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TUNNELING & UNDERGROUND CONSTRUCTION

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TUNNELING UNDER THE HUDSON RIVER

Disc Cutter Design, Development

George A. Fox Conference Highlights

Special Editorial Section from the publisher of *Mining Engineering*

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Special editorial section from the publisher of *Mining Engineering*

CONTENTS

COVER STORY

CONTENTS — When completed in 2017, the Mass Transit Tunnel two-track line will double commuter capacity traffic. The $8.7-billion project will be built under the Hudson River, connecting New Jersey and New York City. Details of this massive underground construction project begin on page 22. Cover drawing courtesy of the Mass Transit Tunnel Project.

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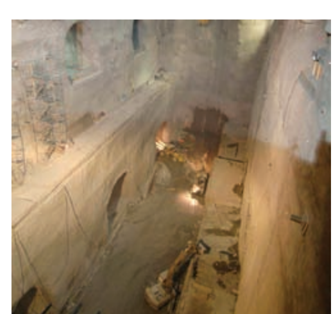
FEATURE ARTICLES



DEPARTMENTS

CHAIRMAN'S COLUMN

Latest legacy projects approved

To the credit of regional stakeholders on both coasts of the United States, the recent approvals of two major tunneling projects mark a turning point in the minds and understanding of the benefits of tunneling and underground construction by public and private stakeholders. The first is the large bore tunnel to replace the Alaskan Way Viaduct along the Seattle, WA waterfront. The second is the Hudson Express tunnel that will provide additional rail capacity between New Jersey and New York City under the Hudson River and into Penn Station. The Hudson Express, or THE Tunnel, has set records in advancing a major public works project through the early planning and the environmental impact statement process with a record of decision, signaling what is possible with common goals among regional stakeholders (see page 22).

The Alaskan Way Replacement Program also has advanced at a fast pace because of the necessity to replace an aging elevated highway along the Seattle waterfront. This project has been under evaluation for about eight years and the governor announced in December the selection of the large bore tunnel alternative. John White of the Washington State Department of Transportation (WSDOT) attended the George Fox Conference in January to reach into the tunneling community. To assist further, UCA is helping WSDOT to plan a one-day conference with an expanded dialogue about the project, the community and the process to move the project toward design and construction. The Alaskan Way Replacement conference tentatively is planned for late April or early May 2009.

These two projects serve as examples to other regions in demonstrating leadership and a process that engaged the various stakeholders. Both projects will provide regional stimulus in the short term through construction jobs. In the longer term, they will provide improved mobility, capacity and accessibility. At the same time, they will minimize the impacts to the surface and near-surface facilities as well as the impacts on the environment, disruption of businesses, traffic and the lives of those along the tunnel alignment.

The Alaskan Way Viaduct and THE Tunnel projects are just two examples of the many projects that are slated for construction in the near term. Each will provide much needed solutions to improving water and wastewater and utility systems across the United States, as well as the increasing demand for public transportation in response to the call for energy conservation and environmental stewardship.

"Benefits of Going Underground." Many of the benefits of building underground have been captured in a PowerPoint presentation produced by the UCA Task Force, chaired by Amanda Elioff. This file was developed to highlight the facilities, merit and opportunities derived from "building underground." I used a version of this slide show during a student outreach lecture at Penn State to demonstrate the career opportunities available in the underground industry. This file will soon be available on the UCA Web site for UCA members. Stay tuned for the notice of file availability.

2009 Fox Conference sets new record. Thanks to a solid slate of presentations and keynote speakers, the 2009 Fox Conference reset the bar for interest, attracting more than 300 people (see page 35). Many thanks go to Lonnie Jacobs of Frontier Kemper and the Fox Conference planning committee for their hard work and continued success. I would also like to thank our many sponsors without whom these conferences would not be possible.

Brenda Bohlke,
UCA of SME Chairman

Budget crunch halts Caldecott tunnel project

The California Transportation Commission froze funding for a long-awaited fourth bore for the Caldecott Tunnel in Berkeley-Orinda County. It was one of 27 projects that had been scheduled to receive part of $293.5 million in state funding.

Because of the state budget crisis and the world credit crunch, the state lacks the money to release money for even those projects that are funded by bond measures.

The $420 million Caldecott Tunnel project would add a fourth bore to the busy tunnel complex on State Highway 24 (SH-24) to connect Contra Costa and Alameda counties. The project depends on $194.5 million in funds from the transportation infrastructure bonds voters approved in 2006.

With that funding frozen, the project cannot move ahead with plans to solicit bids for the tunnel construction and for two related projects to reconfigure an Oakland street and a highway interchange.

The existing Caldecott Tunnel carries SR-24 in northern California. SR-24 carries eight lanes of traffic, four in each direction, except at the Cadlecott tunnel where there are six lanes in three bores. The south bore carries eastbound traffic and the north bore carries westbound traffic. The center bore direction changes depending on traffic demand. It typically switches twice a day on weekdays and as many as five times a day on weekends, depending on events in the area. The fourth bore will allow for four lanes of traffic in each direction.

Bob McCleary, executive director of the Contra Costa Transportation Authority, the agency that is coordinating the fourth-bore project, told the *San Francisco Chronicle* that he was disappointed but not surprised by the commission's decision.

Gov. Arnold Schwarzenegger issued a statement shortly after the commission's action saying it "illustrates why the legislature needs to come together on a compromise for solving California's budget crisis — and why we are working around the clock on the issue."

Benjamin DeLanty, a Caltrans spokesman, described the impact of the commission's decision to freeze funding as "staggering. It means a loss of economic impact, and jobs — a loss of work on our infrastructure and a tremendous challenge we face on working out the details of how to get this back on track and funded." ■

North Shore Connector could be halted without stimulus package

Without help from President Barack Obama's proposed $825 billion stimulus package, work on Pittsburgh's North Shore Connector might come to a halt, Port Authority officials said.

The North Shore Connector project will extend the Port Authority's 40-km (25-mile) trolley line from downtown to the neighborhood where Heinz Field, PNC Park and the future site of a slot machine casino are located.

The twin underwater tunnels have been bored but workers must still install tracks and build new passenger stations at Gateway Center and on the North Shore.

The tunnel boring machine used to mine twin tunnels under the Allegheny River finished boring the second tunnel, arriving at a launch pit adjacent to PNC Park in mid-January. Mining work for the second tunnel began in October 2008, when the machine left the receiving pit in downtown Pittsburgh and bored under the river at a rate of about 10-m/d (34-ft/day). Mining on the first tunnel began in January 2008.

Port Authority chief executive officer Steve Bland said the cost of boring under the Allegheny River for the north shore connector actually came in $6 million under budget. Bland said it's the projected cost of finishing the above ground portion that's the problem.

"The rails, the signals, the power substations, what have you – that's what's driving the overall budget over, not the tunneling at all," Bland told WTAE in Pittsburgh.

The transit system said there's enough money to keep working on the North Shore Connector for the rest of this year. But it projects finishing the job will cost nearly $118 million more than the original $435 million planned.

Port Authority officials said cost overruns for the North Shore Connector result from the rising prices of construction materials, such as steel and concrete — major components of the tunnels and three T stations.

Port Authority officials hope President Obama's proposed $825 billion economic stimulus package will pay the added cost.

Halting work would cost about $21 million. The authority would have spent about $281 million on work that it has authorized.

Two sets of tracks will be built over the 2-km (1.2-mile) expansion from downtown's Gateway Center station to an end point not far from Heinz Field and a casino under construction. ■

Prairie Water projects uses Akkerman microtunneling and conventional methods

Aurora, CO's Prairie Waters Project is the first large-scale water re-use project in the state's history. It is slated for completion in 2010. When completed, water will be pumped from the South Platte River, undergo a six-step treatment process and ultimately replenish the now sparse drinking water situation.

The $754 million project was selected from 54 other bid packages as the most environmentally friendly, cost effective and best long-term solution for the current drought condition. The Prairie Water Project's goal is to make the treated river water taste indistinguishable from the current mountain runoff water. The project will exceed the federal government's two-step treatment process. The outcome will increase the City of Aurora's water supply by 20 percent.

Contractor for trenchless installations, BTrenchless, a Division of BT Construction, Inc. of Henderson, CO, will jack 1.9 and 2.1 m (78 and 79 in.) outside diameter (OD) steeling casing pipe using microtunneling and tunnel boring machine (TBM) methods. Using its new Akkerman microtunnel boring machine (MTBM) SL 74, microtunneling system and 5000 series pipejacking system with TBM 660 at 2.1 m (79 in.) OD, the contractor will complete 10 drives. Of these 10 trenchless crossings, six will be completed with the microtunneling system and three with the conventional pipejacking system and one with the hammer ramming method. The total 865 liner m (2,832 lft) of trenchless crossings range in length from 12 to 182 m (40 to 596 ft) with various shaft depths from 4.6 to 15 m (15 to 50 ft) at a 2 percent grade.

BTrenchless has also been awarded the next phase of the Prairie Waters Project to complete two additional tunnels. One 55 linear m (182 lft) drive will be completed with the microtunneling system to push 1.9 m (78 in.) pipe underneath the Union Pacific Railroad, and another 101 linear m (332 lft) drive pushing 2.1 m (79 in.) pipe underneath Interstate 70 with the 5000 pipejacking system.

Slurry microtunneling methods were chosen in order to avoid the need to secure federal permitting and will be necessary for many of the drives where high levels of ground water will be encountered. The crossings need to meet strict guidelines for grade and surface settlement due to buried utilities and active overhead highways and railroad lines. Many of the drives will be completed in seasonal irrigation waterways and seven drives exist in the Federal Emergency Management Agency (FEMA) 100-year floodplain. Microtunneling and conventional pipejacking allow the contractor to accurately jack pipe sections on line and grade through the use of a laser guidance system.

To date, BTrenchless has completed three crossings, 279 m (917 ft) with its Akkerman microtunneling system and 180 m (596 ft) with its TBM system. This phase of the Prairie Waters Project is slated for completion in November 2010. ■

University of Minnesota steam tunnels nearing completion

A $10 million deep steam tunnel extension project at the University of Minnesota is expected to be completed in the fall of 2009.

The new tunnels will bring 457 m (1,500 ft) of new steam tunnel infrastructure to two buildings on the university campus including the $60 million Medial Bioscience Building and the $288 million TCF Stadium.

Buried 24 m (80 ft) underground, the tunnel will connect to an existing steam tunnel system that snakes throughout the university campus and funnels heat from the university's central steam plant.

The "central steam infrastructure" will allow the university to tap into a combination of fuel oil, coal, wood and oat hulls, something that would not be possible with a stand-alone building boiler.

Tunnel construction began in June 2007 with the use of a roadheader. Workers are now installing the steam pipes, which are expected to be ready by the time the Golden Gophers football team begins playing in their new stadium this fall. ■

Robbins machine embarks on hydropower tunnel

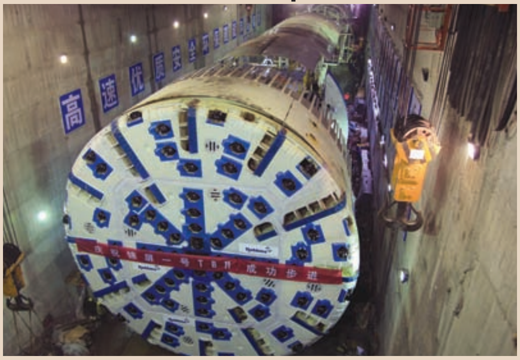
A 12.43-m- (40-ft-) diameter Robbins tunnel boring machine (TBM) was launched in September at the 16.7-km- (10.4-mile-) long hydropower tunnel in Sichuan Province, China. The machine will bore one of four headrace tunnels that will draw water from the nearby Yalong River, a tributary of the Yangtze. The large TBM will join another 7.2-m- (23.7-ft-) diameter Robbins machine, that was launched earlier in 2008 to bore a drainage tunnel on the same project.

Assembly of the Main Beam TBM and backup system began in mid-April 2008 at the Jinping-II headrace tunnel No. 1 and finished on Aug. 11. Crews then walked the TBM and the first three backup gantries 200 m (650 ft) forward to a launch chamber, where the conveyor system and six more gantries were assembled.

"Everything has gone remarkably well in retrospect. Of course, we had problems, but our onsite assembly team was able to manage them as they occurred without adversely affecting the assembly process. The machine assembly was completed on schedule and no-load testing of all critical systems has gone smoothly. Now, we are prepared to begin a 1,000-m- (3,280-ft-) long test boring program to fully commission the equipment," said Steve Smading, Robbins project manager.

The machine was assembled in an underground launch chamber using Onsite First Time Assembly (OFTA). OFTA, without pre-erection in a manufacturing facility, has eliminated many shipping risks to the remote jobsite. The accelerated assembly schedule meant most of the heavy TBM structures were already shipped from the manufacturing facility in Dalian, ahead of the low water season on the Yangtze River when such shipments are not possible.

The 12.43-m- (40.1-ft-) diameter Robbins TBM was launched on Sept. 18, 2008.



Due to go online in 2010, the Jinping-II hydropower station will use a natural 180° bend of the Yalong River, resulting in a 60-m (200-ft) drop in elevation to generate 4800 MW of electricity annually. The project, for owner Ertan Hydropower Development Co. Ltd., is located 17 km (10.5 miles) downstream from the Jinping-I hydropower station, which is slated for completion in 2014 and will have an annual generating capacity of 3,600 MW. ■

Robbins opens office in Hong Kong

Robbins has opened an office in Hong Kong to help push business development in the Asia Pacific region.

The company said the new operation – Robbins Asia Pacific Pty. Ltd. – will focus on expanding the regional earth pressure balance (EPB) machine market and also support hard rock tunnel boring machine (TBM) and small diameter boring.

