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CANADIAN TUNNELLING MAGAZINE 2009



Official publication of the Tunnelling Association of Canada



ITA-AITES 2010 World Tunnel Congress and 36th General Assembly

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From the president
RICK STAPLES



Welcome to all members of the Tunnelling Association of Canada, as well as all of our friends and colleagues in the international tunnelling industry. This is our first edition of the TAC magazine for 2009, and as your newly elected president, I wish each and every one of you a prosperous and productive year. I wish to give a hearty thank you to our past president, Garry Stevenson, for his able guidance over the past four years, and I will make every attempt to serve all of you in the same manner.

Due to the severe worldwide economic downturn currently being experienced, some of you in the mining sector have recently witnessed dramatic slowdowns. At the same time, however, civil tunnelling activity remains very healthy across most parts of Canada, particularly in the areas of transit, hydro-electric development, water supply and wastewater control. Tunnelling often forms a major component of the large infrastructure projects, which the current government leaders promote as having the best potential for funding to help kick-start the flagging economy. Many of us in the tunneling industry have seen little if any slowdown in activity, and there are currently multiple potential tunnel projects on the immediate horizon.

Your association remains active in several regions of Canada, and I encourage all members to contact their regional director for information

regarding local events and activities. Our TAC website (www.tunnelcanada.ca) has recently been updated with the latest information about your association. A complete contact list for all TAC officers and directors, as well as membership information and application forms are also included elsewhere in this issue.

The 20th National TAC Conference was held last October in Niagara Falls. The conference was a tremendous success, with record attendance, multiple exhibitors, quality technical papers, and enthusiastically attended social events. Further information about the conference is detailed elsewhere in this issue.

The organizing committee is now in high gear in advance of the ITA-AITES 2010 World Tunnel Congress and 36th General Assembly in Vancouver, May 14 to 20, 2010. This event should already be a "must attend" on your calendars. Canada and TAC will be in the spotlight as hundreds of delegates from the tunnelling industry around the world convene in Vancouver. Dean Brox, organizing committee chairman, deserves many thanks for representing TAC at international meetings and diligently preparing for this event. More information can be obtained directly from Dean, or at www.wtc2010.org.

May there continue to be bright lights at the end of all our tunnels!

Rick Staples
r.staples@delcan.com ●





INTERNATIONAL TUNNELLING ASSOCIATION (ITA)



Martin Knights, president of the International Tunnelling and Underground Association (ITA), reviews recent ITA activities and looks at what 2009 may hold for the sector

This year will be more defined by what happened over the past few months than the whole year. The effects of the financial markets have undermined many infrastructure plans and funding will be an issue for many more projects in 2009.

It's been disturbing to see how quickly the effects of the "credit crunch" and the plummeting financial markets have translated into pessimism by owners who are concerned to proceed with planned underground infrastructure. As I write this message, a road tunnel project that my own company has been designing over the past year has now been cancelled in Miami because the PFI funding structure has failed.

However, some governments are using the situation to bring forward infrastructure projects in an effort to create jobs and keep "cash" circulating in the country's economy. This year, and potentially the year after, will be uncertain for many in the

construction industry and indeed our own tunnelling industry and profession.

Over the past year, I have had the privilege of talking to government, owners, designers, planners, operators, construction companies, manufacturers and member nations. Interestingly, and in contrast to the financial crisis in the developing world, most of my discussions are centred around the need to attract more people into the tunnelling industry – professionals, artisans and skilled workers.

Before the events of the past six months, it seemed that there was nothing to stop the momentum of tunnel projects that are planned over the next 10 years or so. Now, the industry's determination to continue with the projects is as great as ever, taking advantage of enlightened government initiatives that will use infrastructure construction as a means of generating employment.

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With that determination, there will be a need to train and educate, and to ensure quality and safety standards are maintained or even improved. ITA will work with the industry, the universities and owners to facilitate learning good practice and provide the forums for this to take place. The ITA committees and working groups will be at the centre of this.

Education and training

ITA-CET (Committee for Education and Training) – under the leadership of Andre Assis – is now preparing for a major shift in momentum in education and training. Last December in Frankfurt, his committee met to co-ordinate efforts. The group discussed the various university training initiatives offered by the members (master's courses in Austin, Lausanne, Leoben, Stuttgart and Torino); the needs of continuing education in the industry; the experiences of nozzle-man training; and the results of the EC project Tunconstruct. It is expected that the ITA-CET Foundation will be officially launched in the first half of 2009.

New executive director

In January, Olivier Vion starts work as the newly appointed executive director of the ITA and its secretariat. He and Claude Berenguier will work together to transition the secretariat duties in January and February. Thereafter, Claude will co-ordinate and ensure the preparations for the 2009 World Tunnel Congress and general assembly in Budapest in collaboration with the Hungarian member nation. Claude will remain a member of Exco

as secretary general for the appointed period and oversee the running of the secretariat and be available for ad hoc/specific tasks as required by the executive committee (ExCo).

ExCo continues to implement the 2007 strategy and we are hoping to announce new prime sponsors, member nations and supporters during 2009. We are particularly focused on the working group actions and, following consultation early in 2009, we will be announcing further improvements and changes to raise the effectiveness of the output of the various activities and publications of guidelines.

"ITA Reports" now replace those we used to publish in Tunnelling and Underground Space Technology (TUST). In November, we published the first of these entitled "Guidelines for good occupational health and safety practice in tunnel construction." This is not intended to replace existing national regulations or guidance, but to provide guidance on basic good practice where none exists. As such, these guidelines could be incorporated into contract documents where appropriate.

Finally, I would like to end by wishing you and your colleagues a happy New Year and "safe passage" in 2009. I hope we all share the same determination in 2009. I hope we all share the same determination in 2009 to make our industry safer, more efficient, more attractive to new recruits and a great career option.

The preceding message is published with permission, and previously appeared in the January/February 2009 edition of WORLD Tunnelling magazine. ●

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Gary Stevenson: 2004 – 2008

Brian Garrod: 2001 – 2004

Bruce Ripley: 1999 – 2000

Boro Lukajic: 1994 – 1998

Kwan Yee Lo: 1990 – 1993

Ray Benson: 1984 – 1989

Branko Ladanyi: 1982 – 1983

Don H. MacDonald: 1980 – 1981



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VANCOUVER, CANADA MAY 14 – 20, 2010

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MARK YOUR CALENDAR!

