T&UC

TUNNELING & UNDERGROUND CONSTRUCTION

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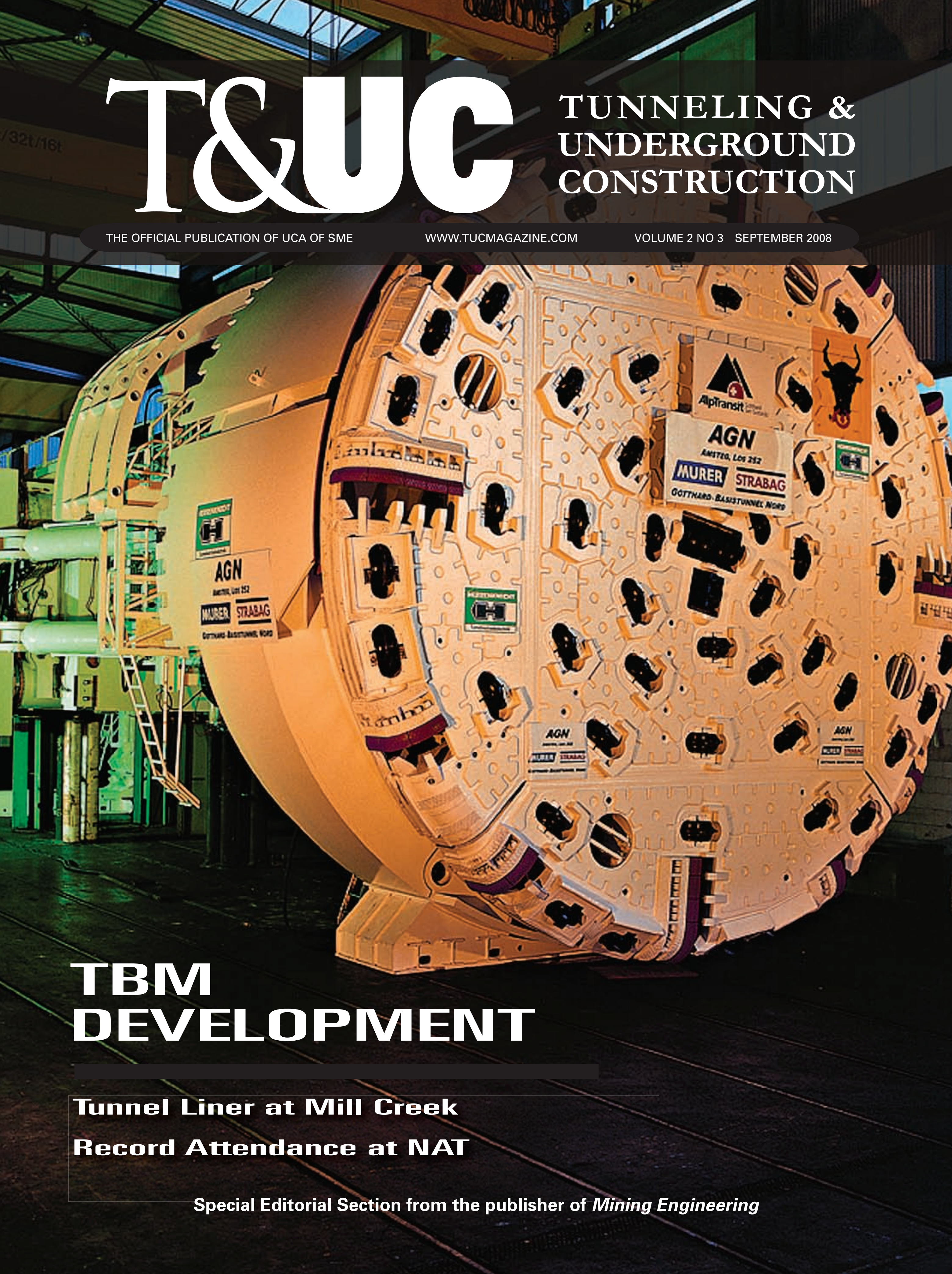

TBM DEVELOPMENT

Tunnel Liner at Mill Creek

Record Attendance at NAT

Special Editorial Section from the publisher of *Mining Engineering*

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COVER STORY

CONTENTS — The continued-development of TBM's include larger diameters and the ability to operate in difficult ground conditions. An update on current TBM development begins on page 14. Also, the NAT conference attracted a record 718 people. Coverage begins on page 23. Cover photo courtesy of Herrenknecht. Cover design by Nate Hurianek, **T&UC's** production designer.

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CHAIRMAN'S COLUMN

UCA of SME: a growing success

Congratulations to UCA, its membership and incoming members — the North American Tunneling Conference was a great success, with record attendance, a full program of papers and a popular field trip to the Devil's Slide tunnels. Hopefully, you didn't miss it. Thanks everyone for a memorable conference. No sooner have we closed the doors to NAT than Lonnie Jacobs and the planning committee have teed up the program and speakers for the George Fox Conference scheduled for Jan. 27, 2009. This year, we will be reaching out to local universities to invite students to attend and learn more about our business and potential career opportunities.

UCA has been in business now for about four years and I thought it was time to provide our membership a status report and a glimpse into its workings. UCA was established in 2004 under the larger umbrella of the Society for Mining, Metallurgy and Exploration. In 2007, UCA was granted full division status by the SME board of directors, recognizing the mutual benefits of our alliance and the significant market importance of the civil underground design and construction worldwide.

With almost 600 members — up more than 100 members since last year — UCA now comprises 5 percent of the SME membership and contributes about 11.5 percent of the total revenues.

SME's fiscal year begins Oct. 1. That means you will be receiving your 2009 membership renewal notices and, possibly, some friendly reminder phone calls from me or other UCA executive committee members. All individual members receive an invoice, and the invoices for corporate and sustaining members are sent to the corporate contact. The near-term goal is 1,000 UCA of SME members.

Executive Committee Rotations have introduced three new members: Marcus Jensen, of the Southern Nevada Water Authority; Art Silber, New Jersey Transit, and Rick Lovat, President of Lovat Inc. Many thanks to the outgoing members, Mike Greenberg, Nick Chen and Ted Budd. They have generously contributed time and effort in our continuing efforts to build UCA as the best source of knowledge and experience in the underground design and construction industry, including transportation, water, waste water, defense, energy and municipal markets.

In addition to the membership dues, UCA revenues are derived from two principal sources: advertising income for *Tunneling & Underground Construction* and two conferences — the North American Tunneling conference and the annual George Fox regional conference. Occasional specialty workshops, such as the waterproofing workshop last spring, regional workshops and technical training workshops, add to UCA's coffers.

Student Outreach and Education and Training Committees get serious: The UCA executive committee approved these two committees. They are tasked with achieving two goals: reaching out to students to inspire and educate the pool of young professionals about the career opportunities in the underground industry; and providing a variety of venues to educate new and continuing professionals about the emerging technologies and practices. Bill Edgerton, once again, is heading up this important activity to identify the needs and set priorities for an early launch.

As part of the Student Outreach efforts, we will be formalizing the UCA Student Scholarship Program

Continued on page 27

Brenda Bohlke,
UCA of SME Chairman

Jacobs, CH2M Hill selected for Sound Transit University project

The Seattle Tunnel and Rail Team (START) has selected the joint venture team of Jacobs and CH2M Hill to provide construction management services to extend light rail service that will connect the region's three most densely populated urban centers in Washington state. The areas are downtown Seattle, Capitol Hill/First Hill and the University District. The contract is from Sound Transit.

Officials did not provide the contract value. However, the total installed cost of the project is valued at $1.6 billion.

The 5-km (3.15-mile) project entails constructing two parallel tunnels that run northward from downtown Seattle to the University of Washington, with stations at Capitol Hill and on the University of Washington campus near Husky Stadium. It is anticipated that the new addition will start operation in 2016 and add 70,000 daily riders to the regional light rail system.

Jacobs, with more than 55,000 employees and revenues exceeding $9 billion, provides technical, professional and construction services globally.

The budget for the 5-km (3-mile) tunnel from downtown Seattle, WA to the University of Washington has been increased from $142 million to $1.95 billion. The Federal Transit Administration (FTA) ordered the increase. The FTA cited seven other projects that had cost increases or overruns, including the Beacon Hill rail tunnel in Seattle, WA. Rising prices for concrete, steel and fuel, and a limited number of tunneling firms, cause financial risk.

Despite the cost increase, Ahmad Fazel, director of Sound Transit light rail, told the *Seattle Times* that the the project remains affordable, and major bids are due next year.

Fazel said federal overseers are satisfied with Sound Transit's engineering work, and FTA will pay for $63 million of the $142 million cushion. That brings the federal contribution to $813 million, or 42 percent of the total cost of construction, trains and financing through opening day in 2016. ■

First East Side Access TBM reaches Grand Central Station in New York

New York's Metropolitan Transportation Authority (MTA) announced that on July 2, the first of two 200-t (220-st) tunnel boring machines (TBM) had reached its first heading under Grand Central Station where a new subway station and concourse will be built as part of a subway line project that will link the New York City borough of Manhattan with Queens.

The TBM, a Robbins double shield that was rebuilt by SELI, had completed the1.6-km- (1-mile-) long tunnel in eight months for contractor Dragados/Judlau joint venture.

The machine was assembled in a rock cavern about 43 m (141 ft) below the corner of Second Avenue and 63rd Street in Manhattan. It began chewing through the rock in October 2007, southwest to Park Avenue and then south to Grand Central on the East Side of Manhattan.

The Robbins Main Beam TBM boring the westbound tunnel was launched about three months after the first. It has maintained good production rates despite difficult ground conditions. The drives are separated by a 1.5-m (5-ft) pillar of rock, providing minimal tunnel support. "Crews have reduced the gripper and thrust pressure by 45 to 50 percent in order to ensure that the force reacted against the tunnel walls is within safe limits," said King Daniels, field service manager for Robbins.

As of early July, the machine had mined about 1,400 m (4,560 ft) of its initial 2,600 m (8,530 ft) drive. It is expected to complete its journey in 2013.

Both machines will be used to excavate multiple headings underneath Grand Central Station, requiring that they be retracted out of the freshly bored tunnels. The split tunnels will connect to various underground caverns beneath Grand Central Station.

When the $6.3-billion project is completed in 2013, one tunnel will carry Manhattan-bound trains and the other will carry trains going to Long Island.

The two 6.7-m-(22-ft-) diameter machines have performed satisfactorily considering the tough conditions, averaging 9.8 m/d (32-ft/day) (double shield machine) and 11.1 m/day (36-ft/day) (main beam machine).■

Supporters make another push for tunnel under Tyson's Corner

In March 2007, the Virginia Department of Rail and Public Transportation said it would enter a $1.6- billion design-build contract for Phase 1 of the Dulles Corridor Metrorail Project that would not include a tunnel through the Tyson's Corner area.

