

MAY 2008

# tunnels



# tunneling

NORTH AMERICA



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**Front cover**

"Rosie" a 25ft (7.7m) diameter Herrenknecht Mixshield S-348 for the Eastside CSO Project, in Portland, OR, is assembled in the Opera Shaft. The largest of all Portland's projects to reduce sewage and storm water overflows into the Willamette River. Works include excavation and lining of an approximately 22ft (6.7m) i.d. diameter tunnel, 85ft (25m) to 165ft (50m) below ground, and seven shafts. The total drive length of the Herrenknecht Mixshield is 5.5 miles (8,910m).

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# The changing face of tunneling...

It was interesting to come across an article recently on the history of tunneling in Seattle (*T&TNA*, June 2005, p29) - especially when viewed against the vast array of design and construction techniques employed on the Beacon Hill Station and Tunnels contract (p13), which is currently being constructed in downtown Seattle as part of the city's new Central Link Light Rail Line.

The first tunnels to be excavated through Seattle's notoriously complex and highly variable glacial deposits, were excavated by hand and lit with candles (risky business considering pockets of naturally occurring methane gas exist in the area). If used at all, ventilation was generally powered by mules or horses at the surface, and primary support was timber ribs and lagging, with brick used for the final permanent lining.

A prime example of major soft ground tunneling in the city is the construction of the mile-long Great Northern Railroad Tunnel, which commenced in the spring of 1903. After a year of surveying and planning, an army of 350 workers with pickaxes, shovels and wheelbarrows worked through the day and night from rudimentary sequential excavation headings.

Although good progress (in the region of 18ft/day) was made in the soft soils initially encountered, the miners were

soon plagued by heavy water seepage that seriously hampered their advance. Later, areas of dense clays and gravels were met, and drilling through these proved to further slow progress.

These challenges, and others, were met to the best of the miners abilities - including the discovery of a buried pre-historic forest, with a naturally preserved tree of more than 3ft in diameter found blocking the advance.

Assisted by the intense rivalry that existed between the day and night crews, the tunnel was eventually completed ahead of schedule, at the end of 1904 - quite some achievement considering the tools on hand at the time.

Despite the advantages our ever-evolving technology brings, it is still important to remember much can be gleaned from studying past experiences

Despite this success, the concept of a highly complicated series of interconnecting soft ground excavations in similar ground conditions, but at depths of up to 180ft, such as those currently being completed for the Beacon Hill Station and Tunnels, would have been entirely inconceivable to those engineers 100 years ago.

The Beacon Hill project is a tribute to, and showcase for, modern tunneling technology.

Employing nearly the entire range of state-of-the-art management, design, investigation, construction and monitoring equipment and techniques available today, the project demonstrates just how far the North American tunneling industry has come on since those early days.

Considering his obvious interest in the construction of past Puget Sound tunnels, it was not a huge surprise to find out the author of the aforementioned article was recently recognized by Beacon Hill's management team for bringing to the project a deep knowledge and understanding of the tunneling conditions in the Seattle region.

However, the point does serve to illustrate that, despite the advantages our ever-evolving technology brings us, it is still important to remember that much can be gleaned from studying past experiences.

With all this in mind, June's North American Tunneling (NAT) conference "The Changing Face of Tunneling" seems particularly noteworthy (p21). Such events continue to serve a vital role in knowledge sharing and the exchange and development of new ideas.

With some of the world's most challenging tunneling projects currently in development in North America, the conference is sure to be a great forum for all.

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# Safety concerns halt twin drives at Seymour-Capilano

**W**orker safety concerns have led to the twin 4.5-mile (7.2km) long Seymour-Capilano tunnels in Vancouver, Canada, being put on stop since early January.

Contractor Bilfinger-Berger had been driving the tunnels for Metro Vancouver since mid-2006, but the contractor suspended works on the raw water tunnel (RWT) at 2.5 miles (4.1km) CH on January 7 this year. Excavation was also suspended on the treated water tunnel (TWT), which was being advanced with a 984ft (300m) lag behind the RWT, on January 10.

Reports said that by January 14, ten incidents of falling rock had been reported, three of which resulted in injury to a worker; one resulted in a lost time injury. Seven of these incidents occurred in January.

After receiving the incident reports, WorkSafeBC, the British Columbia workers' compensation board that monitors compliance with occupational safety regulations, directed the contractor to halt work until the hazardous conditions had been eliminated or controlled. Weak altered rock conditions are said to have resulted in broken and unstable ground that is difficult to support.

A spokesman for Metro Vancouver told *T&TNA* in May: "Worker safety is a prime concern for Metro Vancouver and is the key issue to be addressed so that work can resume."

He added that Hatch Mott MacDonald, Metro Vancouver's engineer for the project, has developed a remediation plan to address the ground conditions, but that it is "a complex geological condition and requires extensive assessment before work can safely resume."

*T&TNA* was also told that an approximately 164ft (50m) section of the RWT was affected, but that work on the TWT was stopped as a precaution, in case similar conditions were encountered. Press reports said Bilfinger-Berger had rejected an initial plan from Metro Vancouver engineers and was reviewing a second plan.

With work suspended, cordons have been established to within 197ft (60m) of the two Robbins 12.5ft (3.8m) diameter

TBMs that had been advancing the tunnels at 33-66ft (10-20m) a day. Several workers have been temporarily laid off while the work is stopped. Doug Neden, an engineer for Metro Vancouver, told local press that there were 90-100 workers on the project (including construction site and office staff) and that 30 people were laid off in March. Robbins told *T&TNA* that its personnel had been removed from site.

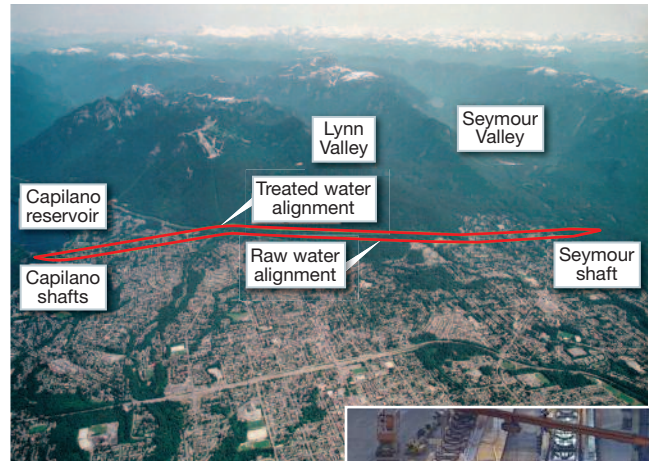
Outside the cordons, work is underway in both tunnels on final support and lining. This includes steel mesh and bolts as well as shotcreting.

The Metro Vancouver spokesman told *T&TNA*: "It is likely that the delays in tunneling will result in additional costs and schedule impact. At this stage, it is premature to determine what the costs and schedule impacts are and how those additional costs will be assigned."

He noted: "Metro Vancouver continues to be in discussion with the contractor Bilfinger-Berger so that an acceptable solution can be implemented."

Bilfinger-Berger confirmed the suspension of work due to safety concerns, but was unable to add further details pending resolution of plans.

Pacific Liacion & Associates / SNC Lavalin are responsible for construction management, Hatch Mott MacDonald is providing resident engineer



**Above:** Route of the twin drives  
**Right:** One of the Robbins' TBMs

services and Golder Associates is supplying geotechnical services for the project.

Once completed, the project will see treated and untreated water run through the contraflow tunnels underneath Grouse Mountain between the Capilano Lake Reservoir and the filtration plant in the Lower Seymour Conservation Reserve (LSCR).

In its last construction update, Metro Vancouver stated the final tunnel alignment was selected based on 12 months of test drilling. Located in bedrock 525-2,100ft (160-640m) below the surface, "this alignment was selected based on the quality of



the bedrock and anticipated tunneling conditions".

Tunneling had been expected to be complete by mid-2008 when the project was awarded in 2004. ■

## South Cobb awarded to JF Shea/Traylor JV

**C**obb County in Georgia awarded a US\$305 million contract to build the 5.5-mile (8.8km) long South Cobb wastewater tunnel to a joint venture comprising JF Shea and Traylor Bros on March 11.

The project estimate has risen by over US\$100 million since late 2006.

The 27ft (8.2m) diameter tunnel will handle 40% of the county's flows. Traylor Bros said the hard rock tunnel would be mined with a main beam TBM. Five additional tunnels totalling more than a mile (1.6km) are to be excavated by drill and blast. In addition, the scope includes two 46ft (14m) diameter shafts and a larger shaft and pump station structure.

The tunnel alignment runs at an average depth of 250ft (76m) through the same geologic formations as the south drive of the Chattahoochee tunnel. The bedrock is expected to vary from fractured to solid and could consist of medium grade metamorphic rocks with granitic intrusions. Approximately 75% of the tunnel is expected to be lined with cast-in-place concrete lining.

The tunnel was designed by Jordan, Jones & Goulding (JJG), a regional consulting firm with past experience on the Chattahoochee Tunnel, Nancy Creek Tunnel and West Combined Sewer Overflow Tunnel in the area.

At the same time as the

construction contract award, JJG was awarded, a US\$7.5 million capped body of additional work to provide construction engineering services such as reviewing submittals, geological mapping and responding to requests for information from the contractor. The Cobb County Water System (CCWS) has previously awarded Parsons and its subcontractor Jacobs Associates the construction management contract for the project.

The South Cobb scheme will allow the county to avoid replacing 16 miles (26km) of aging sewer line and two pump stations. Work is expected to start this summer. ■

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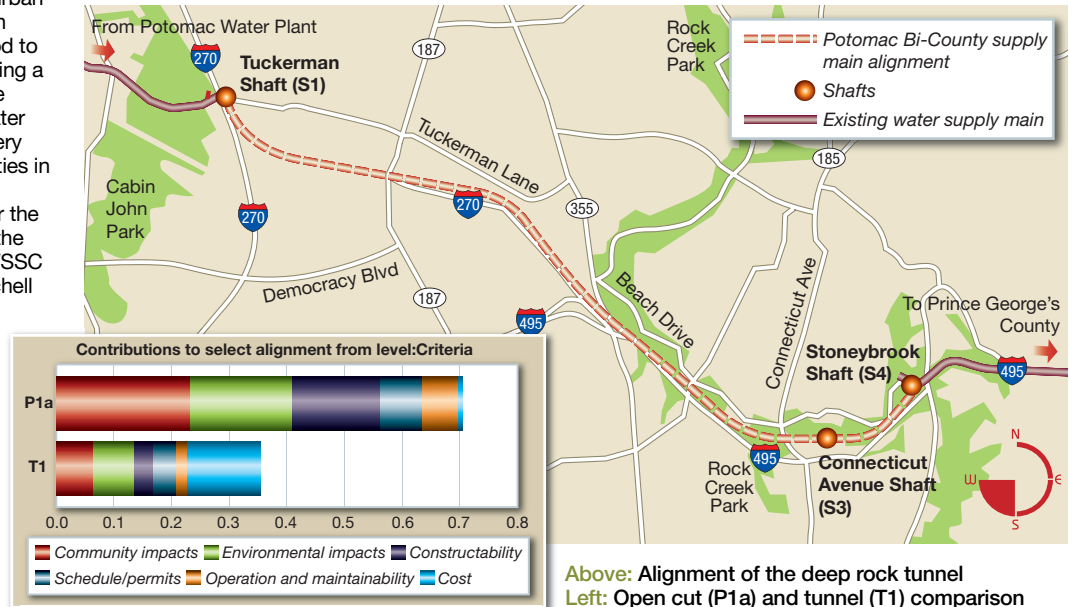
# WSSC set to call for bids on Bi-County Water Tunnel

The Washington Suburban Sanitary Commission (WSSC) is understood to be on the verge of advertising a call for bids for the 5.3-mile (8.5km) long Bi-County Water Tunnel between Montgomery and Prince George's Counties in Maryland.

Plans originally called for the tender to be advertised in the first quarter of 2008, but WSSC project manager John Mitchell told *T&TNA* that, although a number of contractors had already expressed an interest, permit acquisitions had pushed the timetable back and it was hoped the call could be advertised in June.

The 12ft (3.7m) diameter deep rock tunnel will be constructed within solid bedrock between 90-280ft (27.4-85.3m) below the surface. An 84in (213cm) diameter pipe will be installed inside it to carry water.

Designed to connect two existing water mains, the tunnel is part of WSSC's commitment to providing a constant, reliable water supply to all of its customers and meeting all projected future water



Above: Alignment of the deep rock tunnel  
Left: Open cut (P1a) and tunnel (T1) comparison

demands.

After studying the options for the new pipeline, it was decided that a deep tunnel was preferred over an open-cut pipeline as it would "minimize community, historical and environmental impacts, be easier to maintain, and would not cost much more than other methods".

Construction is scheduled to

take four years with a main drive shaft at Connecticut Avenue (S3), with Tuckerman Shaft (S1) at the western limit and Stonebrook Shaft (S4) at the eastern limit of the tunnel reaches. S1 and S4 will primarily be retrieval shafts, but additional small shafts to facilitate grouting and water pipe installation have not been

ruled out. S3 will be 35ft (10.7m) diameter and S1 and S4 will be 25ft (7.6m) diameter. All will be excavated by drill and blast. Any grouting shafts will be between 12-48in (30.5-122cm) wide and excavated by caisson drilling.

