diameter that equals the excavation diameter of the shaft. It is equipped with disc cutters at the periphery and the side areas. The front-loading disc cutters have a diameter of 482 mm (19 in.) with a narrow cutter ring design.

The cutting paths of the disc cutters are circular. During a full revolution of the cutting wheel, the penetration rate of each cutter varies due to the slewing angle and cutter position. In contrast to regular disc cutting with the TBM, there is a significant reduction in cutting forces during slewing because of the free face adjacent to the cutting face. Analysis of similar conditions during partial face excavation with a regular TBM (e.g. pre-excavated station areas) revealed a decrease of up to 65 percent in cutting force.

For safe and comfortable access to the cutting wheel, an inspection and cutter replacement area is located in the upper part of the cutting wheel support close to the 12 o'clock position of the cutting wheel.

Mucking system

The cutting wheel layout follows the principle of a bucket wheel. The bucket-lips at the periphery are arranged so the buckets pick up the cuttings from the bench during the rotation of the cutter wheel. Once in the buckets, the rotation of the wheel is lifting up the muck that starts at a certain position to slide along internal muck channels towards a stationary muck ring–hopper arrangement. Here, the muck is finally discharged into the loading area of a center-arranged vertical conveyor. The vertical conveyor slews inside the SBS mainframe at the cutting wheel and the cutting wheel support, whereby the conveyor skewing does not affect outside installations like grippers, thrust cylinders or rock bolting units.

The bucket lips are at an "aggressive" shallow angle design for high muck loading efficiency and rapid muck removal as well as for efficient invert cleaning.

Rock support

The first step of rock support is the shotcrete application in front below the dust shield. The shotcrete nozzles slew with the cutting wheel that allows the nozzles to apply a complete ring of shotcrete while the bench excavation occurs.

The second step of rock support is generated by the rock bolt installation behind and above the dust shield. In this nonslewing area, all rock support activities can take place while the excavation is ongoing. To achieve a complete bolt pattern, the rock bolting units are able to pivot around the vertical axis of the SBS.

For pre-excavation grouting and probe drilling, two pivoting probe drilling units are installed in front and below the dust shield. To access the bench for installation of standpipes and blowout preventers retractable platforms are installed.

Gripper system

The gripper system is crucial for the overall safety of the SBS since the dead weight of the SBS needs to be supported by this system. Redundancy, fail-safe controls and appropriate factors of safety for structural design are key elements of the safety concept. There are three independent gripper levels on the SBS.

The first gripper level (starting from the bottom) is the dust shield with its extendable segments. It is located at the upper end of the cutting wheel. Gripping is accomplished by hydraulic cylinders extending the dust shield segments to form a closed support ring and bulkhead.

The main purpose of this unit is to stabilize the SBS during trenching. While trench excavation is occurring, the cylinders are under medium pressure to allow the segments to slide vertically on the rock at the same time. In the bench slewing excavation step, there is no more vertical movement of the SBS. Therefore, the dust shield cylinders are under high pressure to achieve maximum lateral support and transfer the resulting torque into the shaft walls.

The second gripper level is the main gripper unit, which consists of four gripper shoes and a common gripper carrier. Each shoe is connected to the gripper carrier by two gripper cylinders and directly to the SBS mainframe by thrust cylinders.

Together, with the dust shield segments, the main gripper unit assures the lateral support of the SBS. It is the only vertical support for the SBS weight while trench excavating.

The third gripper level is the rear adjustment system that is located on the upper end of the SBS mainframe. It consists of four adjustment pads, each equipped with two cylinders. Its function is the adjustment of the SBS axis during the regrip operation to control the vertical alignment.

In certain operating conditions the rear adjustment system and the dust shield segments together can be used as a back up system for vertical SBS support.

The two pairs of main grippers are fed by independent hydraulic power packs. The rear adjustment cylinders and the dust shield cylinders are supplied by independent hydraulic power packs as well.

The following systems are independently capable of supporting the SBS system:

- One pair of main gripper pads.
- Two pairs of adjustment pads.
- All segments of the dust shield.

In case of a power loss, there is an emergency hydraulic power pack installed to supply these cylinders.

Machine support structure

To achieve vertical SBS support when the main gripper unit is not in use (i.e. when vertical adjustment occurs), independently extendable structures are installed at the bottom end of the SBS.

These structures are also designed as an emergency support that can be extended at any time after the vertical rotation of the cutting wheel stops even though bench excavation is not yet finished. For this reason, the mechanical machine support structure is designed in a manner that three of the individual structures are sufficient to carry total SBS weight.

Guidance system

The guidance system of the SBS is based on an inclinometer mounted on the same part of the machine as the cutting wheel. After the machine is adjusted to the vertical, the difference between the center of the shaft and the center of the machine will be detected by scanners. To get an accurate and redundant position of the machine axis in relation to the scanned shaft center, three scanner levels are planned. If this difference is out of a defined tolerance, a correction to the steering is then needed. Therefore, the machine has to be tilted outside of the vertical direction.

To support the steering of the SBS out of the vertical, a function in the navigation system is planned. This shall be implemented by a precalculated point of the machine axis in one advance direction. By moving of the SBS out of the vertical, this precalculated point can be moved onto the planned shaft axis. This system shall be controlled and calibrated frequently by independent control measurements.

Conclusions

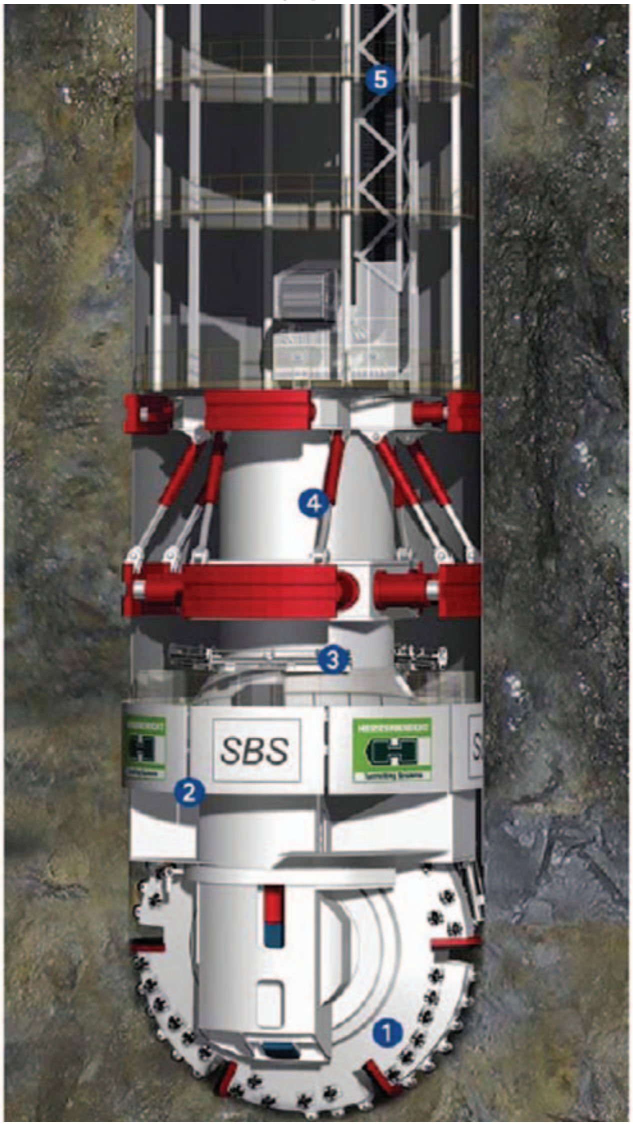
Mechanical excavations systems can have significant advantages over conventional drill-and-blast methods for the sinking of shafts. Herrenknecht has developed two systems for drilling large-diameter blind shafts.