However, tunnel supporters have not given up the fight.

On July 28, 2008, supporters gathered to raise money and show their ongoing support for tunneling under Tysons Corner.

The rally to support tunneling under Tysons Corner — as opposed to taking the Metro above ground on its way to Dulles International Airport — follows a new effort to win support from Fairfax County officials, the *Washington Business Journal* reported.

Among the groups lending support to the tunnel is the Sierra Club. It sent the Fairfax County Board of Supervisors a letter asking the board to lead the effort by requiring the project's sponsor — the Metropolitan Washington Airports Authority and the Virginia Department of Transportation — to ask the Federal Transit Administration to perform an environmental review for widebore tunneling.

With the technology, trains would travel through a single tunnel and the station platform would be in the tunnel itself. The cost estimate for the first phase of the project that includes the Tysons Corner tunnel option is $2.4 billion, about the same estimate for the aerial option, according to Scott Monett, president of TysonsTunnel.org. And operation and maintenance costs are about $5 million less per year with a tunnel, Monett said.

"This gets the tunnel through the most important federal hurdle, which is the environmental question," said Monett. "If we were to switch tracks to the tunnel option we ought to have the environmental approvals in hand so the project remains on track. We have sufficient technical documentation prepared for that review right now. The project sponsor needs to undertake this effort now to ensure the environmental review is completed and as soon as possible." ■

TBM breakthrough at North Shore project

It took a few hours longer than expected, but the tunnel boring machines working on the North Shore Tunnel in Pittsburgh, PA broke through on July 10 and into the receiving pit, completing the first stage of a $435-million project.

The breakthrough was delayed about 12 hours after a bearing in a conveyor belt system broke, stopping the tunnel boring machine (TBM) just a few feet from the receiving pit.

"It (the breakthrough) is a significant milestone," Port Authority construction manager Winston Simmonds said. "We completed the tunnel in a reasonable time, and it was done safely, without any worker injuries."

It is scheduled to begin digging a second, parallel tunnel in mid-August. The tunnels should be completed by 2009, and the entire project by 2011.

Despite $32 million in cost overruns on certain aspects of the transit agency's North Shore Connector construction project, it still remains within its overall $435 million budget.

The cost overruns were blamed on the high price of construction materials for the expenses tied to construction of new T stations along the 2-km (1.2-mile) light rail expansion from downtown to the North Shore.

Authority officials had projected for two months that new contracts would push the total cost above the $435 million approved by the agency and the Federal Transit Administration, which is paying 80 percent of the cost.

The Port Authority plans to tap its capital improvement budget to pay for any expenses beyond $435 million.

Officials also cut costs in the contracts by allowing contractors to use concrete in place of steel in certain areas.

The authority already has approved $300 million in contracts, leaving about $135 million left for the installation of the T tracks, completing the interiors of the new T stations and other finishing touches. ■

Access to the Region's Core project gets funding boost

The Access to the Region's Core (ARC) program includes two new single track railroad tunnels between New Jersey and New York, additional Penn Station capacity and signal and track improvement along the Northeast Corridor. It got more than five times the amount of money appropriated this year than it did in 2007.

New Jersey senators Frank R. Lautenberg and Robert Menendez successfully appropriated $75 million toward the ARC project, further advancing the engineering of two new rail tunnels under the Hudson River.

"The unwavering support from senators Lautenberg and Menendez for this critical project will help provide relief to the state's transportation system," said New Jersey Gov. Jon S. Corzine. "We applaud their efforts to secure record levels of appropriations for this project."

"We continue to receive incredible support for the ARC Tunnel project from senators Lautenberg and Menendez. We are aggressively pursuing a full funding grant agreement with the federal government and the senators' support is invaluable," said Port Authority chairman Anthony R. Coscia.

"Our Washington delegation continues to lead the charge towards moving this vital project from the drawing board to shovels in the ground," said Transportation Commissioner and NJ Transit board chairman Kris Kolluri. "Clearly, they are committed to seeing the project become a reality."

"This funding is keeping the ARC Tunnel project moving towards a full funding grant agreement from the Federal Transit Administration," said NJ Transit executive director Richard Sarles. "The Senators have worked tirelessly to support the project."

The project will double the number of commuter rail tracks between New Jersey and New York and double peak-period trans-Hudson train capacity from 23 trains per hour to 48. ■

COMPANY PROFILES

Kiewit brings 120 years of experience

Kiewit, one of North America's largest construction and mining companies, has been in business for more than 120 years and has been working underground for more than 50 years.

In the early years, Kiewit was responsible for the construction of many Nebraska landmarks and the company expanded out as it began to work on highway construction. The expansion of the nation's infrastructure helped Kiewit expand beyond its local boundaries. Part of that expansion led to a pair of notable tunnel projects; the Eisenhower Tunnel in Colorado and the Ft. McHenry tunnel beneath Baltimore Harbor.

The company now boasts more than 100 full-time underground professionals and has constructed some of the nations most challenging and impressive underground transportation, power, environmental and mine development projects. These involved drill/blast excavation; machine tunneling in hard rock and soft ground; deep shafts, chambers and caverns and large open-cut structures.

The company has worked on underground projects from the Southwestern desert to the Alaskan wilderness, across the Rockies and the Appalachian foothills and into Puerto Rico.

Kiewit has delivered more than $3 billion in underground-related contracts during the last 15 years.

Kiewit has been ranked by *Fortune* magazine as one of America's Most Admired Companies and is consistently ranked as one of the top 10 contractors by *Engineering News-Record.*

Some of the recent notable underground projects that Kiewit has been part of are; Devil's Slide Tunnel, Pacifica, CA; East Side CSO, Portland OR; Dulles Pedestrian Walkback Tunnel and Dulles International Airport, VA.■

Frontier-Kemper has completed more than 180 miles of tunnels

George F. Kemper started his construction company in North Dakota more than 100 years ago. Since then, the company, that got its start building railway grades and bridges for the Northern Pacific Railway, has completed more than 240 construction contracts that involve more than 290 km (180 miles) of tunnels and slopes and more than 53 km (33 miles) of vertical shafts.

Maxwell F. Kemper and R. Bruce Kemper, son and grandson of the company's founder, respectively, have helped the company build a solid reputation in the tunneling and tunnel lining industry. In 1971, Kemper Construction joined Colorado-based Frontier Constructors, a mining contractor established in 1965, to form Frontier-Kemper Constructors. Frontier-Kemper later established its headquarters and shop facilities in Evansville, IN, to serve the Midwestern and Appalachian coalfields.

In 1979, Frontier-Kemper became affiliated through

Frontier, continued on page 11

Frontier, continued from page 10
share ownership with Deilmann-Haniel GmbH of Dortmund, Germany, a respected company with more than 130 years of significant accomplishments in the mine construction and equipment fields.

Frontier-Kemper has grown to become one of the best-equipped and most capable American general contractors specializing in heavy civil and mining underground construction. For the past eight years, Frontier-Kemper been listed by *Engineering News Record* as one of the Top 400 Contractors in North America.

Frontier-Kemper's core workforce includes 90 executive, managerial and professional employees including professional engineers registered in more than 20 states.

Since its beginnings, Frontier-Kemper has completed more than $2 billion worth of projects and has been an industry leader. In the 1970s, Frontier-Kemper pioneered large diameter raise boring techniques, applying this specialized method to mine shaft construction as well as civil projects. The company has also been instrumental in the development of slipformed raise linings and mine slope development with heavy roadheaders. ■

Opinion

Jack Burke

To fully appreciate the irony of what has transpired between the U.S. Attorney's office in Brooklyn, N.Y. and Anthony DelVescova, project manager Water Tunnel #3 project for Schiavone Construction Company, Secaucus, NJ, it would be well worth it to look back to a similar situation between the District Attorney (DA) of Queens County, NY and Raymond Donavan, executive vice president of Schiavone Construction.

Donavan was accused of all kinds of charges related to a rental crane used on the Manhattan to Queens tunnel section of the 63rd Street project. Donavan had just retired from the position of Secretary of Labor in the Reagan Administration when he was arrested and charged. After years of investigations, he was finally tried by a jury of his peers and totally exonerated. Questioned by the media when he exited the courtroom, he told them that he was glad to be totally cleared but asked the question "where do I go to get my reputation back."

After the verdict, Donavan instituted a suit against the DA and before it could be tried the DA died from a heart attack.

Fast forward to February 2008 when DelVescova was arrested handcuffed while the FBI raided the company offices. He was taken and arraigned, then named in the indictment on Feb. 7, 2008. He had to step down as project manager and was not allowed on any job site. Newspapers and trade magazines had a field day with photos of DelVescova in handcuffs together with known mobsters.

His company, and the entire underground tunneling industry, came to his defense with letters and more. It appeared to fall on deaf ears, in my opinion. Fortunately for DelVescova, someone with common sense must have come on the scene as of Aug. 1, 2008. That is when the U.S. Attorneys office in Brooklyn announced it had dropped all federal corruption charges.

Carl Cosenzo, president of Schiavone, stated DelVescova had been totally exonerated.

Having worked with and known DelVescova almost from the day he left college and joined Schiavone I was flabbergasted at the accusations and wondered what would happen when they found out how very wrong they were.