As the scheme design is finalized, there may also be a requirement for riser shafts excavated upwards from within the tunnel to facilitate connections or ventilation.

Mitchell told *T&TNA* that changes were made to access at one of the sites and, although it was favorable to the community and would simplify the construction process, it had delayed the permitting process.

He added: "As a result of the delay, we will not be fast tracking the project. Funding is not impacted because this is a 'growth' project for WSSC. Growth projects receive funding from our Systems Development Charge (SDC). The SDC is a fee WSSC charges to new development so that growth pays for growth. The charges are placed in a separate fund and can only be used for growth projects."

Contractors interested in being placed on a list of potential bidders should contact the Commission's Construction Project Manager, Steve Pinault, by email at [spinaul@wsscwater.com](mailto:spinaul@wsscwater.com)

## Ottawa confirms Can\$4bn transit system scheme

The ambition of Canadian capital Ottawa to develop a world-class mass transit system took a step forward on April 15 with the announcement of a Can\$4 billion preferred scheme that includes a 1.5-mile (2.5km) long downtown light rail transit (LRT) tunnel.

The recommendation to the municipal Joint Transportation and Transit Committee followed an extensive period evaluating four possible options. Further review will now take place and funding options will follow later.

All four options include a downtown tunnel, but the estimated price varies from Can\$555 million to Can\$1,032 million.

Option 1 was a bus-based solution; Option 2 was based on buses with a north-south LRT component; Option 3 had

an east-west LRT variant; Option 4 serviced east-west, with north-south LRT. Options 3 and 4 saw the tunnel serving an LRT only and had the lowest projected price tag of Can\$555 million. The Option 1 tunnel cost was Can\$780 million and the mixed bus and LRT required for Option 2 was costed at Can\$1,032 million.

The downtown tunnel saw strong support throughout the recently completed public consultation. An LRT solution was preferred throughout the city, with majority support for Option 4, some support for Option 3 and virtually no support for Options 1 and 2.

Option 4 was felt to give the greatest benefit and value to the city. It offered the lowest annual operating costs, would produce the lowest emissions, the lowest

salt use and the lowest noise and vibration. It also had the highest property value and offered best overall image for the city.

This option also offered the highest potential for increased success, capacity for growth beyond 2031, and most direct rail connections between key destinations.

*T&TNA* was told that plans were at an early stage, but the LRT system would feature twin tunnels with a diameter of 21ft (6.4m). Driven through rock, the tunnel would follow an alignment approximately 56ft (17m) below the surface downtown.

A spokesman for the city said current plans assumed opening within six years to allow for planning, environmental assessments, design and construction – subject to funding availability. ■

# Niagara team may face re-alignment

In a bid to mitigate the schedule impact of slow advances on the 6.5-mile (10.4km) long Niagara Tunnel Project, in Canada, Strabag has proposed changes to the alignment of the 47ft (14.4m) diameter bore.

As main contractor for the tunnel work, Strabag has advised Ontario Power Generation (OPG) that difficulties with fractured rock mean TBM advance has been slower than anticipated.

The problems are highlighted in OPG's 2007 annual report, which notes that excavation work began in September 2006 and the TBM had advanced 5,279ft (1,609m) by December 2007.

The first 7,546ft (2,300m) of tunnel was always expected to be problematic, due to the learning curve and variable geology. As of mid-May, the

tunnel was confirmed as having advanced 6,600ft (2,012m).

OPG said: "Considerable uncertainty remains with respect to the schedule until the TBM advances to approximately 7,546ft (2,300m), and establishes consistent performance. The contractor has advised the in-service date of the tunnel will be delayed, and is investigating alternatives, including the realignment of the tunnel, to mitigate the impact of the delay. The estimated in-service date will be dependent on the alternative selected by the contractor."

The tunnel is being bored by Big Becky, the world's largest hard rock TBM, a Robbins Main Beam machine. Reports said that the TBM is currently advancing through Queenston Shale, a

mudstone. Despite site investigations having been carried out, it is believed that vertical fracturing that was not evident in samples is responsible for the current difficulties, with loose rock falling behind the TBM as it advances.

In August last year, when the tunnel was at the 3,281ft (1,000m) mark, slow progress had been attributed to rockfalls in the range of 10-20 tons as the TBM advanced. Robbins President, Lok Home, told *T&TNA* that crews are currently averaging 6.5-10ft (2-3m) per day: "They spile and rock support in advance of the face for 16ft (5m), then bore 13ft (4m), and keep repeating the cycle."

Ernst Gschnitzer, Strabag's project manager for the tunnel, said: "You're dealing with nature.

You can't predict rock conditions for 10km (6.2 miles)."

Hatch Energy is providing representative services for OPG in association with Hatch Mott MacDonald. Hatch stated: "The project is a Design Build project with a partnering approach. A negotiated Geotechnical Baseline Report (GBR) was used to equitably share underground risks on the project."

OPG has said that Ontario taxpayers are protected from cost overruns on the Can\$600 million budget, as the design-build arrangement with Strabag means the tunnel was let for a fixed price. However, in its 2007 annual report, OPG conceded: "There is a potential risk that the schedule delay could impact the project cost."

Unlike the situation at Seymour-Capilano (p5), no major injuries have been reported and the TBM is still being advanced, albeit at a slower pace, while the contractor assesses its options.

Strabag has now applied for the necessary approvals for its planned realignment, which would see the tunnel shifted slightly to the east and at a higher elevation, in order to reposition the drive into more predictable rock.

Tunnel completion was scheduled for 2009. Current projections suggest this may now be as far off as 2011. ■



Left: The current alignment of the Niagara Tunnel Project; and (above) a finished section of the tunnel

## Lone bidder revealed for Cincinnati sewer tunnel project

Cincinnati Tunnel Partners was the only bidder for the Eastern and Delta Avenue Sewer Separation Phase 1 when the Metropolitan Sewer District of Greater Cincinnati (MSDGC) opened bids on April 22.

*T&TNA* has learnt that the Cincinnati Tunnel Partners consortium, comprising Jay Dee Contractors, Mole Constructors, Murray Hill Construction and Kassouf Company, submitted a bid of US\$37,386,840 for the microtunnel alignment option. This includes 6,077 linear ft (1,850m) of 72" (183cm) diameter microtunnel at a unit bid price of US\$900/LF for labor, US\$1,920/LF for materials, to give a combined unit price of US\$2,820/LF and US\$17,137,140 for the tunnel bore. This option allows for 15 boulder obstructions at US\$3,000 labor and US\$7,000

materials per occurrence.

An alternative alignment that was not priced, allowed for 6,071 linear ft (1,850m) of 72" (183cm) EPBM, with 20 boulder obstructions.

This phase of the project will see construction of an intercepting sewer and separation of combined sewer overflows. MSDGC said that construction estimates have roughly doubled since those approved by the county in February last year. This is due to new geotechnical reports that document significantly different soil conditions from those previously assumed, plus an increase in pipe size to 72" (183cm) from the previous 48" (122cm) diameter.

The project is due to be substantially completed by March 2010. ■

## Mixed news from Toronto

May 2nd marked both success and setback for McNally/Aecon JV's two EPBM sewer projects, just north of Toronto, Canada. On the same day final breakthrough was successfully achieved on the 19th Avenue project, an incident occurred on the JV's Langstaff Trunk Sewer Project, requiring evacuation of the tunnel and local road closures.

At the time of *T&TNA*'s last report, in March 2008 (p6), the 10.6ft (3.25m) diameter Lovat EPBM on the Langstaff drive had been progressing through the most difficult ground met so far on the two projects. Since then, conditions deteriorated further, with very fine silts and water pressures of up to 1.5 bar causing tail seal leaks.

"On May 2 a breach of the tail seals occurred, at ring 1450, approximately 150m west of the intermediate shaft," said Laura McNally, Project Manager

for the JV. "This resulted in a large inrush of material, which the crew was unable to control. The tunnel was evacuated and fortunately no one was injured."

Crews responded quickly to secure the tunnel and surface, and work is now ongoing to further investigate the cause of the incident and recover the tunnel. "Several options are being considered to minimize schedule impacts, including launching a TBM from the east end of the tunnel drive," McNally added.

On the remaining Bathurst Collector drive, a third Lovat EPBM has achieved record production rates for the JV, with a best shift of 17 rings and a best week of 129 rings. Final breakthrough on Bathurst is expected at the end of August, with just 900 rings remaining.

Following its successful final drive, 19th Avenue is due to be wrapped up next month. ■



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# Lovat acquires a powerful partner for pushing forward

T&TNA contributor **Shani Wallis**, talked to Canadian TBM manufacturer Lovat, following its acquisition by US manufacturing-giant Caterpillar

**N**ews of Lovat's acquisition in early April, by giant US-based corporation Caterpillar, certainly caught industry-wide attention. It was a clear vote of confidence in the health of the tunneling business and confirmed that demand for tunneling equipment into the future will require expansive procurement and manufacturing capabilities.

"I'm over the moon!" is how Rick Lovat described the acquisition, announced April 2, 2008. "This secures our future without compromising our legacy. As President of the company, I could see that within five years we need to be twice as big, if not bigger, to keep pace with demand in terms of capacity, resources and staff. This was going to be difficult from our footprint here in Toronto, and would have required substantial capital. With Caterpillar we gain these resources while retaining our identity. We remain as we are – our identity is unchanged; we stay operating out of Toronto; we remain in charge of our own strategy; we retain all our own people; there is no change of our management – all these were agreed in negotiations. The difference is that, going forward, instead of an amorphous venture capitalist or bank, interested primarily in asset stripping or maximizing profit without investment, we have a like-minded partner. One that has the same global interest; is in the heavy civil construction industry; has like-minded goals; and understands the nature of the business. What is there not to like about this deal?"

Lovat Senior, founder of the family business in 1972, said: "I could see things coming for the market, for the company, and realized change was needed,

and to be selected by the industry leader as their tunneling partner is the highest recognition of our efforts. They are not going to compromise their reputation and neither are we. They wanted the best and we have joined with the best."

It was from humble beginnings after emigrating as a mechanical engineer from Italy to Canada that Richard, and his son Rick, built the company to a world-recognized name with a reputation for sticking with the toughest of projects to a successful end.

As a private company, Lovat doesn't publish annual accounts, but with more than 250 TBMs delivered globally and support companies in Europe and China, Lovat today employs more than 450 and "our order books through 2008 reflect the demanding state of the business," said the President.

The match-up really is a pairing with the mighty. Publicly-traded Caterpillar is one of the world's leading construction, earth-moving and mining equipment manufacturers, with reported revenues of \$45 billion in 2007, and expectations of a 5-10% increase on this in 2008.

Together with its renowned yellow-branded workhorses, the 80-year-old CAT corporation also manufactures diesel and natural gas engines and industrial gas turbines. It also runs its own financial, remanufacturing and logistics divisions and a railway maintenance business.

CAT's 2007 accounts didn't make mention of potential acquisition, but Chairman and President Jim Owens said in his statement: "We expect the world's robust investment in infrastructure to continue into the next decade, and we'll need more capacity to serve our customers." In a statement, Mining and Underground



Richard and Rick have built Lovat into a world-renown company

Products Vice President Chris Curfman said; "we intend to leverage our global business with continued investment in the Lovat product line".

Market share data is closely guarded by the major players, but by rough estimates the global TBM supply business, with all the necessary support equipment, must be over \$US1 billion per year at present and some say closer to \$2 billion. With no slow down in sight, this could double over the next five years and remain elevated thereafter.

The amount of underground infrastructure to be built in developing countries, and the rehabilitation, replacement and expansion needed in developed countries, is in the multi-billions to trillions. The majority of this is needed in cities and through soft or mixed ground – the market sector in which Lovat is centered.

Getting a slice of this action prompted Caterpillar to begin investigations on how to enter the market and become an all-round supplier to the expansive international customer base.

According to Lovat, Caterpillar initiated negotiations. "They approached us saying that, of the investigations they had made, it was us they wanted to partner with."

And there is much to credit the union. The two companies are North American based and therefore operate under the same basic ethos and business management model; they operate under similar legal systems; they speak the same language; and evidently share a common goal.

"As with others in the market, we needed money and resources to be able to meet rapidly growing demand and we get this in the best possible way with Caterpillar," said President Lovat. "We get to partner with one of the biggest construction equipment manufacturers with facilities around the world. We can draw on the company's dynamic R&D department; on its purchasing power; and on its international servicing network."

Other manufacturers have made alliances with banks and financial backers, have set up joint venture manufacturing in other countries, and have found partners among industry leaders. But where other high profile takeovers and partnerships have failed, the CAT-Lovat combination has more going for it for the benefit of the market.