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

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

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

Technical Topics

1. Innovative Techniques and Advances in Geotechnical Investigations for Tunnel Projects
2. Tunnelling in Soft Ground
3. Hard Rock Tunnelling
4. Tunnelling in Weak Rock
5. Tunnelling under High Stress Conditions
6. New Advances and Innovation in Mechanized Tunnelling
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Important Dates

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

Organized by the Tunnelling Association of Canada (TAC) and the National Research Council of Canada (NRC), on behalf of the International Tunnelling and Underground Space Association (ITA-AITES).

WWW.WTC2010.ORG

20th National Conference – Niagara Falls, October 2008

The 20th National Conference of the Tunnelling Association of Canada was held in Niagara Falls, in October, 2008. Organized by the Ontario Chapter, the conference was a resounding success, attracting 137 delegates and 15 exhibitors from both Canada and internationally, to the Sheraton Fallsview Hotel. Also attending was Claude Berenguier, ITA Secretary General at the invitation of TAC. During the two day conference, 28 technical papers were presented from various authors around the globe relating to a variety of topics of interest to the tunneling industry, and following the conference theme “Tunnelling Technology & the Environment”. The post conference feedback was very positive as many delegates expressed great interest in the proceedings and conference format.

In keeping with the conference theme, a keynote address was given by Dr. Thomas Homer Dixon, a professor from the University of Waterloo who is an internationally acclaimed expert, well versed in environmental and industrial impacts. He is the author of several books on the subject, and a proficient public speaker. His speech was well received, and the subject of much follow-up discussion throughout the conference.

A technical tour was arranged on the third day to the local Niagara Tunnel Diversion Project. Twenty delegates took advantage of the opportunity to go underground to visit the

world’s largest open beam rock TBM. This gigantic 14.4m diameter machine is currently driving a water diversion tunnel 10.4 km in length to provide increased generation capacity to the Sir Adam Beck Generating Station.

With Niagara Falls located near the heart of Ontario’s wine district, a very successful social event was held at the local Chateau Des Charmes winery. Breaking away from the traditional sit-down conference dinner, the winery staff presented a tour of their wine-making and storage facilities, with a wine tasting session, followed by an evening of various food stations accompanied with appropriate wines. The format allowed the delegates to mingle throughout the evening, and was well received. In the conference tradition of recognizing the special contributions of certain individuals to the local tunneling industry, awards were presented to Peter Hobden, Pat Cleary, and Murty Devata.

The TAC Annual General Meeting was also held during the conference. Rick Staples was elected as the new TAC president, assuming the role previously held by Garry Stevenson.

The bi-annual TAC National Conference will next be held in conjunction with the ITA-AITES 2010 World Tunnel Congress, in Vancouver, May 14-20, 2010. ●



TBM Tunnelling Completed at the Ashlu Hydropower Project, Squamish, B.C.

By Serge Moalli, Project Manager, Frontier Kemper Constructors ULC

TBM tunnelling of the 4.08-metre diameter, 4.44-kilometre power tunnel at the Ashlu Hydropower project near Squamish, B.C., was completed by Frontier-Kemper ULC in late February 2009.

Outstanding works on the project will continue with final tunnel support comprising additional bolts meshing and shotcrete as needed, as well as the raisebore drilling of the 3.8-metre diameter, 106-metre drop shaft at the end of the TBM tunnel, which will be underway in March, and is expected to take five weeks.

The 49-MW run-of-river hydropower project is being developed by Innergex Renewable Energy (Montreal, Que.), under Ashlu Creek Investments Limited as one of many private hydropower projects currently underway in British Columbia. Ledcor CMI is the civil works contractor, with the power tunnel being constructed by Frontier-Kemper Constructors ULC under



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In November 2008, a site visit to the tunnel was arranged by Frontier Kemper ULC and Hatch Mott MacDonald for over 40 students from the Geological Engineering program at the University of British Columbia.



a design-build arrangement. This TBM tunnel project represents the first TBM application in B.C. for the hydropower industry since the mid-1990s and the future looks bright for several more TBM excavated power tunnels for privately developed power projects to meet the growing energy demand of British Columbia.

Similar hard rock conditions were also encountered over the last half of the TBM tunnel drive since last year. One major unexpected fault zone of 46 metres in length was encountered and was supported with heavy capacity steel ribs and mesh concurrent with tunnel excavation. TBM advance rates varied from 10 metres to 20 metres per day with a best-day production of 24 metres.

TBM tunnelling was carried out on a 24/7 basis with four crews. TBM cuttings were removed via a locomotive muck train comprising four 10-m³ cars that discharged over a tipping wall outside the portal for pick up and road transport by Ledcor to the designated spoil site within the project area.

In November 2008, a site visit to the tunnel was arranged by Frontier Kemper ULC and Hatch Mott MacDonald for over 40 students from the Geological Engineering program at the University of British Columbia. They were given the opportunity to go underground and see the operations of a hard rock TBM tunnelling project. ●



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Pictured:
The Ashlu Creek Tunnel Project
Squamish, British Columbia

OAW Sanitary Sewer – Welland, Ontario

By Murray Malott, P.Eng. and Chris Banks, P.Eng., McNally Construction Inc.

Project description

The OAW Sanitary Sewer Tunnel in Welland, Ont., was designed by AE Engineering of St. Catharines for the Public Works Department of the Regional Municipality of Niagara. It was designed to solve the combined separation and storage capacity needs of the City of Welland, Ont. Phase 1 of the tunnel route started at River Road and travelled east along McMaster and Major streets. At the intersection of Major and Wellington streets, the tunnel made a 90-degree bend, and continued south along Wellington to East Main Street for a length of 1,345 metres. The contract was then extended (Phase 2) another 985 metres up Wellington to Lincoln Street for a total length of 2.33 kilometres.

The project was scheduled to begin December 2006, and was to be completed by February 2009. McNally Construction Inc. was awarded the contract for Phase 1 for a tender cost of \$11.8 million. The

tunnel was a conventional soft ground, rib and lagging tunnel, with a cast-in-place (C.I.P.) concrete liner with a 1.65-metre I.D. The tunnel was constructed utilizing McNally's 2.4-metre (96-inch) Lovat TBM. Ground conditions consisted primarily of stiff silty clay to clayey silt, with some silt and/or sand layers and some sections of very stiff clayey silt till, that contained cobbles and boulders. The conditions were ideal for the Lovat soft ground TBM. The tunnel depth ranged from 10 metres to 15 metres. Also required in the tunnel were five drop pipes for future connections. Three mining shafts were designed and constructed for entrance/exit of TBM and final tunnel manholes.