We now know just words, no apologies. Is there no shame in our Justice department for what they do to ruin people's lives? Luckily. DelVescova did not have to wait years, only months, to ask the question "Where do I go to get my reputation back?" ■

TUNNEL NAME	OWNER	LOCATION		TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
County Grounds Tunnel	Milwaukee Metro Sewerage Dist.	Milwaukee	WI	Flood management	2,700	17	2007	Rebid late 2008
Lake Mead Tunnel #3	SNWA	Las Vegas	NV	Water	15,500	20	2007	Awarded $447 million bid by Impregilio
Bi-County Water Tunnel	Washington Suburan Sanitary Commission (WSSC)	Laurel	MD	Water	28,000	10-12	2008	Advertising fourth quarter 2008
Lake Mead IPS 2 Connection	Southern Nevada Water Authority	Las Vegas	NV	Water	Tunnel 600 Shaft 380	Tunnel 14 Shaft 28	2008	Awarded to Barnard Construction
River Mountain Tunnel #3	Clean Water Coalition	Las Vegas	NV	Wastewater	44,000	15	2008	Under design
CWC Reach 3	Clean Water Coalition	Las Vegas	NV	Wastewater	7,500	15	2008	Under design
DRO-2 tunnel	Detroit Water & Sewer Department	Detroit	MI	Wastewater	6,400	21	2008	Vinci/Frontier-Kemper low bidder
Mission Trails # 1 tunnel # 2 tunnel	SDCWA	San Diego	CA	Water	2,000 2,875	11 11	2008 2008	Advertising 04/2008; bids due 08/06/08
New Crystal Springs Bypass Tunnel	S.F. Public Utility Commission	San Francisco	CA	Water	4,200	13	2008	Bidding due 08/28/08
Bay Tunnel	S.F. Public Utility Commission	San Francisco	CA	Water	25,000	9	2008	Advertising 08/2008
Harbor Siphons Tunnel	NYC-DEP	New York	NY	Water	10,000	10	2008	Advertising 1st Q 2009
Port of Miami Tunnel	Florida DOT	Miami	FL	Highway	4,000	36	2008	Awarded - in negotiation
Port Mann	Greater Vancouver Regional District	Vancouver	BC	Water	3,300	10.5	2008	Advertising 11/2008
SVRT BART	Santa Clara Valley Trans. Authority	San Jose	CA	Subway	22,700 twin	20	2009	Under design
Upper Rouge CSO North Segment South Segment	Detroit Water & Sewage Authority	Detroit	MI	CSO sewer	18,500 21,200	30 32	2008 2008	Advertising late 2009; under design
Univ. Link Light Rail Ext. UW tunnels Capitol Hill Tunnels	Sound transit	Seattle Seattle	WA	Rail	12,000 x 2 3,800 x 2	22 22	2009 2009	Advertising 02/2009; Advertising 07/2009
Sewer Replacement	Miami Dade	Miami	FL	Sewer		5	2008	Under design
Market St. Drainage Improvements	City of Charleston	Charleston	SC	Sewer	3,000	10	2008	Under design
South River Tunnel	City of Atlanta	Atlanta	GA	Wastewater	9,000	14	2008	To bid 10/2008
Snapfinger Interplant CSO Tunnel	DeKalb County	Atlanta	GA	Wastewater	26,400	28	2010	Under design

The editor's of *Tunneling & Underground Construction* encourage UCA of SME members to submit projects to the online Tunnel Demand Forecast at www.smenet.org, log in as a member. The items will be posted on the online TDF once they are verified.

TUNNEL NAME	OWNER	LOCATION		TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
West Edmonton LRT Tunnel	City of Edmonton	Edmonton	AB	LRT	4,000 x 2	22	2011	Under study
W. Corridor LRT Tunnel	Transit Authority	Denver	CO	LRT	280 x 2	18	2009	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	2008	Rebid late 2008
New Irvington	S.F. Public Utility Commission	San Francisco	CA	Water	18,200	12-13	2009	Advertising 05/2009
Caldecott 4th Bore	CALTRANS	San Francisco	CA	Highway	5,000	50	2009	Advertising 02/2009
Near Surface Interceptors	Narragansett Bay Commission	Providence	RI	Sewer	19,500 11,000	3 - 6 3 - 6	2010	Preliminary design
Alum Creek Relief Sewer (1st of 3 phases)	City of Columbus	Columbus	OH	Sewer	26,000	10	2010	Under design
Water Tunnel # 3	NYC Dept. of Enviro. Protection	New York	NY	Fresh	24,000	20	2010	Under design
ESA Queens Bored Tunnel	NYCTA-MTA	New York	NY	Subway	10,500	20	2008	Bids 09/12/2008
Corbalis to Fox Mill Water Main	Fairfax County Water Authority	Fairfax	VA	Water	8,600	8	2008	Advertise 10/01/2008
Lockbourne Interceptor System Tunnel	City of Columbus	Columbus	OH	Sewer	10,000	12	2009	Under design
LBJ Highway	Texas Dept. of Transportation	Dallas	TX	Highway	5,300 x 2	60 x 35	2010	Under design
Kicking Horse Canyon	BC Dept. of Transportation	Golden	BC	Highway	4,800 x 2	45 x 32	2010	Under design
Belmont-Southport Plant Connection	City of Indianapolis DPW	Indianapolis	IN	Sewer	29,000	12	2009	Bid late 2009
Palisaides Tunnel	NJ Transit Board, THE Tunnel Program	Newark	NJ	Subway	5,400 x 2	20	2009	Under design
New York City Tunnel	NJ Transit Board, THE Tunnel Program	New York	NY	Subway	6,000 x 2	20	2010	Under design
THE 34th St. Cavern & Station	NJ Transit Board, THE Tunnel Program	New York	NY	Subway	2,200	60 x 60	2010	Under design
Western Reg. Conveyance Tunnel	Northern KY Sanitation District # 1	Covington	KY	Sewer	36,000	13	2008-12	Bids third quarter 2008
Waller Creek Tunnel	City of Austin	Austin	TX	Highway	5,300 x 2	60 x 35	2010	Under design
San Franciso DTX	Transbay Joint Powers Authority	San Francisco	CA	Transit	6,000	35 to 50	2012	Conceptual design
WASA CSO Program - Phase 1 Blue Plains Tunnel Anacoctia River Tunnel Northeast Branch Tunnel	DC Water and Sewer Authority	Washington	DC	CSO CSO CSO CSO	63,360	23 23 23 23	2008 2010 2011 2020	PM/GEC Bid Bid Bid

FEATURE ARTICLE

Tunnel boring machine development

Tunnel boring machine (TBM) development continues to take on not only larger diameters, but also more difficult ground conditions. Ground conditions consisting of unstable faces with water pressures up to 15 bar have required innovative design approaches. A systems approach has been required to produce tunneling machines that can safely excavate the tunnel in an efficient, cost-effective manner that stresses production and labor saving approaches. This article reviews the current design developments and present recent projects where these most recent principles have been applied.

The world's growing population and rapidly proceeding urbanization are boosting an enormous demand for new and high-capacity infrastructures to secure the mobility of goods and people.

Densely populated areas face the challenge of providing efficient traffic infrastructure such as a modern public transport system. At the same time, the maintenance and modernization of supply and disposal structures for water, sewage, energy and communication are essential. Last but not least, are supra-regional transportation routes such as long distance water diversion schemes. All of these projects are as demanding and are characterized by a tight time schedule.

In this context, the demand for efficient tunnels for traffic and utility lines is increasing, as new infrastructures often leads underground because of limited space above ground. Also, tunnels are the obvious choice to cross natural barriers like mountain ranges.

To handle the complex and variable geological conditions and other constraints, such as low overburden, high water pressure or long tunnel drives while facing increasing demand of a quick completion of a project, mechanized tunneling sets standards regarding safety, profitability and environmental protection in traffic tunneling projects as well as in the trenchless construction of utility tunnels. Different machine types and working principles have been developed to master various geological and hydrogeological requirements. Continuous activity in research and development leads to constant improvement of the mechanized tunneling process.

Martin Herrenknecht and Karin Bäppler

Dr.-Ing. E.h. Martin Herrenknecht is chairman of the board of management and **Dr.-Ing. Karin Bäppler** is with the sales department, respectively, with Herrenknecht AG, Germany, e-mail bappler.karin@herrenknecht.de.

FIG. 1

World's largest mixshield 15.43 m (50.6 ft) TBM for the Shanghai Changxing Under River Tunnel.

Largest TBMs in operation in Shanghai

Since November 2006 and January 2007, the two largest TBMs in the world to date have been building the gigantic Shanghai Changxing Under River Tunnel project in China. The diameter of the machines is 15.43 m (50.6 ft).

The river banks of Pudong mainland and the island of Chongming will be connected. Two parallel motorway tunnels, each tunnel having a length of 7,170 m (23,523 ft), will be built between the mainland of Pudong and the island of Changxing because the waterway in between is a busy main shipping route. A bridge will connect Changxing and Chongming.

The parallel motorway tunnels will have two levels. The upper level will contain three lanes for road traffic and the lower level is planned to integrate a rescue lane in the center and a safety passage.

The main challenges of this project were the large shield diameter of 15.43 m (50.6 ft) and the predicted geological and hydrological conditions with high ground water pressures of up to 6.5 bar.

The tunnel is being built in clayey formations below the ground water table. At its deepest point, the tunnel will run is about 65 m (213 ft) below the surface. Therefore, both mixshields are designed for a maximum working pressure of 6.5 bar. To avoid adhesion of sticky clay at the cutting wheel, its center area is equipped with its own slurry circuit. Large openings in the cutting wheel optimize the material flow and reduce the risk of blockage of material in the center.

A special feature of the soft ground cutting wheel are the six accessible main spokes. They are sealed against the water pressure. The design of the cutting wheel was conceived to allow man access to its interior space in free air, sealed from the ground water pressure outside.

To handle the clayey soil conditions, the cutting wheel is equipped with soft ground tools and buckets. Tool change devices are integrated in the cutting wheel. They allow the personnel to replace tools under atmospheric conditions from the interior of the cutting wheel.

To get reliable information about the condition of the cutting tools, two buckets and eight soft ground tools are equipped with an electronic wear detection system.

This system generates online data on the state of the selected cutting tools that are positioned in the loaded outer area of the cutting wheel. It also provides an early warning to the TBM staff of possible wear. Thus, maintenance works can be planned and the service life of the tools can be optimized, minimizing costly chamber entries under compressed air.

The tunnel is lined with reinforced concrete segments. The heavy segments that weigh up to 15 t (16.7 st) each are delivered by two special trucks from the segment fabrication yard, located about 1.5 km (1 mile) away from the job site. The tunnel lining has an inside diameter of 13.7 m (45 ft). Each tunnel ring consists of 9+1 segments is 2 m (6.5 ft) long.

The tunnel excavation for each 7,170-m (23,523-ft) tunnel is expected to take about 34 months. The commissioning of the BOT-tunnels is planned for 2010.

The structural steelwork for the two new 15.43-m- (51-ft-) diameter mixshields was manufactured in China. An assembly time of only four month displayed a high technical standard in the field of tunneling technology — this for projects with huge demands like the excavation of the two parallel motorway tunnels below the Yangtze River with high ground water pressures.

The following TBM project is also characteristic of the demanding conditions of tunneling in the inner-city area with very low cover to the surface and structures.

North-South urban light railway, Cologne

The North-South urban light railway project in Cologne is one of the largest infrastructure projects in Germany. The new route, connects the southern districts with the city center. It is about 4 km (13 miles) long and includes eight stops.

The challenge of this project was the excavation of a new tunnel alignment in a densely populated inner city area with very low cover to the surface and to old and historic buildings, a storm water collector and railway embankments.

Three mixshields were chosen for this project. Two identical shield machines with diameters of 8.4 m (27.5 ft) will operate in the southern lot and one shield with a diameter of 6.8 m (22.3 ft) will be in the northern lot.