Headed by David Salisbury, the new branch is in Kowloon and will cover East Asia and Australia but not China or India, as the company already has three offices elsewhere in Asia. The new branch will also cover the Middle East. Salisbury was formerly with Arup in Hong Kong.

The branch is to focus on sales, technical support and procurement. Going forward, it will be built up to also provide engineering, field service and other support. It is also to help the development of the company's manufacturing facility in Guangzhou, which is due to be operational by the middle of next year.

Salisbury said: "Fabrication and procurement of components from local sources has the potential to make machine assembly quicker and more efficient." He also said that the location of other offices meant it was difficult to have rapid, face-to-face meetings with East Asian customers. ■

How the decision came about to replace the Alaskan Way Viaduct with a tunnel

On Jan. 13, 2009, in Seattle, WA, Governor Chris Gregoire, King County Executive Ron Sims and Seattle Mayor Greg Nickels signed an agreement to demolish the earthquake-damaged Alaskan Way Viaduct and build a 16.5-m- (54-ft-) diameter, four-lane, two-level, deep bored tunnel under downtown Seattle to be open to traffic in 2015 – requiring accelerated environmental, design and construction.

This reversed a decision exactly one month earlier for two alternates that did not incorporate any tunnels, primarily because the predicted tunnel cost exceeded available funds. A stakeholders group of all interested parties rejected that decision and requested that a tunnel option be considered. What followed was an immediate groundswell of strong support for a deep-bored bypass tunnel, mostly from downtown Seattle business leaders and the Cascadia Center. The Washington State Department of Transportation (WSDOT) spent the next month intensely evaluating the deep-bore option for the city, state and county leaders who agreed with the consensus of the stakeholders and overcame funding constraints. With this decision, the WSDOT selected the deep bored tunnel for environmental documentation, design and construction on Jan. 13.

Harvey Parker and John Reilly

Harvey Parker, member UCA of SME, **is** past President of International Tunnelling and Underground Space Association (ITA), and president, Harvey Parker & Associates Inc, e-mail harveyparker@compuserve.com, **John Reilly**, member UCA of SME, is past president AUA, and is president John Reilly Associates Int. e-mail jjreils@attglobal.net.

This announcement followed more than seven years of planning, debates, proposals, citizen votes, twists-and-turns and counter proposals in one of the most environmentally sensitive and politically active regions of North America. Considered were cut-and-cover tunnels and trenches and elevated replacements along the Puget Sound waterfront plus several alignments of bored tunnels under city streets. There were thousands of hours spent on planning, technical analysis, public meetings, letters and e-mails from the public, interest groups and local jurisdictions.

Associated investments will include new buses and transit services and a new streetcar line. The total investments are \$4.2 billion — \$2.8 billion is associated with the tunnel, of which \$2.4 billion has been voted by the legislature. Tolling is expected to provide the remaining \$400 million.

The 3.5-km (2.2-mile) double-decker viaduct was built in the 1950s to accommodate 65,000 vehicles per day. Currently, about 110,000 vehicles use the viaduct on a daily basis.

In 2001, a 6.8 earthquake damaged the viaduct. It was also determined that the sea wall that supports the viaduct needs to be replaced.

So how did we finally get the decision on the tunnel, more than seven years after it was first outlined?

The answer is that many dedicated people – citizens, governmental, political, planners, environmental, engineers, key stakeholders needed to be involved. All the right elements needed to be in place and they needed to all align at one point in time. The right point in time. Some of the factors include:

- Political will/commitment (governor, mayor, county executive, city council members, legislature).
- Pressure for a decision from the public and key stakeholders including a long-term concerted effort by the Cascadia Center favoring a tunnel option.
- Key stakeholders in agreement and determination to move ahead.
- Key proponents to push key issues at the right time (need not be all at the same time). For Seattle, proponents included the Chamber of Commerce, Stakeholder's Advisory Committee, Downtown Seattle Association, business interests, labor unions, the Cascadia Center and others. Groups that were passionate to find the right solution and commit to finding money to make it work. Groups that did not accept the alternatives proposed (an elevated replacement blocking the waterfront and an insufficient surface-only option).
- A good reason to pick the tunnel solution and find the funding, considering long-term, life-cycle benefits.
- Technical feasibility — successful technology that is suitable for the work. A 16.5-m- (54-ft-) diameter tunnel boring machine (TBM) is now feasible and success can be demonstrated from other applications – see the WSDOT Web site http://www.wsdot.wa.gov/projects/Viaduct/ and Legislative briefing materials.
- Credible cost definition and a range of probable costs – other examples, WSDOT's CEVP.
- Competent consultants - PB, Jacobs Engineering, HMM, ARUP, Shannon & Wilson and many others. ■

THE Tunnel Project receives record of decision

The Trans Hudson Expressway Tunnel project (THE tunnel), a multibillion dollar New York-New Jersey rail tunnel project, took a major leap forward when the project officially completed the federal environmental review process.

The Federal Transit Administration's release of a record of decision on Jan. 14 cleared the way for New Jersey to receive federal matching funds for the project. The local financing share of $5.7 billion is already in place (see story page 22).

New Jersey Sens. Frank Lautenberg and Robert Menendez estimate the project will create 44,000 permanent jobs when completed in 2017.

Known as Access to the Region's Core, or ARC, a new Trans-Hudson Express tunnel would double the number of trains that can travel under the Hudson River between New York and New Jersey to 48 per hour, from 23 now. The extra train service is expected to eliminate 22,000 automobile trips a day.

The new service also would allow more New Jersey Transit riders to reach New York without having to change trains in Newark or Secaucus. A second tunnel would also relieve pressure on the century-old tunnel that New Jersey Transit shares with Amtrak. The project's six new tracks in Manhattan, which would terminate beneath 34th Street, would also allow commuters to connect underground to the subways and PATH trains at Avenue of the Americas.

The tunnel is the centerpiece of the Access to the Region's Core project, which will double train capacity into and out of Manhattan by adding two single-track tunnels under the Hudson River, expanding Penn Station in New York and funding track and signal improvements along the segment of the Northeast Corridor rail line between Newark and New York. ■

ITA • AITES 2010

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Tunnel Vision Towards 2020

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One of the most important International meetings will take place in Vancouver, Canada, May 14 – 20, 2010 at the Vancouver Convention & Exhibition Centre. The meeting's focus will be on recent major developments in tunnelling research, design, management and construction. The new knowledge and experience presented at the meeting will be shared by approximately 1000 attendees from industry, private and public sector including universities.

Under a theme of «Tunnel Vision Towards 2020», the technical program committee, comprised of leading industry leaders, practitioners and researchers from Canada is planning an exciting program.

We look forward to welcoming you in the vibrant city of Vancouver!

Technical Topics

1. Innovative Techniques and Advances in Geotechnical Investigations for Tunnel Projects
2. Tunnelling in Soft Ground
3. Hard Rock Tunnelling
4. Tunnelling in Weak Rock
5. Tunnelling under High Stress Conditions
6. New Advances and Innovation in Mechanized Tunnelling
7. Tunnelling under Sensitive Structures
8. Geotechnical Instrumentation and Monitoring
9. Shafts and Tunnels for Mining Projects
10. The Use of Underground Space
11. New Advances in Rehabilitation and Repair
12. Risk Assessments
13. New Advances in Contract Practices and Procurement
14. Financing of Tunnel Projects
15. Insurance for Tunnel Projects
16. Innovation and Research for Tunnelling

Important Dates

Important Dates	
Call for Abstracts	April 1, 2009
Abstract Submission Deadline	July 1, 2009
Notice of Acceptance	October 1, 2009
Deadline for Final Papers	February 1, 2010
Early Registration Deadline	March 15, 2010
Accommodation Deadline	April 1, 2010

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MARCH 2009

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Makers of Underground History

HC Global – Taking on tunnels

Known for work both in the tunneling and mining industries, Pennsylvania firms Wholesale Mine Supply and its division HC Global recent wrapped another major project – Brightwater East in Washington state.

The project in Bothell, consisting of a 14,000-foot-diameter tunnel located approximately 260 feet below ground at its deepest point, was started in September of 2007 under the direction of firm Kenny/Shea/Traylor. The tunnel will encompass two pipelines to carry untreated water to the new Brightwater treatment facility, scheduled to start in 2011.

According HC Global, who oversaw the Varis communications installation on the project, the tunnel will also contain an independent effluent pipeline that will allow highly-treated wastewater to travel to a deep water outfall in the Puget Sound, along with a separate purple pipeline for reclaimed water.

Varis was selected by project managers for installation at Brightwater because of its robust features and diverse abilities, the companies said.

"The Brightwater project was staged at our shop in Irwin, Pennsylvania, then shipped to the job site for plug-and-play installation," said HC Global's Alan Quinn of the project, "We were able to have the system working end to end within hours."

WMS president Bill Hensler added: "HC Global has grown beyond our wildest expectations and has become the leader in tunneling communications in the US. We have over 25 years of underground communications experience and more than 173 systems installed nationwide."

HC Global and its Varis system has been chosen for a collection of large, high-profile tunneling projects in recent years, including the Washington sister project Brightwater West, the Beacon Hill Project and the highly-anticipated North Shore underwater tunnel in Pittsburgh, Pennsylvania.

In 2009, HC Global plans to continue work on a tunnel rehabilitation project in Minnesota, a drainage tunnel it joined with PCI Roads to complete.

"PCI worked with us, and this system worked great - as soon as we powered it up. We had to work in -18 degree weather," Quinn noted.

"He told us that it works great and they can't believe the difference from our system to the other systems they have had in the past. This was system was not a hard install but was in harsh conditions and shows that our system is very rugged and is made for all types of environments."

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Mining Equipment builds new Jetair Axiflow Fans up to 500 horsepower and 84-inch diameter. They developed a line of Super-Silenced™ Fans that run quieter and take up less space than other integrated fan and silencers. They also roll steel ventilation ducting on-site. Ducting as small as 12-inch and as large as 84-inch can be rolled.

Mine Hoists International is a fully-owned subsidiary of Mining Equipment. Based in North Bay, Ontario, Mine Hoists boasts the largest selection of used mine hoists and stage winches in the world. MHI has more than 35 mine hoists in inventory and 60 stage winches up to 80,000 lbs. capacity.

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Jennmar knows it is important for our customers to have their supplier nearby, so we put our plants where the mining is. Jennmar is just a few hours from most of our customers, that way we can guarantee superior customer service and product availability.

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Performance Characteristics

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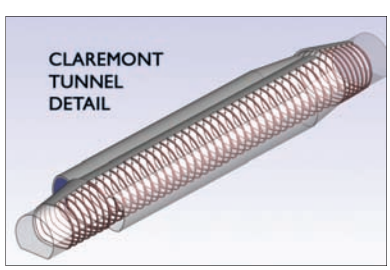

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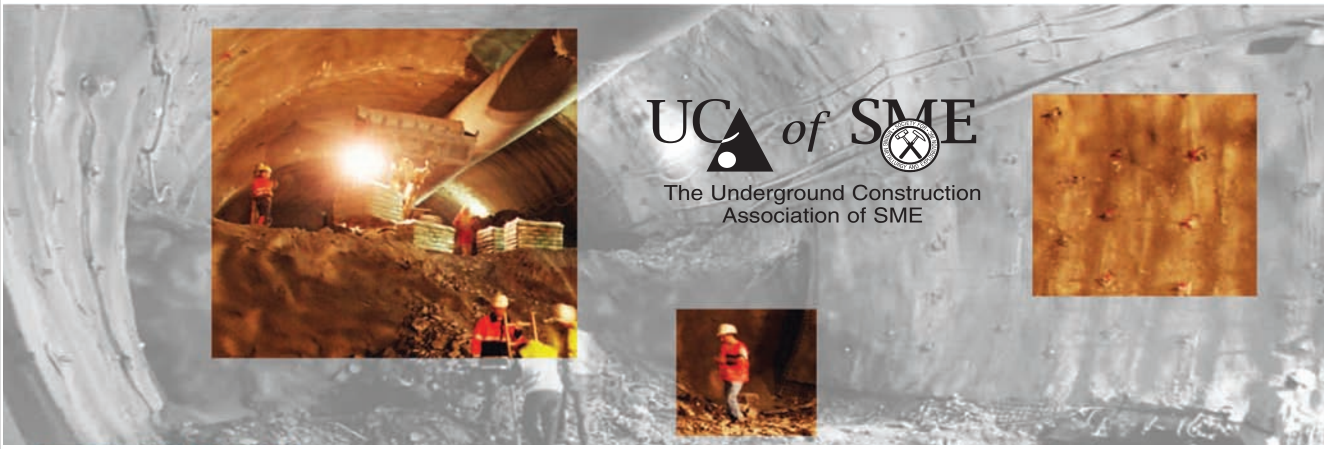