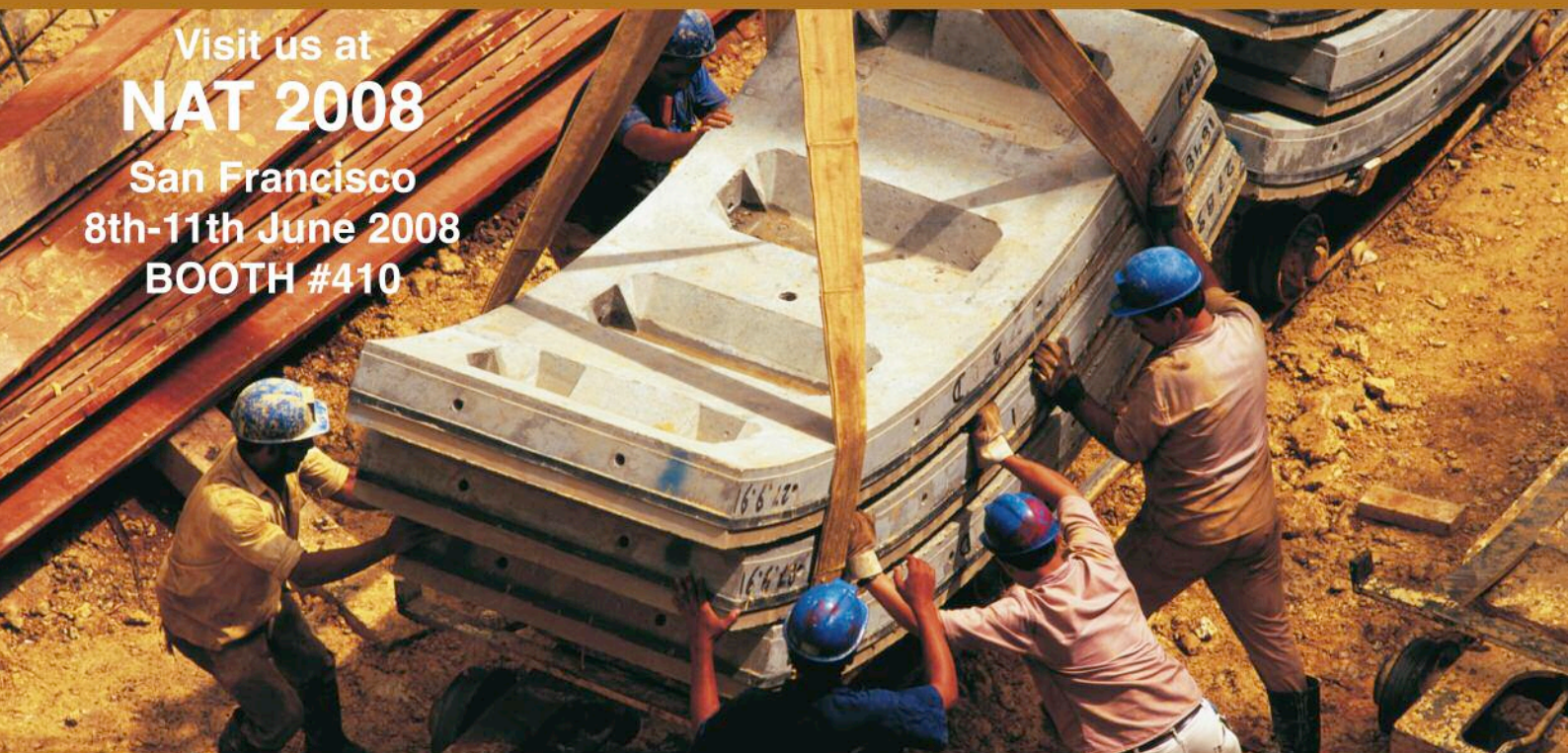
Supply of components in this market for example, has become a critical pinch point for delivery of TBMs. Bearings in particular are on long lead times amid increased competition from the military and wind farm industries. With Caterpillar, Lovat aligns itself with one of the largest buyers of industrial bearings and the pricing and delivery guarantees that brings. On the international stage, while Caterpillar has a broad global reach, Lovat has a long and stronger presence in several countries, including Russia, and can facilitate introductions for CAT.

The 100% acquisition of Lovat by CAT is a boulder into the pond, and is likely to significantly change the future dynamics of the TBM supply business. ■

**"THEY APPROACHED US SAYING, OF THE INVESTIGATIONS THEY HAD MADE, IT WAS US THEY WANTED TO PARTNER WITH"**

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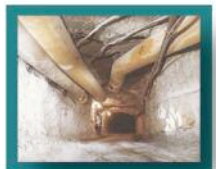
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# Sound Transit's large-scale SEM station

Beacon Hill Station, in Seattle, comprises the largest SEM soft ground excavations in the US to date.

Jürgen Laubbichler, of Dr G Sauer Corporation, describes their design and construction in highly variable soils with multiple groundwater horizons

The \$280 million C710 Beacon Hill Tunnels and Station contract forms part of the 14-mile (22km) long initial segment of Sound Transit's Central Link Light Rail Line, which extends between downtown Seattle and SeaTac Airport. The 4,300ft (1.3km) long twin running tunnels under Beacon Hill were recently completed using a 21ft (6.4m) diameter Mitsubishi EPBM, while the deep mined station has been built using slurry walls for the shafts and the Sequential Excavation Method (SEM) for the tunnels. With an excavated depth of 160ft (49m), the station is the deepest constructed in soft ground in North America.

Beacon Hill Station (Figure 1) consists of twin shafts and a complex configuration of vehicle, pedestrian and ventilation tunnels. From the Station Headhouse, a 181ft deep (55m), 46ft (14m) i.d. Main Shaft was constructed that will house four high-speed elevators, emergency staircases, ventilation shafts and M&E equipment. A 161ft (49m) deep, 26ft (8m) i.d. Ancillary Shaft will accommodate another set of emergency staircases and ventilation shafts.

From the Main Shaft, the 41ft (12m) wide Concourse Cross

Adit (CCA) will provide passenger and emergency access to the Northbound and Southbound Platform Tunnels (NBPT and SBPT respectively). These are 380ft (116m) long by 32ft (9.8m) wide and were designed to accommodate the light rail tracks, platforms, artwork and architectural finishes. Two pedestrian Cross Adits connect the Platform Tunnels, and Ventilation Tunnels will provide airflow in normal operation and for emergencies, these range in size from 16ft (4.9m) to 26ft (8m) in diameter.

A JV of Hatch Mott MacDonald and Jacobs Civil (HMMJ) completed the final design of the Beacon Hill segment of the project between 2002 and 2004. Dr G Sauer Corporation (DSC) was awarded a subcontract by HMMJ for the design of the station platform and concourse tunnels, monitoring and waterproofing. In addition to design support during construction, both HMMJ and DSC have provided SEM resident engineering services throughout. Puget Sound Transit Consultants (PSTC), a JV of Parsons Brinckerhoff Quade & Douglas, Earth Tech and URS Corporation, performed the preliminary engineering and



Above: SEM excavation of a Beacon Hill Station platform tunnel

provided program management services as an integrated team with the client, Sound Transit. Parsons Brinckerhoff Construction Services is providing construction management as Resident Engineer for the contract.

Final design of the C710 contract was completed in February 2004 and bids were solicited following a pre-qualification process in which prospective contractors had the opportunity to examine a 16ft (4.9m) diameter Test Shaft<sup>[1]</sup>, constructed within the footprint of the future Main Shaft.

Three teams of bidders pre-qualified: Obayashi, a JV led by Kiewit, and another JV led by Impregilo. However, Impregilo's team ultimately withdrew its bid. On May 15, 2005, the bids were opened, with Obayashi at \$280 million and the Kiewit JV at \$305 million. The Engineers estimate was \$240 million. On June 28, Sound Transit issued Notice-To-Proceed to Obayashi.

Obayashi subsequently entered into an agreement with Beton und Monierbau to provide key SEM staff.

## Geology

The Beacon Hill geology consists of glacial and interglacial soil units with a high degree of variation. This is evident locally to the extent that some units cannot be reliably correlated between adjacent borings. At the outset of the project, an extensive subsurface exploration program, with over 70 bore holes drilled, showed that most of the Beacon Hill Station would be excavated within glacial, over consolidated, partly fractured or

slickensided clays and tills. Intermittent sand and silt layers were also found present, with multiple perched groundwater horizons. In order to simplify the descriptions of the large number of geological units identified, and to reduce the complexity of the geological profile, the soils were grouped into six classes:

- 1) Loose to dense granular deposits
- 2) Soft to very stiff clay and silt
- 3) Till and till like deposits
- 4) Very dense sand and gravel
- 5) Very dense silt and fine sand
- 6) Very stiff to hard clay

The complex layering of these units, particularly thick zones of sands and silts, was extremely challenging for the design of shafts and tunnels<sup>[2]</sup>.

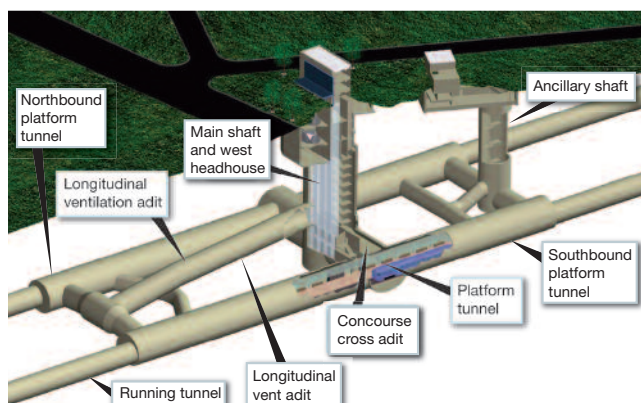
## Ground treatment

For the reasons described above, the designers specified a post contract award subsurface exploration program to refine the geotechnical interpretations. Boreholes, drilled down to platform tunnel level using mud rotary and sonic core recovery methods, were combined with instrumentation including inclinometers, extensometers and piezometers.

The variable ground conditions, with the potential for saturated and unstable sand lenses, led to the consideration of large-scale ground improvement measures prior to structural excavation. A series of deep dewatering wells and vertical jet grouting program was therefore specified<sup>[3]</sup>.

Depending on the soil properties encountered during exploration and instrument drilling, the need for additional

Below: Fig 1. Ultimate configuration of Beacon Hill Station



Temporary	Twin sidewall drift excavation	Single sidewall drift excavation	Top heading/ bench/invert excavation
Location & area	Concourse cross adit (1,500sf)	Platform tunnel (1,000sf)	Ventilation adit (400sf) Cross passage (130sf)
Excavation sequence			
Excavation support	Shotcrete t=14" Girder @ 3'-3" WWF W12xW12, 6x6	Shotcrete t=12" Girder @ 4" WWF W12xW12, 6x6	Shotcrete t=10" Girder @ 4" WWF W8xW8, 6x6

Below: Fig 2. Baseline excavation and support scenarios

jet grouting or dewatering measures would be determined.

Between August 2004 and November 2005, 50 bore holes were drilled, with core extraction and sampling conducted under the engineering oversight of Shannon & Wilson<sup>[4]</sup>.

It became evident during these investigations that sand layers, subject to water pressures of approx. 50ft (15m), within the Station tunnels were far more extensive than previously anticipated. This would have meant a 300% increase in the quantity of jet grouting specified in the contract<sup>[5]</sup>. Not only would the additional jet grouting cause significant delay to the construction progress and have major cost implications, there would also be a significant impact on the local community, as a large portion of the work would have to occur outside of the worksite, within street right-of-way and on private property.

Ultimately, Sound Transit and Obayashi developed the concept of a major "shift" in the configuration of the station components, including reversal of the Platform Tunnels lengths on either side of the Main Shaft and repositioning the East Damper Chamber. The final volume of jet grouting required as a result of this "Ultimate Shift" was only 10% greater

than the original bid quantity.

The jet grouting was carried out by a JV of Condon-Johnson/Soletanche and provided a very competent soil stabilisation mass, with virtually no water influx encountered.

**Primary lining & SEM pre-support**

As discussed, the tunnel sizes required for the station set a new record for SEM tunneling in the US. The stability assessment for the excavation sequences and support measures was performed with 3-D Finite Element (FE) models using the programs ABAQUS and FLAC.

The lining forces derived from the numerical analysis were subsequently used to design the primary and final lining<sup>[6]</sup> using capacity limit curves based on ACI 318. Due to the mixed face conditions present over large portions of the tunnel alignment, no 'prescriptive' support was designed, but a baseline scenario (Figure 2) was chosen that included excavation sequence and standard support measures, such as shotcrete, welded wire fabric (WWF) and lattice girders.

The contractor later paid for a redesign and pre-construction performance flexural beam tests in order to substitute steel fibre reinforced wet-mix shotcrete for the double mats of wire mesh.

This was primarily improve productivity and reduce worker risk at the tunnel face, as well as improve the overall quality of shotcrete application.

Additional SEM "Toolbox" items<sup>[7]</sup> were also included in the contract (supplemental unit price bid items) to be used in conjunction with conventional excavation support. These included: Pre-support measures such as rebar spiling, grouted pipe spiling, metal sheets and grouted barrel vaults (pipe arch); Face stabilisation measures including the use of a face stabilisation wedge, pocket excavation, reduction of round length, face bolts and additional shotcrete; Ground improvement measures such as gravity and vacuum dewatering, permeation grouting, fracture grouting and jet grouting; and annular support measures, including additional shotcrete, soil nails and use of a temporary invert.

The contract required a certain amount of shotcrete nozzle time for nozzlemen, which proved difficult to find in a tight labor market. In order to assist in boosting human resources available for SEM crews, a variance was made to allow for on-the-job training of nozzlemen, albeit under the direction of the certified nozzlemen and foremen already on site.