The 6.8-m- (22.3-ft-) diameter mixshield for the northern lot excavated the two parallel sections of 260 m (853 ft) each between the start shaft Breslauer Platz to the Museumskomplex. Tunneling for the first single-track tunnel tube with an inside diameter of 5.85 m (19 ft) started in June 2006 and ended in September 2006. The machine was then moved back to a second starting shaft where it was provided with a new shield skin and a new cutting wheel to continue for the 260-m- (853-ft-) long western tube.

The mixshield was equipped with soft ground tools and disc cutters to handle the blocks and boulders incorporated in the soil structure and also to handle numerous areas of treated ground. Because of tunneling in urban area with its minimum cover, settlement control was essential. In one section, the distance between the 6.8-m- (22.3-ft-) diameter shielded soft ground TBM and the foundation was no more than 1 m (3.3 ft). The machine was adapted accordingly. The cutting wheel could be retracted into the shield to minimize

FIG. 2

Tunnel alignment for the North-South Urban Light Railway, Cologne, Germany.

FIG. 3

The two mixshields 8.4 m (27.5 ft) TBM's for the southern lot of the North-South Urban Light Railway in Cologne, Germany.

possible settlements.

The two mixshields (8.4 m or 27.5 ft) for the southern lot each excavated a section of 2,700 m (8,858 ft) between the start shaft at Bonner Wall and the target shaft at Kurt-Hackenberg-Platz. The tunnel is lined with reinforced concrete segments and has an inner diameter of 7.3 m (24 ft). Both machines started from the same shaft. This tunnel drive was also characterized by demanding sections with minimal overburden. In the starting zone, the cover between the shield and the surface was only 4.6 m (15 ft). During the course of the tunnel, a maximum cover of up to 19 m (62 ft) was achieved. The maximum ground water level at tunnel face was 21 m (69 ft).

To minimize settlements along the two parallel drives, the appropriate measures were taken in advance of the shield passage, such as the support of 48 buildings in the southern section by compensation grouting.

The three mixshields that have been used for this demanding tunnel construction project have been designed and manufactured according to the latest state-of-the-art tunneling technology. The machines have been equipped with:

- Systems for seismic probing ahead that allow "insights into the unknown" ahead of the cutting wheel to detect, for example, unpredicted wells, or natural or man-made obstacles.
- An electronic wear detection system for an efficient excavation process and to avoid damage to the tools and the steel structure of the cutting wheel.
- An extensive data acquisition system that gives continuous information about the support of the tunnel face and many further machine parameters essential for a controlled excavation process.

The last tunnel drive for the western section of the southern lot was successfully excavated by the beginning of August 2007. Performances were up to 22.5 m/d (74 ft/day) under complex and challenging conditions in variable ground conditions.

The focus of development and improvement processes in tunneling technology is not just focused on the soft ground TBMs with slurry supported tunnel faces. It also includes all of the existing tunneling technologies both for soft rock and hard rock and mixed face conditions. A big step regarding the application range of earth pressure balance (EPB) shields was also achieved. The EPB technology was further extended towards noncohesive soil conditions and hard rock. A further step was taken toward an increased EPB tunnel excavation with a diameter larger than 15 m (49 ft). The current largest EPB shield, with a diameter of 15.2 m (49.8 ft), was manufactured by Herrenknecht for the M30 Highway tunnel project in Madrid, Spain.

FIG. 4

An 11.16-m (36.6-ft) earth pressure balance shield for the Katzenberg Railway tunnel in Katzenberg, Germany.

Katzenberg railway tunnel project through tertiary sedimentary rocks

The Katzenberg railway tunnel project is located between Karlsruhe and Basle in Germany. This new high-speed railway line of the Deutsche Bahn (German Railway) is part of the Rhine Valley Railway that was upgraded from a two- to a continuous four-track line.

The rail line is part of the Trans-European net of the European Union with high international significance. It serves as the main inlet to the Gotthard Base section, the connection to Italy.

The project includes the excavation of two parallel 9,385-m (30,790-ft) single-track tubes, of which 8,984 m (29,475 ft) are excavated by EPB shields with a diameter of 11.16 m (36.6 ft).

The tubes are connected every 500 m (1,640 ft) by cross passages. The tunnel is lined with a single shell lining consisting of reinforced concrete segments.

The geology along the tunnel was forecast to be comprised of various geological conditions from quaternary surface layers in the portal areas to tertiary sedimentary rocks (mudstone, siltstone and isolated sandstone) of different weathering grades. In the southern part of the tunnel, there is an approximately 800-m- (2,625-ft-) long section of Jurassic limestone with possible karst structures and structures from the tertiary period in the transition areas. The overburden along the tunnel alignment ranges from 25 m to maximum 110 m (82 ft to maximum 361 ft) and the water pressure up to 9 bar.

The two identical EPB shields started excavation from the southern portal from a 320-m (1,050-ft) opencut section.

Characteristic for this project is the demand for TBM technology and tunnel linings that are adapted to specific geological and hydrogeological conditions. One requirement was the single shell lining designed for a maximum water head of 90 m (295 ft).

The shield machines are adapted to these specific conditions to fulfill the requirement of handling soft ground and hard rock conditions with one machine. In soft ground, the tunnel face is supported in a closed EPB mode. In stable rock conditions, the EPB machine can operate in open mode with extraction of the rock by the screw conveyor onto a belt conveyor.

In case of unstable geological conditions, the rock can be stabilized in advance with additional measures such as grout injections or drainage of the water. Therefore, the two EPB shields are equipped with drill units for exploratory and injection drillings. Drilling and grouting can be carried out in open mode (given a depressurized extraction chamber) and closed mode when acting against the existing ground water pressure.

To counteract unplanned overexcavation of soft rock, the EPB shields are equipped with a system for controlling the mass and volume of the excavated material. The system is based on the recording of the excavated mass flow on the conveyor belt and the comparison of this value with the theoretical mass flow that is determined relative to the stroke of the thrust rams. The in situ density of the prevailing geological formation and the theoretical values of the mass flow to be expected are graphically shown on the control panel and facilitate a prompt reaction to changed conditions. Standard systems for muck control in EPB machines include robust belt conveyors and a laser scanner.

In total, about 2.6 Mm^3 (91.8 million cu ft) of material will be excavated. The extracted material is transported directly by covered conveyor belts to a nearby limestone quarry about 3.5 km (2.2 miles) away from the job site. By choosing the covered conveyor for transportation of the excavated spoil, consideration was shown for the adjacent communities by reducing the amount of construction traffic and noise emissions.

Convertible mixshield used at the Socatop road tunnel

The excavation of the second section of the Socatop tunnel, a double-deck motorcar tunnel, was completed at the end of August 2007. The tunnel completes the motorway A86 around Paris, France. Each 2.55-m- (8.36-ft-) high level carries two lanes of one-way car only traffic and a hard shoulder.

The 10.5-km- (6.5-mile-) long tunnel alignment passes beneath an environmentally sensitive area of forest parkland, historic sites like the Chateau de Versailles, residential areas and a railway line. The tunnel excavation was divided into two tunnel drives — the first 4.5-km- (2.8-mile-) long section from Rueil-Malmaison to Vaucressin and the remaining 6 km (3.7 miles) to Pont Colbert and the connection with the A86.

A convertible 11.56-m (38-ft) mixshield was designed and constructed for this light traffic tunnel that generally runs through heterogeneous soil formations and soft rock below the ground water table. The TBM can be converted inside the tunnel from open mode to closed hydroshield mode to EPB mode and vice versa. With this capability, the machine can be used in extremely heterogeneous soils with a clear interface definition between the logistics of the tunneling system and the logistics of the material transport system.

FIG. 5

Material transport to a quarry via covered conveyor belts.

The mixshield was launched in December 2000 for the first 4.5-km- (2.8-mile-) long tunnel section in open mode. The machine was converted twice along this part of the route due to the varying ground conditions. The conversion from open mode in free air to closed EPB mode and finally to mixshield mode with slurry supported tunnel face went smoothly.

Along the first tunnel drive, the TBM had to pass under a busy railway line with minimum cover of 11 m (36 ft) in sandy soils below the ground water table. Before tunneling through this sensitive zone, the following measures were taken to guarantee a trouble free excavation without stoppage:

- Installation of a new set of wire brush seals (tailskin sealing).
- Sinking several ground investigation boreholes in the vicinity of this zone.
- Installation of supplementary rails to stiffen the track.
- Monitoring of the track.
- Speed restrictions for the trains during the crossing period.
- Modifications of the spoil handling system to prevent clogging.

In early July 2005, the 11.56 m (38 m) mixshield started its second section with the mixshield mode. Two conversions have been planned along this part of the tunnel.

The cutterhead of the mixshield is of closed type. It works in EPB and slurry mode without any modifications. Depending on the operation mode, the backup systems change to suit tunneling mode. The conversion from one operating mode to another occurs by using the first divider wall, which is used as a pressure wall during EPB operation, and also used as the submerged wall during slurry supported tunnel face mode. The opening for the conveyor in the submerged wall is sealed after the conveyor is retracted. Once the conveyor is retracted, the feed and suction lines become accessible, thus a conversion of the excavation chamber is possible.

Gripper TBMs for the Gotthard base tunnel in Switzerland

The Gotthard base tunnel in Switzerland will be the longest railway tunnel in the world with two parallel tubes of 57 km (35 miles).

The mechanized tunnel sections that are being excavated with Gripper TBMs comprise in total the following four subsections:

- Erstfeld (2 x 7,178 m or 23,550 ft).
- Amsteg (2 x 11,350 m or 37,237 ft).
- Faido (1 x 12.4 km or 7.7 miles, 1 x 11.9 km or 7.4 miles).
- Bodio (2 x 14 km or 8.7 miles).

The first mechanized tunnel of the subsection Amsteg was completed in June 2006. The parallel section was excavated by the beginning of October 2006 about six months ahead of schedule.

The two approximately 14-km- (8.7-miles-) long parallel tunnels of the subsection Bodio were completed at the beginning of September 2006 and the end of October 2006, respectively.

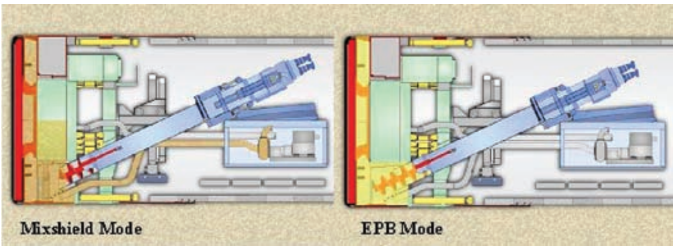
The four gripper TBMs that excavated the often quite demanding rock massif and fault zones nevertheless finished the total of about 50 km (31 miles) on time.