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TUNNEL NAME	OWNER	LOCATION		TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
County Grounds Tunnel	Milwaukee Metro Sewerage District	Milwaukee	WI	Flood management	2,700	17	2008	Shea-Kenny JV low bid
Bi-County Water Tunnel	Washington Suburban Sanitary Commission (WSSC)	Laurel	MD	Water	28,000	10-12	2008	Under design
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	Pipe Jacking Unlimited; Shank/ B-B low bids
New Crystal Springs Bypass Tunnel	S.F. Public Utility Commission	San Francisco	CA	Water	4,200	13	2008	Shank/B-B low bid
Bay Tunnel	S.F. Public Utility Commission	San Francisco	CA	Water	25,000	9	2009	Advertising 1st Q, 2009
New Irvington	S.F. Public Utility Commission	San Francisco	CA	Water	18,200	12-13	2009	Advertising May 2009
Upper Rouge CSO North Segment South Segment	Detroit Water & Sewage Authority	Detroit	MI	CSO Sewer	18,500 18,500	30 30	2008 2008	Bids 12/09; Kenny/ Obayashi low bid
Harbor Siphons Tunnel	NYC-DEP	New York	NY	Water	10,000	10	2009	Advertising late 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	2009	Advertising May 2009
SVRT BART	Santa Clara Valley Tranportation Auth.	San Jose	CA	Subway	22,700 twin	20	2010	Under design
Univ. Link Light Rail Extension UW Tunnels Capitol Hill Tunnels	Sound Transit	 Seattle Seattle	 WA WA	 Rail Rail	 12,000 x 2 3,800 x 2	 22 22	 2009 2009	Advertising 1st Q 2009; Advertising July 2009
Sewer replacement	Miami Dade	Miami	FL	Sewer		5	2010	Under design
Market St. Drainage Improvements	City of Charleston	Charleston	SC	Sewer	3,000	10	2010	Under design
South River Tunnel	City of Atlanta	Atlanta	GA	Wastewater	9,000	14	2008	Gilbert Southern, Low bid
W. Corridor LRT Tunnel	Transit Authority	Denver	CO	LRT	280 x 2	18	2009	Under design
Drummanard Tunnel	Kentucky DOT	Louisville	KY	Highway	2,200 x 2	35	2010	Under design
Drummanard Tunnel - Pilot Tunnel	Kentucky DOT	Lousiville	KY	Highway	2,200	12 x 12	2009	Bid 2009

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TUNNEL NAME	OWNER	LOCATION		TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Caldecott 4th Bore	CALTRANS	San Francisco	CA	Highway	5,000	50	2009	Postponed
Near Surface Interceptors	Narragansett Bay Commission	Providence	RI	Sewer	19,500 11,000	3-6 3-6	2008	Preliminary design
Lockbourne Interceptor System	City of Columbus	Columbus	OH	Sewer	10,000	12	2009	Under design
Alum Creek Relief Sewer	City of Columbus	Columbus	OH	Sewer	26,000	10	2010	Under design
OSIS Aug. & Relief Sewer	City of Columbus	Columbus	OH	Sewer	25,300	18	2010	Under design
Olentangy Relief Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2012	Under design
Water Tunnel #3	NYC Dept. of Envir. Protection	New York	NY	Fresh	24,000	20	2010	Under design
ESA Queens Tunnel	NYCTA-MTA	New York	NY	Subway	10,500	20	2008	Bids under evaluation
Corvalis to Fox Mill Water Main	Fairfax County Water Authority	Fairfax	VA	Water	8,600	8	2009	Advertising 12/10/08
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	2010	Under design
Hudson River Crossing	NJ TRANSIT Board THE Tunnel Program	Newark	NJ	Subway	8,000 x 2	20	2009	Under design
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 Regional Conveyance Tunnel	Northern KY Sanitation District	Covington	KY	Sewer	36,000	13	2008-2012	Renda/ Southland low bidder
Waller Creek Tunnel	City of Austin	Austin	TX	Highway	5,300 x 2	60 x 35	2010	Under design
San Francisco DTX	Transbay Joint Powers Authority	San Francisco	CA	Transit	6,000	35 to 50	2012	Conceptual design
WASA CSO Program -Phase I Blue Plains tunnel Antacostia River Tunnel Northeast Branch Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	63,360	 23 23 23 23	 2008 2010 2011 2020	PM/GEC Bid Bid Bid
Snapfinger Interplant CSO Tunnel	DeKalb County	Decatur	GA	CSO	26,400	28	2010	Under design
Southeast Collector Trunk Sewer	York Region	Markham	ON	Sewer	15 km	10	2010	Under design
Spadina Line Extenstion	Toronto Transit Commission	Toronto	ON	Subway	8.6 km	20	2010	Under design

New York-New Jersey's Mass Transit Tunnel moves ahead

The Mass Transit Tunnel, an $8.7-billion project, will help reduce road traffic between New Jersey and New York, pictured here, by doubling the rail capacity under the Hudson River.

The economic success and growth of any metropolitan region depends on mobility. Today, mobility between New Jersey and New York is threatened by a transportation system that cannot meet 21st century travel demands. The transportation bottleneck created by the Hudson River threatens the viability of one of the world's great centers of commerce and culture. Fortunately, there is a solution: The Access to the Region's Core Mass Transit Tunnel.

The US$8.7-billion Mass Transit Tunnel's (MTT) new two-track line will double commuter rail capacity under the Hudson and create a new, state-of-the-art cavern station in Midtown Manhattan, with wide platforms, high-speed escalators and other features to improve riders' travel experience. The capacity and other benefits of the MTT project will launch a new era of prosperity for the region, just as the Pennsylvania Railroad did almost 100 years ago when it built the existing two, single-track rail tunnels that now form the sole commuter rail link between New Jersey and New York. The existing tunnels run from North Bergen, NJ, under the Hudson River to Pennsylvania Station at 33rd Street in Manhattan.

Construction on the MTT, the largest public works project in the United States, is scheduled to start this year and continue through 2017.

Arthur D. Silber

Arthur D. Silber, member UCA of SME, is project chief of the Mass Transit Tunnel project, New Jersey Transit, e-mail info@thethunnelproject.com.

The MTT is ready to go to construction thanks to a major commitment of financial, engineering, project management and other resources from NJ TRANSIT, New Jersey's statewide mass transit agency, and the Port Authority of New York and New Jersey, a bistate agency that operates the Holland and Lincoln tunnels, the George Washington Bridge and other major transportation facilities in New York and New Jersey. The project is also strongly supported by the state governments of New York and New Jersey, as well as that of New York City. The MTT is New Jersey Governor Jon Corzine's number one transportation priority.

Key infrastructure elements of the project include:

- A new direct connection at Secaucus, N.J. between NJ Transit's Main, Bergen County and Pascack Valley lines and the Northeast Corridor (NEC) in New Jersey;
- New track capacity along the NEC between Frank R. Lautenberg Station in Secaucus and the Palisades in New Jersey;
- Two new single-track tunnels under the Palisades in New Jersey and the Hudson River, with continuation of these two tunnels under the west side of Manhattan;
- A new underground cavern station (new Penn Station Expansion NYPSE) under West 34th Street between Eighth and Sixth Avenues, adjacent to existing Penn Station New York;
- A mid-day train storage yard in Kearny, NJ;
- Five NYPSE station entrances, Americans with Disabilities Act (ADA)-compliant elevator entrances, and
- One fan plants/construction access shafts in New Jersey and four fan plants/construction access shafts in Manhattan.

Construction will be contracted for about 25 defined-scope contracts, each of which will have a relatively short duration to match specialized contractors with specific work scopes.

Like the Pennsylvania Railroad's tunnels, the ARC MTT was born of transportation necessity.

Since 1982, NJ TRANSIT ridership to New York Penn Station has quadrupled to 46 million passenger trips a year. Planners expect that number to double again in the next 20 years. The continued growth of commuting is being driven by two major factors. Manhattan continues to be a world-class center of commerce, offering a multitude of employment opportunities. Meanwhile, New Jersey offers a range of attractive homes in communities featuring an enviable quality of life. The result of this close bistate relationship is that commuter rail ridership demand now outstrips the carrying capacity of the existing rail tunnels, creating a bottleneck that inconveniences passengers and threatens regional prosperity.

NJ TRANSIT and the Port Authority began planning some 15 years ago to add trans-Hudson capacity, performing a major investment study that detailed the need for a new rail tunnel. This was followed by a series of environmental impact studies, which were finalized by the Federal Transit Administration (FTA) in November. The FTA then issued the MTT a Record of Decision in January, making the MTT eligible for final design and to receive federal construction funding.

The New York Penn Station Expansion will include a three-over-three track platform and mezzanine in the middle left, 46-m (150-ft) below street level at Seventh Ave. in Manhattan.

Project alignment

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

The two tunnels will traverse through the Palisades at an average depth of 61 m (200 ft) and then continue under the Hudson approximately 15 m (50 ft) under the riverbed. When the tunnels reach Manhattan, they will navigate a course 31 to 44 m (100 to 145 ft) below street level, traveling beneath 34th Street to Sixth Avenue. The total length of the tunnels will be approximately 5.5 km (3.4 miles) each. Cross-passages between the tunnels will be constructed at approximately 244-m (800-ft) intervals.

At its eastern end, the tunnel will connect with a new, modern underground cavern station, called the New York Penn Station Expansion. This facility will be adjacent to the existing station at a depth of 46 m (150 ft) beneath Seventh Avenue at the new station's mezzanine. The station will include a three-over-three track/platform arrangement between Eighth and Sixth Avenues, with a spacious mezzanine in the middle level.

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

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

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

Meanwhile, local funding for the project is committed, thanks to a commitment of $2.7 billion from New Jersey and $3 billion for the Port Authority of New York and New Jersey. The federal government has indicated its intent to provide $3 billion to fully fund the project's cost. These negotiations are expected to proceed quickly, allowing the MTT to obtain construction bids for the first three major contracts, the design-build contracts for the tunnel sections under the New Jersey Palisades, under the Hudson River and under Manhattan.

Geology

Extensive studies of the geological conditions along the tunnel alignment have included borings, sample investigations and geophysical testing. The results show that the geology varies significantly at different sections of the alignment, presenting unique challenges.

The project area's western portion is underlain by rocks of the Newark Basin, a northeast-trending late Triassic-early Jurassic rift basin filled with a thick sequence of sedimentary rocks, and intrusive and extrusive igneous rocks.

The eastern portion of the project area is underlain by a deeply eroded assemblage of folded and faulted Proterozoic-to Ordovician-age metamorphic and igneous rocks.

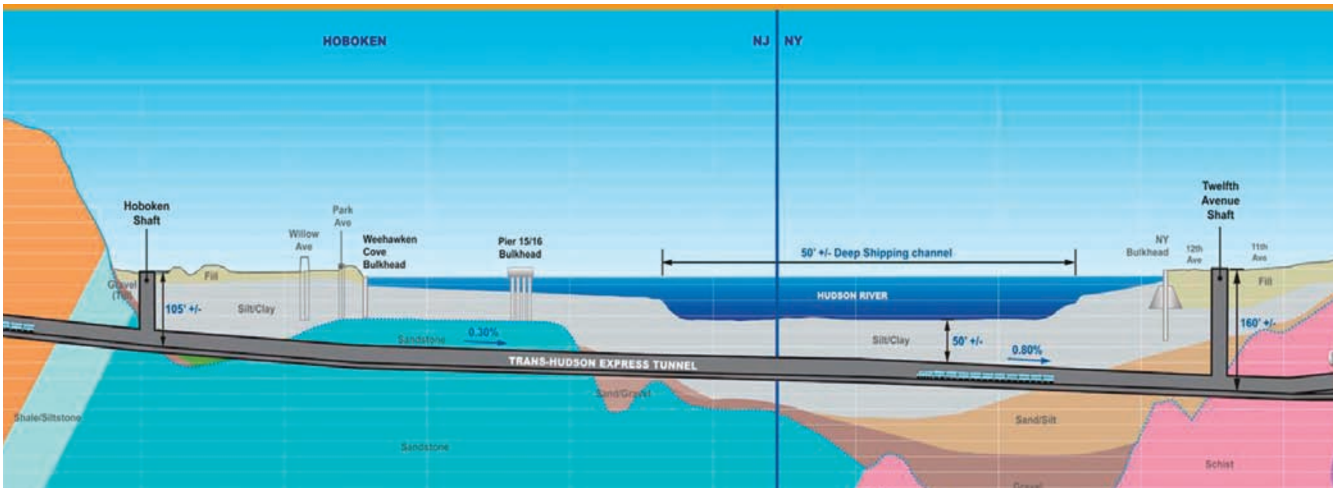
Starting at the western portal, the Palisades tunnels will traverse around 1,463 m (4,800 ft) of diabase (dolorite), almost the full thickness of Jurassic-age Palisades diabase sill. Chilled margins and baked contacts are generally concordant with bedding of the surrounding sedimentary rocks and nearly orthogonal to the tunnel alignment. The fine-grained phases of the diabase exhibit exceptionally high strength. At least two steeply normal faults are anticipated.

Continuing beneath the east side of the Palisades ridge, the tunnels will penetrate a 183-m- (600-ft-)long sequence of hornfels, interbedded shale, mudstone and siltstone of the Triassic-age Lockatong formation, and arkosic sandstone with interbedded conglomerate and siltstone of the Stockton Formation, also Triassic-age.