Shaft construction

The main shaft at River Road was completed with steel sheet piling due to its close proximity to the Welland River. The construction of the shaft was complicated due to the presence of

existing utilities that were situated at the east end of the shaft. An existing 450-mm water main and 150-mm gas main had to be located and supported during the shaft excavation. The shaft was 13 metres deep, 25 metres long and 12 metres wide. It allowed for two sets of mining tracks, locomotives and muck cars. This arrangement could accommodate two complete trains in the bottom of the shaft, therefore minimizing delays in the mining operation due to the dumping of trains and supply of materials.

The second shaft (turning shaft) was located at Major and Wellington streets and was constructed using steel soldier piles and 75-mm hardwood lagging. The piles were driven using a hydraulic vibratory hammer.

The upper portion of the shaft was excavated with a backhoe, but the lower portion of the 15-metre-deep shaft was excavated with a mini backhoe, feeding a clam bucket. When the TBM arrived, from the River Road heading, it was picked, turned 90 degrees and then sent on its way to the exit shaft at Lincoln Street. This would break the total tunnelling distance into two runs allowing for a shorter tram time. This also allowed McNally to immediately begin concreting the first tunnel while mining the second tunnel.

The exit shaft at Lincoln Street was also constructed using steel soldier piles and hardwood lagging, and was constructed in a similar fashion to the turning shaft at Major and Wellington streets.

Tunnel construction

The design of the preliminary lining of the tunnel consisted of rib and lagging.





The ribs were 100 mm x 100 mm steel I-beams bent into three semicircles that, when put together, would complete a full circle (2.4-metre outside diameter). The 75 mm x 150 mm x 1,200 mm hard wooden lagging would fit into a steel ring I-beam on each side much like an old wooden barrel. The TBM would then push off the



steel I-beam, with jacks for a distance of 1,200 mm, while the tail can of the Lovat TBM supported the ground. The cutter head of the TBM would turn during the push and the excavated ground would be transported by conveyor to the four 3-cubic-metre muck cars. When the push was over the locomotive would transport

the muck cars out of the tunnel back to the shaft. The cars were then hoisted to the surface by a 60-tonne crane and dumped into a muck bin. The material was eventually loaded into dump trucks and disposed of at a local dump site. Once the muck cars were out, another locomotive with empty cars would immediately enter

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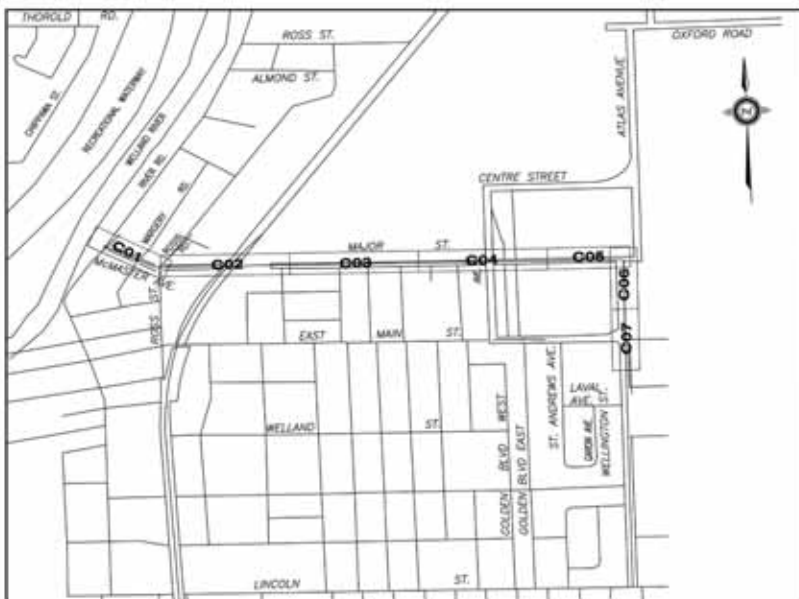
and move into position. The rib and lagging would be erected, in the safety of the tail can of the TBM, while the muck cars were being changed out. After about eight pushes/rings, the train track was extended. Subsequent activities were required as production continued, including: pulling in the 600-volt TBM cable, installing tunnel lights, extending air vent bags (to supply the workers with a

fresh air supply) and installing the 100-mm diameter air pipe for small tools. The 600 volts would either be supplied by a hard wire feed from a power drop on surface, or by a large diesel generator. A laser was set up by surveyors for line and grade and was checked frequently.

Phase 2 (an additional 985 metres) of the sewer was awarded to McNally Construction Inc. after the turning shaft

was complete. The owners negotiated with McNally Construction Inc. in an effort to eliminate mobilization charges of another contract. Phase 2 was initially designed as open cut, but would have required Wellington Street to be slashed from property line to property due to the depth. Since the potential was there for Phase 2, the shaft was made wide enough to accommodate two sets of tracks, but

The Regional Municipality of Niagara Public Works Department



OAW SANITARY SEWER

PHASE 1

In the City of WELLAND

October 2006

Location Plan (Not To Scale)

CONTRACT NO. RN 06-16



During mining it is important to continually monitor the air for oxygen levels and dangerous gases.

was not made long enough for two trains side by side. To deal with this problem after the fact, a 3.4-metre diameter starter tunnel was hand mined for 20 metres. The starter tunnel was lined with 1-metre long by 400-mm wide curved steel liner plates bolted together. Twelve plates are needed to complete a full ring. This starter tunnel, in combination with the shaft, would accommodate two full trains, which allowed an efficient mining operation.

Although the ground was generally silty clay, it also contained boulders. At times the boulders were larger in diameter than the TBM. A small boulder could be attacked with a rock splitter and broken down until it was small enough to come through the TBM doors and go down the conveyor. In the event larger boulders were encountered the boulder was drilled and explosives were used. Due to the large amount of boulders that were encountered, the average weekly mining rate was about 35 metres per week.

During mining it is important to continually monitor the air for oxygen levels and dangerous gases. At one location during the tunnel excavation, oxygen levels fell below acceptable values and even went as low as 12 per cent.