For the following subsection Faido to Sedrun, the two Bodio Gripper TBMs were completely refurbished. The geology along this section is characterized by two tectonic units, the Penninic Gneiss zone (approximately 5 km or 3 miles) and the Gotthard Massif (approximately 10 km or 6 miles). The predicted Piora Zone is characterized by solid, compact and partially metamorphic dolomite anhydrite rocks at tunnel level. The TBMs to be used for the subsection Faido have been modified according to the geological conditions. Apart from increasing the excavation diameter to 9.4 m (31 ft) to be prepared for the greater overburden from 1,200 m (745 ft) up to 2,470 m (8,100 ft) and thus greater rock pressures along this section and the application of 12 instead of eight buckets, the 432-mm (17-in.) disc cutters have been replaced by 457-mm (18-in.) cutters. The gripper and the walking legs were adapted to a support diameter of 9.5 m (31 ft). Modifications were also done on the cutterhead dust control system, to increase from 600 m^3/min (21,200 cu ft/min) to 1,100 m^3/min (38,800 cu ft/min).

The first Gripper TBM for the east tunnel of the subsection Faido started at the beginning of July 2007. The TBM start for the west tunnel was scheduled for October 2007.

FIG. 5

Convertible 11.6 m (38 ft) mixshield (slurry/EPB) for the Socatop road tunnel.



The geology along the remaining Erstfeld lot of the Gotthard base tunnel project is characterized by mainly solid and geotechnically favorable highly metamorphic gneisses (Erstfelder gneiss). The AlpTransit Gotthard AG administrative council awarded the subsection Erstfeld to the joint venture Gotthard Base Tunnel North. The joint venture consists of Murer-Strabag, of Erstfeld, Switzerland and Strabag AG, of Spittal/Drau, Austria. The TBM section comprises the excavation of two single-track tunnels of 7.2 km (4.5 miles) from Erstfeld to Amsteg. The tunnels will be excavated by the two TBMs that have driven the 2 x 11.35-km- (7-mile-) long subsection Amsteg. During the summer of 2007, the TBMs were being refurbished and assembled. Start of excavation was planned for the first half of 2008.

Outlook

The projects cited show the variety of successful TBM applications in sensitive and inner-city environment, and also in complex geology such as extremely hard and abrasive rock conditions.

Administrative authorities, project owners and contractors involved in large scale tunnel projects depend on and ask for reliability, safety and speed. This defines today's innovative machine technology in mechanized tunneling. Furthermore, machine design and the process engineering is, therefore, continuously improved and further developed.

TBMs in diameters ranging from 100 mm (4 in.) to 16 m (52 ft) today are reliably used for the realization of complex projects. In the future, tunnels will be built at even greater depths and become even longer. Diameters of more than 16 m (52 ft) are envisaged. They pass under densely populated areas, through natural barriers like mountain ranges or under rivers and estuaries. The market requires practical engineering skills under the toughest conditions. Innovations such as seismic probing ahead, cutting wheels accessible under free air, muck control, drill units for ground stabilization measures from the TBM and cutter wear detection systems were designed and further developed. Information technology and sophisticated measuring techniques in tunneling are increasing safety as well as economic profitability. ■

FEATURE ARTICLE

Final tunnel liner at the Mill Creek 3 project

The 6-m- (20-ft-) diameter cast-in-place tunnel lining for Phase 3 of the Mill Creek Tunnel (MCT3) has been completed. This article summarizes aspects of liner design and addresses the construction approach in placing the liner in areas of tunnel that experienced crown overbreak. Tunnel lining production rates, installation procedures and form buoyancies experienced during concrete placement will also be presented.

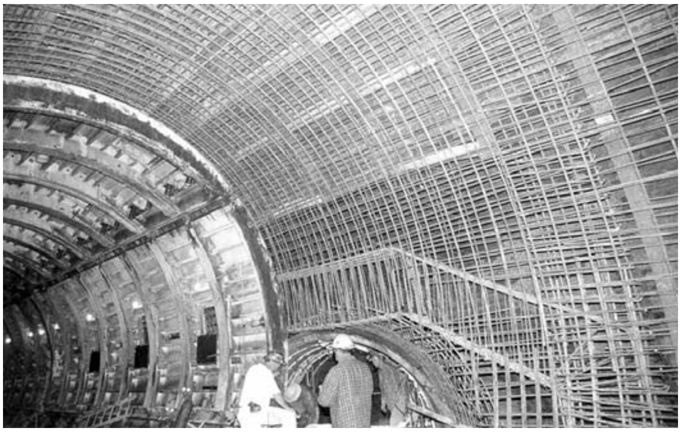
The Mill Creek Phase 3 tunnel (MCT-3) is expected to be completed this year. It is one of the largest tunneling projects undertaken by the Northeast Ohio Regional Sewer District (NEORSD) to date. The tunnel horizon is situated within the Devonian Chagrin Shale rock formation at an average depth of 85 m (280 ft). The tunnel was excavated using a two-pass method. A full face, fully shielded, Robbins 7.2-m- (23.8-ft-) diameter tunnel boring machine (TBM) was used to excavate approximately 4,500 m (15,000 ft) of tunnel and facilitate installation of initial supports (first pass).

The final lining (second pass) consists of 305-mm- (12-in.-) thick cast-in-place reinforced concrete and integral low flow channel.

Seven shafts were constructed on the project. The excavation of the tunnel commenced at Shaft 14 and proceeded down grade to Shaft 9, the terminus shaft. Because of the presence of overbreak in the tunnel crown, measures were required to support the form and counteract the effects of buoyancy during concrete placement.

FIG. 1

View of steel reinforcement and concrete form.



Liner design

Final lining design for the Mill Creek tunnel was selected in accordance with the requirement for permanent tunnel support, ground water control and hydraulics. Three load cases were considered, with constant rock loads of 0.5B to 0.7B for each load case. The three cases considered were:

- Case 1: Loading imposed on the liner from internal pressure with no external hydrostatic pressures.
- Case 2: Internal hydrostatic pressure with external water pressure.
- Case 3: External water pressure with no internal pressure.

Where the tunnel lining intersects shafts and shaft adits, additional reinforcement was required to carry loads around the intersecting opening. In this case, concrete reinforcement was configured to create hidden ring beams inside the tunnel walls.

Liner placement method and specification criteria

The contractor chose to use collapsible steel forms to install the final concrete liner. Each section of form consisted of a 270° top panel and a 90° invert panel. A total of eight, 7.3-m- (24-ft-) long, full circular form sections and one additional invert panel were used on the project. A view of the concrete reinforcement and main tunnel form is shown in Fig. 1 and 2.

Prior to the commencement of tunnel lining operations, the contractor expressed concern regarding the condition of the tunnel crown. Due to the extent of overbreak, the tunnel crown might not be capable of supporting the buoyancy load generated during tunnel lining concrete placement. If movement of the form occurred, the tunnel form would be lifted, potentially damaging the form and losing tunnel grade.

In preparation for lining operations, the areas of

M. Schafer, B. Lukajic, R. Pintabona, M. Kritzer, R. Switalski and S. Janosko

M. Schafer, B. Lukajic and **R. Pintabona** are with MWH, Cleveland, OH. **M. Kritzer; R. Switalski** and **S. Janosko** are with Northeast Ohio Regional Sewer District, Cleveland, OH, e-mail michael.j.schafer@us.mwhglobal.com.

FIG. 2

Full view of concrete form.

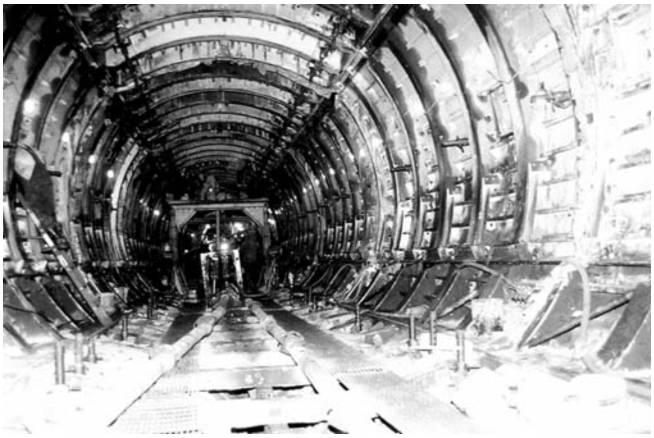


FIG. 3

View of Z-beams and tunnel support.

tunnel exhibiting crown overbreak were inspected to determine if the form spud pins in the tunnel crown could be placed on stable rock surfaces. Crown overbreak occured at various locations of the tunnel ranging in depth from 0.15 m (0.5 ft) to 0.6 m (2 ft). Based on this inspection, it was determined that the overbreak areas could potentially allow the forms to be lifted during concrete placement.

To properly support the tunnel form, two steel beams (Z-beams) were installed in the tunnel crown. The fabricated Z-beams were fastened to the primary tunnel support system (W6¥20 steel ribs) in the 10:30 and 1:30 clock positions. The form support beams were erected in a manner creating two continuous beams running the length of the tunnel. With the installation of the Z-beams, the loads generated during the placement of concrete were transferred to the tunnel ribs, resulting in a wider distribution of the rock load. A photo of the installed Z-beams is shown in Fig. 3.

The concrete specifications required that the forms remain in place until a strength of 6.9 MPa (1,000 psi) was achieved and not less than eight hours of curing time had passed. To meet this requirement, the contractor submitted multiple concrete mix designs for review. Approval was granted for two mixes, providing the contractor with concrete suitable for cold and warm weather conditions. Regular quality control tests were performed in the field to verify the mix met the specification requirements.

Form buoyancy monitoring

With the installation of the form support Z-beams, the buoyancy loads were transferred to the ribs and shale in the tunnel crown. However, in distinct areas of the tunnel, the overbreak was extensive enough that no rock was present behind the ribs. In these areas, the contractor expressed concerns that additional measures might be required to resist the effects of buoyancy.

To determine the significance of the buoyancy effect, a load-cell monitoring program was performed in the initial stage of the concrete lining operation. The following summarizes the monitoring, performed from Nov. 22 to Dec. 13, 2006:

- A total of 36 load cell tests were conducted using Geokon type model 3000-100-1.
- Immediately before the placement of concrete, load cells were placed on the end of several spud pins in the crown of the tunnel and preloaded to an average of 7.25 t (8 st), using an air impact tool. The load cells were fitted with a custom-made bracket that allowed the cell to be installed between the spud pin and Z-beam (Fig. 4).