The vertical shaft machine is designed for shallow shafts in ground water-bearing soil and soft rock, which allows for excavation of presinks. Further development is focusing on extending the depth limitations.

For deep shafts in hard rock, the shaft boring system has been developed in collaboration with Rio Tinto. The system uses conventional disc cutting in a unique setup. The mucking system is an integral part of the system and uses the principle of a bucketwheel excavator and vertical conveyors.

FIG. 4

Overview of the shaft boring system (SBS).



Both mechanical excavation systems allow for significantly enhanced level of health and safety due to the high degree of mechanization and industrialization.

Due to high production performance, the SBS and the VSM can create a positive impact on the overall mine development schedule and help to increase the net present value of the mine project. ■

References

Hood, M. & Alehossein, H., 2000, "A development in rock cutting technology," *Int. J. of Rock Mechanics and Mining Sciences*, No. 37, p. 297-305.

Suhm, W., 2006 "Area of application of mechanised tunneling in the mining industry,: Martens, P. N. (Ed.): *AIMS Proceedings 2006* - Rapid Mine Development, p. 523-536.

FEATURE ARTICLE

Tunnel education in the United States

Until well into the 20th century, most construction work was performed under the auspices of a master builder or in a manner that would be described today as design-build. In addition, many civil engineers served as "interns" under the tutelage of a master builder in order to learn how to design and construct a certain type of structure. This was certainly the case for tunneling projects with various individuals having been identified as tunneling experts as a result of successfully completed projects.

The master builder approach began to change in the early 1900s to a model that would be referred to today as design-bid-build. A design-bid-build approach to project procurement gives the owner more control over the final product and allows the contractor to know exactly what is expected of them before the work is constructed. As a result of this transition in project procurement, civil engineering schools placed a greater emphasis on the training of "design" professionals. This article will document how the training of tunnel design professionals progressed within the United States.

Although it is difficult to generalize about the hundreds of tunnels that were constructed in the first four decades of the 20th century, there is one project that stands out as having resulted in a university program related directly to tunneling and that is the Chicago Subway. During a visit to the United States in 1938, Dr. Karl Terzaghi met a student named Ralph Peck who was then studying at Harvard University in a program established by Arthur Casagrande. Shortly thereafter, Terzaghi traveled to Chicago for a lecture and was asked to consult on the Chicago subway project that was then under construction. The Chicago subway was being constructed in clay, and the owners were worried about possible settlements to nearby buildings. Terzaghi asked Peck to serve as his field engineer for that project. Thus was established one of the most productive relationships in the history of civil engineering in the United States.

Peck, who would become Dr. Peck, moved to Chicago in 1939 to participate in an extensive research project that continued until subway construction was halted in 1941 because of World War II. During that time, the cost of subway construction in Chicago was reduced substantially as a result of Peck's observations and Terzaghi's recommendations. In fact, it was reported that subway construction in Chicago cost less than one-half of similar projects in London even though the clay in London is considerably stiffer compared to Chicago. Upon the completion of his work on the Chicago Subway, Peck accepted a professorship with the University of Illinois in Champaign/Urbana.

Gary Brierley and Andre Hawks

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Following the Chicago project, Terzaghi continued his interest in tunneling. In 1946, he participated in the writing of *Rock Tunneling with Steel Supports* by providing a section entitled "Rock Defects and Loads on Tunnel Supports." Anyone interested in tunneling should read this treatise on ground conditions. It sets the stage for understanding the concept of how the ground responds to tunneling activities, which is still applicable to many types of tunnel construction. Until his death in 1963 in Winchester, MA, Terzaghi continued his association with Harvard University and with Peck.

University of Illinois

Peck continued his teaching, research and consulting activities at the University of Illinois with tunneling assignments in Chicago, at Garrison Dam in North Dakota and at the Wilson Tunnel in Hawaii. The Wilson Tunnel project, in particular, became part of Peck's case history class at the University of Illinois that included a discussion of how he was sued for libel by the contractor. He used it as a lesson about being careful what you put into writing.

In the mid-1950s, another extremely fortuitous meeting of the minds took place when Dr. Don Deere joined the faculty at the University of Illinois. In the early 1950s, Deere was living and working in Puerto Rico when he invited Terzaghi to deliver some lectures at the University of Puerto Rico. At that time, Terzaghi told Deere that he should further his education at the University of Illinois. Deere and his partner, Jose Capacete, followed through on that recommendation, resulting in Deere joining the faculty in 1955. It is also reported that Deere and Terzaghi cooperated extensively on the then emerging topic of engineering geology.

With respect to tunneling, the educational program at University of Illinois gained additional momentum when Ed Cording and Skip Hendron joined the faculty in the early 1960s. At that time, the University of Illinois became involved with a large number of research projects for the Department of Transportation (DOT), U.S. Department of Defense (DOD), U.S. Federal Highway Administration (FHWA), the Upper Midwest Trails Association (UMTA), and U.S. Federal Railroad Association (FRA). Graduate students who attended University of Illinois in the 1960s included Ray Benson, Bob Conlon, Dick Coon, Andy Merritt, Jim Monsees, Birger Schmidt, Frank Patton, Ron Heuer and Thom Neff. It was at this time that the University of Illinois developed an unbeatable tunneling curriculum consisting of geotechnical engineering, structural engineering, engineering geology and, most important of all, a strong emphasis on case histories from the consulting practices of the four professors mentioned above (Peck, Deere, Cording and Hendron).

In 1970, the University of Illinois became involved with the Washington Metropolitan Area Transit Authority (WMATA) in what is still considered one of the most significant tunneling research projects in the United States. At that time, Cording spearheaded a group of graduate students who undertook intensive observational programs for soft ground tunnels, braced excavations, drilled and blasted tunnel and station excavations in rock, and shotcrete that resulted in numerous doctoral dissertations on the performance of underground openings. Prominent University of Illinois alumni who participated in the WMATA program include Bill Hansmire, Tom O'Rourke, Jim Mahar, Red Robinson, Harvey Parker, Gary Brierley, Gabe Fernandez, Chuck Dowding, Marco Boscardin and Michel Van Sint Jan. Prominent tunneling alumni who graduated from University of Illinois in the years following the WMATA project include Tracy Lundin, Lee Abramson, John Wolosick, Joe Gildner, John Critchfield, Dan Dobbels, Dan Van Roosendaal and Steve Hunt.