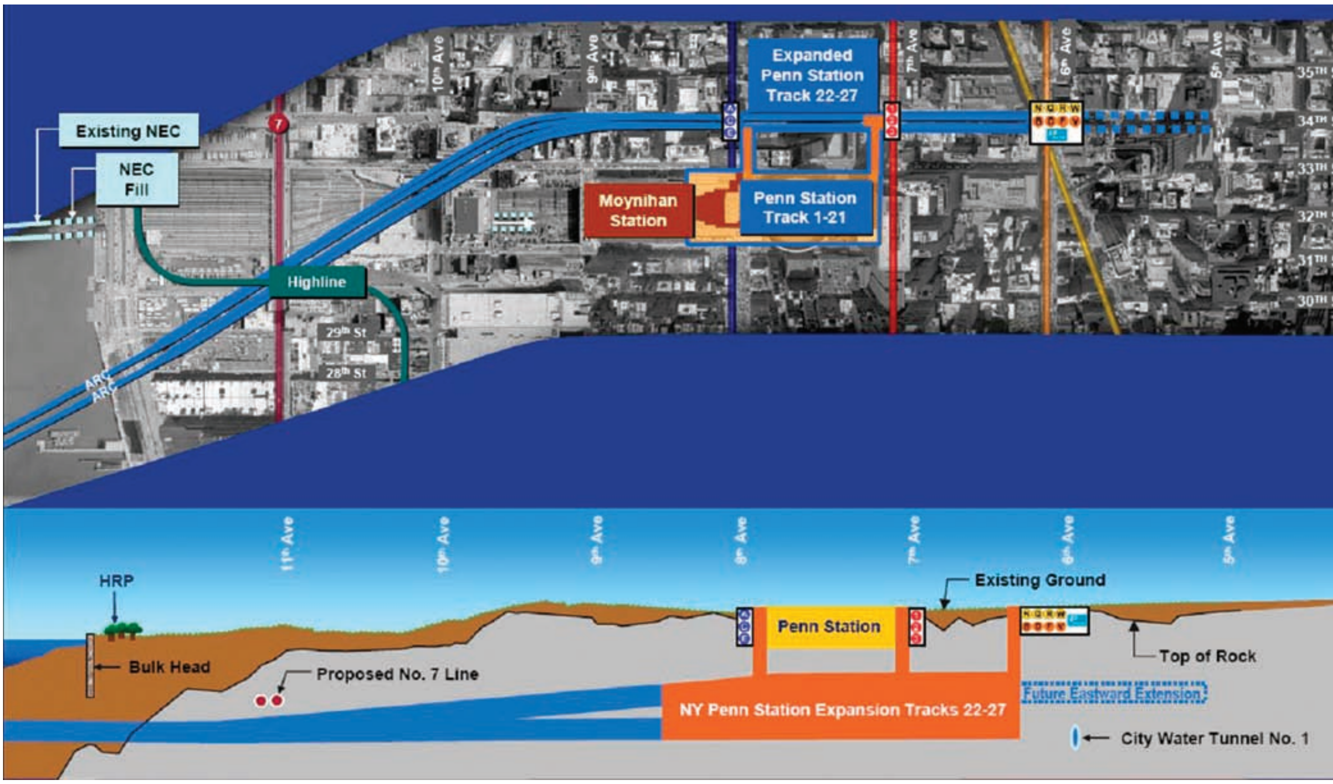
The Hudson River tunnels will continue intermittently in the Stockton Formation sandstone beneath the western portion of the Hudson River, with some mixed faced zones, before encountering a full soft-ground face. The 2,255-m (7,400-ft) length of the Hudson River tunnels will be constructed mainly through a thick sequence of Holocene and late Pleistocene post glacial estuarine deposits of soft, gray, organic silty clay and clayey silt with traces of fine sand and shells.

In Manhattan, the 1,615-m (5,300-ft) length of the

The Hudson River tunnels.



The Manhattan tunnels alignment.



Manhattan Tunnels, as well as the NYPSE, will be built through intermixed Paleozoic-age mica schist, granite and amphibolite, with permatite intrusions and minor amounts of talc schist, chlorite schist, serpentinite, marble and mylonite.

The tunnels will trend across the northeast strike of foliation, which generally parallels the long axis of Manhattan Island and dips steeply to the northwest. Faults are anticipated both across and sub-parallel to the tunnel alignment in Manhattan.

Tunnel boring machines to be used

Borings will be achieved using a rock TBM in each section under the Palisades in New Jersey and under Manhattan. A mixed-face/soft ground shielded TBM will be used in the Hudson River segment.

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

Work will proceed on the new, 30-m- (96-ft-) wide open cavern Penn Station Expansion using drill-and-blast operations and conventional mining methods after the Manhattan tunneling work has been completed.

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

Altogether, about 1.22 Mm^3 (43 million cu ft) of rock and 252,300 m^3 (8.9 million cu ft) of soil will be hauled away by truck, to cap a property in Kearny that will become a mid-day train storage yard.

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

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

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

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

FEATURE ARTICLE

Current state of disc cutter design and development directions

Rolling disc cutters are the business end of hard-rock and mixed-face tunnel boring machines (TBMs). Since their first successful employment on a TBM more than 50 years ago, disc cutter technology has constantly evolved, allowing modern TBMs to excavate very hard and abrasive rock efficiently.

Disc cutters have also been employed successfully on earth pressure balance (EPB) and slurry machines, cutting rock under water and ground pressure. The range of materials excavated by machines today is broader, excavation rates are higher and cutter costs are lower than ever before, proving the value of investment in cutter development.

Disc cutters are used on a range of tunneling equipment, from pipe jacked slurry micro-TBMs less than 1 m (3.3 ft) in diameter to 15 m (49 ft) in diameter, hard-rock boring TBMs. The geological conditions under which they are employed range from sands and gravels, with several bar of water pressure, to extremely hard, massive rock with UCS up to 420 MPa.

Regardless of the type of machine or geology, one thing remains constant: changing worn out cutters is costly. When cutters must be changed in the middle of a tunnel, the contractor incurs the cost of downtime as well as the cost of refurbishing or replacing the cutters.

In the case of catastrophic cutter failures, the project can be stopped completely for long periods, and the costs mount up rapidly while tunnel production is at a stand still. Catastrophic cutter failures include the occasion when hard-rock disc cutters are failed in groups (called a "wipeout" phenomenon) and the operator fails to stop the machine, which results in severe damage to the cutterhead. The cause of this can be either an undetected failed cutter propagating damage to surrounding cutters or operator error in steering. Regardless of the cause, the resulting damage can take days or even weeks to repair.

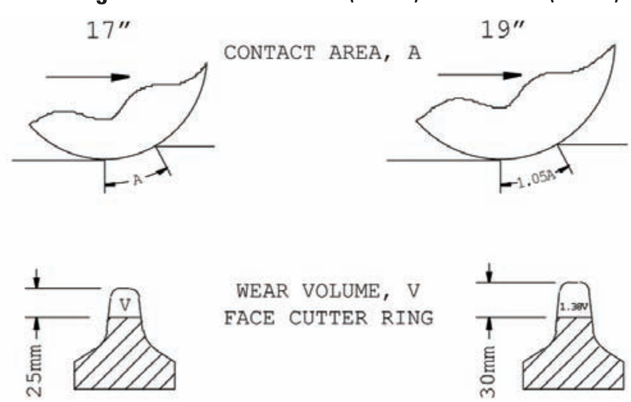
Joe Roby, Tyler Sandell, John Kocab and Leif Lindbergh

Joe Roby, **Tyler Sandell**, **John Kocab** and **Leif Lindbergh** are vice president, sales engineer, engineering manager and electrical design engineer, respectively, with The Robbins Co., 29100 Hall St., Solon, OH 44139, e-mail sales@robbins.com.

When cutters fail prematurely on EPB or slurry machines in certain geological conditions, it is impossible to evacuate the chamber and, therefore, impossible to get into the chamber to change the cutters. The solution is frequently an unplanned intervention shaft that must be sunk at great cost. The importance of being able to predict cutter life accurately, and in all geological conditions, cannot be overemphasized.

FIG. 1

Cutter ring wear volume: 340 mm (17-in.) vs. 480-mm (19-in.).



For these reasons, cutters have been developed for specific machine types and sizes, as well as for specific geological operating conditions. Different size cutters are required for different size machines. For example, while 483- and 508-mm (19- and 20-in.) cutters are used on large diameter TBMs, it is impossible to employ cutters so large on a small micro-TBM. Also, the cutter must be designed for the specific geological conditions under which it will be operating. The disc cutter rings required to bore extremely hard rock are the most expensive of cutter rings. However, they provide little advantage in weaker rock formations where less expensive rings will do the job as well. It is important to choose the correct cutter for the machine and the geological conditions in order to get the best balance of cost and risk.

Large diameter, hard-rock disc cutter development

In the early days of hard-rock tunnel boring, TBMs were being employed primarily in weak to moderate strength sedimentary formations. The first successful use of disc cutters was on the Robbins main beam TBM 910-

101 in 1952 on the Oahe Dam project in South Dakota. There, the machine excavated faulted, jointed shale at only 1 to 3 MPa. The cutters were small and looked little like modern hard-rock disc cutters.

Because the rock could be excavated with low cutter loads, the cutter bearings did not need to be very large. The cutters were kept small, which made them very easy to handle and change. However, soon TBMs were forced into harder rocks. This resulted in an unacceptable rate of cutter wear on the small cutters, along with a rising number of cutter failures due to catastrophic bearing failure. As a result, throughout the succeeding years, cutter size and bearing capacity increased (Table 1).

Development of the 480-mm (19-in.) cutter. The story of the development of a successful 480-mm (19-in.) cutter and its application is one of incremental improvements in component design. As one component was improved, another component became the weak link and required further development. However, it was not just the cutter assembly that required continual design improvement, but the application. Cutterhead design, cutter management and cutter lubricants all received investigation and improvement over the years.

During development of the 480-mm (19-in.) cutters, Robbins engineers collected large amounts of data from job site cutter shops, examining and counting failed 430-mm (17-in.) cutter components. When Robbins introduced the first 480-mm (19-in.) cutter in 1989, many things were new in the design and much improved compared with the existing 430-mm (17-in.) cutter design:

- The cutter ring wear volume of 480-mm (19 in.) cutter was increased by 38 percent (Fig.1).
- The ratio of cutter load rating to cutter bearing load capacity was reduced. Robbins 480-mm (19-in.) cutters full load rating is only 84 percent of the bearing's rated capacity (32 t/38 t) whereas the 430-mm (17-in.) cutter's full load rating is 93 percent of the bearing's rated capacity (27 t/29 t) (Fig. 2).
- The new Wedge-Lock cutter mounting system provided a major improvement in reliability versus the previous V-block mounting system.
- The face seal torics were much larger in cross-sectional diameter, allowing greater misalignment. Seal torics, the silicone or nitrile o-ring that supports the metal face seal, in the 430-mm (17-in.) V-block cutter had a small cross-section diameter (6.35 mm or 0.25 in.), which allowed only slight misalignment of the shaft to the hub. Finite element analysis revealed that, when the cutter is severely impact-loaded, deflection of the shaft can cause misalignment exceeding that allowed by the small cross-section toric, thus allowing ingress of foreign materials. The original toric material also tended to become non-elastic quickly if the cutter temperature was too high. The larger, silicone torics used on the 480-mm (19-in.) Wedge-Lock cutters eliminated both of these problems.
- Cutter hub life was increased dramatically through improved materials and processing to give a wear-resistant hub surface at the hub-to-ring interface.
- The new Wedge-Lock cutter mounting system provided great improvement in reliability versus the previous V-block mounting system. Cutter housing life was also significantly improved.

Table 1

Cutter diameters and load rating vs. year.

Diameter (inch)	Load (kN)	Year introduced
11	85	1961
12	125	1969
13	145	1980
14	165	1976
15.5	200	1973
16.25	200	1987
17	215	1983
19	312	1989
20	312	2006

FIG. 2

Bearing load rating and assembly weight: 340 mm (17-in.) vs. 480-mm (19-in.) cutter.

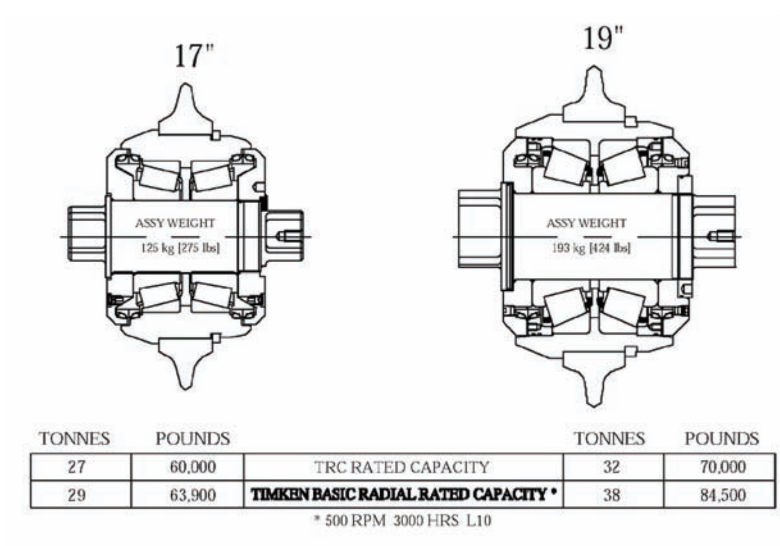


Table 2

Improvements in 480-mm (19-in.) cutter ring life.

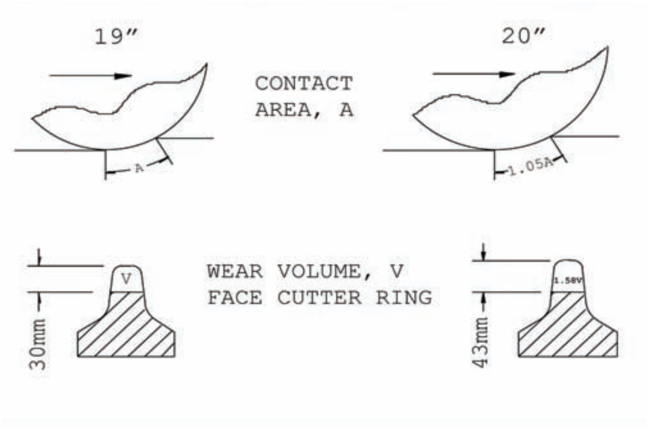
Project location	**Svartisen, Norway 1990**	**Atlanta, Georgia 2005**
Rock types	Micaschist, granite, chalkstone	Very fine-grained medium grade metamorphic rocks
UCS Range (MPa)	49 to 196 MPa	Average UCS of 255 MPa and localized maximum of 530 MPa
Cutter life (m^3/ring)	146 m^3	187 m^3

Initially, cutter ring life on the 480-mm (19-in.) cutter was not as long as had been expected. Too many rings failed prematurely due to spalling rather than slow wear and some were fracturing. While the larger bearings could provide good support at the higher loads, the existing cutter ring materials were not capable of withstanding the increased Herzian contact stress. Increasing the cutter ring tip width would reduce the contact stress but also resulted in reduced penetration into the rock for a given cutter load. This moved the problem from the cutter ring to the bearing.