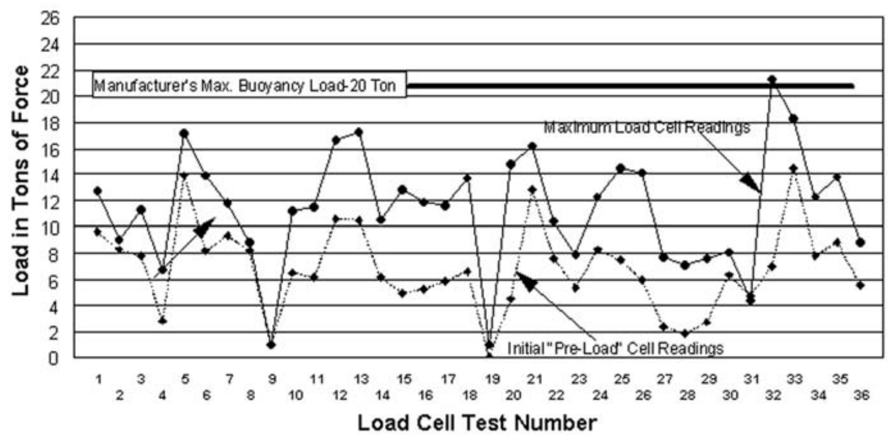
FIG. 4

Load cell reading in progess.

- As concrete was pumped in behind the tunnel forms, data loggers continuously monitored the change in load to the spud pins for the duration of the concrete placement.
- As shown in Fig. 5, buoyancy loads were detected. However, all recorded loads were below the manufacturer's maximum expected buoyancy load of 18 t (20 st).
- As anticipated, the highest loads occurred in the last tunnel form at the end of the concrete pour.

FIG. 5

Summary of buoyancy.



Based on the results of tunnel mapping and load-cell monitoring data, it was determined that additional means of resisting forces generated by buoyancy would be required in areas of the tunnel with more extensive crown overbreak. As a solution, the invert of the tunnel form was fitted to allow rock bolts to be installed. In areas of the tunnel requiring additional support, a series of "tie-downs," consisting of 3-m- (10-ft-) long resin bolts, were installed through the form invert, anchoring the form to the tunnel invert to help resist buoyancy. Figure 6 shows tie-downs installed in the form invert.

Construction sequence

The final liner was placed after completion of all tunnel excavation and removal of the TBM. The contractor used the following steps to install the liner.

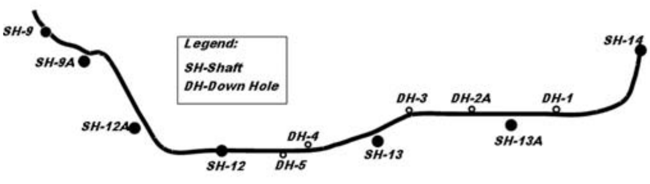
- The reinforcing steel was placed in two separate operations. The upper two-thirds of tunnel was installed first to maintain the operation of the rail system. This operation was accomplished from two platform cars riding on two outer tunnel rails. The top steel was set at about 457 m (1,500 ft) in advance of the poured concrete.
- Concrete was pumped from the surface through a series of down holes and shafts, using a 127-mm (5-in.) delivery line. The concreting operation commenced at Shaft 14 and ended at Shaft 9. Figure 7 shows the locations of shafts and down holes. The concrete pump was capable of an instantaneous delivery rate of 153 m^3/h (200 cu yd/hour), and was capable of a maximum pumping length of 427 m (1,400 ft). However, the contractor chose not to exceed a 305-m (1,000-ft) pumping length. Typically during the placement, two concrete trucks were simultaneously discharging concrete into the pump hopper (Fig. 8).
- Concrete placement was performed every other day during first shift, between 7 a.m. and 4 p.m. At the beginning of a placement, concrete was poured through an opening on the top of the form, located at the upper reach of a slopping concrete joint. During the previous day's pour, this port was cleaned and readied for this purpose. Placement was continued through this hole until the next intended hole was reached with the crown concrete. Then the delivery

FIG. 6

View of tie-downs at form invert.

FIG. 7

Location of shafts and down holes.



line was quickly moved to the next hole (about 18 m or 60 ft away) and pumping was resumed. The pour was terminated when concrete in the crown covered the last form joint (about 6 m or 20 ft from the form bulkhead).

- Using this approach, the joint at the downgrade end of each concrete placement consisted of a vertical joint from the tunnel floor to the tunnel spring line, and a sloping joint from the tunnel spring line back about 6 m (20 ft) to the crown of the tunnel. The next day's pumping port in the crown of the form was cleared of concrete at the upper end of the sloping joint. At the beginning of the next day's pour, grout was then injected through this port along the sloping joint to promote bonding between the fresh and previously placed concrete.
- Provided that eight hours of curing time and 6.9 MPa (1,000 psi) of strength had been achieved, the forms were stripped and moved for the next placement. Stripping and setting the formwork was done on the second and graveyard shifts.
- The final cleanup of the tunnel invert and installation of invert steel was done just ahead of form placement. Finishing the tunnel cleanup and invert steel placement were first and second shift operations.

Production schedule

It required 118 pours to install the liner. The length of the lining pours varied from 29 to 51 m (96 to 168 ft) with typical pour length ranging from 37 to 44 m (120 to 144 ft). The actual construction time required to line the tunnel was approximately a year, from Sept. 6, 2006 to Sept 11. 2007. Figure 9 shows production and total footage placed.

Contact grouting behind the liner

FIG. 9

Concrete lining production.

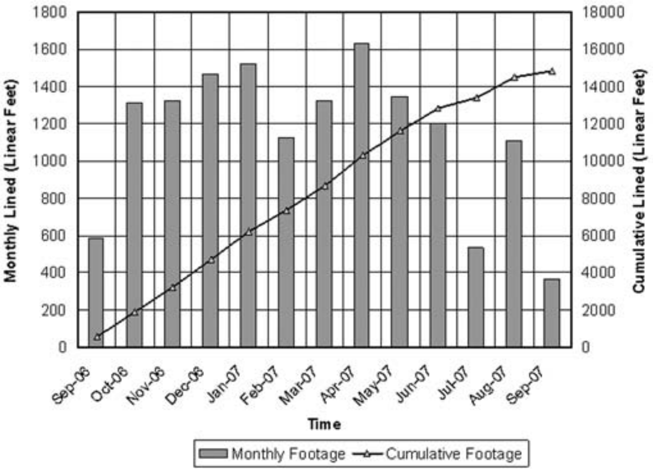


FIG. 8

Concrete delivery at down-hole position.

The primary objective of contact grouting is to fill any remaining voids between the rock and concrete liner. The MCT-3 contract documents required that the grout have a minimum 24-hour compressive strength of 6.9 kPa (100 psi) and a minimum compressive strength of 10.3 MPa (1,500 psi) at 28 days. It also specified that the grout should consist of a mixture of water and portland cement, with fillers as necessary to achieve a nonshrink, nonbleeding and noncorrosive, flowable grout.

To meet the specification criteria, the contractor, in collaboration with his concrete supplier, formulated a grout mix, consisting of water, 454 kg (1,000 lbs); Type 1 cement, 298 kg (658 lbs); fly ash, 488 kg (1,075 lbs) and fluidifier additive. 8 kg, (17 lbs).

Contact grouting is accomplished by drilling through the concrete liner every 8 m (25 ft) and installing a packer. Starting at the downgrade end of the tunnel, grout is forced through each packer and pressurized to 413 kPa (60 psi). Once the contact grouting is completed, check holes are drilled in select areas to confirm that the voids behind the tunnel lining have been properly filled with grout.

Summary

At the time of finalizing this paper, the tunnel-lining task was completed and the contact grouting operation was in progress. A team from the Northeast Ohio Regional Sewer District (NEORSD) and MWH Americas provides oversight on tunnel construction by KMM&K-joint venture the contractor. ■

Acknowledgments

The authors thank Northeast Ohio Regional Sewer District and Charles Vasulka, director of engineering for his review and approval to publish the paper. Special thanks go to Carol Chavis for managing the paper and communicating with the NAT organizing committee.

FEATURE ARTICLE

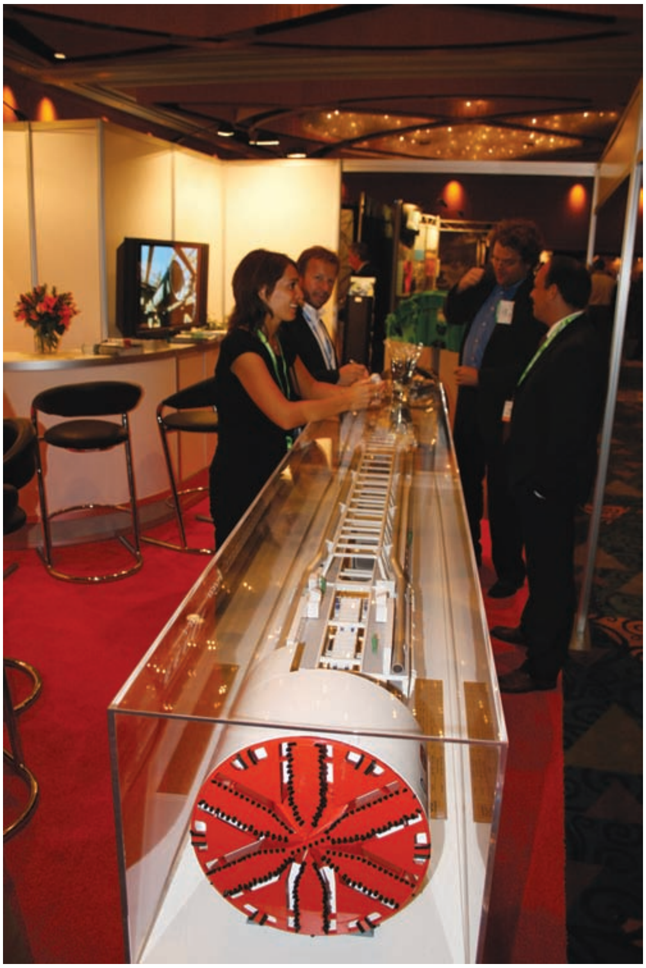
NAT attendees get a glimpse of the future of underground space use

In 1950, about a third of the world's population lived in cities. That figure has steadily risen throughout the following decades. Now it is believed that about 60 percent of the estimated 8.1 billion people in 2030 will be living in urban areas.

The strain on infrastructure in cities in the developed world is already showing. And the rapid growth in developing nations today is adding to the shortage of materials, equipment and labor needed to keep up with this growth.

So, while materials and labor may be in short supply, there is no shortage of work for the underground tunneling and space industry. In June, 718 of those professionals from around the world were in San Francisco, CA for the North American Tunneling (NAT) conference, put on by the Underground Construction Association (UCA) of SME. The attendees spent the three days of technical sessions listening to international authors discuss the state of the industry, new technologies that have become available and updates on major tunneling projects throughout the world. The accompanying exhibit attracted 79 vendors, who displayed the latest in tunneling and underground space equipment and services.