**Shaft construction**

Slurry wall construction of the Main and Ancillary Shafts, and the East and West headhouses, began in October 2004 and was completed in February by Obayashi's subcontracted JV partners Condon-Johnson/Soletanche. Main shaft excavation, including West Headhouse tiebacks and demolition of the remnants of the original Test Shaft, began in March 2005 and by the end of May 2005 the shaft had been sunk to a depth of 120ft (36.5m),

ready for the West Longitudinal Vent Adit (WLVA) breakout.

WLVA breakout through the Main Shaft slurry wall began in June 2005 and SEM work, albeit for a 12ft (3.7m) stub tunnel, began in earnest. Originally sequenced for excavation in nine stages for the three lattice girder rounds, the work was adjusted in the field to five rounds, by combining bench and invert rounds. Only a few dozen rebar spiles were used in the top heading second round to bridge the gap between the remnants of the jet grout columns and the roof over the headwall.

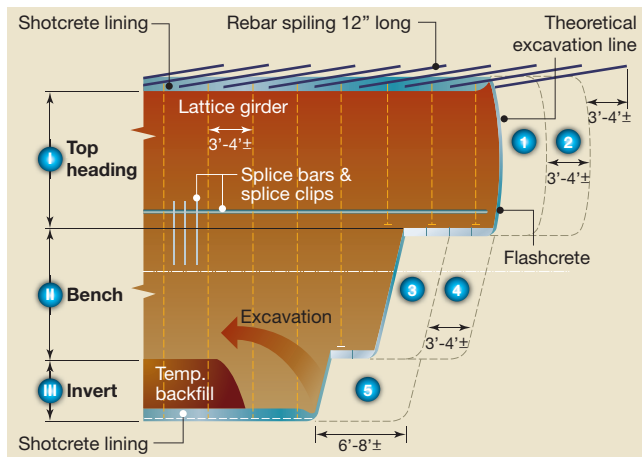
The on-site wet mix batch plant was still being assembled and fine-tuned while having trial batches run through and brought up to strength, so the initial lining for this breakout section was sprayed in with a 10" (250mm) thick dry-mix steel fiber flashcrete mix. A total of 33 shifts were needed to to complete the breakout, including securing the headwall for the better part of a year and the installation of deformation monitoring instrument pins.

**Concourse construction**

Excavation work in the Main Shaft continued after completion of the WLVA breakout in July 2005. The shaft was lowered down to just below the crown level of CCA for installation of the upper row of barrel vault pipes.

Northwest Cascade was subcontracted to drill 134 lost-casing pipes, evenly split with 67 each over the North and South Concourse brow of each heading. However, drilling over the North Concourse encountered more sandy soils and drew in groundwater along several of the first round of holes, which led to the lengthening of 12 holes along the inner row. Drilling over the South Concourse was relatively dry and clayey prompting deletion of the

Below: Fig 3. SEM excavation sequence for Platform Tunnels



Below: Waterproofing of the Platform Tunnels



outer row entirely. Barrel vault drilling, surveying and double-packer staged grouting with microfine cement was completed by mid-August 2005, setting the stage for further shaft sinking to the CCA springline.

A Cat 325 and a Cat 320 excavator, both with hoe rams, were used to break through the 4ft thick slurry walls for the NCCA and SCCA top headings. A series of line-drilled holes were drilled with a twin-boom drill jumbo to outline the breakout area and to help weaken the wall. Initially designed for localized breakout of each individual top heading, Obayashi broke through the wall in five stages, including a portion of the center drift top heading, leaving a concrete pedestal for interim face support.

Initial excavation of the first Concourse Cross Adit (CCA) top headings began in late August 2005 for both the North and South Concourses. The permanent lattice girders along the side drifts and the temporary TH-girder sections in the center drift were installed. A single lattice girder set from the center crown was also installed, connecting the East and West sides of each heading. This was used to help align the temporary interior sidewalls as the initial top heading excavation began. The South CCA East side drift was the first top heading excavated starting in September, followed by the South CCA West side drift. The North CCA East side, and then West side, followed.

After completion of all four top headings in December 2005 the Main Shaft was excavated down to the final invert elevation of 181ft (55m) below surface. A 30" (750mm) thick concrete invert slab was poured, then backfilled up to a working level.

The South CCA sidewall drift benches and inverts were then excavated before again filling the shaft temporarily to complete the

centre drift top heading and upper bench of the South CCA.

The South CCA center bench and invert were excavated in February 2006, including demolition of the temporary sidewalls.

### Platform tunnels

The Southbound Platform Tunnel (SBPT) was on the contract's critical path, with its completion necessary before the 21ft (6.4m) diameter Mitsubishi EPBM driving the running tunnels could break-in at the west end of the platform. The TBM would then be "walked" through the station and re-launched on the remainder of the Southbound running tunnel bore, before being removed and reassembled for the Northbound bore<sup>[8]</sup>. Work to complete the North Concourse and subsequent North Platform Tunnel (NBPT) excavation followed start-up on the SBPT concurrently.

A single sidewall drift method was specified for the Platform Tunnels, comprising a total of six segments per round (Figure 2). The first drift was excavated as a pilot tunnel, with the second drift following behind the first with a minimum specified offset. This offset rule allowed time to complete ring closure and gave the shotcrete time to develop strength in the first drift.

Obayashi investigated several ways to try and improve cycle times, in the interests of the schedule, and several minor changes were implemented. The single most effective of these was to increase the round length when possible, taking into account the results of probings, face maps and feedback from instrumentation in the shell.

In the design given to Obayashi, the lattice girder served only as a template and was not taken into account in the structural analysis. Therefore, the span length could be increased if



**Above:** Centre bench excavation of a Concourse Cross Adit (CCA)

the ground permitted. In the end, Obayashi adjusted the lengths in places, from 4' to 4' 6" or 5'.

Given the space constraints and practical limits of equipment resources, the way excavation crews were organized was also analyzed and adjusted.

Since at times there were two headings working both side drifts, there were four available faces. In these cases, Obayashi established excavation crews, girder crews and shotcrete crews that rotated between headings, rather than establishing these capabilities in each individual heading team. This proved to be a more efficient use of resources and improved the overall progress globally.

### SEM decision making

Experience levels were specified in the contract for key personnel responsible for the SEM activities. Under the oversight of the Obayashi Tunnel Manager, these key personnel include the SEM Manager, SEM Project Engineer and SEM Superintendents.

The SEM Superintendents worked shifts to facilitate

immediate decision-making at the face during the six day, 24 hour week, schedule and were supported at the headings by Walkers and Shift Engineers. Generally two crews were working three 8 hour shifts. Sound Transit recognized the inherent risks involved and agreement was reached during the design stage to have the Designer represented on site during the implementation of the SEM design. To this end HMMJ and DSC provided experienced SEM engineers and inspectors to support the Construction Management team (Parsons Brinckerhoff) and oversee the SEM activities. Shannon & Wilson were also represented on site, providing oversight on geotechnical activities.

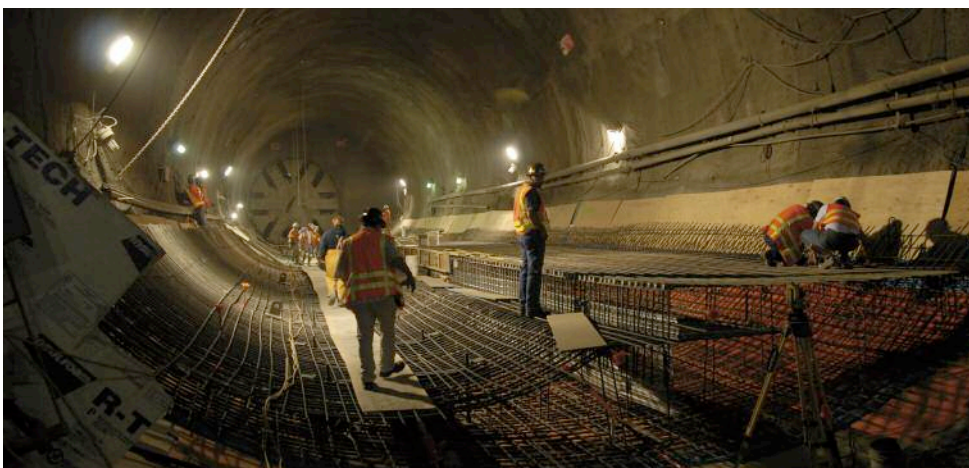
Daily SEM Meetings held at the site office followed joint inspections at the headings each morning. Sound Transit, Obayashi and HMMJ/DSC were represented at all of these meetings, to discuss the status of the works and the planned activities for the next 24 hours. Any necessary changes to the Construction Work Plans were agreed, and face maps were presented and discussed as well as the results of probing. A review of the latest instrumentation readings was also included to confirm stability of the headings.

On a weekly basis, shotcrete strength results were presented and discussed. RESS sheets (Required Excavation and Support Sheets) confirmed the required support and pre-support for each tunnel section and were used to assist communications.

### Dewatering, monitoring & settlement

Geotechnical instruments specified for ground monitoring outside the excavated tunnels

**Below:** The Mitsubishi EPBM waits to be pulled through the South Platform Tunnel



included extensometers, inclinometers, open standpipe and vibrating wire piezometers, as well as optical survey points. Shannon & Wilson technicians read each instrument periodically, with the exception of the survey points that are checked by CH2M crews. Vertical and lateral displacements were tracked from the tunnel invert up through the crown to street level prior to excavation, then just above tunnel crown up to ground surface after SEM mining was completed, for any given tunnel section.

Data from the instrument readings are reviewed at the Daily SEM meetings and to date have shown a maximum of 1.6" (40mm) of vertical settlement over the station tunnels roughly 150ft (46m) below ground.

Street level surface settlement has only reached a maximum of 0.6" (150mm), most of which appears to be attributed to some water line replacement work in Beacon Avenue. In general surface settlement contours have followed the tunnel excavation sequence albeit with very small measurements, and not surprisingly there has been little to no measurable surface settlement over the jet grouted zones. All of this data compares quite favorably to the expected 4" (100mm) anticipated upon completion of tunneling.

Similarly, dewatering wells have proved quite effective with groundwater levels in the predominant sand layers above the tunnel crowns having dropped 20-40ft (6-12m). Groundwater levels are measured at 17 individual locations on site, typically with open standpipe bottom casings and vibrating wire piezometers at intermediate elevations in the upper sand layers. The vacuum-assisted dewatering well system has dropped from an initial 50gpm, through a steady state of 30gpm, down to 10-15gpm.

**Waterproofing**

The Beacon Hill Station is designed as a tanked structure and equipped with a membrane waterproofing system, which is placed between the initial shotcrete lining and the final lining. It consists of a non-woven geotextile to protect the waterproofing layer and flexible PVC membrane sheets welded together to form a continuous, impervious layer.

A remedial system consisting of a sectioning system and control and grout pipes is also installed. Obayashi contracted with specialty subcontractor Wisko America for the installation of the waterproofing.

**Current status**

As of May 2008, tunneling at Beacon Hill is complete: The TBM completed the second running tunnel drive by breaking through at the East Portal in early March. Subsequently, the excavation of the two remaining cross passages at the end of April marked the completion of the SEM works.

Currently, waterproofing installation and steel fiber reinforced cast-in-situ final lining construction<sup>[2]</sup> are ongoing in the North Bound Platform Tunnel, while finishing works are already progressing in the South Bound Platform Tunnel, the Concourse Cross Adits and the ventilation tunnels and egress tunnels. The waterproofing and concrete works in the Main Shaft, the Ancillary Shaft and the East and West Headhouse are also well underway.

**Conclusion**

The successful completion of the SEM tunnels was a major milestone for Sound Transit, but also for the contractor, designer, the construction manager, the geotechnical engineer and the inspection team.

The multitude of technical challenges that needed to be addressed throughout design and construction of this project could be resolved by a group of respectful and dedicated professionals working closely together. Open communication, good discipline and having qualified individuals in a partnering environment on site proved to be invaluable components for success. ■

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# Specifying steel fibers for segments

**Jeff Novak**, Technical Manager for Bekaert Corporation in the North America and Andina regions, provides his views on the specification of steel fibers

**D**ue to their ability to provide robustness during handling and installation, as well as long-term durability, steel fibers have become an accepted form of reinforcement for segmental tunnel linings.

Regardless of the properties steel fiber reinforced (SFRC) concrete is chosen for, designers must prepare specifications that direct precast manufacturers in the selection of the proper fiber type and dosage rate.

During mix development, precast manufacturers use specifications to form a mix that will meet compressive, flexural and bursting strength requirements. Once these parameters are confirmed, the type and quantity of steel fibers is chosen to provide the specified equivalent flexural strength (EFS) value. Confirmation of the EFS value is achieved by conducting bending tests on beams in accordance with standard test methods.

## Flexural resistance

Flexural resistance properties are determined using beam tests, and evaluating the load carrying capacity of a beam after the concrete cracks. There are many publications that describe how to determine SFRC flexural properties, but the methodology involves casting small sample beams and testing them in a 3 or 4 point displacement controlled bending apparatus.

Sample sizes vary slightly between test methods, but the generally accepted size of test beams are 150x150mm square cross section with a test span of at least 3 times the depth. The use of smaller beams tends to exaggerate test results, due to size effects and preferential alignment of fibers in the molds and should not be used.