Increasing ring tip width was the short-term solution. However continuing metallurgical research eventually resulted in rings made from tool steel and, later, from proprietary modified tool steels. With proper heat treatment, these rings have higher hardness as well as increased fracture toughness compared with the previous materials. In addition, these steels retain their strength at the elevated temperatures incurred when boring very hard rock. Today's 480-mm (19-in.) cutter rings can be used in most geology at the same tip widths as 430-mm (17-in.) cutters, allowing 480-mm (19-in.) cutters to penetrate at the same rate with only a slightly increased load.

FIG. 3

Wear Volume: 480-mm (19-in.) vs. 510-mm (20-in.) ring.



Another problem with the early deployment of the 480-mm (19-in.) cutter was its tendency to be susceptible to multiple cutter, wipeout failures. In effect, if one cutter failed catastrophically (broken ring, failed bearing) there was a tendency for the cutters in the paths next to that cutter to also fail. And the failure pattern might repeat until five to 10 cutters were failed in a group. This was eventually identified to be a result of the cutter spacing and was corrected during the following years.

As cutterhead design evolved, 480-mm (19-in.) cutter data was collected from the field. With improvements made throughout the years in cutter rings, 480-mm (19-in.) ring life became very good and the weak link in the cutter seemed to be the bearing, once the strongest part of the design.

When cutters are worn and removed from the TBM, they are subject to one of two treatments before being returned to the TBM:

- Re-ring: Remove and replace the cutter ring and change the lubricant.
- Rebuild: Completely disassemble and replace cutter rings, bearings, seals, other small parts and/or lubricant.

Rebuilding is more expensive than re-ringing. Routine monitoring of the cutter re-ring-to-rebuild ratio is necessary to maintain the lowest consumable cost on projects. A high cutter re-ring-to-rebuild ratio is indicative of a high-quality cutter body assembly and always results in lower total cutter cost for the project.

For the 480-mm (19-in.) cutter, Robbins wanted to increase the cutter re-ring-to-rebuild ratio. The solution was two-fold: improved lubricants and precise record keeping. The lubricants recommended today are expensive, but their return on investment is substantial. Precise record keeping allows the cutter manager to be constantly aware of each cutter's time in service, providing the cutter manager the information necessary to predict the probable end of life of the cutter assembly and rebuild it in advance of failure.

Ten years after its introduction, the 480-mm (19-in.) cutter proved itself a clear choice for excavating hard and mixed face rock. TBMs employing the 480-mm (19-in.) cutter were excavating the hardest rock worldwide and setting impressive production records while doing so. Table 2 compares cutter ring life at the introduction of the 480-mm (19-in.) cutter with that from more recent projects.

Having increased the cutter re-ring-to-rebuild ratio, the next step was for engineers to once again extend the life of the cutter ring.

Development of the 510-mm (20-in.) cutter. There are two methods by which one can increase disc cutter ring life — increasing cutter ring strength and abrasion resistance and increasing the wear volume available on the cutter ring.

Research of new disc metallurgy and processing to increase cutter ring life in hard and abrasive rock has yielded incremental improvements, at high cost for the research. Currently, 480-mm (19-in.) cutter rings are being manufactured using three different cutter ring metallurgies and heat treatment processes (standard, heavy duty and extra heavy duty). Some research test rings have shown marked improvement in ring life, but only at an unacceptable cost for the rings. While metallurgical research continued, in the short-term there was no economical way to improve cutter ring life through increases in material strength and/or abrasion resistance. It became clear that an increase in wear volume was the most cost effective way to improve cutter ring life for the 480-mm (19-in.) cutter.

To increase the wear volume one can increase the cutter ring tip width, the cutter ring diameter or both. Obviously, increases in cutter ring tip width have an adverse effect on cutter ring penetration into the rock. To achieve the same penetration, a cutter ring with an increased tip width would require an increase in thrust, which would have an adverse affect on the cutter bearing. However, an increase in diameter would have only a negligible effect on cutter load to achieve the same penetration. Essentially, one can increase the "tip length" to provide more wear volume in the ring. The risk of a longer cutter ring tip is the potential for fracturing of the long tip.

This story is somewhat similar to the advent of the 430-mm (17-in.) cutter, which was simply a change in the cutter ring diameter mounted on the original 390-mm (15.5-in.) cutter assembly. The same logic was used when the extended tip 430-mm (17-in.) cutter was employed successfully on many sedimentary rock jobs. The cutter provided deeper penetration capability and larger wear volume compared with a standard 430-mm (17-in.) cutter ring. This experience provided empirical field data to support the concept that an extended tip 480-mm (19-in.) cutter might prove successful.

Using a conservative approach, new 510-mm (20-in.) cutters were developed for use on TBMs that could use either 480- or 510-mm (19- or 20-in.) disc rings. The 480-mm (19-in.) cutter hub/bearing/shaft assembly is used for both 480- and 510-mm (19- and 20-in.) cutter rings. So either cutter ring can be employed. Cutter housings and cutterheads were initially designed to accept either the 480- or 510-mm (19- or 20-in.) ring cutters for the following three TBMs:

- 14.5-m (47.5-ft), hard-rock open, high performance TBM (HP-TBM) for the Niagara, Canada hydropower expansion.
- Two 10-m (33-ft), hard-rock double shield, HP-TBMs for the AMR water transfer project in India.

FIG. 4

The cutter on the left quit turning and wore flat. The cutter on the right experienced a massive bearing failure that resulted in a damaged seal retainer and shaft.

The 510-mm (20-in.) cutter rings produced offer a 58-percent increase in wear volume compared with the 480-mm (19-in.) cutter ring (Fig. 3).

Initial reports from the Niagara project are good. The 510-mm (20-in.) cutter rings are in continual use in the sedimentary rock, giving good penetration and good life to date. The AMR project requires boring through hard rock from 160 to 190 MPa UCS. This will be the first hard-rock test of the new 510-mm (20-in.) cutter ring. The machines started boring in mid-2008 and cutter ring performance will be reported after data has been collected from the project.

Cutter bearing development

Cutter bearings. Most rolling disc cutters use two tapered roller bearings that are arranged in what the bearing industry calls "indirect mounting." These bearings are asked to cope with extremely dynamic loading and vibration in a very harsh environment. As cutter rings have grown, so have the bearings and the loads they must handle.

Catastrophic failures — post mortem inspection. When a cutter assembly fails catastrophically, it is never easy to determine how the failure was initiated (Fig. 4). A post mortem inspection is the only way to diagnose and remedy the problems. There is always some amount of doubt as to why the cutter assembly is full of tunnel muck, which results in some classic questions. Did a bearing(s) fail, allowing misalignment and letting muck pass the seals? Or did the seals fail and allow contamination of

FIG. 5

Example of a cutter wipeout phenomenon.

the bearing? Fortunately, most cutter/bearing failures are not this severe and are usually detected and repaired or replaced before they get to this point.

Seal inspection. Seal failure is a death sentence for a mechanical assembly in an underground environment and nowhere is this more certain than with TBM cutters. Post mortem inspections of catastrophically failed cutters generally start with the seals. If for no other reason, they are the first part to be removed during disassembly. In some instances, post mortem seal inspection will immediately reveal the "smoking gun" but, quite often, the mode of failure is not so obvious. Complicating things further, it is not always easy to determine the cause of failure once the failure mode is isolated.

Modes of seal failure include damaged torics, fused faces and abrasive wear. Causes of seal failure include assembly error (too much drag, face pressure too low), rust from long periods of no use, packing — seal filled with clay or mud that is allowed to harden while the cutter is not turning, and use past service life.

Bearing inspection. In most hard-rock tunneling conditions, the cutter bearings will remain serviceable through multiple cutter rings if they are properly maintained. Proper maintenance requires frequent inspections and these inspections often reveal impending problems. If failing bearings are not detected, adjacent cutters will become overloaded and prematurely fail, leading to a chain reaction of multiple cutter failures. The TBM industry calls this phenomenon a "wipeout," which can cost thousands of dollars in equipment and downtime (Fig. 5). Much like seal failures, this mode of failure does not always leave a clear path to the original cause of the failure.

Modes of bearing failure include spalled or grooved raceways (Fig. 6), worn or broken roller cage, damaged rollers and brinelling/false brinelling. Causes of bearing failure include extreme dynamic loading, overloading, loss of lubrication, overheating, assembly error (too much or too little pre-load) and contamination — ingress of tunnel muck — usually a seal failure.

Bearing life — theoretical versus actual. There is a wealth of information and many studies have been done on calculating and estimating bearing life in mechanical assemblies. Bearing manufacturers and third party associations, such as ISO, SAE and the ASME, have done comprehensive scientific research and have developed mathematical models that predict serviceable duration under controlled conditions. ISO 281 is generally accepted as the industry standard that provides an estimated number of cycles or hours that the bearing can be expected to perform.

Unfortunately, experience reveals that these models are not able to accurately predict bearing life in disc cutters. Problems with predicting bearing life in disc cutters are two-fold. First and foremost, the industry has not been able to accurately define and quantify the extreme dynamic loads to which these bearings are subject. Secondly, geology dictates that conditions are always far from controlled or consistent.

Theoretical life. The following definition is from the ISO's Web site (ISO 281, 2007). "[ISO 281:2007] specifies methods of calculating the basic rating life, which is the life associated with 90 percent reliability, with commonly used high quality material, good manufacturing quality and with conventional operating conditions. In addition, it specifies methods of calculating the modified rating life, in which various reliabilities, lubrication condition,

FIG. 6

Close up of spalling in the load zone of the inner race.

contaminated lubricant and fatigue load of the bearing are taken into account. ISO 281:2007 does not cover the influence of wear, corrosion and electrical erosion on bearing life."

Table 3 provides examples from two long-term tunnel projects. One of the jobs used 430-mm (17-in.) cutters for 7,950 total operating hours. The other job used 480-mm (19-in.) cutters for 3,117 hours. In both cases, the rock was generally considered to be hard to extremely hard (100 MPa UCS and higher). The calculated bearing set life per ISO 281 should have been 43 hours for the 430-mm (17-in.) cutters and an impressive sounding 2,165 hours for the 480-mm (19-in.) cutters.

Table 3

Comparison of calculated vs. actual bearing life.

	340 mm (17 in.) cutters	480-mm (19-in.) cutters
Calculated Bearing Life (Hours)	43	2165
Actual Field Data:	Manapouri, NZ	Cobb County, Atlanta
TBM Working Time (Hours)	7950	3117
Actual Bearing Sets Used	1612	191
Average Bearing Set Life (Hours)	5	16
Ratio of Actual / Standard L10	11.47%	0.75%

Actual life. In practice, service life varies considerably from theoretical life estimates. In addition to extreme dynamic loads on bearings, cutters can also be damaged due to service factors such as ingress of debris and water (seal failure). The damaged cutters typically show bearings with severe spalling in the load zone, damaged rollers, broken cages and/or overheating.

Sometimes the normal inspection or servicing of cutters may show early impending bearing damage. In these cases, bearing components are replaced much more frequently than their theoretical lifespan. Table 3 shows that actual bearing life in the aforementioned projects was orders of magnitude shorter than the ISO 281 calculation predicted.

Cutter seal development

One of the most significant developments in disc cutter technology came with the application of the Caterpillar metal face seal in the early 1970s (*Handbook of Mining and Tunnelling Machinery*, 1982). This seal type uses two metal rings that are loaded axially such that they ride against each other with a film of lubricant between them, creating a dynamic face-seal interface. Each ring, one on the rotating hub and one on the stationary shaft, is sealed to the mounting gland by a rubber ring (toric, or o-ring). This ring also allows a relatively generous hub-to-shaft misalignment tolerance. And it acts as a spring to load one seal ring against the other (Fig. 6). Although proven effective for 30 years of hard-rock disc cutter application, there are problems associated with the seals in some specific applications.

One of the problems encountered with this seal is when a slurry of certain rock types pushes through the labyrinth created by the hub and seal retainers and then, given time, dries, effectively cementing one metal face seal ring to the other. When the cutter starts rolling again, the cemented metal rings may momentarily spin with each other and stretch the rubber toric holding the metal seal rings. This can rip the toric, allowing leakage of lubricant out of the cutter as well as ingress of dirt and abrasives into the bearing cavity. To alleviate this problem, the toric should minimize the amount of metal ring exposed to the slurry, hopefully allowing the rings to break free and rotate against each other as intended.

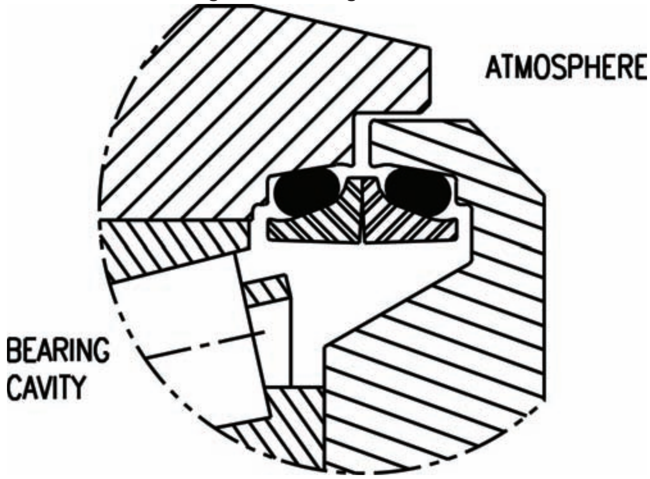
Another problem arises when the cutters are used in high-pressure applications, such as on EPB and slurry machines. The standard seal is rated, per the manufacturers' recommendations, for about 3 bar of pressure differential between the atmosphere and the bearing cavity. Three bar of pressure is reached at 30 m (98 ft) below the water table and many tunnels are far deeper. The problem that arises with higher pressure is the fluidized slurry pushes against the toric, forcing it down the seal gland ramps. This forces the metal rings tighter against each other, increasing face contact pressure of the seal surfaces, causing the seal rings to act as a brake. This has the effect of "locking up" the cutter, preventing it from rolling in softer material. In extreme cases, with the smaller diameter torics used in many older cutter designs of the 1970s and 1980s, a portion of the toric on the nonrotating side of the seal can push past the back of the seal, causing a major leak (Fig. 7). This problem is lessened considerably by the use of larger diameter torics, such as those used today.