Tunneling education and research has continued at the University of Illinois. Professors Stan Paul, Hendron and Cording conducted extensive research on tunnel lining behavior and Alberto Nieto continued with Deere's emphasis on engineering geology. Most recently, Dr. Yousef Hashash (a MIT graduate) is teaching courses on numerical modeling, earthquake engineering and soil/structure interaction and teaming with Cording for a course entitled "Tunneling in Soil and Rock."

University of California at Berkeley

The tunneling program at Berkeley is associated almost exclusively with the arrival of Dr. Tor Brekke. Brekke had been recommended by Laurits Bjerrum to serve as a consultant on the Bay Area Rapid Transit (BART) project in San Francisco, CA together with Peck. In his memoir, Peck stated that Brekke was offered a faculty position at the University of Illinois, but he preferred to live near the ocean. Brekke joined the staff at Berkeley in 1970 and added his expertise to that of Harry Seed, Dick Goodman and Paul Witherspoon who were part of a strong geotechnical engineering program at Berkeley. Brekke's program at Berkeley was similar to the program at the University of Illinois combining geotechnical engineering theory and practice with engineering geology, research, and especially, case histories. Brekke loved to teach and was proud that many of his students went on to professional careers in tunneling. The list of employees at the tunneling firm of Jacobs Associates, in particular, reads like the alumni association of Berkeley. A partial list of alumni from Berkeley, including many Jacobs employees, is as follows: Gregg Korbin, Randy Essex, Steve Klein, Greg Raines, Glenn Boyce, Don Deere, Tom Freeman, Victor Romero, Brenda Bohlke-Meyers, Mike McRae, Ian Brown, Bruce Ripley, John Bischoff, Jon Kaneshiro and Mat Fowler. Unfortunately, the tunneling program at Berkeley ended with Brekke's retirement in 1993.

Massachusetts Institute of Technology (MIT)

The tunneling program at MIT is strongly associated with Dr. Herbert Einstein, who has been associated with MIT since 1966. As was the case for both University of Illinois and Berkeley programs, MIT was already blessed with a strong geotechnical engineering department under the auspices of Bill Lambe, Chuck Ladd and Bob Whitman. Einstein introduced a strong element of "underground construction" with an emphasis on tunneling, rock mechanics and engineering geology. Over the years, MIT has been associated with research projects for the Massachusetts Bay Transportation Authority (MBTA) Orange and Red Lines and for the Northeast Corridor and Big Dig projects. MIT consulting assignments have resulted in significant contributions to tunnel cost estimating, lining design and ground/lining interaction as well as decision risk analysis. Beginning in 1988, Andrew Whittle joined the staff at MIT and has contributed significantly with respect to the design of deep opencut construction. Prominent MIT alumni who have become involved with tunneling include Joe Guertin, Walt Jaworski, Ron Hirschfield, Andy McKown and Rob Dill. MIT has also contributed to many faculty positions at universities throughout the world.

University of Minnesota

The tunneling and underground engineering program at the University of Minnesota dates back to 1958 when Dr. Charles Fairhurst began teaching rock mechanics with an emphasis on tunneling and mining applications. The University of Minnesota was also at the forefront of developing various computer-based numerical methods for the analysis and design of tunnel linings, especially the work of Peter Cundall. During the 1970s, the University of Minnesota developed a strong interest in the activities of the International Tunneling Association (ITA) and was instrumental in the formation of the U.S. National Committee on Tunneling Technology, the American Underground Association (AUA) and the Underground Space Center, which was underwritten by funding from the State of Minnesota. Fairhurst also helped establish the technical journal *Underground Space* that enthusiastically promoted the use of underground space for infrastructure needs.

Fairhurst was joined in the early 1970s by faculty members Chuck Nelson, Don Yardley, Ray Sterling and John Carmody. In addition, Susan Nelson served as executive director of the AUA for many years. Funding issues resulted in the closing of the Space Center in 1995. Alumni from the University of Minnesota formed the nuclei of two successful tunnel consulting practices that are based in Minnesota; Itasca Consulting Group, with offices throughout the world, and CNA Consulting Engineers, which has worked on many large projects for the U.S. Department of Energy. As has been the case for many of the tunneling programs discussed in this article, the underground program at the University of Minnesota came to a close with the retirement of Fairhurst, the programs driving personality.

Colorado School of Mines (CSM)

The Earth Systems Engineering program at CSM developed largely around the efforts of Dr. Levent Ozdemir. Ozdemir graduated from CSM in 1977 and has been involved in tunnel education and research since that time. In 1981, Ozdemir became the director the Excavation Engineering and Earth Mechanics Institute (EMI), one of the leading research institutes in the world for the development of excavation technologies for civil engineering and mining. In 1992, he also started the Microtunneling Research Institute (MRI) and, together with Tim Coss, instituted a short course on microtunneling that is held every year in February at the CSM campus in Golden, CO. During the years, Levent has also participated extensively in the North American Tunneling (NAT) conference and the Rapid Excavation and Tunneling Conference (RETC). In 2008, CSM began offering a three-day short course on large diameter tunneling. During his time at CSM, Levent served as advisor to more than 60 PhD and Masters students.

Most recently, the new head of CSM's mining department, professor Kadri Dagdelen, has organized a team to develop a tunnel engineering minor to be offered at the undergraduate level. Dagdelen has been working closely with faculty members from the mining, geological and civil engineering departments at CSM to offer a minor in tunnel engineering in all three departments. Early planning efforts are also under way to offer a graduate degree in tunnel engineering with Dr. Gary Brierley and Dr. Raymond Henn providing industry input for this effort. Additionally, CSM is the proud home to the first ever student chapter of the Underground Construction Association of SME. It was established at CSM in 2009. Henn is the faculty advisor and Kiewit Underground is the corporate sponsor. And finally, CSM hopes to create an underground construction research institute to help develop advancements in soft ground and hard rock tunneling, microtunneling and underground grouting.

Louisiana Tech University (LTU)

LTU entered the tunneling arena in 1985 when Dr. Tom Iseley founded the Trenchless Excavation Center (later to become the Trenchless Technology Center – TTC). The key feature of this center was to help industry solve the numerous technical challenges associated with microtunneling and trenchless excavation. Over the years, the TTC has accomplished this objective to a high degree with numerous industry, academic and government-sponsored research projects, short courses and seminars. Of particular note for the TTC is a strong emphasis on helping public works employees learn more about the potential for trenchless technologies to contribute to infrastructure solutions. Dr. Ray Sterling became director of the TTC in 1995 and continued and improved on many of the successful initiatives begun by Iseley. Most recently, Dr. Allouche and Dr. McKim have taken over as directors of the TTC.