Test methods such as JSCE-SF4, ASTM C-1609, and EN-14489-1 are typically specified based on the country in which the project is located. In general, load deflection curves are produced for the sample beams

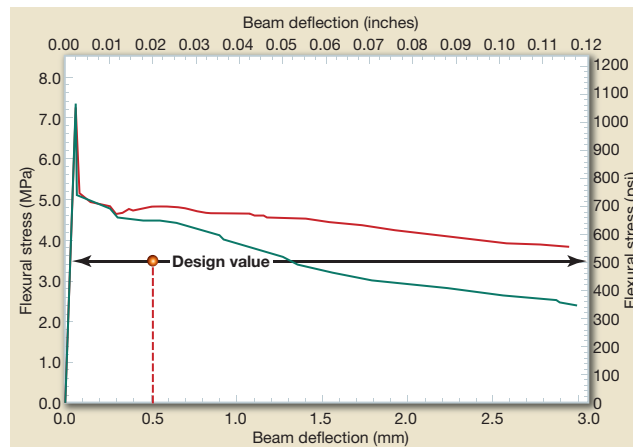


Fig 1 - Single point acceptance criteria

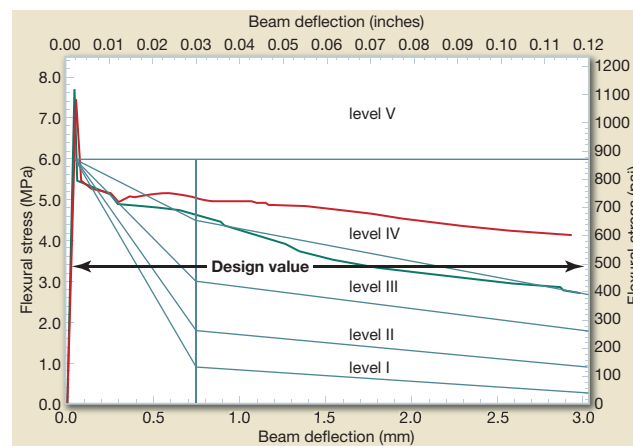


Fig 2 - Toughness performance level acceptance criteria

and values are determined for the post crack flexural strength, usually using data up to a deflection of span/150 or 3mm. The post crack flexural strength is a measurement of the strength provided by the steel fibers.

Design engineers should be aware that each test method provides slightly different performance values. Understanding this is critical when preparing acceptance criteria for steel fibers. After all, it is vital the material performance used in design is in fact specified in the contract documents and used during manufacturing.

Unfortunately, there is currently no clear consensus on how best to specify acceptance criteria.

Figures 1 through 4 show load deflection curves for two different fibers with different acceptance criteria shown. The red and green lines represent an average of five individual tests from manufacturer Red and manufacturer Green. Both Red and Green fibers are advertised as being identical and the same dosage was used in all tests. A value of 3.2Mpa (500psi) is used as the design value for the ultimate flexural capacity of the segments. These figures illustrate acceptance criteria that have been used on actual projects in the past few years.

Figure 1 shows a single point as the acceptance value. Both Red and Green fibers meet this



Above: Beam test underway

acceptance criteria. The deflection value occurs at 0.5mm, which is very early in the test and is still in what is considered the unstable portion of the load deflection curve.

None of the test methods referenced herein recommend using single point values at deflections less than span/600, which is 0.75mm. Furthermore stress values at span/600 should only be used for serviceability checks and not for ultimate strength determination.

Figure 2 shows toughness performance classes as the acceptance criteria. The design value represents an average value for Level IV performance class. This criteria is somewhat subjective since it is not clear if the entire fiber performance line must exceed the Level IV line or can drop below the line for some percentage. For this criteria Red fibers are acceptable while Green fibers would require a higher dosage to meet the acceptance criteria. Since this criteria uses an average of stress levels to span/150 it would be appropriate for ultimate strength determination.

Figure 3 shows two-point acceptance criteria. This criteria is specified using ASTM C1609. It is similar to the toughness performance classes and may use the end points of one level. This criteria is less ambiguous since it is clear acceptable fiber performance must exceed both points. The average value of the two points is used as the design value. Therefore, Red fibers are acceptable and Green fibers would require a higher dosage rate. Since this criteria uses an average of stress levels to span/150 it would be appropriate for ultimate strength determination.

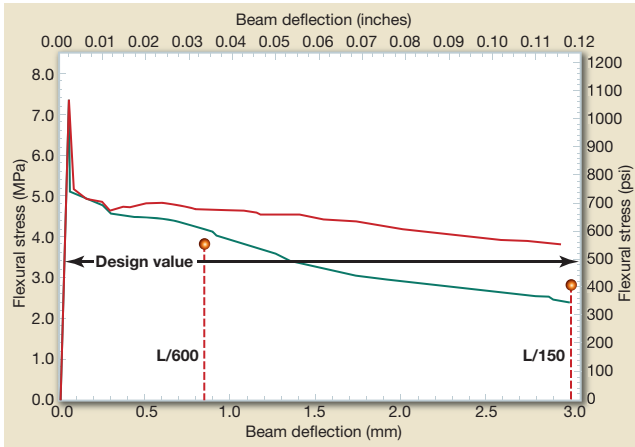


Fig 3 - Average two-point acceptance criteria

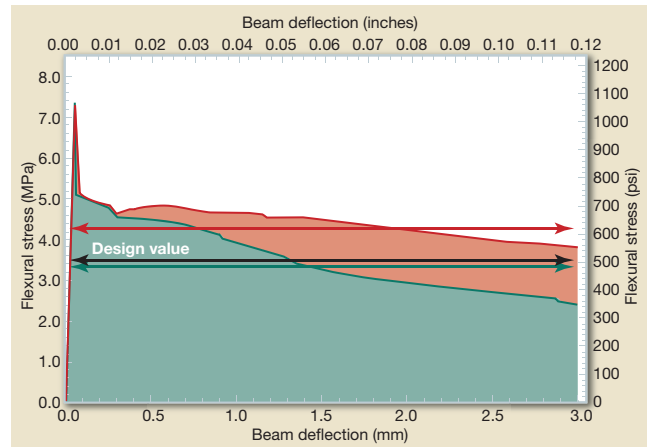


Fig 4 - Fe3.0 acceptance criteria

Table 1 - Performance Levels		
Source	Performance Class Definition	Method to determine acceptance
European Standard EN 14487-1: Sprayed concrete - Part 1: Definitions, specifications and conformity	Minimum strength levels which are average values over a deflection interval: D1 – 0.5mm to 1mm D2 – 0.5mm to 2mm D3 – 0.5mm to 4mm	A horizontal line indicating a minimum stress level
German DBV Recommendation: Design Principles of Steel Fibre Reinforced Concrete for Tunneling Works	Equivalent flexural strengths are defined using the area under the load deflection curve. An average value is determined at $\delta_1+0.65\text{mm}$ and $\delta_1+3.15\text{mm}$ ; where $\delta_1$ is the first crack deflection. These are similar to $R_{e3}$ values	A horizontal line indicating a minimum stress level
Rusty Morgan, et al.: Toughness of Fibre Reinforced Shotcrete	Toughness performance levels I through V using the points L/600 and L/150: Level 1 – 15% Pd to 5% Pd Level 2 – 30% Pd to 15% Pd Level 3 – 50% Pd to 30% Pd Level 4 – 75% Pd to 45% Pd where Pd equals the first crack load	A sloping line is defined using 2 points to establish a minimum threshold

Figure 4 shows acceptance criteria using an average value calculated with the area under the load deflection curve. This criteria is specified using JSCE SF-4. An average value is used as the design value. Flexural toughness ( $T_b$ ) is determined as the area under load deflection curve up to deflection of span/150, which is 3mm ( $\delta_{tb}$ ) for a 150mm (b) x 150mm (t) x 450mm (L), or 6”x 6”x18”, square beam.

Flexural toughness factor, expressed as an engineering stress, is calculated using:

$$\sigma_b = \frac{T_b}{\delta_{tb}} \times \frac{L}{b \times t^2} \quad [\text{Mpa}] \text{ (psi)}$$

where ( $\delta_{tb}$ ) = 3 mm

Using this criteria, the Red fibers are acceptable and Green fibers would require a higher dosage. This criteria uses an average of stress levels to span/150 and would be appropriate for ultimate strength determination.

As can be seen from the above discussion, different conclusions are reached depending on the criteria chosen. Listed in Table 1 are

three published SFRC performance level criteria. Although these are designed for steel fibre shotcrete they work equally well for cast concrete.

It is recommended to use one of the methods in Table 1, an equivalent flexural strength value such as an  $R_{e3}$  using an average of the area under the load deflection curve up to 3mm, or an average of the  $f_{150,0.75}$  and  $f_{150,3.0}$  values. In this way, all of the post crack load deflection data, until the end of the test at 3mm deflection, is used to evaluate acceptance of the steel fiber concrete.

Beam tests represent average equivalent or residual flexural strength values. Appropriate statistical methods should be applied to ensure that the specified SFRC mix provides the minimum equivalent or residual flexural strength design values.

The following is an example of specification language in a contract document, using ASTM C1609, to ensure a project is supplied with consistent steel fiber performance:

“Steel fiber reinforced concrete shall provide a post-crack average equivalent flexural strength toughness, of xxx psi, minimum, which represents the average of the  $f_{150,0.75}$  and  $f_{150,3.0}$  values obtained according to ASTM C1609.”

**Bursting resistance**

Bursting resistance, or splitting tensile strength, of SFRC is less well understood than flexural properties. Bursting in segments occurs from two different types of loads. Bursting stresses are created during installation by the application of ram loads to the edge of the segments and from the in-place forces due to compression by the ring (Figures 5 and 6). The magnitude of the bursting force is related to the configuration of the segments, the TBM and the geology.

It is well known the presence of steel fibers in concrete do not significantly influence its unconfined compressive strength or it’s modulus of rupture in flexure. However, it is not well known that the presence of steel

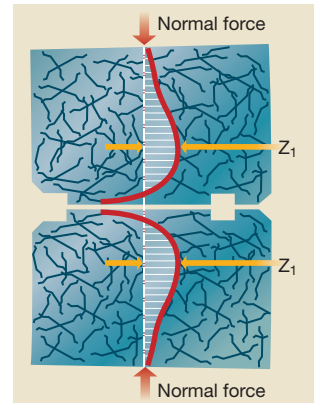


Fig 5 - Ring bursting

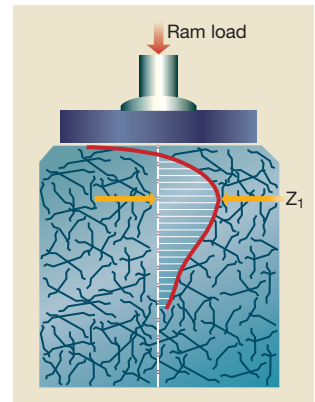


Fig 6 - Ram bursting

fibers increases the bursting strength of concrete. This is one of the primary benefits in using SFRC in segments.

The forces created by the applied loads are redistributed by the fibers as micro tensile cracks develop. This allows larger loads to be carried by SFRC than can be carried by plain concrete. This is confirmed by large-scale tests and small cylinder splitting tests.

Tests have shown that increases of 10-30% over plain concrete bursting strengths have been achieved with steel fiber dosages of 30-40kg/m<sup>3</sup> (50-66lb/yd<sup>3</sup>). Obviously, the magnitude of the increase is related to the steel fiber type and

dosage rate. Another significant observation of full-scale bursting tests is that the failure mode with SFRC is more ductile than with conventionally reinforced segments. Full-scale test have also shown that SFRC segments can provide similar bursting load capacities as those with conventional reinforcement.

Since the concrete used to manufacture segments is usually high-strength, designers may question whether the formulas contained in the structural concrete codes in Europe and US are appropriate for high-strength concrete. A recent paper evaluated the splitting tensile strength formulas for a number of sources for application with concretes up to 120Mpa (17,400psi)<sup>[4]</sup>.

The results of their integral absolute error analysis showed that the CEB-FIB code formula gives a good correlation to observed data. In contrast, the formula in ACI-318-99 did not have a very good correlation, particularly at higher compressive strengths where there is a significant divergence between the two methods. Table 2 shows splitting tensile strength values calculated using the two methods.

The CEB-FIB formula for splitting tensile strength is:

$$f_{tsp} = 0.3 f_c^{2/3} \text{ (metric units)}$$

$$f_{tsp} = 1.53 f_c^{2/3} \text{ (imperial units)}$$

Experience on past projects has shown that when the steel fiber contents are determined for flexural resistance requirements then the splitting tensile resistance requirements are also usually met. Design engineers should specify the required value for splitting tensile needed to carry the applied loads.

Test methods used to determine splitting tensile strength include ASTM C496, BS 1881- Part 117 for cast cylinders or the "Brazilian Method" for cores obtained from finished segments. Since there is no standardized test method for preparing cylinders for splitting tensile tests it may be prudent to

place in the specification some language to indicate cylinders for splitting tensile strength should be consolidated using external vibration not by rodding the sample. Rodding will disturb the random orientation of the steel fibers, which may affect results.