During this time it was found that the carbon monoxide levels were also increasing to well above acceptable levels. Carbon monoxide is highly toxic and reduces the blood's oxygen-carrying capacity. As with other toxic gases, the level and duration of exposure determines the severity of the effects. This low oxygen/high CO level resulted in an immediate evacuation of the workers from the tunnel. To overcome this problem, additional ventilation was added in order to supply fresh air to the work area and face of excavation, thereby increasing the oxygen level, while at the same time depleting the CO level. Although the cause of the low oxygen levels was never fully determined it was believed that it was the result of "deoxygenated ground." As a fresh face of material was exposed,

the material would consume the oxygen and release carbon monoxide.

Concrete lining

The secondary concrete lining was completed using a set of used round steel telescopic tunnel forms. The forms consisted of 40 metres of full 360-degree steel plates, with an additional 10 metres of inverts. The forms were moved using a small hand-powered "form jumbo," which allowed moving and setting of a 3-metre section at a time. Approximately 40 metres was formed in the night shift and then poured by concrete pump during the day shift. The forms come in two pieces – a bottom plate and the body. The body of the form has hinges on each side so that the sides can fold in and fit, like a telescope, through the pre-existing forms.



The secondary concrete lining was completed using a set of used round steel telescopic tunnel forms. The forms consisted of 40 metres of full 360-degree steel plates, with an additional 10 metres of inverts.



Conclusions

The OAW sanitary sewer was completed on time and within budget. Total cost for both phases was approximately \$17,000,000. Great credit should be given to the inspector (Don Cook) and AE Engineering and their ability to react throughout the project. The Region of Niagara and City of Welland were always open to problem solving and mitigation proposals. Although many unforeseen obstacles were encountered, all issues were dealt with openly and professionally by all parties. This resulted in quick and fair resolutions at the site level, thereby

avoiding any delays, claims or additional costs. The 96" Lovat TBM was beat up from the boulders, but emerged at its destination online and on grade.. From its purchase date in 1974, by McNally

Construction Inc., this Lovat TBM (the ninth made) has completed over 25 kilometers of tunnel in all types of soft ground throughout Canada and the United States. ●

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Seymour Capilano Twin Tunnels

Drinking water tunnel completion contract awarded



Metro Vancouver has finalized negotiations and awarded a contract to the Seymour-Cap Partnership – comprising the companies Frontier-Kemper/J.F.Shea/Aecon – for completion of the twin tunnels component of the Seymour Capilano Filtration Project.

The Seymour-Cap Partnership bid \$181 million to complete the tunnels, and will proceed using the original engineering design and the two tunnel boring machines currently in place.

The project, which will provide filtration and ultra-violet disinfection of drinking water from two of Metro Vancouver's three source water supplies, has four key elements: the filtration plant, located in the Lower Seymour Conservation Reserve; the Capilano pumping station; twin tunnels that will convey water from the Capilano source to the plant for treatment and return treated water for distribution; and an energy recovery facility.

While both the filtration plant and energy recovery facility are nearing completion, and the pumping station is

complete, work on the twin tunnels was halted in January 2008, by Bilfinger-Berger Canada Inc., the original contractor. Bilfinger-Berger refused to proceed with work in accordance with the contract, and as a result its right to perform further work was terminated in May 2008.

In late summer and fall 2008, Metro Vancouver conducted a pre-qualification and RFP process inviting proposals from potential contractors capable of completing the two 7.1-kilometre, 3.8-metre diameter tunnels. Following pre-qualification, three consortia were identified and bids were received from Frontier Kemper-JF Shea JV, Obayashi-Aecon-McNally JV, and Seli-Dracagos JV. Two of the three consortia submitted compliant bids.

Initially budgeted at \$200 million, which included Bilfinger-Berger's \$105-million contract for tunnel construction, as well as engineering, tunnel liner and other associated expenditures, overall costs for the tunnels component are projected to double to \$400 million.

Work on the tunnels is expected to commence in April, with completion anticipated at the end of 2012 or early 2013. There remains a significant amount of outstanding work including TBM tunnel excavation, raisebore drilling of two, 270-metre-deep shafts, and installation of steel lining within the tunnels and shafts. Filtration plant construction is expected to be completed this spring and the plant fully operational by the fall. ●

Toronto's Deep Lake Water Cooling Distribution by Tunnel

By Mike McNally, McNally Engineering Corp., Kevin Loughborough, Enwave District Energy



Toronto's unique situation with abundant cold water nearby in Lake Ontario has provided the opportunity to develop a central cooling system to serve the downtown core. The system is called "Deep Lake Water Cooling."

The story of collection of the cold water from the lake using submerged pipes on the lake bottom has been told elsewhere. The other part of the system, distribution to the customer buildings throughout the downtown, has not drawn much publicity. The reason is that tunnelling has been used for the majority of this work.