Cornell University

When Tom O'Rourke left the University of Illinois in 1978, he joined the faculty at Cornell University where he remains to this day. O'Rourke's University of Illinois research project at WMATA involved the measurement of lateral pressures and deformations associated with deep cuts for station excavations. This has been a major part of his teaching career at Cornell. O'Rourke has also conducted extensive research related to the effects of earthquakes on pipelines and underground facilities with numerous consulting assignments around the world. Cornell has developed a large-scale testing facility for lifeline engineering with money provided by the National Science Foundation and has performed many pipeline research projects for the Gas Research Institute.

With respect to tunneling, Cornell was heavily involved with field research projects for the Combined Server Overflow Abatement Program (CSOAP) in Rochester, NY, and for the Big Dig in Boston. Pricilla Nelson's PhD thesis addressed the excavation performance of TBM's in Rochester and AJ McGinn conducted research on soil mixing technologies in Boston. Other Cornell alumni involved in prominent underground projects include Craig Harris, Mike McCaffrey and Piexin Shi.

O'Rourke was also editor of the ASCE publication, *Guidelines for Tunnel Lining Design* which was published in 1984 under the auspices of the Underground Technology Research Council (UTRC). He was also chair of the National Committee on Tunneling Technology and the ASCE Earth Retaining Structures Committee, and a member of the National Academies Geotechnical Board. Cornell's contribution to the education of underground engineers during the past 30 years has been significant.

Other tunneling programs

There has been a strong interest of late in developing tunnel education programs in the United States. Of most note are the following:

University of Texas at Austin

Dr. Fulvio Tonon is developing a program at UT/Austin based largely on recommendations provided by the International Tunneling Association. Tonon is developing research programs, obtaining internships for his students, and advancing online instructional opportunities.

Pennsylvania State University (PSU)

Dr. Jamal Rostami (a graduate of CSM) joined the faculty at PSU with the intention of establishing an educational program associated with tunneling. Rostami has begun a short course associated with shaft construction and has established a rock mechanics testing laboratory at the university. PSU has a strong history of input to underground construction thanks largely to the efforts of Dr. Richard Bieniawski.

Idaho State University

Dr. James Mahar (a graduate of the University of Illinois) has been teaching courses at Idaho State University. Mahar has a strong background in tunneling, engineering geology and consulting. In essence, Mahar represents a one-man-band approach to tunnel education.

New Jersey Institute of Technology

Dr. Pricilla Nelson (a graduate of Cornell University) has recently affiliated with the New Jersey Institute of Technology. Becoming Provost in 2005, Dr. Nelson returned to the faculty in 2009. With a career spanning Cornell University, the University of Texas at Austin and the National Science

Foundation. With advanced degrees in structural engineering and geology, Nelson is well-positioned to make a significant contribution to tunnel education.

Tunnel Education

It is not easy to develop an educational program devoted specifically to tunneling. Probably the most successful program for tunneling existed at the University of Illinois beginning in the early 1970s and continuing until the late 1980s. The earmarks of that program consisted of the following:

- Strong academic offerings from dedicated faculty in civil engineering and engineering geology. Tunnel engineering must be firmly grounded in structural design, soil and rock mechanics, engineering geology, and ground water hydrology. Some universities are also able to supplement the above with course offerings in mining engineering such as mine design, ventilation, drilling and blasting, and ground support.
- Funding must be provided so that graduate students can perform independent research with respect to ground behavior, lining design, subsurface investigation, laboratory testing, tunnel machine performance, finite element modeling and numerous additional topics of interest with respect to "underground construction." Numerous excellent studies have been conducted over the years with respect to all of those topics and many case history studies are available from technical proceedings such as RETC, UTRC, NAT and ARMA. Independent study of this information is invaluable to becoming a knowledgeable "underground designer."
- It is impossible to become a good tunnel designer without knowing how a tunnel will be constructed. Time in the field observing how a tunnel is constructed and, most importantly, how the ground reacts to various forms of excavation and ground support is essential to tunnel engineering. It is simply not possible to become an experienced tunnel designer without at least 10 years of experience in the field following a master's degree in engineering.

From the above, it is easy to see why so few tunneling programs are available Here is what is needed:

- Dedicated faculty with active tunnel consulting practices.
- Cooperation among various university curricula.
- Strong government and/or industry funding.
- Active research associated with underground construction projects.
- Opportunities to be in the field observing construction and documenting ground behavior.

Many have tried, few have succeeded, but the need is real and becoming greater. The cost effective application of tunneling technology to infrastructure needs is substantial and adds lasting value to densely populated urban areas that are increasing in both size and frequency. As an industry, we must do more to train those individuals who will design and construct the underground projects of the future.

Closing

This paper would not be complete without a discussion of two additional topics associated with tunnel education in the United States. The first is the enormous contribution that has been made by professional organizations. In 1969, the American Society of Civil Engineers (ASCE) and the Society of Mining Engineers (SME) collaborated on the creation of the Rapid Excavation and Tunneling Conference (RETC) and the Underground Technology Research Council (UTRC). Both of these organizations have contributed literally hundreds of papers about case histories and research topics dating back 40 years.

At about the same time, the National Academy of Sciences created the U.S. National Committee on Tunneling Technology (US/NCTT) primarily to serve as the national representative for the International Tunneling Association (ITA). For many years, this committee sponsored meetings and research topics and published the *Tunneling Technology Newsletter* that provided a great deal of important information about tunneling. Probably the two best known publications from US/NCTT are *Better Contracting for Underground Construction* published in 1974 and *Geotechnical Site Investigations for Underground Projects* published in 1984.

Finally, the contributions of the American Underground Construction Association (AUA) must be noted. The AUA was started in Minnesota and contributed mightily to tunneling knowledge and tunneling education, primarily with respect to the nontechnical aspects of tunnel construction such as contracting practices and risk mitigation. In 1992, the AUA began sponsoring the North American Tunneling Conference in an attempt to further cooperation among the United States, Mexico and Canada. Recently, the AUA became the Underground Construction Association of SME.

The second topic that needs to be discussed is providing recognition for all of the fantastic tunneling personalities in this country that did not attend any of the above institutions dating back all the way to the Shanley Brothers who built the famous Hoosac Tunnel in North Adams, MA from 1852 to 1876. Also of note in this regard is the famous author of the book on the history of tunneling, Henry S. Drinker, published in 1878. Although most of these individuals have been lost to history, this paper would not be complete without mentioning the contributions to tunnel education that have been made by Bob Mayo, Al Mathews, Tom Kuesel, Norm Nadel, Hugh Cronin, Ken Lane, Mohamed Irshad, Dru Desai, Dave Hammond, Dave Thompson, Bill Edgerton, Jim Wilton, Peter Petrofski, Tom Lang, Wayne Clough, George Fox, Bob Pond, Jack Lemley, Harry Sutcliffe, Bob Jenny, Gene Waggoner, Dennis Lachel, Joe Sperry, J. Donovan Jacobs, Jim Gould, Joe Kellogg and Dick Robbins. It would be fair to say that all of these individuals, and many others, have attended the Tunneling University of Hard Knocks. ■

FEATURE ARTICLE

Portland hosts North American Tunneling Conference

This year's most prestigious tunneling and underground construction conference, the North American Tunneling (NAT) Conference, will be held at the Marriott Downtown Waterfront Hotel in Portland, OR June 20-23.