### All fibers are not equal

Steel fibers have been successfully used for over 20 years to reinforce concrete segments. However, contractors should be wary of selecting a supplier based simply on price, as there are many low-quality look-a-likes currently available on the market. Many suppliers do not manufacture their own fibers. Distributors purchase from manufacturers and place their label on the bag. Often these distributors change suppliers and never inform their customers.

As an example of quality issues that have been identified for steel fiber suppliers, examine the data in the Figures 7 and 8. Figure 7 shows the results of tensile tests conducted on ten individual fibers from ten different suppliers taken over a seven-year span. Most were sampled once but one was sampled four times in one year. The published tensile specification was the same for all of the suppliers: An average of 1300Mpa ±100. The results are startling. Only one test was within the published specification, 11 tests had minimum values significantly outside of specification, and only three were close to the published average value.

Contrast this with the data in Figure 8, which was collected over a one year time span for a single supplier. The results show a consistent pattern of tensile strengths within the published specification.

Fiber quality can be determined by consistency of length, diameter, tensile strength and hook formation. In order to ensure consistent quality it is recommended the following language be placed in the contract documents:

*"Test steel fiber in accordance with ASTM A 820 or EN-14489-*

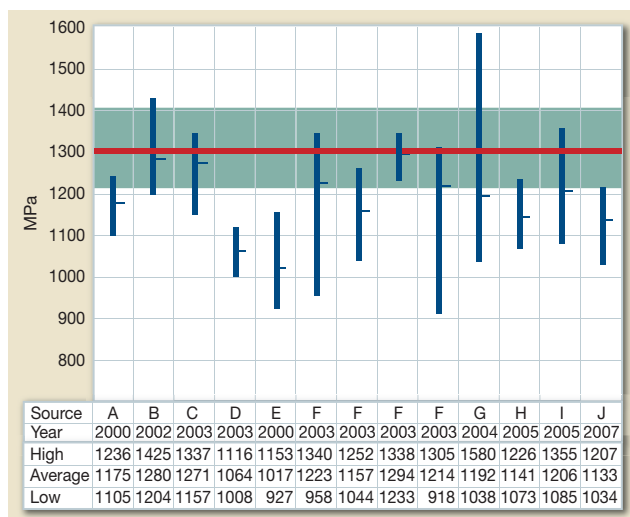
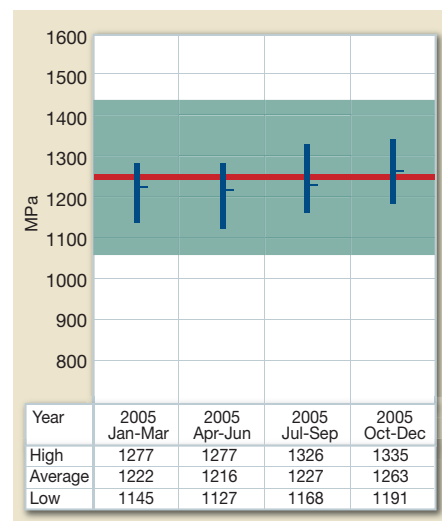


Fig 7 - Tensile strengths of various suppliers (specification is 1300Mpa ±100)

Fig 8 - Tensile strengths of one supplier (specification is 1260Mpa ±190)



1. Test 10 fibers per lot. Determine steel fiber length, diameter and aspect ratio. Individual samples shall be ±10% of specified values and the average of 10 samples shall not deviate more than ±5% of the specified values.

Determine tensile strength of steel fiber. No more than 10% of the individual samples shall be below the specified values."

In reference to manufacturer, or supplier experience, the following language is also recommended:

*"If the supplier of the steel fibers is not the manufacturer, the distributor shall document that they have a minimum 5 years experience in distributing steel fibers from the same source.*

*If steel fibers are supplied from different manufacturing facilities the supplier shall provide documentation that material being produced meets the same quality at all locations."*

### Conclusions

It is imperative that engineers specify acceptance criteria in alignment with assumptions made during design, otherwise the delivered segment performance may not meet expectations.

The recommendations offered herein aim to provide clear and concise guidance for the preparation of specifications. When implemented, steel fibers will be supplied from a consistent quality manufacturer and provide the flexural resistance and bursting strength needed to match the design. ■

Table 2 - Comparison of splitting tensile strength formulas

Compressive Strength		ACI 318-99		CEB-FIB Code	
Mpa	Psi	Mpa	Psi	Mpa	Psi
34.5	5000	3.29	476.8	3.18	460.8
41.4	6000	3.60	522.3	3.59	520.4
48.3	7000	3.89	564.2	3.98	576.7
55.2	8000	4.16	603.1	4.35	630.4
62.1	9000	4.41	639.7	4.70	681.9
69.0	10000	4.65	674.3	5.05	731.5
75.9	11000	4.88	707.2	5.38	779.5
82.8	12000	5.09	738.7	5.70	826.1

### REFERENCES

- EN 14489-1, Fibres for concrete – part 1 Steel Fibres – Definitions, specifications and conformity. BSI London 2006
- ASTM C1609, Standard test method for Flexural Performance of Fiber Reinforced Concrete (Using beam with third point loading)
- JCI, Method of test for flexural strength and flexural toughness for fibre reinforced concrete, JSCE SF-4 Japan Concrete Institute 1984 (Also published by Japan Society of Civil Engineers 1985)
- N. Anoglu, Z. C. Girgin and E. Anoglu, Evaluation of Ratio Between Splitting Tensile Strength and Compressive Strength for Concretes up to 120 Mpa and its Application in Strength Criterion, ACI Materials Journal, 103-M03, 2006.

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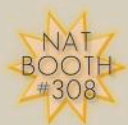


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# The Changing Face of Tunneling

## North American Tunneling - June 7-11, 2008

### Hyatt Regency, San Francisco, California



This year's North American Tunneling Conference (NAT 2008), sponsored by the Underground Construction Association of the Society for Mining, Metallurgy & Exploration (UCA of SME) will be held in June at the Hyatt Regency Hotel, in San Francisco, California.

"It's a great location. The city has some world-renowned tunneling projects currently in design and under construction," says Conference Chair, Greg Raines. One of the most notable of these is the Devil's Slide Tunnel, which will bypass a section of highway along the impressive vistas of the California Coastline. The final day of the conference includes a field trip to the project.

The conference is already expected to be a great success, principally due to the high-quality papers received, the caliber of the authors, and a dedicated event organizing committee.

The presentations have been divided into four tracks: Technology, Design, Project Planning & Implementation, and Case Histories, all running concurrently from Monday through to Wednesday.

"We received over 120 abstracts from an impressive array of technical specialists in the tunneling and underground construction industry," says Raines. "It always amazes me how dedicated the tunneling community is."

The final paper count stands at approximately 100, all of which have been peer reviewed by the Program Sub-Committee. The Organizing Committee coordinated all these efforts with support from the staff of SME.

"This arrangement for NAT has advanced our ability to produce a high-quality and industry leading

conference with great opportunity for knowledge sharing," says Raines.

The volunteer Organizing Committee consists of over 20 individuals, who broke up into sub-committees including the Program Committee, Speaker Committee, Student Outreach Committee, and Special Programs Committee.

Some of the highlights to get the conference started include short courses, workshops, and

keynote speakers. On the Sunday before the conference Short Courses on Soft Ground Tunneling and an Underground Blasting will be offered, covering a wide spectrum of tunneling technology. "We also have a Disputes Review Board Workshop on Sunday," says Raines, "the other aspect of tunneling we cannot seem to get by without."

Monday starts the conference in earnest with the first keynote speaker Bijan Sartipi, from Caltrans (California Department of Transportation), which has

both the Devil's Slide Tunnel, in construction, and the third bore of

the Caldecott Tunnel, in design. This year there will also be a second speaker, Maria Ayerdi, from Transbay Transit, which has the San Francisco Transbay Transit Center in design, with an underground station and NATM tunnel through the city, among other features.

There will be ample opportunity to network between technical sessions with three exhibit hall sessions, one on each day. "The exhibit hall is completely sold out, with over 60 exhibitors including suppliers, contractors, engineers, media, and owners, such as the San Francisco Public Utilities Commission," says Raines. "I'm sure there will be plenty of good information to pick up during a round through the exhibit hall. Food and drink will also be provided by the exhibit sponsors, who seemed overly eager to

provide lunch for everyone."

Sunday night starts off the social events, with an easy going Ice Breaker Reception. Breakfasts and luncheons are planned on all three days, with lunch for the Keynote Speakers on Monday; and breakfast for UCA of SME & ITA on Tuesday; and for the International Shaft Drillers Association on Wednesday.

The UCA of SME/ITA breakfast will also include Paper Presentations from the Student Outreach finalists, with paid expenses and monetary awards for the best paper given. "We have pushed hard to bring more students into the mix and came to the conclusion that offering them cash awards to get involved might be a good start," says Raines. The industry has been keen to support the program also. "We've had a fantastic response," says Student Outreach Committee member, Hannes Lager. "In the region of 20 sponsors have come forward, from throughout the industry, everybody has contributed!"

The Awards Banquet is on Tuesday night, with special awards being presented by UCA for Lifetime Achievement, Outstanding Individual and Outstanding Educator. "This leaves Monday night as the only open time slot," says Raines, "which of course we always leave open for outside functions; boat rides on the Bay; or for visits to famous San Francisco landmarks."

## 2 N O A O T 8

### NAT 2008 ORGANISING COMMITTEE

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**Mark Ramsey**, Conference Vice Chair, Kiewit

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**Dennis Ofiara**, The Robbins Company  
**Michael Roach**, Traylor Bros  
**Bradford Townsend**, Hatch Mott MacDonald

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**John Hawley**, Hatch Mott MacDonald  
**Raymond Henn**, Lyman Henn



# 2008

## Monday, June 9 – 8:30am

**Welcoming Remarks:** Brenda Bohlke, UCA of SME Chair  
Greg Raines, NAT 2008 Chair  
Dave Kanagy, UCA of SME Executive Director

**Keynote:** Bijan Sartipi, Caltrans  
Maria Ayerdi, Transbay Joint Powers Authority

## NAT Track and Program Chairs

### Track I: Technology

**Dennis Ofiara**  
The Robbins Company,  
Solon, Ohio

### Track II: Design

**Bradford Townsend**  
Hatch Mott MacDonald,  
San Francisco,  
California

### Track III: Project Planning & Implementation

**Marc Kritzer**  
Northeast Ohio Regional Sewer  
District, Cleveland, Ohio

### Track IV: Case Histories

**Michael Roach**  
Traylor Brothers, Apex, North  
Carolina

## TECHNICAL PROGRAM

### Technology: Technology in the Big City

**Monday, June 9 - 10:30am - Track I**

**Chair:** Brian Fulcher, JF Shea

**Water Tunnel Beneath New York Harbor:** M Jafari, M Schultz & R Howard Jr, Camp Dresser & McKee

**Rehabilitation of New Croton Aqueduct Shafts:** WJ Marold & C Zambrano, MWH Global; A Fareth, NYC Dept. of Environmental Engineering & Construction

**Designing Conveyor Systems in Urban Environments – The 63rd Street Tunnel in NYC:** D Workman, The Robbins Company

### Design: Fire Life Safety & Rehabilitation

**Monday, June 9 - 10:30am - Track II**

**Chair:** Amanda Eloff, Parsons Brinckerhoff

**Fire Safety Design for the New South Ferry Terminal, New York City Subway:** JG Sanchez & S Chakraborty, New York City Transit

**Overview of NFPA 502 – Standard for Road Tunnels, Bridges & Other Limited Access Highways, 2008 Edition:** W Connell, Parsons Brinckerhoff & J Gamache, NFPA

**Connections to Old Tunnels – Design Guidelines:** J Zurawski & E Petrossian, Dawn Engineering

**Rehabilitation of the 80-year old North Outfall Sewer (NOS) Tunnel:** W Roth, E Dawson & P McDonald, URS Corporation; A Naudts, ECO Grouting; A Reyman, Bureau of Engineering, City of LA

### Project Planning & Implementation: Overcoming Changes

**Monday, June 9 - 10:30am - Track III**

**Chair:** Robert Pintabona, MWH

**San Francisco's Central Subway, Extending the Third Street Light Rail to Chinatown:** M Fowler, PB/Wong JV, San Francisco

**The Fallacy of Tunnel Formwork Removal:** N Chen, Jacobs Engineering

**Beach Sewer Tunnel Rehabilitation:** A Ruiz & D Jurich, Hatch Mott MacDonald

**Dulles Metrorail Extension – Tunneling Options for Tysons Corner:** J Rudolf, Bechtel Infra & V Gall, Gall Zeidler Consultants

### Case Histories: NATM/SEM Tunneling

**Monday, June 9 - 10:30am - Track IV**

**Chair:** David Girard, Hatch Mott MacDonald

**Mining Cross Passages Using NATM/SEM on the LA Metro Eastside Extension Tunnels:** C Bragard & B Zernich, Traylor Brothers; J Jäger, Beton-und Monierbau

**L-73 Tunnel Woodbury Minnesota:** M Gilbert, Camp Dresser & McKee & ES Dentz, MCES

**Stanford LCLS Project – Detailed Construction Design for the Intersection between Access Tunnel and FEH:** H Sander, S Matthei, Z Skovajsova, M John & T Marcher, ILF Consultant