Various methods have been tried throughout the years to try to compensate the internal pressure in cutters to match the exterior pressure in order to overcome the pressure differential problems noted in the paragraph above. The following is a list of some of the methods by which pressure compensation has been attempted:

- A pressure-compensating piston in the center of the shaft moves with the increase in exterior pressure, causing the interior pressure to rise to an equal level. The problem with this method is plugging of the exterior side of the pressure compensator with muck, preventing the piston from traveling in the opposite direction. This can overpressurize the interior, destroying the seals.
- A diaphragm, in the shape of an annular ring mounted in the seal retainer, moves as the atmosphere side pressure rises, causing the internal pressure to rise.

FIG. 7

Cross-sectional diagram showing cutter seal.



This, too, has problems with the breather holes in the diaphragm's protective cover becoming easily clogged.

- A spring-loaded piston can supply between 2 and 3 bar of pre-load pressure internally, causing a maximum differential of 3 bar when the exterior pressure is up to 6 bar. This method was left open to atmosphere (through a breather) on one early version. However, it was found that closing the atmosphere side and allowing a partial vacuum to develop still allowed the devise to work satisfactorily.

The first two methods have been successful in applications where the amount of fluid greatly exceeds the amount of muck, thus having a flushing affect on the exterior side of the pressure compensator. Where the muck is in more of a paste form, plugging of the exterior side of the devices is a major problem for these two methods.

All of these types of cutters generally use grease as the lubricant and, in most cases, the cutters have a pressure relief valve. It has been shown that without a pressure relief valve, heat from normal operation can cause internal pressure to increase sufficiently to push the torics hard toward each other, locking the cutter rotation as the seal rings act as a brake (Fig. 8).

An obvious, but as yet untried method of pressure compensation would be to have all of the cutters plumbed together to a common lubricant supply. Pressure in the cutterhead chamber would be sensed and the cutter hydraulic system would automatically apply the proper internal pressure to the cutters through the plumbing lines. The drawbacks to this method would be isolation of the lubricant during cutter change and the danger of a leak anywhere in a common lube system.

The overall goal is to develop either an effective pressure compensation devise or a modified/new seal design that uses the robust characteristics of the metal-to-metal seal currently in widespread use, but make modifications that prevent pressure differential from affecting seal operation.

To provide rapid development of an improved EPB cutter, a test fixture was built that allows mounting either a single or twin disc cutter inside a pressure vessel (Fig. 9). The atmospheric side and cutter bearing cavity can have their pressures adjusted and monitored independently. The cutter can be rotated during testing at any chosen rpm. The rolling torque of the cutter can be measured at various pressure differentials or temperatures. The temperature of the lubricant adjacent to the seal can be monitored. The pressure (atmosphere and/or bearing cavity) can be raised to as much as 60 bar.

A variety of tests have already been run on standard and modified seal sets. These tests have shown the effect of various pressure compensation devises. While new designs have not yet been finalized, a better understanding of standard seal performance has been realized. Tests on slightly modified seals (material and surface finish changes) have shown promising improvements are possible (at some cost trade-off, naturally). While initial major redesigns of seal configurations have been less promising so far, the test fixture has proven valuable in efficiently reaching conclusions at a speed that cannot be duplicated in the field.

Cutter ring development

Goal: increase advance rates, decrease downtime. Cutter rings have frequently proven to be the limiting component for further improved cutter performance. Recent advancements in cutter technology have increased production while lowering overall cutter costs. Continual refinement in proprietary alloys and metallurgical processes has improved the hardness, abrasion resistance and, most importantly, the toughness of today's high performance heavy duty (HD) and extra heavy duty (XHD) cutter rings. Cutter ring development has improved production in two ways:

- Higher penetration per revolution is possible because the HD cutter ring stays sharper longer than standard rings. Furthermore, because the HD cutter ring is stronger than standard material, narrower tip width rings can be used without breaking.
- Longer cutter life means less downtime for cutter changing and more time available for boring.

Hardness. The high contact stress seen by the highly loaded 480-mm (19-in.) cutters has pushed metallurgical research to new highs. Engineers quickly moved from commercial steels to proprietary steels in the search for higher strength and toughness. In 1995, a Main Beam TBM was put on to the Midmar project in South Africa. This project included dolerites and sandstones with strengths to 350 MPa.

The demands on rings were severe and resulted in another round of materials and processing research and development. The result was state-of-the-art HD rings, in use on more hard-rock projects today than any other ring. This new material improves the cutter life because it has high "hot strength." The material has a reduced wear rate compared to the standard cutter when boring hard rock.

Toughness. It is intuitive to think that the key to creating a high performance disc cutter is extreme hardness. This is true to some degree but it is not the sole factor. Hardness is needed to retard deformation when the ring is pressed against rock but the hardness is useless if it is too brittle. Therefore, toughness and hardness are the most important properties for the cutter designer to manage.

The standard toughness test for steels is the Charpy Impact test. It consists of one blow from a swinging pendulum under defined, standard conditions. To increase toughness, sophisticated analysis and post processing methods have been used to monitor and control grain size, microstructure and chemical composition.

Continued refinement of the heat treating and tempering processes has proven to be of equal importance to specifying the proper alloy if the goal is to increase toughness and hardness simultaneously. The toughness obtained in proprietary steel rings has allowed the manufacture of rings that are even harder than was considered possible just a few years ago.

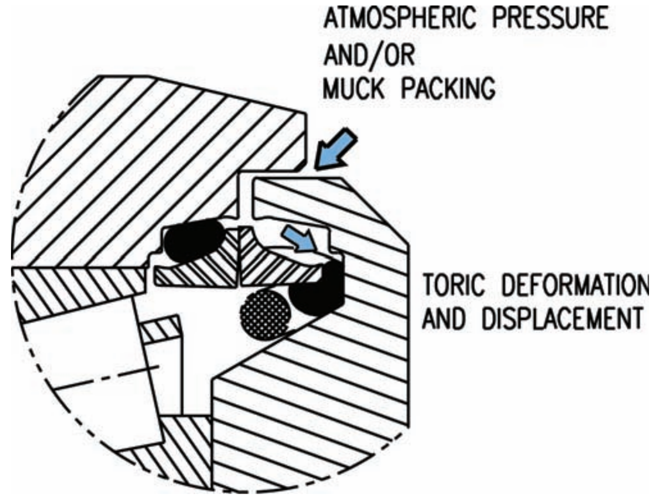
Developing technology: remote cutter status monitoring

The current focus in disc cutter design and application is finding the optimum cross point of disc cutter cost versus boring system performance, measured in penetration rate and availability. There are three basic components to TBM downtime related to cutters:

- Cutter inspection: Hard-rock TBMs must be routinely stopped to allow workers to inspect the condition of all the cutters, to ensure that there are no failed cutters or severely worn cutter rings, to ensure that the TBM can continue to be operated until the regularly scheduled cutter change.
- Cutter change: Routine maintenance encompasses inspections for mechanical fitness and replacement of cutters with worn rings or damaged bearing/seal assemblies, as well as moving cutters for even ring wear.
- Cutterhead repairs: This is related to either extreme geological conditions (abrasive rock in fault zones or blocky rock) or the failure of a series of cutters, either of which can lead to cutterhead damage. The work required may include repair of cutter housings, cutterhead wear plating, muck buckets and/or conveyor components.

FIG. 8

Seal toric displaced by fluidized slurry at high pressures.



A system that constantly monitors the status of every cutter on the cutterhead would provide a tremendous advantage. If one could monitor all the cutters at all times, it would not be necessary to make routine physical inspections, which would reduce TBM downtime. Furthermore, if it was possible to constantly know the status of every cutter, then the operator would know immediately when a cutter failed or was beginning to fail. He could then stop the machine, preventing a wipeout cutter failure before its occurrence and preventing damage to the cutterhead.

Historically, it was entirely up to the TBM operator to detect a failure by noting an increase in cutterhead torque requirements. This is difficult to detect given a single cutter failure on a machine that may be fitted with 20 to 80 cutters. Some TBM operators have reported being able to detect the aroma of overheating cutter lubricant in the tunnel from a very hot cutter — not a desirable or dependable failure detection system. TBM users have long sought a cutter monitoring system where the operator would get more precise information on the status of each cutter. In the past, the only way to get this data from the rotating cutters and cutterhead to the operator was by a hard-wired system with multiple contact rotating union. This proved wholly unreliable in the harsh environment.

New developments in remote cutter status monitoring. Today, engineers are developing real-time cutter monitoring systems with the following specifications:

- Monitoring of every cutter on the TBM.
- Indication of smooth rolling of all cutters on a human-machine interface (HMI) display in the TBM.
- Cutter rolling alarm, with cutter number, when any cutter stops rolling.

- Indication of cutter wear, for every cutter, on an HMI display.
- Indication of cutter temperature, for every cutter, on an HMI display.
- Cutter temperature alarm, with cutter number, when any cutter temperature exceeds the pre-set limit.
- Wireless transmission of all data.

Rotational speed of the cutter. Cutters are not individually powered. They roll only because the cutterhead in which they are mounted presses the cutters against the rock face as the cutterhead rotates. The diameter of their circular, concentric path is determined by how far they are mounted from the rotating cutterhead center. The rotation speed of the cutter is a function of the radius of their mounting position on the cutterhead, the rotational speed of the cutterhead and the diameter of the cutter ring, which changes as the cutter wears. Knowing the rotating speed of each cutter will provide two pieces of information:

- Whether the cutter is rolling or not rolling. This information helps detect catastrophically failed cutters before the failure propagates to other cutters or causes cutterhead damage.
- The diameter of the cutter, which gives the cutter ring wear. This information eliminates the need for downtime for routine cutter inspections and helps to plan in advance for cutter changes.

Temperature of the cutter. The temperature of the cutter is also an indicator of mechanical condition of a cutter. Unusually high temperatures can indicate slipping seals, failing bearings, loss of lubricant or ingress of foreign materials. The temperature of the entire cutterhead increases during a boring stroke. Other TBM mechanical problems might be indicated by the temperature rising above the average normal increase during a boring stroke.

FIG. 9

Locking cutter rotation through internal pressure.

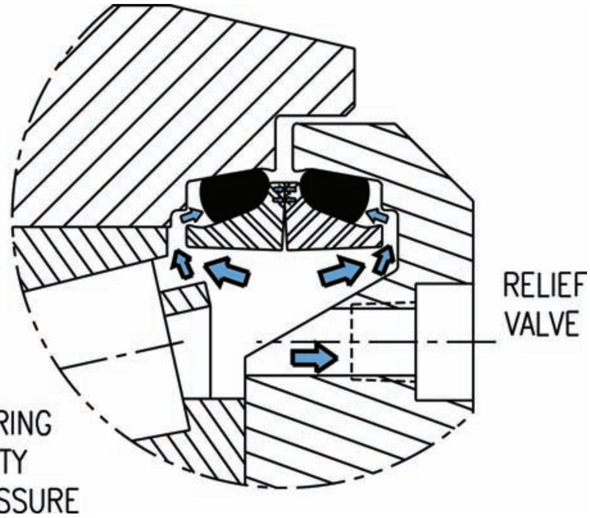


FIG. 10

Test fixture to examine cutter rolling torque at various pressure differentials and temperatures.

Conclusions

Industry investment in cutter development has resulted in cutters today that efficiently bore through a wider range of materials at lower costs in real, inflation-adjusted dollars. Improvements in pressure compensation devices will improve the survivability of cutters operating under pressure. Continuous, real-time cutter condition monitoring will become a standard in a short time. This will result in saving several times the system cost.

However, substantial challenges remain. Funding of metallurgical and materials processing research must continue in order to find the next cutter ring material, allowing rings to be loaded ever higher and increasing TBM advance rates in hard-rock. The industry must search for more abrasion resistant materials and improved sealing systems to improve cutter life on EPB and slurry machines.

Improvements in cutter technology have resulted in lower total project costs for contractors and owners worldwide. However, the industry must remain aware of the need to continually fund research and development in this area if it hopes to continue the trend of improved systems reliability and performance with reduced cost. ■

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FEATURE ARTICLE

Big news and excellent sessions define 2009 Fox Conference

William M. Gleason,
Senior Editor

As the 2009 George Fox Conference neared its conclusion, Arthur Silber, project chief of the Mass Transit Tunnel (MTT) project was able to pull away from the constant buzzing of his Blackberry long enough to give a short presentation and a significant piece of news to the record 318 attendees at the Graduate Center, City University of New York regarding the MTT project.

"As the former administration (The Bush administration) was leaving office, we were told that Congress was notified of the FTA'a (Federal Transit Authority's) intent to issue final design construction approval to us," Silber said of recent advancements concerning the $7.2-billion dollar project. It will add passenger rail service from New Jersey to New York City as part of the Access to the Region's Core project in the form of the Trans Hudson Express Tunnel (THE tunnel). "That 10-day waiting period ended yesterday (Jan. 26)."