The biannual conference will be conducted under the theme "Tunneling: sustainable infrastructure," and promises to be the premiere event in the industry.

More than 100 papers are scheduled to presented during the robust three-day technical session that will be divided into four categories — technology, planning, design and case histories.

Innovation, pressurized face tunneling, applied technology, tunnel lining, and remediation and sustainability are topics scheduled for the technology category.

Project cost estimating, project delivery, project planning and implementation, project risk and budget risk will be discussed in the planning sessions.

The design category will cover design validation by instrumentation, monitoring and mapping; challenging conditions and site constraints; strength, stresses and stability assessment and optimization and alignment selection.

Attendees will also be able to sit in on many case histories during the conference including papers about tunneling on Brightwater West and a look at Canadian fast-track drill-and-blast at the Rupert Tunnel in Quebec, Canada.

It is the first time that Portland has played host to a major tunneling event, but it has a history of tunneling that makes it a worthy host, most notably the East Side and West Side CSO tunnels.

Workshops and short courses

The workshops are "Better specifications for underground projects: perspectives of owners, engineers, contractors and suppliers." Mike Bruen of MWH and David Klug of David R. Klug and Associates will be the instructors for this course.

David Hatem and David Corkum of Donovan Hatem will be the instructors for the other workshop "Professional liability issues for consulting engineers on tunneling projects: perspectives of owner, constructor and consulting engineer."

The short courses will focus on: "Grouting in underground construction," Raymond Henn, Lymann Henn Inc., and Paul Schmall, Moretrench, instructors; "Soft ground tunneling," Levent Ozdemir, Ozdemir Engineering Inc., and Jack Brockway, Herrenknecht Tunneling Systems, instructors; "Shaft and tunnel blasting," Andrew McKown, McKown Associates and Jerry Wallace, Wallace Technical Blasting, instructors; "Shaft design and construction," Jamal Rostamia, Pennsylvania State University, instructor.

In addition to the technical sessions and workshops, NAT will boast a vibrant, and sold out, exhibit floor with more than 90 companies showcasing their wares.

Field trips

The East Side CSO Tunnel Project is the largest of all Portland's projects to greatly reduce the overflows to the Willamette River. It is being constructed to intercept, store and convey overflows from 14 existing combined sewer outfalls that discharge along the east side of the Willamette River. When this project is complete in 2011, the volume of combined sewage and stormwater that now overflows to the river when it rains will be reduced by more than 94 percent.

The sewer tunnel is 6.7 m (22 ft) in diameter and will be 9.6-km- (6-miles-) long. The project is the largest and the last of Portland's 20-year, $1.4-billion CSO program.

The tunnel boring machine (TBM) started boring in May 2007 from the Opera shaft and is moving north toward the Port Center shaft at the Swan Island pump station. From there, the TBM will be removed and transported back to the Opera shaft to tunnel south toward the McLoughlin shaft.

The confluent shaft connects to the Swan Island pump station. The pump station will pump sewage through the Portsmouth Force Main. The force main will discharge to an existing tunnel, which will take the flow to the Columbia Boulevard Wastewater Treatment Plant.

Keynote and social functions

Portland Mayor Sam Adams has been invited to give the keynote presentation to kick off the conference on Monday, June 21.

Richard S. Staples, president of the Tunneling Association of Canada is scheduled to speak about tunneling in Canada during the NAT Luncheon on Monday, June 21.

An awards banquet on Tuesday, June 22 will feature a fascinating presentation "The mystery of terroir in Oregon Wines" from Scott Burns, professor of geology at Portland State University.

Awards

Ed Plotkin will be given the Lifetime Achievement award. Refik Elibay will be given NAT's Outstanding Individual Award. The Outstanding Educator Award will be given to Levent Ozdemir and the Project of the Year award will be given to the Metro Gold Line, Eastside Extension Project (see page 26), during the awards banquet on Tuesday, June 22. ■

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Hudson River Crossing	NJ Transit Board THE Program	Newark	NJ	Subway	8,000 x 2	24.5	2010	5 JV's qualified
Palisades Tunnel	NJ Transit Board THE Program	Newark	NJ	Subway	5,400 x 2	24.5	2009	Awarded to S3 JV
Manhattan Tunnel	NJ Transit Board THE Program	New York	NY	Subway	6,000 x 2	24.5	2009	Barnard/ Judlau low bidder
THE 34th St. Cavern & Station	NJ Transit Board THE Program	New York	NY	Subway	2,200	100 x 100	2010	Under design
Second Ave. 72nd Street Station	NYC-MTA	New York	NY	Subway	1,000	70	2010	Bid date 05/20/2010
Water Tunnel #3	NYC-DEP	New York	NY	Water	24,000	20	2012	Under design
Harbor Siphons Tunnel	NYC-DEP	New York	NY	Water	10,000	10	2010	OHL/Tully JV low bidder
Cross Harbor Freight Tunnel	NYC Regional Development Auth.	New York	NY	Highway	25,000	30	2013	Under design
Cross Sound Link Highway Tunnels	Sound Link	Long Island	NY	Highway	190,000	55	2014	Under design
Cross Sound Link Service Tunnel	Sound Link	Long Island	NY	Highway	95,000	38	2014	Under design
Silver Line Extension	Boston Transit Authority	Boston	MA	Subway	8,400	22	2011	Under design
Near Surface Interceptors	Narragansett Bay Commission	Providence	RI	Sewer	19,500	3-6	2011	Preliminary design
East-West Subway Extension	Baltimore MTA	Baltimore	MD	Subway	32,000	18	2012	Under design
WASA CSO Program Blue Plains Tunnel Anacosita River Tunnel Northeast Branch Tunnel Northeast Boundry Tunnel	DC Water and Sewer Authority	Washington	DC	CSO CSO CSO CSO	23,400 12,500 11,300 17,500	23 23 15 23	2011 2013 2018 2021	RFQ 1Q 2010 Under design Under design Under design
Snapfinger Interplant CSO Tunnel	Dekalb County	Decatur	GA	CSO	26,400	28	2010	Under design
Port of Miami Tunnel	Florida DOT	Miami	FL	Highway	7,400	39	2011	Funding secured
Lockbourne Interceptor Sys. Tunnel	City of Columbus	Columbus	OH	Sewer	10,000	12	2012	Under design
OSIS Aug. & Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	25,300	18	2010	Kenny/ Obayashi JV low bidder
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2012	Under design
Alum Creek Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	74,000	10 - 18	2014	Under design

The editors of Tunneling & Underground Construction encourage UCA of SME members to submit projects to the Tunnel Demand Forecast online at www.smenet.org. The items will be posted on the online TDF once they are verified.