### Technology: Technical Advances

**Monday, June 9 - 1:30pm - Track I**

**Chair:** John McDonald, Traylor Brothers

**The Current State of Disc Cutter Design & Development**

**Directions:** J Roby, T Sandell, & J Kocab, The Robbins Company

**Comparison of Different Blast Design Models, Using Blasting**

**Software:** R Afzali, Tooss Ab; M Yavari, Dept. of Mining Engineering, Tehran University; A Naghibzadeh, Islamic Azad University

**Tunnel Boring Machine Development:** M Herrenknecht & K Bappler, Herrenknecht AG

**Solid Cast Polymer Tunnel Segments – The Corrosion Resistant**

**Solution for Sewer Tunnels:** R Cubeta, SolidCast Polymer Consulting

**Extensive Concrete & Shotcrete Systems for the World's Longest Tunnel – Gotthard Base Tunnel 56km:** J Schlumpf, Sika Services AG

### Design: Underground Design Considerations

**Monday, June 9 - 1:30pm - Track II**

**Chair:** Colin Lawrence, Hatch Mott MacDonald

**Initial Support Design for Tunnels in Horizontally Bedded Sedimentary Rock:** I Halim & N Chen, Jacobs Engineering; R Ilsley, Geotechnical Consultant

**Design of Rock Shafts Adjacent to Heavily Loaded Columns:** N Sokol & E Wang, PB Americas

**Geology of the Clean Water Coalition's Proposed Reach 4 Tunnel & its Effect on Design:** R Brainard & R Rudd, Black & Veatch; E Smith, University of Nevada; J Devlin, Clean Water Coalition

**California High Speed Rail – Driving the Next Level in Dynamic Tunnel Design:** C Pourvahidi, California HSR Authority; D Temlis, Hatch Mott MacDonald

**Field Application of NTH Fracture Classification at the Second Manapouri Tailrace Tunnel, New Zealand:** D Macfarlane, URS New Zealand; C Watts, Meridian Energy; B Nilsen, Norwegian University of Science and Technology

**Analysis of the Hydro-fracture Potential Around Water Tunnels in Rock:** E Iskander, URS Corp

**Rock Mass Mechanical Behavior Assessment at the Porco III Powerhouse:** L Suarez-Burgoa, Universidad Nacional de Colombia

### Project Planning & Implementation: Construction Management

**Monday, June 9 - 1:30pm - Track III**

**Chair:** Heather Ivory, URS Corporation

**Benefits of Early Collaboration Between Designers & Suppliers in Tunnel Design:** G Volkmann, ALWAG Tunnelausbau; S Stephenson, Mott MacDonald; T Ireland, Connell Wagner

**Transbay Transit Center – Keeping DTX On Track:** D Penrice, Hatch Mott MacDonald; B Townsend, Hatch Mott MacDonald; R Beck & E Sum, Transbay Joint Powers Authority

**Bold and Visionary Planning of Tunnels and Underground Space:** H Parker, Harvey Parker & Associates

**Columbus Circle Station Complex – History & Rehabilitation:** A Grigoryan, PB Americas

**Caldecott Improvement Project:** C Ferraz & R Anderson, California Dept. of Transportation; P Maxwell & K Raj, Contra Costa Transportation; W Edgerton, Jacobs Associates

**CM Saves Time, Money, and Improves Quality During Design and Construction:** B Tehrani, MWH Americas

**Rock Mass Characterization for the Bi-Country Tunnel:** P Headland & M Younis, Black & Veatch; N Strater & D Dobbels, Haley & Aldrich

### Case Histories:

#### Soft Ground/Pressurized Face Tunneling

**Monday, June 9 - 1:30pm - Track IV**

**Chair:** Mike Krulc, Traylor Bros

**Design and Construction of the DLR Extension to Woolwich, London, UK:** A Alder, Halcrow Group

**Tunneling-Pipe Jacking in O'Hare International Airport:** M Djavid, MWH Americas; L Shapiro, Jay Dee; CP Arman, City of Chicago

**Battery Park Truck Sewer Emergency Tunnel Project:** M Rybak & T Brown, Bradshaw Construction Corporation

**Completion and Commissioning of the SMART Dual-purpose Tunnel:** A Darby, Mott MacDonald

**EPB Tunneling In Canada:** Laura McNally & Steve Skelhorn, McNally Construction

### Technology: Old Problems/New Solutions

**Tuesday, June 10 - 8:30am - Track I**

**Chair:** Larry Snyder, Snyder Engineering

**Small Diameter Tunneling – Pipe Jacking Under Leipzig Main**

## TECHNICAL PROGRAM

**Train Station:** *K Rieker, Wayss & Freytag Ingenieurbau AG*  
**Investigation and Cement Grouting of Big Creek Tunnel 2 – A Leaking Historic Hydroelectric Tunnel:** *D Van Horsen, Southern California Edison*

**Increased TBM Mobility and Adaptations for Special Projects:** *D Ofiara, The Robbins Company*

**Utilization of Strain Measurements on Shielded TBMs:** *B Murray & S Swartz, Jacobs Associates; J Waggoner, GeoPentech; H Lum, Metropolitan Water District of Southern California*

**Underground Construction Photography – Documenting a Success Story:** *Susan L. Bednarz, Jacobs Associates*

### Design: Tunnel Designs

**Tuesday, June 10 - 8:30am - Track II**

**Chair:** *Derek Penrice, Hatch Mott MacDonald*

**NATM Tunnels at Stanford Linear Accelerator Center:** *PJ Doig, Hatch Mott MacDonald*

**Design of the University Link Tunnels and Stations:** *DN Adams, I Lamb & A Morgan, Jacobs Associates; J Sleavin, Sound Transit*

**NATM/SEM Analyses for San Francisco's Transbay Extension Tunnel:** *S Klein, Y Sun & E Cooney, Jacobs Associates*

**East Side Access – Segmental Lining Design Challenges for Closely Spaced and Shallow Tunnels:** *DI Smith, PB; S Sadek, HNTB; J Liu, Ryerson University*

**Design of Large and Shallow Caverns on Second Avenue Subway:** *V Nasri, C Carranza Torres & N Pettersson, DMJM Harris*

**Geotechnical Considerations for the Final Design of the Upper Rouge Tunnel CSO Project:** *J Habimana, I Halim, N Chen & R Barbour, Jacobs Engineering; MM Rabbaig, Detroit Water & Sewerage Dept*

### Project Planning & Implementation: Risks for Engineers & Constructors

**Tuesday, June 10 - 8:30am - Track III**

**Chair:** *Mike McKenna, Jacobs Associates*

**Risk Based Evaluation of Life-Cycle Costs for the Upper Northwest Interceptor:** *S Gambino, GS Klein, RB Kulkarni, DH Deutscher & W Thistlewaite, URS Corp; DD Nguyen, Sacramento Regional County Sanitation District*

**Risk Considerations & Design for the Downtown Deep Sewer Tunnels, Austin, Texas:** *G Wieland & E Dawson, Parsons; J Kaneshiro & P Colton, Parsons Corp; R Jernigan, Brierley Associates; L Yates, Fugro Consultants; R Pohren & S Evans, City of Austin*

**Establishing Geotechnical Baseline Values for Deep Soft Ground Tunnels:** *J Newloui & M Gilbert, CDMS, Brightwater Services; L Maday, King County Dept. of Natural Resources*

**Nacimiento Lake Tap:** *CE Haynes, Black & Veatch Corp; JR Hollenbeck, San Luis Obispo County Flood Control & Water Conservation District; C Mueller, Black & Veatch Corp*

### Case Histories: Rock Tunneling

**Tuesday, June 10 - 8:30am - Track IV**

**Chair:** *Lee Abramson, Hatch Mott MacDonald*

**Final Tunnel Liner at Mill Creek 3 Project-Case Study:** *M Schafer, B Lukajic & R Pintabona, MWH; M Kritzer, R Switalski & S Janosko, Northeast Ohio Regional Sewer District*

**Design and Construction of the Bored Two-Pass Niagara Water Diversion Tunnel:** *R Delmar, Hatch Mott MacDonald; M Hughes & D Besaw, Hatch Energy; E Kapeller, Strabag AG*

**The Construction of the Manhattan Water Tunnel, NYC:** *E Dowey, Department of Environmental Protection, New York City*

**San Vicente to 2nd Aqueduct Pipeline Tunnel – Drill and Blast in Advance of an Open Face Shield:** *B Campbell, Traylor Shea JV; G Revey, Revey & Associates; B Garrod, Hatch Mott MacDonald*

### Technology: Applied Technology

**Tuesday, June 10 - 1:30pm - Track I**

**Chair:** *John Caulfield, Jacobs Associates*

**Comparison of Performance of Two Commonly Used Flexible Dilatometers (FDT) in Determining Deformation Modulus of a Tunnel Host Rocks:** *M Gharouni Nik, Iran University of Science & Technology (IUST)*

**Pre-conditioning/Pre-excavation Grouting of the Soils Prior to Tunneling Below Highways & Railways – Case Histories from the Past Decade:** *A Naudts & W Naudts, ECO Grouting Specialists*

**Disc Cutter Performance in Boulder Laden Ground:** *DS Kieffer, Graz University of Technology; C Leelasukseree, Chaing Mai University; GGW Mustoe, Colorado, School of Mines*

**A 4.75m Contractor Manufactured EPB Machine:** *B Richardson, Southland Contracting; L Snyder, Snyder Engineering*

### Design: Complex Underground Systems

**Tuesday, June 10 - 1:30pm - Track II**

**Chair:** *Boro Lukajic, MWH Global*

**Large-Diameter Tunnelling Collapses – Recovery Design and Execution:** *B Townsend, Hatch Mott MacDonald; C Speers, Snowy Mountain Engineering Corp; G Peach, Singapore*

**Risk Management of the Canada Line Transit Tunnels:** *B Henry, SNC Lavalin; M Moccichino, Seli*

**Design and Construction of Tunnel & Shaft Plugs:** *WJ Marold & P Kolenda, MWH Global*

**A Discussion on Design Methods to Improve Long Term**

**Performance of Tunnel Projects:** *L Fu, URS Corporation*

**Connection of TARP Tunnel to Thornton Quarry Reservoir:** *M Djavid, MWH Americas; K Fitzpatrick, MWRDGC*

**Engineering Geology & Cavern Design for New York City:** *C Snee, Sneegeoconsult*

### Project Planning & Implementation: Cost Estimating & Scheduling

**Tuesday, June 10 - 1:30pm - Track III**

**Chair:** *Jeff Hewitt, Canada Line Rapid Transit*

**Devil's Slide Tunnels – Unique Challenges:** *YN Wang, HNTB Corp; S Kowko & M Amini, California Dept. of Transportation*

**This Is Where The Money Is! The Impact of Contract Front End Documents on Tunneling Projects:** *JG McKelvey, R Goodfellow & C Hirner, Black & Veatch Corp*

**Probable Cost Estimating & Risk Management:** *J Reilly, John Reilly Associates International*

**Scheduling Fast-Track Tunnel Construction Projects:** *V Rebar, URS Corporation*

**Allegheny River Tunnel Crossing Project:** *PA Roy, DMJM & Harris; MD Boscardin, Boscardin Consulting Engineers; A Miller, Faber Maunsell*

**Tunneling Challenges in the Nation's Capital:** *M Wone, Hatch Mott MacDonald; LR Benson & RE Bizzari, District of Columbia Water & Sewer Authority; FG Bernardeau, CDM/HMM JV, Camp Dresser & McKee; AM Stone & SB Fradkin, CDM/HMM JV, Hatch Mott MacDonald*

**Phased Approach to Stormwater Tunnel Rehabilitation:** *T Wanless & J Martens, URS Corp; S Vollink, US Army Corps of Engineers*

### Case Histories: Shafts & Portals

**Tuesday, June 10 - 1:30pm - Track IV**

**Chair:** *Dan Dobbles, Haley & Aldrich*

**Mitigating Tunnel Launch and Reception Challenges:** *SW Hunt & AJ Finney, CH2M HILL*

**Design & Construction of the Fields Point Tunnel Pump Station for the Narragansett Bay Commission CSO Abatement Program:** *G Hughes, The Louis Berger Group; J Kaplin, Gilbane Building Co; I Halim, Jacobs Engineering; P Albert, Narragansett Bay Commission*

**Design & Construction of EPB Tunnels within an Artesian Groundwater Aquifer-Addressing Environmental Issues:** *A Coombs, York Region; S Skelhorn, McNally Construction; D Zoldy, Earth Tech Canada*

**Shaft Sinking at Seymour-Capilano:** *A Prucker & Joe Rotzien, Hatch Mott MacDonald; A Saltis, Pacific Liaison & Assocs/SNC Lavalin*

**Tunnelling Under Glaciers – Construction Update – Galore Creek Mine Access Tunnel, BC, Canada:** *D Brox & P Procter, Hatch Mott MacDonald; C Venne & D Lepinay, EBC-Neilsen JV; L Frost, Galore Creek Mining Corp*