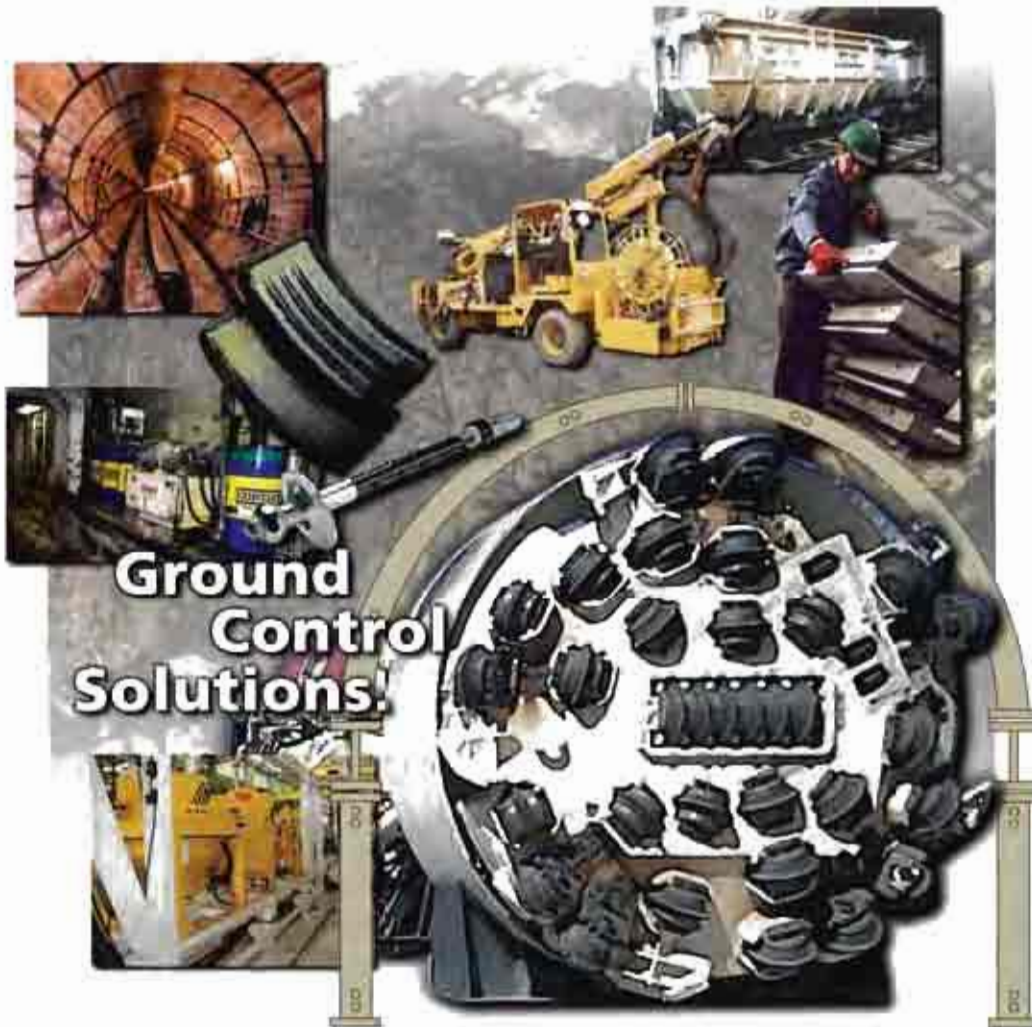
Currently, about 4.3 kilometres of Deep Lake Water Cooling distribution and feed tunnels are operating on the following

streets: York from Front to Queen, Queen from York to James, Wellington from Simcoe to Bay, Bay from Adelaide to Grosvenor, Hayter from Bay to University and Simcoe from Lakeshore to Adelaide. Connections to customer buildings along these streets are developed as side drifts into the building basements or underground parking areas. When the connections are in service the buildings' chillers are decommissioned.

The likely reason that this work did not attract publicity is that only four mining shafts were used. The tunnels range in diameter from 3 to 3.5 metres. They provide space for a closed loop water circulation system. The water picks up heat from heat exchangers in the buildings and

carries it to heat exchangers adjacent to the city's John Street Pumping Station where it warms the incoming city water. The general tunnel arrangement has the supply and return water pipes (diameter 30 inches to 48 inches) encased in concrete in the lower portion with a walkway and valve area in the upper portion. Chambers for full-diameter control valves are located at intersections in the system.

By taking advantage of the consistent shale formation under the downtown and C&M McNally Engineering Corp's patented tunnel support system, the tunnels were developed at a depth that allowed them to avoid conflicts with any existing utilities and without geotechnical surprises. ●



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Lakeview Dividend Tunnel Rehabilitation (Bats in the Adit)

By Bill Stellar and Lara Reggin, EBA Consultants



View from inside the open stope.

The Lakeview Dividend Mine near Osoyoos, B.C., produced gold and copper intermittently from 1898 to the 1940s. Mining ceased and the site was abandoned before reclamation legislation was in effect and property ownership reverted back to the province. In 2007, the Ministry of Energy, Mines and Petroleum Resources prioritized this site for reclamation due to hazards posed by the remaining tunnels, shafts, unstable rock ledges, and a stope which had partially caved to surface. EBA Engineering Consultants Ltd. (EBA) was retained to design and manage the reclamation work.

The site contained extensive underground workings surrounding a 120-metre



Rock breaker removing a pillar.

long by 50-metre wide stope which had partially caved to surface. On the north side of the stope, a 20-metre wide overhang was supported by slender, 10-

metre tall pillars of weak ore. The higher south side of the open stope was near vertical and also had large overhangs associated with mined out areas of the ore body.

Numerous tunnels and multiple raises (ore passes) intersected the open hole formed by the caved stope. There were three main access adits which led into the underground workings and open stope from the hillside below the mine. Although

the site was fenced off, the old mine was still frequented by local youth, and it was only a matter of time before a serious injury or fatality would occur.

The conceptual mine closure plan was to infill the open stope and block the portals providing access to the underground workings. However, inspection of the site in advance of closure revealed that the mine tunnels provided habitat for several species of bats, including Townsend's Big-eared bat and Western Small-footed Myotis, which are on the blue list for endangered species, and the Pallid bat, which is a red-listed. The area is surrounded by vineyards and orchards where bats serve as an insect control agent so the local community were proponents



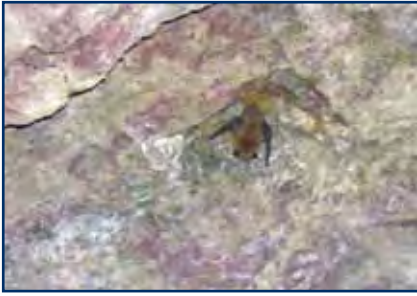
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A lonely bat.

of maintaining the bat habitat. Therefore, mine remediation planning needed to consider methods to maintain climate and ventilation conditions within the adits to preserve this habitat.

Various studies have shown that factors contributing to favourable bat habitat in abandoned mine workings are poorly understood. It is believed that convective air flow during summer months draws warm air through the workings, which heats the rock mass. This stored heat is then radiated during winter months providing favourable over-wintering habitat. Preservation of the pre-existing ventilation and climate conditions is considered to be the best approach for preserving bat habitat in abandoned underground mines slated for closure.

A three-week study of the air circulation within the tunnels indicated significant convective air flow from the adit portals through the mid-level underground mine workings and into the caved stope. This indicated that a surface vent was necessary to preserve the climate within the underground workings; the stope could not simply be filled in. As a starting point, all underground workings and interconnections were surveyed to assess potential air flow pathways. The air quality was found to be good in all areas, including dead-end drifts. Monitoring indicated that the total convective air flow through the workings was up to about 1.4 m³/s (50 cfs). Ambient air temperatures in the dead-end drifts during winter months were typically about 10 C (5 to 10 degrees above the average surface air temperatures).