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Black Lick Tunnel	City of Columbus	Columbus	OH	Sewer	32,000	8	2013	Under design
Euclid Creek Tunnel	NEORSD	Cleveland	OH	CSO	18,000	24	2011	Under design
Dugway Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,000	24	2014	Under design
Water Treatment Plant #4	City of Austin	Austin	TX	Water intake	15,000	7 to 9	2010	Bid date 05/01/2010
Waller Creek Tunnel	City of Austin	Austin	TX	CSO	5,300	22	2010	Under design
Deep Rock Connector Tunnel	City of Indianapolis	Indianapolis	IN	CSO	34,000	18.5	2011	Under design
Pogues Run Tunnel	City of Indianapolis DPW	Indianapolis	IN	CSO	11,000	18	2013	Under design
Drumanard Tunnel	Kentucky DOT	Louisville	KY	Highway	2,200 x 2	35	2010	Under design
Drumanard Tunnel - Pilot Tunnel	Kentucky DOT	Louisville	KY	Highway	2,200	12 x 12	2009	Under funding review
Alaskan Way Highway Tunnel	Washington DOT	Seattle	WA	Highway	10,500	54	2011	3 JVs qualified
Third Ave. Subway Tunnel	S.F. Muni Metro	San Francisco	CA	Subway	10,000	20	2011	Under design
Bay Tunnel	S.F. Public Utility Commission	San Francisco	CA	Water	26,200	10	2009	Michels/Jay Dee/Coluccio low bidder
New Irvington Tunnel	S.F. Public Utility Commission	San Francisco	CA	Water	18,200	10	2009	Southland/ Tutor Perini JV low bidder
Sunnydale Aux. Sewer Tunnel	S.F. Public Utility Commission	San Francisco	CA	Sewer	4,000	11	2010	Super Excavators low bidder
San Francisco DTX	Transbay Joint Powers Authority	San Francisco	CA	Transit	6,000	35 to 50	2012	Under design
LA Metro Wilshire Extension	Los Angeles MTA	Los Angeles	CA	Subway	24,000	18	2010	Under design/ delayed
SVRT BART	Santa Clara Valley Trans. Authority	San Jose	CA	Subway	22,700	20	2011	Under design
Spadina Line Extension	Toronto Transit Commission	Toronto	ON	Subway	22,000	18	2010	Advertising 3rd Q 2010
Eglinton West Tunnel	Toronto Transit Commission	Toronto	ON	Subway	10 km	20	2010	Under design
Yonge Street Extension	Toronto Transit Commission	Toronto	ON	Subway	15,000	18	2011	Under design
Port Mann	Greater Vancouver Regional District	Vancouver	BC	Water	3,300	10.5	2011	Design complete
Evergreen Line Project	Trans Link	Vancouver	BC	Subway	10,000	18	2012	Under design
UBC Line Project	Trans Link	Vancouver	BC	Subway	12,000	18	2014	Under design
Kicking Horse Canyon	BC Dept of Transportation	Golden	BC	Highway	4,800 x 2	45 x 32	2012	Under design

PROJECT OF THE YEAR AWARD

Metro Gold Line Eastside Extension Tunnels deemed UCA project of the year

By Fred Smith, Metro, and Amanda Elioff, Parsons Brinckerhoff

Hailed as a model for America by U.S. Transportation Secretary Ray LaHood, the successfully delivered Metro Gold Line Eastside Extension (MGLEE) celebrated its grand opening Nov. 14, 2009. The line extends the Los Angeles County Metropolitan Transportation Authority's (Metro) light rail system to the densely populated and continuously growing East Los Angeles communities. Much of the alignment consists of at-grade track, but the project also features a 2.7-km (1.7-mile) underground segment in cut-and-cover and twin-bored tunnel structures. For the first time, Metro specified, the use of pressure face tunnel boring machines (TBM) to advance the tunnels through soft ground. The tunnel design, construction management and construction methods adopted resulted in the successful completion of the tunnel segment with virtually no surface impact.

Tunnel design

The design of tunnels and underground stations in the Los Angeles area has always included special considerations for seismic design and subsurface gas exclusion. All Metro subway tunnel designs have included two-pass lining systems. Typically, they use an initial lining comprising expanded precast concrete segments with a final cast-in-place concrete lining. High-density-polyethylene material placed between the linings was added to further protect against gas inflow. Operating systems also include gas detection and automatic ventilation systems. All soft ground Red Line tunnels used open face shields, the traditional soft ground tunneling method in Los Angeles. The MGLEE design included new challenges, given some settlement issues on prior tunnels and the discovery of a new, potentially active seismic feature in addition to the regional seismic and naturally occurring gas conditions. For the tunnel liner, Metro designed a double-gasketed, precast segment system to add redundancy to the gas exclusion system. The segments have convex radial joints designed to flex during earthquakes, so that the tunnel will remain sealed.

The completed Metro Gold Line tunnel extends the line to East Los Angeles, adding 9.7 km (6 miles) to the system.

Considering the potential for settlement and the growing use of pressure-face machine (PFM) technology worldwide, Metro specified PFMs. For additional settlement control in some areas, a program of compensation grouting injected above the tunnel crown from the surface during tunneling was designed to reduce settlement to acceptable levels.

Contract packaging

Design bid build (DBB) was used for the tunnels and underground station excavations and design build (DB) for the at-grade and station structures. Both contracts were awarded to Eastside LRT Constructors, a joint venture of Washington Group International, Obayashi and Shimmick, with the tunnels subcontracted to Traylor Brothers and Frontier-Kemper in joint venture. Traylor Brothers and Frontier-Kemper subcontracted ground improvement to Hayward Baker. Metro issued a notice to proceed in July 2004, with a total contract value of $600.5 million for the combined DBB and DB contracts. Metro also implemented an integrated project management office (IPMO). This separate project office included Metro and consultant technical and project management staff as an integrated team at the jobsite. The IPMO for the underground segment was comprised of Metro management, designer Eastside LRT Partners (Parsons Brinckerhoff, Barrio Planners, JGM) and KBR with Carter & Burgess for the construction management. One measure of success of this system

TBMs at Herrenknecht's plant in Schwanau, Germany.

was the response time on the contractor's submittals and requests for information (RFIs). As of November 2008, the contractor made more than 5,000 submittals and 1,000 RFIs (DB and DBB contracts). The average response time was about 12 work days on each.