The exhibit at the 2008 NAT conference attracted 79 equipment and service vendors and more than 100 technical papers were presented and are available in the proceedings volume.



Steve Kral, Editor

In addition to the technical sessions and the exhibit, the NAT featured three short courses — "DRB Process Update Workshop," "Soft Ground Tunneling Technologies" and "Underground Blasting Technology and Risk Management." And the post-meeting field trip to the Devils Slide tunneling project near San Francisco was sold out.

Keynote

Bijan Sartipi. The California Department of Transportation (Caltrans) currently has about $10 billion in transportation projects under way, according to Bijan Sartipi. He is region four director with Caltrans and one of the NAT keynote speakers. About 60 percent of that $10 billion is for work being done in the San Francisco area, he said. And California voters earlier approved an additional $20 billion in bonds to repair the state's roads, bridges and other transportation infrastructure.

Among the projects in Sartipi's region are the Devils Slide tunnels located south of San Francisco along the Pacific Coast in San Mateo County. Devils Slide is a notorious stretch of Highway 1 between Pacifica and Montara that has been plagued with landslides and road closures since it was built.

The Devils Slide tunneling project came about after several years of study and public input. It will consist of

Gray Brechin, visiting scholar, University of California-Berkeley, was the luncheon speaker during the NAT conference. He provided a history of the Sutro tunnel and its effect on San Francisco.

two tunnels, each 1,250 m (4,100 ft) long and 9 m (30 ft) wide. The tunnels will connect a pair of 330-m- (1,000-ft-) long concrete arch bridges.

The tunnels are being built at the same time, with one tunnel face about 40 m (130 ft) ahead of the other. This is to reduce possible damage from blasting in each tunnel. Cross passages will connect the tunnels at every 120 m (395 ft). Jet fans will provide ventilation. Roadheaders and drill-and-blast methods are being used in conjunction with NATM/SEM ground support designs.

Work began on the project in 2007 and is expected to be completed in 2011. Kiewit Pacific, a subsidiary of Kiewit Corp., is the main tunnel contractor.

Maria Ayerdi-Kaplan. The Transbay Transit Center is an ambitious, $4.1-billion transportation project in San Francisco aimed at centralizing the city's fractured public transportation network.

Ayerdi-Kaplan is executive director of the Transbay Transit Center project. She said the project would involve creating a new Grand Central Station of the West surrounded by housing, shops and offices. The project would be managed by the Transbay Joint Powers Authority. Its five-member board of directors includes Bay Area governments and transportation agencies.

The Transbay Transit Center will centralize the region's transportation network by accommodating nine different transportation systems in one station — above and below ground. Those systems include AC Transit, Caltrain, MUNI, Golden Gate Transit, Sam Trans, Greyhound, BART, WestCAt and the planned California High-Speed Rail, she said.

The project would take place in two phases, Ayerdi-Kaplan said. The first would be the construction of an elevated regional bus facility at the Transit Center building, along with foundations for a future rail system train system.

The second phase would be the construction of an underground rail extension for Caltrain and the future high-speed rail. That is expected to begin in 2012 and be operational by 2018. The Downtown Extension part of the project would involve a 2-km (1.3-mile) extension of Caltrain's current commuter service. It would be a three-track alignment with a two-track lead. Six new tracks would also be built on three underground platforms at the Transit Center to accommodate the Caltrain rail line and the proposed high-speed commuter train.

The Transbay Transit Center is scheduled to be operational by 2015. Once the rail component is completed, about 20 million people are expected to use it annually.

Session papers

Technical presentations at the 2008 NAT included more than 100 papers in four tracks. The tracks covered technology, design, project planning and implementation, and case histories. All of the presentations are published in the NAT proceedings volume and are available from SME, e-mail cs@smenet.org, Web site www.smenet.org. The following is a sampling a few of the papers.

The Gotthard base tunnel in Switzerland will be the longest tunnel in the world. It is part of a new railway system in Switzerland designed to guarantee the delivery of the increased flow of goods between northern and southern Europe, according to Jurg Schlumpf, of Sika Services of Zurich, Switzerland. He described the durability requirements for cast and sprayed concrete and shotcrete systems necessary to complete the 56-km- (35-mile-) long Gotthard tunnel.

As the world's population grows, attention will be given to megacities, cities with more than 10 million people, according Harvey Parker, of Harvey Parker and Associates. In 2001, there were 19 megacities throughout the world. That should increase to about 60 by 2015, he said, and many of those will be in developing countries. That means planners and decision makers will need to

UCA of SME chairman Brenda Bohlke presented William Edgerton with a special award during the NAT conference for his work on the updated *Recommended Contract Practices for Underground Construction*, the first update to the book in 30 years.

place more emphasis on the use of underground space for infrastructure and other living needs. Greater use of underground space will be beneficial to the environmental and the sustainability of cities, Parker said, particularly in water, waste water, utilities and transportation. But he added that planners and the underground construction profession must also promote the use of underground space for bulk storage, manufacturing, living and office space. And longer tunnels will be needed in the future to maintain the efficiency of the transportation networks between the megacities.

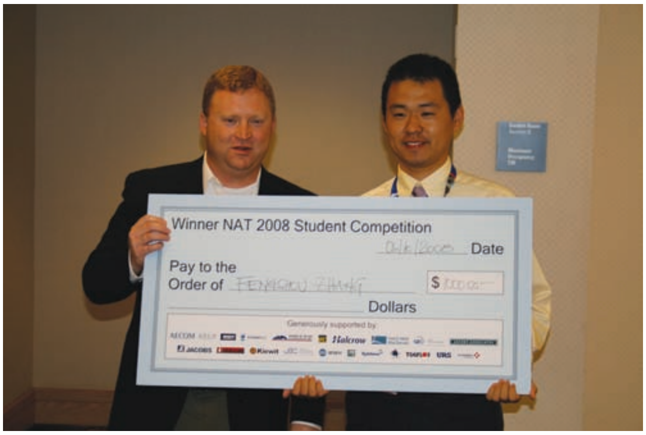
The Greater Vancouver Water District is building the largest water treatment plant in western Canada. When finished, the plant will have a capacity of 1.8 GL/day (475.5 million gal/day). Included in the plans were two water transfer tunnels. The project also required the sinking of two shafts. Andreas Prucker and Joe Rotzien, both of Hatch Mott MacDonald, and Andrew Saltis, of Pacific Liacion & Associates, described the shaft sinking at one of the shafts — the Seymour shaft at the Seymour-Capilano filtration plant. The Seymour shaft is 11 m (36 ft) in diameter and 180 m (590 ft) deep and was sunk by conventional drill-and-blast methods, the authors said. It served as the launch point for two Robbins tunnel boring machines. Once the project is completed, water will be pumped from the Capilano reservoir up the Seymour shaft for treatment.

Awards

The UCA of SME presented awards to outstanding members during the NAT. And three students won cash awards for their outstanding papers.

James E. Monsees received the UCA of SME's Lifetime Achievement Award. He is senior vice president of Parsons Brinckerhoff and is the company's technical director. Monsees is an internationally recognized expert on tunneling and has worked on such projects as transit and water tunnels, nuclear waste disposal in geologic

Mark Ramsey, left, presented a $1,000 check to Fengshou Zhang, a student at Georgia Tech. His paper was judged the best in the student paper contest. Two other students also won cash awards for their papers.



The NAT conference's 718 attendees were able to see the latest in underground space technology and equipment at the conference's exhibit.

media and he participated in the design in several major subways and tunnels in the United States.

Ray Henn received Outstanding Individual Award. He is a principal with Lyman Henn of Denver, CO. Henn has 37 years of experience in tunnel engineering and consulting, working for contractors and construction management assignments. He has published two textbooks and is working on a third. He is past president of AUA and a 33-year member of SME.

Torr Brekke received the Outstanding Educator Award. Since 1993, he has been professor emeritus at the University of California-Berkeley's Department of Civil Engineering. Some of Brekke's notable projects include the Eisenhower and Glenwood Canyon highway tunnels in Colorado, the Crosstown stormwater interceptor in Austin, TX and the Europipe landfall tunnel in Germany. While doing all of that, Brekke inspired many students to pursue careers in underground design and construction.

William Edgerton, of Jacobs Associates, received a special award for his work on the updated *Recommended Contract Practices for Underground Construction*. Several years in the making, Edgerton oversaw this large effort. This book is the first industry-wide effort to improve contract procedures in more than 30 years. It is available from SME, e-mail cs@smenet.org, Web site www.smenet.org.

Three students were chosen to present their award-winning technical paper during SME/ITA breakfast. A panel of judges chose the best paper. Fengshou Zhang, of Georgia Tech, was the first place winner and received a check for $1,000. Second place went to Shawna Voh Stockhansen. She received a check for $750. Shuying Wang, of the Missouri University of Science, was the third place winner and received a check for $500.

The next North American Tunneling Conference is scheduled for June 12-16, 2010 in Portland, OR. Before that, though, the UCA of SME's George A. Fox Conference is set for Jan. 27, 2009 in New York City. And the 2010 Rapid Excavation and Tunneling Conference will be held June 14-17 in Las Vegas, NV. ■

UCA of SME moves concrete technology forward

By Robert J.F. Goodfellow

From time to time we should ask ourselves whether we are satisfied with our industry. If the answer is no, we must then ask what we are going to do about it. This article is a call to arms for those who wish to see improvement in one aspect of the tunnel industry. Recent industry efforts in geotechnical baseline reporting and contracting practices have shown the way for the tunnel industry to improve. These efforts engaged the profession at large in assessment, review and production of guidelines documents in areas where the practice had been identified as lacking.

With efforts concluded for now in the fields of geologic interpretation and contracts, the focus naturally turns to technical specifications and design procedures. Understanding of ground behavior, numerical modeling procedures and guidelines, and load cases for tunnel design are some of the many points of potential improvement within these areas. Specification and implementation of concrete products — cast-in-place, pre-cast and sprayed concrete — is another area that merits special attention. Constraints on placement, loading conditions and equipment are all different in underground applications, and this places different demands on mixing, chemistry and admixtures that should be more widely known and considered in design specification and construction.

UCA of SME has formed a subcommittee to improve the specification and use of concrete in underground applications and to provide a central point of reference for the industry. There is real benefit in developing and implementing updated, state-of-the-practice, industry-approved guidelines to provide owners and designers with recommended practices in the use of concrete in underground applications. These guidelines should differentiate between underground applications and existing guidance for above-ground applications. Specifically, they should address:

- Standards and testing procedures for concrete products.
- Basics of gradation of coarse and fine aggregate.
- Easy reference on cement types and availability by region.
- Testing and quality control guides for underground concrete linings — including sprayed concrete.
- Use and purpose of cement replacement.
- Mixing and placement equipment and requirements.
- Basics of admixture chemistry and the description of what is required.
- Generic guidance on the use of pumpable, low-slump and high-strength mixes.
- Training and experience requirements for shotcrete application.
- Dealing with high pH tunnel discharge water during concreting.
- Specifying and achieving acceptable concrete finishes — particularly sprayed concrete.