Brief post closure monitoring indicated that the ventilation shaft was successful in preserving the natural convective air flow, although the flow was more concentrated

as multiple air flow pathways into the open stope had been replaced by a single ventilation shaft at a central location in the underground workings.

The mine site was located immediately adjacent to a residential development, and there were public concerns over the use of explosives for rock excavation that was required during the rehabilitation work. The closure plan included filling the stope with clean fill rock from an adjacent subdivision development, and utilizing

two excavators (Hitachi 350 and Hitachi 370) equipped with 10,000-kg rock breaking hammers to remove overhangs and flatten the surrounding steep rock faces. Natural ventilation was maintained by installing a near vertical corrugated metal culvert from an ore pass in the floor of the stope, up through the fill concurrent with the infilling the open stope. A vent cap was designed for the top of this ventilation shaft to allow bats to escape, yet prevent tampering by the public, such



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Constructing a bat gat at portal one.



Portal two under construction.

as throwing debris down the vent. The portals for each of the three main tunnels to the underground mine were in various stages of collapse and required some rehabilitation. As the largest portal dimensions were approximately 2.5 metres by 2.5 metres, this was a relatively simple



Final grading of the site.

process accomplished with rock bolts, welded wire mesh and shotcrete. “Bat Gates” with 150-mm-wide horizontal louver openings were designed and installed at each portal to allow bats free access to the underground, but prevent unauthorized human access. The gates include a removable (locked) louver bar to allow future research access. The tunnels have survived almost 70 years without rock support and most areas remain relatively safe for access by trained personnel.

One of the many challenges of this project was selecting and co-ordinating multiple specialist contractors and to



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Bat vent installation.

complete the work on a very tight schedule. Preserving the bat habitat, without disturbing the bats, also proved challenging. At the conclusion of the project, the mine site was re-graded to blend in with the surrounding topography and left in a condition safe for public use.

At completion of the remedial works, a plaque was mounted on the central ventilation shaft to commemorate the mine site and its place within the community. The ceremony was attended by residents, stakeholders, Town Council, First Nations, members of local parliament

including the Honourable Bill Barisof, and the Minister of State for Mining, Kevin Krueger. Through active public engagement and good communication practices, the project was completed without complaint from the public – or the bats. ●



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Sudbury South End Rock Tunnel: The difficulty of passing under Lily Creek with “thin” rock cover

By Adam Stremcha, McNally Construction Inc.

The City of Greater Sudbury, in an effort to update their existing sewer system and add needed capacity for the developing south end of the city, awarded a contract in early 2005 for the South End Tunnel Project. The project commenced in September 2005, and consisted of 6.5 km of tunnel, three access shafts, and nine drop shafts. The 1.5-metre by 2.1-metre tunnel will gravity feed north to the

existing Lockerby Tunnel and from there, the sewer will flow to the Sudbury Treatment Plant. With the elimination of several lift stations and added capacity, the tunnel will alleviate the already over extended sewer system.

Conventional drill and blast methods were used to excavate the tunnel. Typical rounds were 1.8 m in length, drilled with small diameter holes and charged with blown anfo or emulsion chubs,

depending on ground conditions. Secan S250 jacklegs were selected for drilling and Eimco 12B muckers were used for removing material. Muck was conveyed in side dump muck cars or Hagglund cars depending on the access points.

Nine underground chambers, consisting of a concrete wall and baffle plate, were constructed around the drop shafts. Air vents were located adjacent to the drops and within the chambers. Both



drop shafts and air vents were excavated using a Robbins raise bore machine. Final invert of the tunnel is a concrete "v" at .11 per cent. The tunnel will be commissioned in three sections as each is completed. This article focuses on the section of tie-in to the existing Lockerby Tunnel and the difficulty passing under Lily Creek.

Lily Creek flows approximately 300 m west of the Regent/Bouchard Street junction. One hundred metres west of the creek lies the South End/Lockerby Tunnel connection. Urbanization in the recent past has led to the "re-routing" of Lily Creek and the subsequent backfilling of its original path. Borings done in 1964, 1972, 1976 and excavations during the Lockerby Tunnel construction encountered difficult ground in this area.

Geotechnical studies done leading up to the project show approximately 5.5 m to 9 m of crown pillar along the tunnel alignment near Lily Creek. Three boreholes with Q values between 4.4 and 20.9 were located in the vicinity. Due to access restrictions none of the boreholes were located over the tunnel alignment. Geophysical surveys were done across the creek and over the tunnel alignment instead.

In April 2008, a fault zone was encountered at approximately 170 m from the Lockerby connection. Steel sets poured back with concrete were required to stabilize the ground. About 20 m worth of steel sets and concrete was necessary. Excavation commenced again in mid-June along the proposed alignment heading towards Lily Creek. Later in the month, while drilling probe holes, it was discovered that the crown pillar had significantly decreased to a range of 1.25 m to 1.5 m. The tunnel was some 30 m from the creek bed at this point. Tunnelling was immediately halted while an alternate plan was formulated.

Using a borehole with known high rock elevations and projecting a new path towards it, a set of NQ-sized holes were to be drilled to prove ground conditions.

Due to the necessity to drill over the new alignment, permission was granted to place a barge in the creek and drill from it. Access issues and environmental concerns were monitored by a patient community and a watchful DFO department. From July 26 to July 28, four cores were taken in the creek and along its western bank.

From the core data it was determined that the crown pillar was an estimated

2.3 m with a $Q_{\text{equivalent}}$ in the area of 12.9. Based on this information the tunnel was realigned and excavation proceeded with caution. Instead of 1.8-m rounds, 1.2-m rounds were taken. As with the regular 1.8-m rounds, cushion blasting techniques were utilized. Every second round, four probe holes were to be drilled at the face. The back was shotcrete with 30MPa dry mix with 50-mm cover. One

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achieved. Regular 1.8-m rounds were reinstated and the original pattern bolts installed.

Excavation continued as the tunnel began crossing under the east bank of the creek. One vertical probe hole at 1.8 m and one probe hole drilled at 45° out from the face to a depth of at least 2.6 m were drilled every other round. In mid-September, while probing out in front of the face, the bedrock contact was encountered at 1.5 m above the back. Minimal water inflow occurred, but once again the heading was stopped until further investigation could be performed.