Tunnel construction

Construction began in July 2004, with TBM tunneling accomplished between February 2006 and December 2006. Tunnels were completed using two new Herrenknecht earth pressure balance TBMs. Among the unique features of the machines was the 58.9-m (193-ft) long screw conveyor, designed to discharge into the train muck cars, well away from the segment erection and working areas. The overall schedule for TBM tunneling was 10 months. The best daily production rate for the east bound tunnel was 27.8 m/d (91 ft/day), with an average of 11.3 m/d (37 ft/day). The production rate for the west bound tunnel averaged 13.4 m/d (44 ft/day), with a best day of 29.2 m/d (96 ft/day).

As with most American tunneling projects, variations of the design to accommodate the contractor's means and methods are often proposed. Of note was the compensation grouting program. The plans indicated grout holes to be drilled from public right-of-way, from the streets or alleys fronting the buildings. This called for more than 200 grout pipes to be installed for full coverage of all the structures. Instead of the surface installation, Hayward Baker proposed use of directionally drilled grout pipes installed from either the project worksites or smaller areas within the street. The final number of pipes installed was 35, which significantly reduced neighborhood impacts. Ultimately, no settlement was measured that would require grouting to be initiated.

Implications of successful tunneling

Success of the project has allowed Metro planners to add underground alternatives on future lines. During completion of the MGLEE project, legislation prohibiting tunneling in the Methane Zone (westside of Los Angeles) was reversed. Plans for new projects, such as the Westside Subway Extension, Regional Connector Transit Corridor and the Crenshaw/LAX Transit Corridor, now includes tunnels or tunnel alternatives. Further enabling these projects, Los Angeles County voters passed Measure R, a 0.5 cent sales tax to help fund transportation projects, including subways. In addition to its technical achievements, the MGLEE project achieved more than four million man hours worked with no lost-time accidents. ■

Double-gasketed segment at the heading.

Outstanding Individual Award to Refik Elibay

Refik Elibay has received the UCA of SME Outstanding Individual Award. Elibay is a tunneling practice leader with Jacobs Engineering Group. Prior to Jacobs' acquisition of Jordan, Jones and Goulding (JJG), Refik served as the vice president and tunnel practice leader of JJG's Tunnels and Geotechnics Group for 20 years. Elibay is a civil engineering graduate of the City College of New York. His career spans nearly 40 years in tunneling and underground construction.

ELIBAY

Since 1977, Elibay has helped manage more than 80 km (50 miles) of large sanitary sewer overflow and combined sewer overflow (CSO) tunnel projects. In recent years, he has managed the design and construction phases of multi-award winning projects, such as the 5-m (16-ft) finished diameter, 15-km (9.5-mile) long Chattahoochee tunnel; the 13.3-km (8.3-mile), $132-million Nancy Creek tunnel, consent-decree-driven project; the 13.6-km (8.5-mile) $210 million West Side CSO storage tunnel with a 378.5 billion L/d (100 million gpd) pumping station and the $305 million South Cobb tunnel.

Elibay also served as the project manager for the design of twin, soft ground tunnels using New Austrian Tunneling methods and for the extension of the automatic people mover trains at Atlanta's international airport.

Elibay started his career 1971 with Al Mathews' organization in New York City as a member of a construction management team working on major wastewater tunnels on the west side of Manhattan. He gained significant experience in hand-mining techniques, in soft ground and rock tunnels and in tunnels using compressed air. He worked on the first successful tunnel boring method tunnels in New York and worked with Local 147, the Sandhogs.

Elibay is a licensed professional engineer in 12 states. He is a member of the American Society of Civil Engineers, the Institute of Shaft Drilling Technology and the Dispute Review Board Foundation He was recently elected to the Board of Directors of Southeast Society for Trenchless Technology, a chapter of the North American Society for Trenchless Technology.

Lifetime Achievement Award to Edward S. Plotkin

Edward S. Plotkin is the recipient of the UCA of SME Lifetime Achievement Award. He graduated from the City College of New York with a B.S. and M.S. in civil engineering. He received an M.B.A. from the City University of New York, Baruch School. He is a professional engineer in New York, New Jersey, Connecticut, Washington, D.C. and Massachusetts.

PLOTKIN

Plotkin is a member of many professional organizations. He served as president of the Municipal Engineers of New York City and received its Engineer of the Year Award. He served as president of the NYS Society of Professional Engineers, Westchester Chapter, and later received Engineer of the Year Award. He is a Fellow of American Society of Civil Engineers (ASCE), a member of the ASCE Metropolitan Section, a director and chair of the Geotech Group, a director in the Westchester Planning Federation and a member of the Moles.

Plotkin has worked as a tunnel constructor and as a project manager for a 63rd Street cross-town subway section, two stations on the Washington subway, a station cavern on the Boston subway and a section of the New York City Department of Environmental Protection water tunnel. As a designer, he was assistant director with Deleuw Cather for the 1970 plans for the Second Avenue subway and was a consultant with the DMJM+Harris-Arup team for the current Second Avenue subway.

Plotkin was commissioner of public works for Westchester County. His responsibilities included the maintenance of county facilities and a $200-million annual budget for new and ongoing capital programs. He has chaired the Village of Dobbs Ferry Planning Board for 45 years, reviewing, planning and approving land development and conservation.

Plotkin was an adjunct professor of physics at Manhattan College and now teaches environmental science at Mercy College. He works as a consultant involved nationally with constructability issues, peer review, mediation and dispute review boards.

UCA OF SME AWARDS

Outstanding Educator Award to Levent Ozdemir

Levent Ozdemir retired from the Colorado School of Mines (CSM) in 2009 after 32 years of teaching and research in tunneling and underground construction. During his tenure at CSM, he developed and taught undergraduate and graduate courses in design and construction of underground structures, tunneling, site investigations, excavation project management and underground mining. He served as the advisor to masters and Ph.D. students and spent considerable effort in promoting tunneling and underground construction as a career for students in mining, civil and geological engineering. He encouraged and placed many students in internship and co-op programs with major tunneling contractors and designers. He also developed educational collaborations with prominent engineering universities and research establishments worldwide in tunneling and underground construction.

Ozdemir also served as the director of CSM's Excavation Engineering and Earth Mechanics Institute (EMI), which is recognized as one of the world's leading research organizations involved in tunneling related research. He secured and managed more than $35 million in federally and privately funded research projects. This included the U.S. Department of Energy's Yucca Mountain Nuclear Waste Repository program and the U.S. Air Force's Deep Missile Base program.

Ozdemir has been organizing one-day tunneling courses in conjunction with the NAT and RETC conferences since 1994. He also serves as the co-director of the three-day Microtunneling and the Breakthroughs in Tunneling short courses held annually at CSM.