As the chair of the new subcommittee, I encourage any UCA member with an interest in this project to join this effort, either as a core committee member who will produce the guideline document or as an expert who will contribute information and expertise to the core committee in an advisory capacity. For more information, or to join the subcommittee and help the underground industry move forward, please contact me at Goodfellow-RJF@bv.com. ■

MEETINGS

New York City hosts Channel Tunnel seminar

David Orr, the president of the British Institution of Civil Engineers (ICE), will be the keynote speaker at a seminar on the high-speed Channel Tunnel Rail Link project in the United Kingdom (UK). The seminar will be held at New York University's (NYU) Kimmel Center, in New York City, on Oct. 2, 2008.

The line is officially named High Speed 1 and it links the Channel Tunnel with Europe through the St. Pancras Station in London. The last section of the 117-km (69-mile) line opened to the public some months ago after getting full government approval in 1996. The total project costs were around $10 billion and the project was delivered on time and in budget. The planning, procurement and contract processes are very different from what happens in the United States.

The New York Local Association of ICE, David Caiden, chairman, has invited speakers from the project team in the UK, as well as respected local industry leaders, for a closing panel debate. They will discuss whether the lessons learned on the project could be used in the United States, how such a project would be delivered here and whether there is anything that could be done differently or better. The discussion will be based on the material presented by the

(Continued on page 27)

OBITUARY

DONALD CHARLES ROSE

Donald Charles Rose died July 26, 2008. He was 75. Rose was an activist in the tunnel and dam industry and in the civil engineering and engineering geology professions. He served as a visiting associate professor at Cornell University, he lectured on civil engineering and engineering geology for the U.S. Department of Agriculture and the Association of Engineering Geologists, and he wrote chapters in tunnel textbooks. His latest endeavor was teaching the Tunnel Engineering and Cost Estimating course at the University of California, Los Angeles (UCLA) as part of its professional construction management certificate program.

Rose made notable contributions to the dam industry. He reported on the Auburn Dam, the Queen's Dam and participated in the design and construction of dams in California, Washington, Oregon,


ROSE

Michigan, Thailand, Yemen, and East Pakistan (Bangladesh). In the tunneling industry, he was a consultant on the Superconducting Super Collider and the Hai Van Pass Tunnel in Vietnam. He was the tunnel geologist for the Trans-Koolau H-3 Pilot Tunnel and the Honolulu interceptor sewers on the University of Hawaii campus.

Rose served as editor for the Metropolitan Atlanta Regional Transit Authority's *Atlanta Research Chamber Monographs* and was the principal author on revising *Terzaghi Rock Loads*. He was an active subcommittee member on the U.S. National Committee on Tunneling Technology Geotechnical Investigations. He was the project manager for the Stanford Linear Collider, the largest application of steel-fiber reinforced shotcrete in the world at the time. He was also a tunnel cost estimator for major tunnel projects.

Rose started work as a Caterpillar heavy equipment operator — a Cat skinner. He later graduated with a degree in geology from UCLA and earned an M.S. in civil engineering from the University of California, Berkeley. In his early years, he was a debater and a long-distance runner, both at the championship level. And throughout his life, he was an accomplished jazz trumpet player. He lived his life with no regrets and doing what was always above board. He is survived by his ex-wife and best friend, Elizabeth Rose; a daughter, Victoria; a son, Donald Jr., and three grandchildren. ■

MEETINGS

(Continued from page 27)

invited speakers.

The Wagner Rudin Center for Transportation Policy and Management at NYU is assisting in organizing the event. The center has completed two high-speed rail studies in the United States and is currently involved in an international study of mega-projects involving 10 countries. Corporate sponsors for the event will be Arup, Bechtel, Halcrow, Parsons Brinckerhoff, Skanska and Systra.

The seminar organizers intend to offer certificates for 2.5 professional development hours. The event will cost $100 per person, including breakfast and lunch; the student rate is $60. Tables of 10 can be reserved for $800. Contact Martin Ellwood at 212-695-2463 or MEllwood@MTA-ESA.org to reserve a place at the seminar. ■

CHAIRMAN'S COLUMN

(Continued from page 4)

to make this an important and sustainable connection between emerging professionals and their future industry and potential employers. The Benefits of Going Underground Task Force is putting together a PowerPoint show highlighting the the many types of facilities constructed in a variety of geology with a plethora of methods.

As a UCA of SME member, you have complete use of SME's new digital library, OneMine.org. This online resource contains more than 40,000 documents and nearly 500,000 pages of current and historical material relevant to mining as well as underground construction. I encourage you to register and use this unique benefit as a UCA member. In January 2009, the SME staff will launch OneTunnel.org, the UCA's exclusive digital library. ■

PERSONAL NEWS

STEVEN KRAMER (SME), P.E., has joined Parsons Water and Infrastructure, a primary business unit of Parsons Corp., as vice president and business development manager. He will be responsible for leading sales and marketing initiatives in the eastern United States and internationally.


KRAMER

Previously, Kramer worked for Jacobs Engineering where he headed up its east coast infrastructure sales and technical development strategies. He has managed more than 50 projects for municipalities, utilities and transportation authorities in North America, Europe and Asia. ■

Atlas Copco hydraulic high pressure pump for Swellex rockbolt installation

Atlas Copco's Swellex H1 pressure pump was designed to provide a tool to customers for proper installation of Swellex rockbolts. The Swellex H1 mechanism is simple and tough. This assures high reliability, low maintenance costs and a long life. The pump is intended to be mounted on hydraulic drill rigs or powered by a separate power pack.

Swellex H1 is available in only a stainless steel version to resist corrosion for long life expectancy and low maintenance costs. The mechanism is simple and sturdy and the quality of bolt installation is definite. The operator has full control for completion of the bolt installation.

Atlas Copco Geotechnical Drilling and Exploration is a division within Atlas Copco's construction and mining technique business area. It develops, manufactures and markets equipment for exploration drilling and ground engineering.

Atlas Copco's Swellex H1 pressure pump.

www.atlascopco.com

Upgraded airflow anemometer available from Mine and Process Service

The PMA-2008 pocket mining anemometer is the second generation of battery-powered electronic anemometera for use in underground mining and construction.

Battery powered and small enough to fit into a shirt pocket, the pocket mining anemometer is certified as intrinsically safe by U.S. Mine Safety and Health Administration (MSHA). The new PMA-2008 anemometer adds an audible signal, to indicate when the 60-second count has started and ends. Also, the LCD can now be programmed to display in metric.

With the push of a button, the PMA-2008 pocket mining anemometer automatically takes a 60-second reading. It can also be stopped for partial readings of feet-of-air. An audible alarm informs the user when the count starts, stops and at 15-second intervals.

MPS pocket mining anemometer.

The pocket anemometer is well sealed so it can be submerged in water. If dropped into a puddle or sump, it floats.

No adjustments or calibration are required. After approximately 100 hours of use, the impeller assembly easily slides out for replacement. This is all that is required to ensure precise readings with the pocket anemometer.

Feet per minute mode allows for immediate checks of airspeeds behind line curtains, on longwall faces, over conveyor belts or anywhere air flow must be verified.

www.mpsinc.com

Innovative sweat bands for industrial work

Sweat GUTR is an innovative sweatband that protects worker's eyes from sweat by diverting the sweat away from the eyes rather than simply trying to absorb it like traditional sweatbands.

The Sweat GUTR sweatbands never saturates and is dry after use and is reuseable. It works well with hard hats, caps and safety glasses.

The GUTR also provides a heat stress management benifit that is superior to bandanas and wraps that cover the head.

It was designed with a slim profile to allow heat to escape from the top of the head, unimpeded. This assists the body to stay cool. ■

Sweat GUTR sweat band.

www.sweatgutr.com

October 2008

• **2, Channel Tunnel Rail Link: an urban success story seminar,** NYU Kimmel Center, New York, NY. Contact: Martin Ellwood, phone 212-695-2463, e-mail mellwood@mta-esa.org, Web site www.iceusa.org.

22-24, Underground Urban Infrastructure 2008, Wroclaw University of Technology, Wroclaw, Poland. Contact: Andrzej Kolonko, phone 48-71-320-2914, fax 48-71-328-1889, e-mail andrzej.kolonko@pwr.wroc.pl, Web site www.pwr.wroc.pl.

27-28, 20th National Conference, Tunneling Technology & The Environment, Sheraton Fallsview Hotel, Niagara Falls, Ontario, Canada. Contact: The Tunneling Association of Canada, phone 1-604-629-1736, e-mail info@tunnelcanada.ca, Web site www.tunnelcanada.ca.

November 2008

10-12, International Conference of Deep Excavations (ICDE) 2008, Suntec International Convention and Exhibition Center, Singapore. Contact: AV Consultants Pte, 1-B Aliwal Street, Chenn Leonn Building, Singapore 199894, phone 65-6735-6255, fax 65-6392-4090, e-mail events@avconsultants.com.sg, Web site www. icde2008singapore.org.

More meetings information can be accessed at the SME Web site — http://www.smenet.org.

February 2009

• **8-11, 35th Annual Conference on Explosives and Blasting Techniques,** Hyatt Regency, Denver CO. Contact: International Society of Explosives Engineers, 30325 Bainbridge Road, Cleveland, OH 44139, phone 440-349-4400, fax 440-349-3788, e-mail isee@isee.org, Web site www.isee.org

May 2009

23-28, 35th Annual ITA-AITES World Tunnel Congress, Budapest Congress and World Trade Center, Budapest, Hungary. Contact: phone 36-1-214-7701, fax 36-1-201-2680, e-mail secretariat@wtc2009.org, Web site www. wtc2009.org/00entry.htm.

June 2009

• **14-17, RETC 2009,** Las Vegas, NV. Contact: Meetings Dept., SME, 8307 Shaffer Parkway, Littleton, CO 80127, phone 800-763-3132 or 303-973-9550, fax 303-979-3461, e-mail sme@smenet.org, Web site www.smenet.org.

• **22-25, 5th Symposium on Strait Crossings,** Trondheim, Norway. Contact: Strait Crossings 2009, NTNU VIDERE, Pavilion A, Dragvoll, NO-7491 Trondheim, Norway, Attn: Astrid Bye/Jorunn Sommervold, phone 47-73-59-52-54 or 47-73-55-04-41, fax 47-73-59-51-50, e-mail sc09@adm.ntnu.no, Web site www. straitcrossings.com. ■

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