### Technology: Soft Ground Technology

**Wednesday, June 11 - 8:30am - Track I**

**Chair:** *Kurt Kroner, Kroner Environmental*

**The Use of Polymer Concrete in Sewage Tunnels for One Pass Segmental Linings:** *C Maguire & E Iskander, URS Corp*

**EPB TBM Technology:** *W Burger, Herrenknecht AG*

**Pre-Support Measures for Shallow NATM Tunneling in Urban**

**Settings:** *V Gall & K Zeidler, Gall Zeidler Consultants*

**Jet Grout Ground Modification For the Brightwater Conveyance System:** *R Hanke & M Blanding, Hayward Baker*

**EPBMs for the Silicon Valley Rapid Transit Project – Basis of Design:** *J Thompson, Hatch Mott MacDonald; J Chai, Santa Clara Valley Transportation Authority; A Biggart & D Young, Hatch Mott MacDonald*

**Recent Developments in North America in the Design of Precast Tunnel Linings:** *B Garrod & T Gregor, Hatch Mott MacDonald*

### Design: Design Parameters & Seismic Design

**Wednesday, June 11 - 8:30am - Track II**

**Chair:** *Jon Hurt, Arup*

**Geological Parameters Affecting Open Hard Rock TBM Performance:** *T Kim, PB Americas*



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**TECHNICAL PROGRAM**

**Geotechnical Investigation for Design of Largest USA Highway Tunnel Cross Section In Challenging Geotechnical Conditions:** J Prada, D O'Neill & R Blanchard, Hatch Mott MacDonald

**Geotechnical Conditions & TBM Selection for the Bay Tunnel:** L Erickson, P Raleigh & V Romero, Jacobs Associates

**Numerical Analysis of Time Dependent Creep Behaviour of Tunnel Support Systems:** R Chen & JC Small, University of Sydney

**Seismic Design Considerations for a Highway Tunnel in California:** D Young, A Dean, S Warren, A Haldin & T Gregor, Hatch Mott MacDonald

**Design Analyses for a Large-Span Tunnel in Weak Rock Subject to Strong Seismic Shaking:** BB Thapa, J Van Greunen, Y Sun & MT McRae, Jacobs Associates; H Law, Earth Mechanics

**Seismic Design Evaluation of the Bay Tunnel:** Y Sun, S Klein & J Van Greunen, Jacobs Associates; P Louie, San Francisco Public Utilities Commission

**Project Planning & Implementation: Alternative Delivery & Contracting Strategies**

**Wednesday, June 11 - 8:30am - Track III**

**Chair:** Richard Switalski, NE Ohio Regional Sewer

**The Owner's Manual on Contracting Strategies for Large Projects:**

F Oksuz, R Goodfellow & C Mueller, Black & Veach Corp

**Getting the Right Contract Package:** W Edgerton & G Davidson, Jacobs Associates

**Alternative Contracting Methods – Part II:** John Reilly, John Reilly Associates International

**Geotechnical Baseline for Construction Second Edition:** R Essex, Hatch Mott MacDonald

**Case Histories: Tunnel Rehabilitation & Repair**

**Wednesday, June 11 - 8:30am - Track IV**

**Chair:** David Young, Hatch Mott MacDonald

**MTBM Mines Side-by-Side Twin Tunnels Below Railroad – West Elizabeth Avenue Storm Drainage Project, New Jersey:** K Schaeffer, J Zurawski & L Glodkowski, Dawn Engineering

**Condition Assessment, Repair & Rehabilitation of Tunnels – Case Histories from California's Historic Water Tunnels:** D Van Horsen, Southern California Edison; J Kaneshiro & F Kintzer, Parsons Water & Infra; G Korbin, Consultant; K Lovelle, Shotcrete Technologies; R McManus, Pacific Gas & Electric; C Ovalle, Metropolitan Water District of Southern California

**Raw Water Tunnel Condition Assessment:** R Castro, G B & B Rothfuss, Jacobs Associates; B Lakin, Regional Water Authority

**Case Histories of Rehabilitation of French Railway Tunnels:** V Nasri & C Winum, SNCF

**Heartland Corridor Tunnels:** F Frandina, P Gabryszak & B Strauss, Hatch Mott MacDonald

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**Exhibit hours & functions**

<b>Sunday, June 8 (move in)</b>	11.00am – 5.00pm	<b>Tuesday, June 10</b>	11.00am – 2.00pm
		Luncheon	Noon
		Banquet Reception	5.00pm – 7.00pm
<b>Monday, June 9 (move in)</b>	9.00am – 3.00pm	<b>Wednesday, June 11</b>	11.00am – 2.00pm
Opening Reception	5.00pm – 7.00pm	Luncheon	Noon



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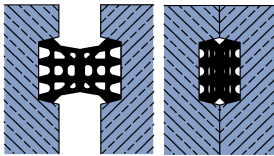
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# Balanced performance



**A**nother Akkerman Earth Pressure Balance Machine (EPBM) is slated for delivery this summer. The machine is for the Avenue 45 and Arroyo Drive Relief Sewer Project, for the City of Los Angeles, California. The contractor is Buntich Pacific JV, of CA. The machine will be used to create a 6,357ft tunnel, which features 11 curves with 94" i.d. concrete segments. Akkerman's previous EPBMs have been used for pipejacking installations. The new machine

erects pre-cast trapezoidal tunneling segments and advances off of the segments to move forward. It is equipped with a 400hp (298kW) variable speed electric cutterhead drive, 18.5" (470mm) open center ribbon screw conveyor, foam and slurry additive system and mixed face cutterhead with disc cutters. Visit Akkerman at Booth 511 for more information. **Akkerman** [www.akkerman.com](http://www.akkerman.com)

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At NAT 2008, booth 213, ACI will be highlighting Wirth's shaft sinking equipment. The company has represented Wirth for nine years now. To date there have been more than 15 rigs placed in North America and more than 25 projects completed using the Wirth RCD (Reverse Circulation Drilling) method for drilling holes in hard rock.

During the summer of 2007, Wirth, ACI and Frontier Kemper entered into a JV agreement to build a Blind Shaft Boring machine for FK. This machine will incorporate the RCD technique, which allows for a relatively small amount of air to bring all of the rock cuttings to the surface very easily, quickly, and economically.

Wirth is providing assistance and equipment to update and modify existing FK equipment that will allow drilling diameters of 8' to depths of roughly 1000', plus



assisting with a design and the fabrication of a new rig that will allow for drilling diameters up to 16' to depths of roughly 1300' in hard rock. Equipment from Wirth is in various stages of manufacture; some has already been delivered and FK is expecting for the first of many shafts to be drilled late in the first quarter of 2008.

Wirth and FK are also in the planning stages to build another rig together, which will be capable of drilling into the 26' diameter range x 1000' deep. Cutters, multi-diameter staged cutting heads, spares, and technical assistance will all be supplied by Wirth and ACI, over and above the orders in motion, to support the co-operative agreement entered into by this team.

**American Commercial Inc** [www.americancommercial.com](http://www.americancommercial.com)

# Chemical solutions

**T**he Underground Construction (UGC) Group of BASF Construction Chemicals will be exhibiting at booth 415 during NAT 2008. The show will provide a platform for UGC to demonstrate its broad product offering for the civil tunneling industry. With products from UGC, TBM drives can be more successful, even through highly challenging ground conditions. UGC's comprehensive TBM portfolio includes soil conditioning foams, soil conditioning polymers, anti-clay agents, tail shield grease, and anti-wear and dust agents. Products include:

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  - MEYCO FIX TSG
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  - RHEOSOIL 211 anti-clay agent
- In addition to TBM, UGC offers a range of products and services for

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CDM's field equipment includes geotechnical instrumentation and construction data acquisition equipment. All of the company's field personnel are NICET, OSHA

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- Conventional Soft Ground and Rock Tunnel Design, Microtunneling, Pipe Jacking and Directional Drilling
- Evaluation and Rehabilitation of Existing Tunnels
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At this year's annual North American Tunneling conference, Halcrow is showcasing some of



its top tunnelling talent. Andy Alder will be presenting to the conference his work on the Docklands Light Railway Woolwich extension, under the River Thames in London, UK. Mike King, technical director and world-renowned tunnelling expert, will be taking questions at Halcrow's booth 408.

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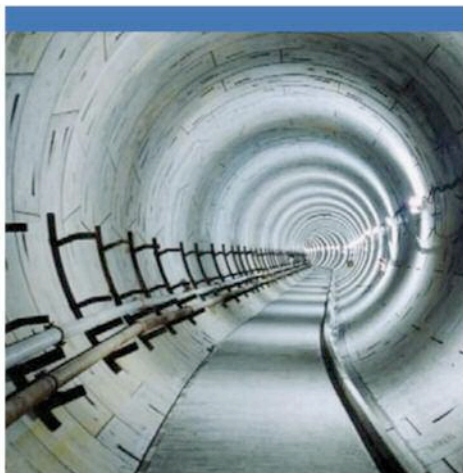
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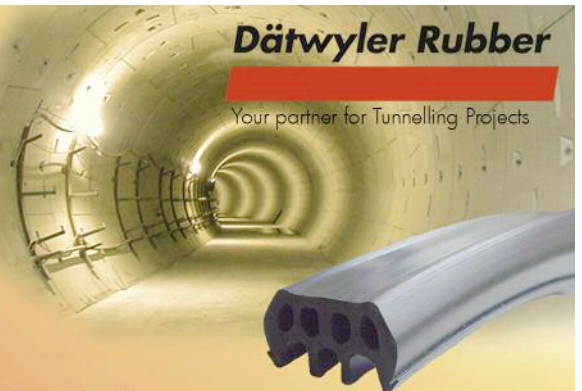
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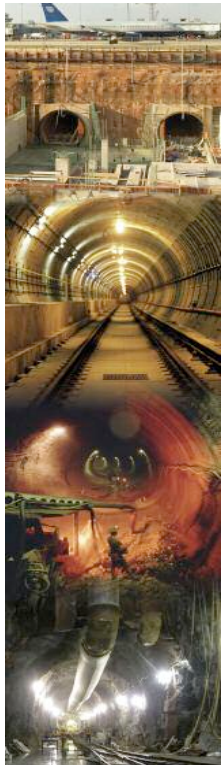
Engineering. ILF maintains permanent offices in Austria, Germany, Switzerland, Poland, Russia, Czech Republic, UK, Italy, Kingdom of Saudi Arabia, Slovakia, China, Pakistan and the USA, and has a permanent staff of over 1200 professionals worldwide. ILF has been responsible for

many distinct and well recognized international tunneling projects over the past forty years. ILF provides engineering services for tunnel designs using New Austrian Tunneling Method (NATM), TBMs, microtunneling, cut and cover, and immersed tube tunnels. ILF also

offers construction management and supervision throughout the project duration.  
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# Technical excellence



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At present, Jacobs Associates is leading the joint venture for final design of Sound Transit's University-Link Light Rail, 3.15-miles of twin-bore, soft-ground tunnels. Ultimately, this project will provide a quick 9-minute commute between downtown Seattle and the University of

Washington. The adjacent picture shows our team's design for one of two cut-and-cover stations.

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For the navigation of TBM projects with segmentally lined tunnels and unlined rock tunnels the SLS system has now been used on over 400 projects.

Various derivatives have been developed to accommodate the ever-changing demands of TBM design. All systems are based on a laser reference that is projected from a motorized total station onto an active target.

With the requirement for more information to be supplied to the machine operator with respect to geodetic, geotechnical and TBM operations, VMT has developed its Tunnel Construction Measurement System (CBP) that enables the integration of all data into one common database to give near real-time evaluation of incoming data for the continuous monitoring and visualization of surface structures and the display of deformations in front, above and behind the TBM.

For pipejacked tunnels that are either curved or of extended distance the SLS-LT system has



now been used on over 300 projects totalling over 150,000m including many of the most complex curved alignments.

The Convergence Measuring System based on the chained inclinometer principle for determining the deformation of the lining within the confines of the trailing gear of a TBM has now been supplied to several critical projects.

High precision measuring services for tunnel construction using metrology systems based on Digital Photogrammetry, LaserTracker and Theodolite systems are routinely supplied for mould and segment measurements as part of a QA/QC procedure.

VMT will be promoting its technology at NAT 2008, booth 307.

**VMT**  
www.vmt-gmbh.de

# Cutting capability

**T**unnelTec has more than 30 years of experience in the tunnel business. One of its core competencies is the supply of specialized, extremely robust and low-wear drilling tools for TBMs. The special features of these tools are their durability and high economic efficiency. An outstanding constructional highlight is the fact, that these tools can be mounted on existing cutterheads without any

further alterations. If TunnelTec tools come into operation, the daily progress of the TBM can be increased, tool changes and downtime can also be reduced.

Since 2007, TunnelTec has also added cutterheads for Microtunneling machines to its range of products. In 2008, its representative American Commercial Inc, started to sell equipment in North America and in April the first Rock Cutter Head was delivered to a project in Calgary, Canada. It is equipped with Double Roller Cutters and has the ability to be totally converted from hard rock to soft ground conditions. To find out more about TunnelTec, visit ACI at booth 213.

**TunnelTec**  
www.tunneltec.com





# Hard Fact No. 10

## System Solution for Tunnel Construction

Your challenge: Building constructions in time with high application safety and efficient cost structure.

Our solution: Sika Systems from the excavation support to the tunnel surface coating.

For Information about the Sika Solutions and Products or additional Hard Facts, please visit [www.sika.com/hardfacts](http://www.sika.com/hardfacts)



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