This time the services of an underground diamond drilling contractor were employed with a Bazooka drill to probe +10 m out in front of the tunnel face. Several rings with a number of holes in each ring at various azimuths and upward angles were proposed. Due to the confinement of the tunnel and the

dimensions of the drill the proposal was not practical, however, a number of holes were drilled out in front of the face and encompassing the back along the alignment. Bedrock contacts were noted; trajectories recorded and core samples taken during drilling. From this data a 3-D model of the crown pillar was realized. It was determined that the worst area was directly above the last tunnel advancement and that the rock was sound.

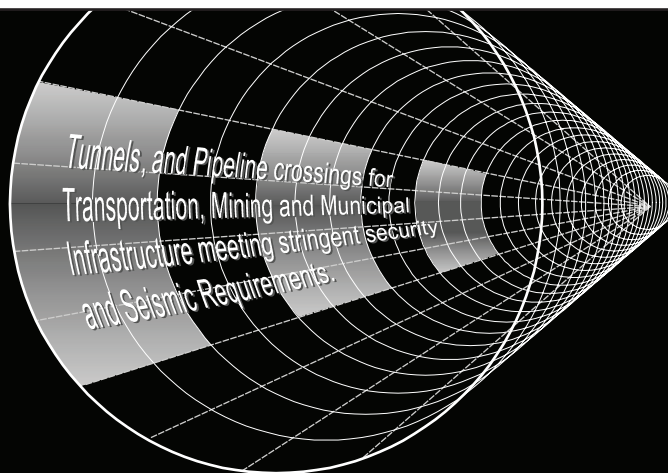
A similar approach, as the previous zone, was used in advancing the tunnel: 1.2 m rounds were taken, spiling bolts installed, and probe holes drilled after ever other round. Extra precautions were necessary, being directly under the creek. Groundwater inflows were closely monitored. Split powder was used in the perimeter holes to minimize overbreak and fracturing of the surrounding rock. Steel sets were erected and shotcreted

completely in after every round to provide long-term stability. After approximately 12 m, the west bank of the creek was reached and the crown pillar increased dramatically. Normal mining and support systems were once again employed.

After several months of delay the South End Tunnel broke through into the Lockerby Tunnel in early January 2009. The successful completion of the crossing under Lily Creek was due in part to the expertise and diligence of the mining crews and the extra geotechnical investigations. As is the case in most underground work, there is always a certain factor of unknowns. However, a more thorough geological study on the front end of the project in the area of Lily Creek would have minimized schedule impacts, cost overruns and the extra risks incurred. ●

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Technical Considerations for TBM Tunnelling in the Andes

By: *Dean Brox, Hatch Mott MacDonald, Vancouver, Canada;*

Renzo Valentino Cardoza, Pacific Hydro, Santiago, Chile; Guido Venturini, Sea Consulting, Turin, Italy

INTRODUCTION

The technical considerations for the use of tunnel boring machines (TBMs) in the Andes of South America are different from those of other mountainous regions due to unique conditions associated with the geological conditions of the Andes and the tunnelling practices in these countries comprising these regions. Several TBM tunnelling projects have been completed in the Andes with mixed success dating from the 1980s, and several new hydro and mine access projects are currently contemplating the use of TBMs. The use of TBMs in the Andes appears to have a negative connotation due to the mixed past success even though most projects were completed within, or shortly thereafter, the respective construction schedules. Two (2) TBMs were abandoned in the Andes from a total estimated 12 projects. This paper outlines the key technical issues that need to be considered for the use of TBMs in the Andes, the advantages and disadvantages of the use of TBMs, some minimum requirements for their use, and some unique approaches for geotechnical investigations required for their use. This paper represents a short version of a full length paper that is to be published and presented at RETC 2009.

HISTORICAL USE OF TBMs IN THE ANDES

Several long and small size tunnels have been successfully constructed in South America using TBMs since the late 1970s for water supply and hydroelectric projects. There, however, exists a misunderstanding that there are several tunnelling projects in South America with unsuccessful applications of TBMs. Table 1 presents a summary of relevant information from several completed and ongoing TBM tunnelling projects in South America. Additional TBM tunnel projects may have been completed in the Andes, but have not been identified by the authors. Many of these projects faced problematic geological conditions and associated delays however several of these projects were completed successfully in terms of schedule and costs using TBMs.

The first use of a TBM in the Andes is believed to have been in 1976 for the 24-km Yacambu Quibor Water Tunnel Project in Venezuela. This project was associated with low strength phyllite rock of about 15 MPa with rock cover over 1,200 m that resulted in significant deformation and squeezing as shown in Figure 1 that caused one of two TBMs to be removed in 1987 after about 1.5 km of progress and suspension of works. In comparison, TBM tunnelling was completed successfully for the 6.5-km headrace tunnel of the Carhuaquero hydropower project in Peru. The Misiscuni water diversion project in Bolivia, however, faced extreme geological conditions with weak and loose materials combined with high groundwater inflows associated with a 700-m

wide fault zone under high cover where TBM progress was very poor. These conditions caused the contractor to leave the project that was completed by the TBM supplier. TBM progress rates of 840 m/month were, however, achieved during some of the project. It should be noted that the experience of the contractor with the use of a TBM was believed to be very limited for this project.

Name	Location	Year ²	Length, km	Size, m
Yacambu Quibor	Venezuela	1975-2008	24	4.5
Carhuaquero	Peru	1990-1992	6.52	3.8
Rosales ¹	Columbia	1991-1992	9.1	3.5
Rio Blanco	Chile	1992-1993	11.0	5.7
Pappallacta	Ecuador	1988-1990	6.2	3.2
Misicuni	Bolivia	1998-2003	19.5	3.5
Chimay	Peru	1999-2001	9.6	5.7
Manubi ¹	Ecuador	2000-2002	11.4	4.0
Yuncan	Peru	2000-2003	6.7	4.1
San Francisco	Ecuador	2006-2007	9.7	7.1
Olmos	Peru	2008-2009	13.8	5.3
Los Bronces ¹	Chile	2009-2011	8.0	4.2

¹ Double Shield TBMs used
² Year of Start of Project

Table 1. Past TBM projects in the Andes

In 1992, the 11-km Rio Blanco Water Diversion Tunnel completed at the El Teniente Mine in Chile using an under powered 5.7-m diameter TBM was used, that resulted in initially low rates of progress for the competent and very strong dioritic rock. Upgrades were completed on the TBM during the early stages of the project that resulted in sustained production rates of 30 m/day.