A record 311 people attended the 2009 George Fox Conference at the Graduate Center, City University of New York on Jan. 27.

In days leading up the Fox Conference, those involved in the tunneling industry, and the MTT in particular, had a lot to be optimistic about. The MTT received environmental approval on Jan. 14 (see page 9) and, with the acceptance of the final design, the multi-billion dollar project moved that much closer to a ground-breaking ceremony. So close, in fact, that before leaving his office for the conference, Silber posted the contract documents and plans for the Manhattan Tunnel project online at www.arctunnel.com (an indepth look at the project from Silber is on page 22).

While many were interested in the progress of the project, Silber also spoke about the new plans for the cavern complex at the New York Penn Station expansion.

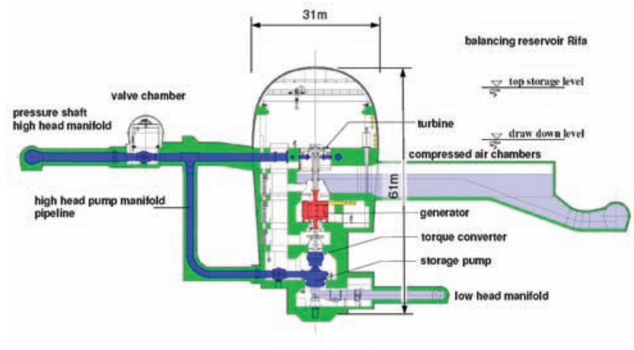
The original plans called for two lines that would come into a large cavern complex with a north and south cavern to access the trains. After numerous core samples were taken from the streets of Manhattan, it was determined that this design was not feasible and changes were made that will include a deeper cavern under Sixth Avenue, with 14-m (45-ft) of cover with a 30-m (96-ft) wide cavern that resides entirely under 34th Street. The cavern was also moved 20 m (60 ft) to the west to remain at least 61 m (200 ft) away from New York City Water Tunnel #1.

The new design will include three-over-three track arrangement. The mezzanine will be 46 m (150 ft) below street level at 8th Ave, Silber said.

Kops II cavern

The theme of the 2009 conference was "Large Rock Caverns and Soft Ground Mechanical Excavation," and a representative from one of the world's largest caverns

The Kops II Powerhouse cavern.



was one hand to speak about it.

Gerd Wegeler, engineering services, Bautechnik, Votarlberger Illwereke, spoke about the large rock cavern at the Kops II power plant in Austria, one of the largest artifical caverns in the world. The hard rock cavern measures 90-m- (300-ft-) long, 30-m- (100-ft-) wide and 60-m- (200-ft-) deep.

The Kops II plant is a pumped-storage power station built in a rock cavern located at the end of the Montafon Valley. The Kops II plant uses the existing Kops Lake as an upper storage reservoir and the existing Rifa balancing reservoir as a lower storage reservoir. All major plant components of the Kops II scheme are located below ground.

The nominal head of the plant is 798 m (2,600 ft) between the headwater reservoir Kopssee situated at an altitude of 1,800 m (5,900 ft) and the downstream Rifa reservoir at 1,000 m (3,300 ft). The plant contains three machine units with turbine, generator, pump and converter on a vertical shaft. Each unit has a nominal power of 150 MW.

The uniqueness of these hydro power units is the fast regulation time of 20 seconds from 0 to 100 percent power output and the power control range of ±100 percent in turbine as well as in pumping mode.

Wegeler explained that the insitu geological conditions and the overburden of 130 m (427 ft) were some of the most important factors for designing the support an excavation concept of the cavern. The underground powerhouse is situated in the crystalline rock units of the Silvretta complex, which consists of amphibolites, gneisses and layers of mica schist. A 290-m- (950-ft-) long exploration tunnel was excavated parallel to the top heading of the cavern to investigate the rock mass conditions and the primary insitu stresses.

The Kops II Powerhouse Cavern in Austria is 90-m- (300-ft-) long, 30-m- (100-ft-) wide and 60-m- (200-ft-) deep.

The exploration tunnel enabled engineers to identify the most important mechanical properties of the surrounding rock mass as a basis for the final design. To optimize the excavation procedure and the support concept, some nonlinear finite element and rock wedge calculations were done. The results of the calculations provided the determination of an economical support and excavation concept of the underground powerhouse.

The excavation works of the top heading were divided into two side drifts and the core. Subsequently, the remaining excavation of the cavern was subdivided into 11 bench steps with a height of approximately 5 m (16 ft) each. After the excavation of the middle part of bench, two side parts of 4-m- (13-ft-) width were removed.

As a first support after each excavation step reinforced shotcrete and rock bolts were applied. To support the close-up range of the side walls and the crown, 12- and 16-m- (39- and 52-ft-) long rock bolts were installed in a 2.5- x 5-m (8.2- x 16-ft) pattern. In the crown and the sidewalls, down to the access tunnel level, four layers of reinforced shotcrete with a thickness of 10 cm (4 in.) each were applied. Two layers of reinforced shotcrete were required below the access tunnel level. To ensure the stability of the whole cavern, prestressed and double corrosion protected strand anchors with a length of up to 43 m (141 ft) were installed. These in a 5- x 10-m (16- x 33-ft) pattern in the crown and in the sidewalls installed anchors had to be prestressed until the top-heading core or the next bench step was excavated.

A continuous verification of the predicted cavern deformations took place with a deformation monitoring system that was installed simultaneously during the excavation process.

Special recognition was given to Fox Conference Planning Committee Members. Lonnie Jacobs, Paul Scagnelli, David Caider, Hugh Lacy and Richard Redmond are pictured. Robert Goodfellow, David Hatem, Colin Lawrence, Michael McHugh and Henry Russell are not pictured.

In total about 125,000 m³ (4.4 million cuft) of hard rock were excavated in several different steps. In December 2005, after one year of construction, the whole cavern excavation works were finished on schedule.

Projects

The business of tunneling and working underground has, for the most part, continued through the difficult economic times and possible funds from a proposed $787 billion federal stimulus package had many in the crowd thinking more infrastructure projects could be starting soon.

Of course, the tunneling industry, like all others, has seen its share of setbacks. Plans for a multi-million dollar project in California that would have added a fourth borehole to the Caldecott Tunnels was shelved (see page 5), and officials with the North Shore Connector Project in Pittsburgh, PA were warning of a possible shutdown if federal funds were not made available for that project (see page 5).

But while those projects were struggling, another project on the West Coast, the replacement of the Alaskan Way viaduct with a four-lane deep bore tunnel continued to gain support (see page 8).

Other projects that continued to move forward were discussed by Mike McHugh, vice president Moretrench, in his annual review of projects on the East Coast.

Projects discussed included:

New York's East Side Access Manhattan tunnel excavation. A $6.3-billion, four-tunnel project linking Long Island to Manhattan.

The East Side Access project is currently excavating tunnels approximately 37 m (120 ft) beneath Manhattan streets. Two tunnel boring machines (TBMs) are being used, one manufactured by SELI and one manufactured by Robbins.

The two TBM's in Manhattan will make eight tunnel drives starting and ending at various points along the alignment. The first two tunnel drives, starting at 63rd Street and 2nd Avenue with the first ending at 43rd Street and the second ending at 37th Street, have been completed. The next set of drives will begin in early 2009, at approximately 49th Street, and all the Manhattan tunnels will be mined by 2010.

The Second Avenue Subway project. This is a project that will include a two-track line along Second Avenue from 125th Street to the Financial District in Lower Manhattan. It will reduce overcrowding and delays on the Lexington Avenue line and improve travel for all riders while providing better access to mass transit for residents of the far east side of Manhattan.

Under the current plan, the project will be built in four phases. The first construction contract involves the construction of new tunnels between 92nd and 63rd Streets, the excavation of the launch box for the TBM machine at just south of 92nd to 95th Streets, and access shafts at 69th and 72nd Streets. These shafts will be excavated toward the end of Contract One and be used for the subsequent construction of the 72nd Street station. Contract One is expected to take about 45 months to complete.

The Harlem River Tunnel. Consolidated Edison Company of New York Inc. awarded Kiewit Constructors the $85.2 million Harlem River Tunnel contract. The project includes two 51-m- (165-ft-) deep circular shafts connected by a 205-m- (675-ft)-long horseshoe tunnel.

Other projects that were discussed were the No. 7 line extension; CRO-313 Croton Tunnels and the WSSC Bi-County Water Tunnel.

Looking to the future, McHugh mentioned a number of projects in the works, including two that will be undertaken the District of Columbia Water and Sewer Authority. The WASA CSO Potomac tunnel in Washington, DC is a 2,450 m- (8,000-ft-) long, 6-m- (20-ft-) diameter tunnel with bidding anticipated to be in 2014. The WASA CSO Rock Creek tunnel in Washington, DC is a 792-m- (2,600-ft-) long, 3.6-m- (12-ft-) diameter tunnel with anticipated bidding in 2015.

Other future projects mentioned included the Manhattan West Side to LaGuardia Airport tunnel in New York. It is a 4,500-m (15,000-ft) tunnel that is in preliminary study. And the New York City-DEP Water Tunnel #3 KCT tunnel in Westchester, New York. This is a 7,300-m (24,000-ft), 3.6-m (12-ft-) diameter tunnel with anticipated bidding in 2010.

Keynote

Galyn "Ripp" Rippentrop, retired president and chief executive officer of Frontier-Kemper Constructors, opened the conference with the keynote address. He spoke about "the wonderful world of underground construction" and how its not only a science, but an art as well.

The business of working beneath the ground is a complex one. The projects tend to be huge and there are many hands that work on the job.

His years of experience, Rippentrop said, taught him well about the many aspects of the business and how all of the stakeholders in a project play an important role. They include vendors, insurance companies, sureties, banking facilities, lawyers, engineering firms, owners/clients and employees.

Speaking of the business relationship between the various players in any project Rippentrop borrowed a few rules from the late Bob Pond including, "do not insult the crocodile until you have crossed the river."

Tunnels large and small

The headlines swirling around the tunneling industry are usually about the massive projects that will move people from point A to point B. But, at the Fox Conference the other aspects of the industry were covered as well.

Ted Budd, vice president, tunnel division for Kenny Construction, spoke about the Middlesex County Raritan River Crossing project.

Colin Lawrence, senior vice president, Hatch Mott MacDonald, spoke about the NYC-DEP Siphon project, a project that will replace the existing siphons under the Hudson River between Brooklyn and Staten Island. It is part of larger project to deepen the harbor to accommodate new cargo mega ships in one of the most heavily used transportation arteries in the world.

When speaking of the challenges that come with tunneling under the river, Lawrence quipped that in addition to the dangers from the ships in the channel, it was illustrated dramatically that you can never be prepared for possible event. "If I had told you two months ago that we have to worry about a plane landing on the tunnel you would have thought I was crazy, yet an American Airlines plane was put down on the Hudson River."

Richard Palmer, tunneling manager, Northeast Remsco, wrapped up the session by speaking of a micro tunneling project in Bergen County, a project that includes 3.2 km (2 miles) of 18.2 mm (72 in.) relief sewer line.

Soft ground excavation methods

Since their introduction, tunnel boring machines (TBM) have changed the business. The complex machines have made it possible to tunnel efficiently and safely and it was the TBM's that was the topic of conversation during the afternoon sessions.

Galyn Rippentrop gave the keynote address at the Fox Conference.

Some of the industries foremost authorities on the subject of TBM's shared their knowledge of operating the machines in various ground conditions.

Brett Robinson, of Traylor Brothers, opened the section focusing on soft ground with a presentation titled "Earth pressure balance tunnel boring machine, principles, benefits and lessons learned."

Scott Redmond, vice president, and Terry Yokate, contract engineer for the Vinci/Parsons/FKCI joint venture that is working on the Brightwater Conveyance Project in Seattle, WA, discussed the use of slurry tunnel boring machines.

Glenn Frank, project engineer, Jay Dee Contractors, discussed mixed faced tunnel boring machines as used at the BWARI project in Columbus, OH.

Christian Neumann, technical director, Beton-und Monierbau spoke about cross-passage excavation methods and Werner Berger, chief engineer, Herrenknecht, spoke about interventions, necessity, risks, preparations and management.

The George Fox Conference will return to the Graduate Center, City University of New York on January 26, 2010. ■

Herrenknecht double shield breaks records in Spain

The Cabrera Tunnel in northeast Spain was bored out and ready to accommodate the railway technology that will serve as a connection between Valencia and Madrid in just 14 months. A Herrenkencht double shield tunnel boring machine (TBM) S-373 broke through on the project's second tunnel on Sept. 25 — five months ahead of schedule.

The Herrenknecht TBM has a diameter of 9.69 m (32.7 ft) and bored as fast as 106 m/day (347 ftpd) on the two 6 km (19,685 ft) railway tunnels. The planned overall construction time was cut by 25 percent.

In November 2007, three months after the construction began on the first tunnel the TBM arrived. With a top performance of 83.2 m/day (272 ftpd), the S-373 TBM was optimally designed for the geology of the tunnel.

In November 2007, a total of 1,600 m (5,250 ft) of tunnel were excavated. The tunneling of the first tube was completed just six months after the beginning of the construction work. At that time, the Herrenknecht branch manger Juan Arroyo forecast the following for the completion of the second tube: "If everything continuous to runs smoothly, we can finish work in December 2008." His best estimate was exceeded by three months. tunneling work was completed already at the end of September 2008.

Herrenknecht double shield tunnel boring machine.

The Cabera Tunnel in Spain was bored five months ahead of schedule.

For the construction of the second tube, the site was logistically equipped in such a way that the tunneling performances outmatched those achieved in the first tube. The lining segments were produced around the clock, and the production of the mortar to fill the space between the lining segments was extended correspondingly, so that the double amount of material was available all the time.