OZDEMIR

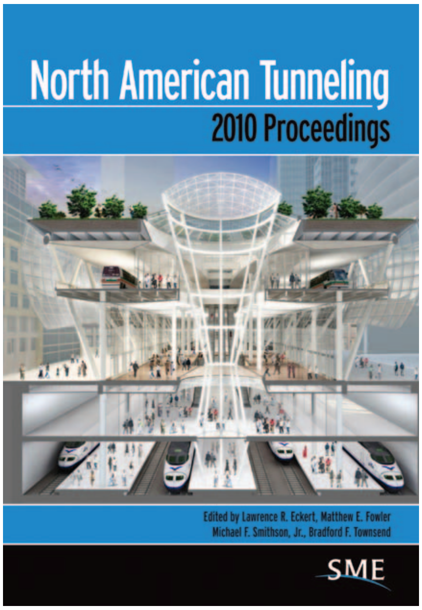
Ozdemir received the *Engineering News Record* 1992 annual award for making a significant contribution to the advancement of mechanized underground construction technologies. He has written more than 150 papers, reports and proceeding volumes. He has served on committees for professional societies on tunneling education and research. He has also worked as a tunneling consultant. ■

NEW MEDIA

North American Tunneling 2010 Proceedings

2010, edited by Lawrence R. Eckert, Matthew E. Fowler, Michael F. Smithson, Jr., Bradford F. Townsend, published by SME, 8307 Shaffer Pkwy., Littleton, CO 80127, phone 1-800-763-3132, ext. 225, e-mail books@smenet.org, website www.smenet.org/store, ISBN-13: 978-0-87335-331-1, 992 pp., list price $189 list price, includes CD.

North American Tunneling 2010 underscores the important role that the tunneling industry plays worldwide in the development of underground space, transportation systems, conveyance systems and other forms of sustainable infrastructure. The proceedings describe the evolving nature of underground work, methods and technology. This book documents the challenges faced and the lessons learned while advancing projects in support of a sustainable future. The contributions reflect the ability to adapt and excel in the environment of continual evolution



that characterizes the tunneling industry today.

Taken from a collection of papers presented at the prestigious 2010 North American Tunneling Conference, the authors take readers deep inside projects from around the world:

- Advancements in technology and sustainability, pressurized face tunneling and tunnel lining, and remediation.
- Design considerations, including design validation, optimization and alignment, and strength and stability assessment.
- Project planning, from estimating cost and project risk to delivering projects on time.
- Case histories of small-diameter and conventional tunneling and lessons learned while operating under difficult conditions.

Whether it is building a subway extension under the streets or New York City or dealing with microtremors and rock bursts during construction, readers will learn from the successes and failures of some of the most challenging construction projects undertaken in this rapidly evolving industry. ■

OBITUARIES

JAMES WILTON

James Wilton, former president and chairman of Jacobs Associates, died March 13, 2010. He was 83.

Wilton was born in Los Angeles, CA in 1926. He received his discharge from the U.S. Navy in 1946 and enrolled at Stanford University to study civil engineering. He received his B.S. in 1950 and immediately went to work for Macco Corp. It did not take long for him to realize that his vocation was construction engineering. In 1957, he joined Jacobs Associates. With his on-the-job experience and his aptitude for designing, he assumed responsibility for the firm's construction engineering services. He became a principal in 1963, was made president in 1974 and was elected chairman of the board of directors in 1985. He worked at Jacobs Associates for nearly 40 years.

WILTON

Most of Wilton's noteworthy projects were underground structures, excavation support systems, cofferdams and custom-built construction plants. Some of the designs he handled included tunneling alternatives to opencut construction on sections of rapid transit systems in San Francisco and Washington, D.C.; the Yacambu Irrigation Tunnel, Venezuela; the Arenal Power Tunnel, Costa Rica and the Renton Effluent Transfer System tunnels in Seattle, WA. In addition, he undertook significant consulting assignments on more than 30 tunnels in the United States and abroad. In the 1970s, he published several papers and studies on these subjects under federal research grants. These papers are still relevant today.

Excavation support systems incorporating Wilton's designs were used on more than half of the San Francisco Bay Area Rapid Transit stations, the N-1 and N-2 sewer tunnels in San Francisco, an 2,438.4-m (8,000-ft) open trench in San Francisco for the West Side Sewage Transport, the Chicago Deep Tunnel project, the Victoria Arts Center foundations in Melbourne, Australia and individual cut-and-cover contracts for subway tunnels in New York City, Atlanta, GA, Boston, MA, and Washington, D.C. He was known for his expertise in deep, complex excavation support systems and was the author of the cut-and-cover chapter of the *Tunnel Engineering Handbook*, second edition.

A few of his other projects include the world's largest aggregate processing plant for the Mangla Dam in Pakistan; a 3.2-km (2-mile) downhill belt conveyor system to transport 18.14 mt (20 million st) of core material for the Trinity Dam in California and aggregate processing plants for several dams in the western United States. These included the San Antonio and Bullards Bar in California and the Lower Granite Dam on the Columbia River.

After retiring from Jacobs Associates, Wilton continued his involvement in consulting and dispute resolution through 2009. He was a Fellow of the American Society of Civil Engineers and received a Golden Beaver Award for Engineering in 1987. Wilton is survived by his wife of 60 years, Ellen, of Woodside, CA; his two daughters, Shelly and Leslie; four granddaughters and a grandson. ■

CHAIRMAN'S COLUMN

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project engineers. I was frequently asked if I could assist them in finding engineers that would like to work in Europe. So, if you are having a midlife crisis or desire a change of scenery to work on international projects in central and eastern Europe, send me an e-mail (dklug@drklug.com) with what you desire and your résumé, and I will forward it to my engineering and construction contacts in Europe. There are numerous tunnels under construction that are being planned to complete the north/south high speed rails systems, and there are numerous energy projects being evaluated.

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On March 2, Ray Henn chaired the UCA program for the SME Annual Meeting in Phoenix, AZ. And I assisted as co-chair. We had two, half-day sessions where we presented papers on civil construction practices and procedures that are applicable to mine decline, drift and shaft construction. We had eight papers presented inclusive of blind shaft drilling, shaft freezing, roadheader drift excavation, accessing deep orebodies with vertical mechanical excavation, high-speed hoisting systems for deep shafts and two papers on lessons learned from drill-blast and TBM drift development projects. Attendance at each session was good, with an average of 50 people at each session. I would like to thank all of the presenters for taking time to prepare the papers and for incurring the time and expense of traveling to Phoenix to present the papers on behalf of the UCA.

In appreciation of the presenters taking their time to assist us, I advised all of the presenters that Ray and I would host a dinner for them and their significant others at a nice restaurant in Phoenix. I was afraid that Ray, known for his frugality, would have a heart attack when I told him of my plan, but he graciously agreed. I want to advise that, when the bill came, Ray paid his half and everyone was happy and most appreciative. On a serious note, Ray did an excellent job in organizing the sessions and coordinating with the presenters. I would like to thank him on behalf of the UCA. The UCA will have a similar session at the SME Annual Meeting in Denver, CO in February 2011. Please contact me if you would like to submit a paper for consideration.

If you any questions or would like to comment on any of the above items or have suggestions on how the UCA can be of service to you or your organization, please call my office, 724-942-4670, or e-mail me at dklug@drklug.com. ■

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