After the beginning of the tunneling work on the second tube on May 5, 2008, the team achieved weekly performances of more than 400 m (1,312 ft) on several occasions; on average, the machine excavated 284 m (932 ft) of tunnel per week and laid 178 lining segments.

Double Shield TBM allows non-stop tunneling

The Herrenknecht Double Shield TBM drilled continuously through the rock. The

TBM held fast to the rock using gripper plates, creating the necessary contact pressures for the tunneling work. At the same time the lining segments were installed with the help of the lining segment erector. Concrete segments weighing up to 8.8 t (9.7 st) and one keystone create a ring with a width of 1.6 m (5.2 ft) thus forming the frame of the tunnel.

The Spanish Herrenknecht branch managers Francisco Avila Aranda and Juan Arroyo mentioned several factors to explain the speedy progress in the tunneling activities: the experienced construction site team of FCC Construcción S.A. and Construcciones Sanchez Dominguez-Sando S.A., the logistics system which was planned in detail and the tunnel boring machine which was precisely adapted to the geology consisting of hard limestone. Consultant and tunneling expert, such as Ingeniero de Caminos, Canales y Puertos Don Felipe Mendaña said he was impressed at the speed achieved by the machine and the construction site team: "The right machine type was chosen for the geology: a double shield. This made it possible to carry out almost 100 percent of the tunneling work in the "double shield mode," allowing the simultaneous installation of the tunnel lining and the excavation work. Furthermore, the construction site team, excellently trained and coordinated by the construction company and the perfect logistics system contributed to this extraordinary performance."

The La Cabrera Railway Tunnel

The La Cabrera Tunnel crosses beneath the Sierra de La Cabrera and overcomes a difference in height of around 170 m (557 ft) with a gradient of up to almost 3 percent between the western and eastern portal. As part of the extension of the highspeed railway network between Madrid and Valencia, the tunnel forms the core part of the 11.2 km- (7 mile-) long section "Siete Aguas-Buñol." The plan is to put the tunnel into operation at the end of 2010, after the installation of the necessary railway technology. ■

NEW TECHNOLOGY

Refuge chambers added to TBMs in Hong Kong

Following the recent tunnel collapse in Hangzhou, Eastern China, Herreknecht has incorporated two purpose-built refuge chambers into their emergency plans for the Hong Kong Drainage project, to help protect personnel from potential hazards.

In November 2007 the Hong Kong Drainage Services Department (DSD) awarded the construction of its West Drainage Tunnel to the JV of Dragages-Nishimatsu, with a contract value of HK$2.75 billion. The 11 km (7 mile), 6.25 to 7.25 m (20.5 to 23.8 ft) drainage tunnel will be built in two sections – West to East of Hong Kong Island – by two converging Herrknect tunne boring mashines (TBM).

As designers of the two double shield TBMs to be used in the project, Herrenknecht, incorporated two custom-built Refuge Chambers to sit within each TBM gantry.

The CE certified refuge chambers have been developed by MineARC Systems of Australia, which also design and manufacture hard-rock and coal chambers for use in underground mining operations around the world.

Each chamber is designed to be fully self-sustaining; providing a minimum of 24 hours refuge for up to 20 occupants, including oxygen supply, carbon dioxide/monoxide filtering, gas monitoring and air-conditioning to maintain internal temperature. Rail-mounted, remote-controlled chambers are also available for the tunneling industry.

The MineARC refuge chamber can accomodate up to 20 people.

MineARC General Manager Mike Lincoln: "In situations where fire, smoke, or tunnel collapse has made it unsafe or impossible for personnel to evacuate the area, MineARC refuge chambers provide a potentially life-saving solution, as part of a wider emergency plan."

www.minearc.com.au

Atlas Copco launches new scaling rig

Atlas Copco has launched a new version of its Scaletec scaling rig giving operators a stronger and faster scaling tool for mining and tunneling applications.

The new Scaletec LC from Atlas Copco is based on the Scaletec MC.

In addition to the standard four-cylinder, Tier III, low-emission diesel engine, the rig is also available with a six-cylinder version that enables faster tramming between sites.

"Our customers have asked for a fast-tramming scaling rig," said Mathias Edhammer, product manager Boltec/Scaletec, Atlas Copco. "With the six-cylinder engine, you increase your tramming speed climbing ramps by almost 50 percent on average."

Other features on this version have been further improved on both Scaletec models, such as the ergonomically designed, FOPS-approved operator's cabin. It features the single seat concept that allows the operator to switch between scaling and tramming mode in one movement.

In addition, the cabin's lift- and tilt-function gives excellent visibility during scaling. A 375-mm (14.75-in.) vertical lift and a 15° tilt provide a superior overview of the working area from the same spot.

The patented boom design helps to improve the visibility and this, combined with its mechanical parallel holding system, makes scaling faster, easier and more accurate.

For a stable setup, Atlas Copco has integrated the front hydraulic jacks on the shovel blade. "By doing this we have placed the support in front of where the boom is attached, instead of behind," said Edhammer. "This gives much better stability and reduces the movement in the cabin."

Atlas Copco's new scalling rig.

www.atlascopco.com

Tunnel Engineers Directional Software being used at Belfast project

Morgan Est., a provider of infrastructure services across the public and private sector in the United Kingdom, has decided to use The Tunnel Engineers Directional Software System (TEDSS) as the laser guidance system for its tunnel alignment control at its mulit-million dollar contract to upgrade Belfast's sewer system for Northern Ireland Water.

TEDSS is owned by Alignment Surveys Ltd. and is a result of many years of development and testing in the field by the company's principal, E.W. Janes.

The TEDSS system can be used for a tunnel project affected by the tight alignments and also for more conventional alignments. Thus, it offers a complete tunnel guidance system in any environment.

In two systems of tunneling, pipe jack and fixed lining, the use of "new technology" gyros for azimuth (heading) information will benefit tunnel boring machine (TBM) operations by reducing downtime caused by system guidance failures and TBM survey checks. Additionally, the reduction of manual survey checks and "survey control" advance within the cramped environment of both tunnel types will also enhance the safety standards of TBM operations.

The rate gyros used for TEDSS are laser gyros. They are compact and more reliable than mechanical gyros, providing greater accuracy with the consumption of less power. These are for use as a stand-alone unit within a pipe jack environment or as part of an integrated system, incorporating a robotic total station, for use within conventional mechanized tunneling. ■

www.alignmentsurveys.com

• Denotes new listing.

Industry Events

March 2009

• **20- April 3, 2009 International No-Dig Show,** Sheraton Center Toronto Hotel, Toronto, Canada. Contact: Benjamin Media, 1770 Main St., P.O. Box 190, Peninsula,OH 44264-0190, phone: 330-467-7588, fax: 330-468-2289, e-mail: mmagyar@benjaminmedia.com, Web site www.benjaminmedia.com.

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

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.

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

September 2009

9-11, Euro:Tun 2009, Ruhr University, Bochum, Germany. Contact: Institute for Structural Mechanics - Ruhr-University Bochum, phone 49-234-32-29069, fax 49-234-32-14149, e-mail felix.nagel@rub.de, Web site www. eurotun.rub.de.

• **23-25, Tunneling Short Course,** Colorado School of Mines. Contact: Office of Special Programs and Continuing Education Colorado School of Mines, Golden, CO 80401, phone: 303-273-3321, fax 303-273-3314, e-mail space@mines.edu, Web site www. mines.edu.

January 2010

• **26, George Fox Conference,** Graduate Center, City University of New York. 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.

June 2010

• **12-19, North American Tunneling Conference,** Portland, OR. 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. ■

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or (+) Reinstatement Fee:	$10
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UCA INDIVIDUAL PROFESSIONAL MEMBER

A person eligible for election or transfer into the class of Individual Professional Member shall be either: (i) employed in a position of responsibility in an area relevant to minerals exploration, extraction, production, processing, economics or metallurgy, including employment as an educator, engineer, scientist (including chemistry or any related earth science) management (including but not limited to chief executive officer, financial, legal, or human resources personnel); or (ii) hold a baccalaureate degree, masters degree or doctorate degree in engineering, mineral economics or any related earth, chemical or environmental sciences; or (iii) employed or educated in mineral exploration, extraction, production, processing, economics or metallurgy; or (iv) actively involved, directly or indirectly, with mineral exploration, extraction, production, processing, economics or metallurgy, whether through engineering, scientific, related earth science, management, executive, financial, legal, or human resources experience; or (v) engaged in marketing or technical sales of equipment and supplies used in mineral activities.

If at any time your record of experience and/or education is questioned for qualification of member grade, you may be requested to provide an endorsement for membership by an SME member in good standing.

UCA STUDENT MEMBER

A person eligible for election into the class of Student Member must be a full-time college undergraduate or graduate student in good standing. A Professional Member who subsequently returns to school for an additional degree cannot become a Student Member. All Student Members must be nominated by an existing Member.

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UCA of SME Corporate and Sustaining Memberships are designed especially for companies seeking opportunities to promote their organizations, its services and employees. Any industrial organization in the underground construction industry may become an UCA of SME Corporate or Sustaining Member.

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Membership was recommended to me by: ______________________________________

Signature (All Applicants)

If elected, I agree to abide by the bylaws and rules of the Society for Mining, Metallurgy, and Exploration, Inc. as the same are now in effect and as they may hereafter be modified while I am a member. I understand that under certain laws and regulations, SME must have my permission in order to communicate with me via fax or email. I hereby give SME Foundation, SME Local Sections and SME business associations permission to send me information and advertisements. If SME does NOT have your permission to communicate with you via fax or email, you may not have access to some of your electronic member benefits.

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Record of Experience

Include most recent record of employment as related to minerals industry.

From: / To:		*Position of Responsibility*
From: To:	Title: ______________ Employer: ______________ Nature of employer's business: ______________ Primary responsibilities: ______________	☐ Yes ☐ No

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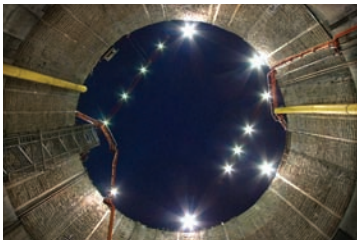

SAVE THE DATE

Shaft Design and Construction Short Course
September 10-11, 2009
The Westin Atlanta Airport, Atlanta, Georgia

UCA of SME
Underground Construction Association of SME

DAY 1:

	TOPIC	PRESENTER
GENERAL	<u>Introduction:</u> Application and Classification of Shafts	Jamal Rostami, PhD, PE, *Penn State Univ.*
	<u>Planning:</u> Shaft Sizing, Layout, and General Design Guidelines	Brenda Bohlke, PhD, PG
	Geotech Site Investigation: Planning & Execution	Mike Gilbert, PE, *CDM*
	BREAK	
EXCAVATION	Large Diameter Shaft in Rock, Drilling and Blasting	Jamal Rostami, PhD, PE , William Leech, PE
	Small Diameter Shafts in Soil, Auger Drilling/Raise Boring	Alan Zeni, *Frontier Kemper*
	Large Diameter Shaft in Rock, Shaft Boring	Peter Schmäh, *Herrenknecht*
	BREAK/LUNCH	
GROUND SUPPORT	Large Diameter Shafts in Soil, Sheet Piling, Soldier Piling, Steel Support	Ron Smith, *American Commercial*
	Large Diameter Shafts in Soil, Slurry Wall, Ground Freezing	Francois Bernarduea, PE, *CDM*
	Large Diameter Shafts in Soil, Jet Grouting	George K. Burke, PE, *Hayward Baker*
	Large Diameter Shafts in Soil, Sinking Caisson	Robert Goodfellow, PE, Vojtech Gall, PE
	BREAK	
APPLICATIONS	Water, Sewer, CSO, SSO, Drop Shaft	Jozef F. Zurawski, PE, *Dawn Engineering*
	Urban Shaft Construction for Subway or Metro	Verya Nasri, PhD, PE, *DMJM*
	Mine/Service Shaft Design and Construction	Peter Brokenshire, PE, *McIntosh Mining Consultants*
	Microtunneling Launch Shafts	Glenn Boyce, *Jacob Associates Inc.*
	Banquet Key note : "Manhattan Layered Cake, Dealing with Utility Relocation for Shaft Construction. A Case Study of 2nd Ave., Subway"	Speakers: Gary Almarez, Alaeden Jelaty, *Sakanska Construction Co*

Program Starting at 8:30am and Closing at 5:30pm., Dinner at 7:00pm.

DAY 2:

	TOPIC	PRESENTER
SPECIAL TOPICS	Shaft Dewatering and Drainage and Groundwater Issues	Hugh Lacey, *Mueser Rutledge*
	Shaft Construction Underwater, Coffer Dam	Flat Iron Contractors, Fugro
	Shaft Hoisting/Haulage	Steve Crudson, *Wagner, Frontier Kemper*
	Shaft Enlargement	Shavonne
	BREAK	
CASE HISTORIES	Shaft Layout, Surface Facilities for Slurry Machine	Bill Mariucci, *Kiewit Construction, East side CSO, Portland, OR*
	Case Histories: Mining Shafts	Andy Fearn, *The Redpath Group*
	Discussion and Closing Remarks	Jamal Rostami, *Penn State University*
	LUNCH	
	Site Visit: Atlanta Area Shaft	Tour coordinated by: Refik Elabay, *Jordan Jones Golding Inc.*

Program Starting at 8:30am and Closing at 5:30pm.

Complete Details Available in March. www.uca.smenet.org

To book a sleeping room contact:
Westin Atlanta Airport, 4736 Best Road, College Park, GA 30337 • 404-762-7676
Hotel room rate is $139 single/double

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