At the Pappallacta hydropower project in Ecuador, the TBM completed 5.7 km of a 6.2-km tunnel before encountering a major inrush of 1,200 m³ of loose material, requiring the remainder of the tunnel to be excavated by drill and blast. Double shield TBMs in conjunction with pre-cast concrete segments were used for two of the listed projects, where highly mixed rock conditions were present and world record rates of progress of over 1,800 m/month were achieved at Manubi. The Yuncan hydropower project in Peru is the second project in the Andes, where a TBM was buried and abandoned. One of the two TBMs at Yuncan was abandoned upon intersection of a 10-m fault with significant water inflows and loose material and required a mine-bypass around the TBM. The San Francisco Hydropower project in Ecuador is the last completed TBM tunnel project in the Andes. TBM progress was

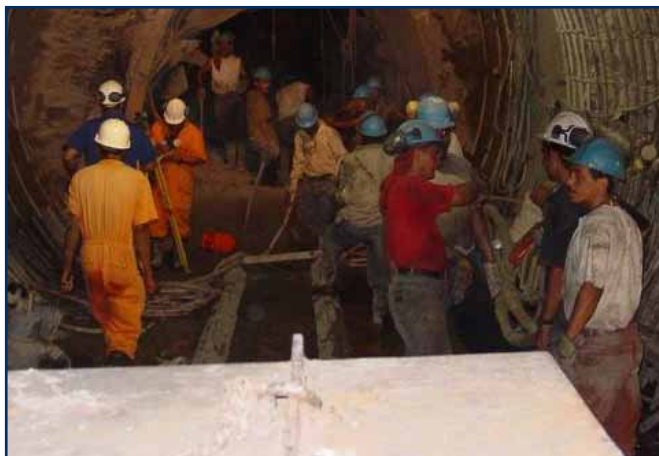


Figure 1. High deformation at Yacambu Quibor

reported as good at about 25 m/day over the entire project without any major delays.

The Olmos Water Project in Peru is currently underway and the successful use of the McNally System™ for TBM roof support is discussed in a separate article in this journal by Mike McNally. Future projects that are planned with TBMs in the Andes include a 4.5-m diameter, 8-km tunnel at the Los Bronces Mine in Chile, hydropower tunnels in Chile and Peru, as well as mine access tunnels in Chile.

KEY CONSIDERATIONS

There are a number of key technical considerations to be addressed for the use of TBMs in the Andes as follows:

- Geological Conditions.
- Depth of Cover/Potential Overstressing.
- Site Access and Terrain.
- Portal Locations.
- Contractor Experience.
- Available Intermediate Access Adits.
- Minimum TBM Size.
- Final Support and Lining Requirements.

Geological conditions

The Andes of South America are a relatively young geological environment with highly variable rock conditions from poorly indurated and low durability volcanic tuffs and/or highly altered andesites to extremely strong (> 300 MPa) and highly abrasive andesites that present some unique challenges for consideration for the planning of long tunnels. These series of volcanic rocks have been extremely folded and faulted in some areas. Figure 2 shows an example of differentially eroded interlayered volcanic tuffs and andesites that have been folded upright at moderate elevation of 2,000 m in the Andes. Deleterious minerals, including zeolites containing smectites, gypsum/anhydrite, or vein filled laumontite, are also commonly present within the volcanic bedrock. The main concern of deleterious minerals is their

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susceptibility to scour and/or erosion in unlined water conveyance tunnels. However, deterioration can occur during construction and cause problems with instability and tunnel floor softening (Castro et al 2003). The presence of deleterious minerals will also typically result in moderate to low rock strengths that can lead to overstressing even under moderate rock cover.

TBMs are most appropriately applied in homogeneous rock conditions that are conducive for excavation including very strong rock varying from 150 MPa to 250 MPa. Extremely strong, massive (widely jointed), and abrasive rock will impact TBM progress, however, larger (19" = 483 mm) cutters in conjunction with high-power capacity can result in attractive TBM progress rates. TBMs are also most appropriately applied along tunnel alignments where there exists a relatively low percentage of poor quality rock associated with faults/shears and/or highly altered rock.

Depth of cover/potential overstressing

One of the key considerations for the use of TBMs is the depth of rock cover along the tunnel alignment and the potential for overstressing. Overstressing will occur under the following conditions:

- High rock cover.
- Low/moderate rock strength.
- High in situ stresses.

Evaluation of the potential for overstressing requires knowledge of the uniaxial compressive strength and in situ stresses. Estimates of rock strength can be made by field observations at bedrock outcrops and knowledge of the type of rock and the presence of alteration. Laboratory testing of rock block or drillcore samples should, ideally, be undertaken.

In the absence of site-specific stress data, the evaluation of the potential for overstressing or initiation of spalling and damage of brittle rock can be based on the empirical findings of observed overstressing in deep tunnels. (Diedrichs 2007). A comprehensive assessment of the extent of



Figure 2. Differentially eroded tuffs

overstressing should, however, be carried out using readily available software programs such as Phases or FLAC.

Site access and terrain

Appropriate site access and terrain with low-grade roads must be considered to allow for the practical mobilization of TBM equipment. The weight of large size TBMs (> 8-10 m) can exceed 130 tonnes and special low-boy access vehicles are typically required to bring TBMs to portal areas for assembly. Alternatively, the maximum payload for high capacity helicopters (Mi26) is limited to 20 tonnes and, therefore, restricts the use of only small TBMs in very remote locations.

Portal locations

Practical locations with sufficient area must exist that facilitate the assembly of TBMs unless large span caverns/chambers can be excavated to allow for the assembly of TBMs and for the starter tunnel. Tunnel portals are always sited at the base of slopes where rockfall and/or avalanche hazards may exist. The site laydown for a TBM is much larger than that for a drill and blast operation and, therefore, there is greater risk for rockfall/avalanches to impact TBM operations during construction.

Contractor experience

There exist very few tunnel contractors in South America with good TBM experience. There exists a long history of mining in South America where contractors have achieved high production rates for drill and blast excavation. Accordingly, TBMs have mainly been used in South America in joint venture with specialist TBM contractors from Europe.



Figure 3. Intermediate access adit for long tunnel

With the introduction and experience of user-friendly TBM tunnel support systems through challenging rock conditions there may be an increased use of TBMs for future tunnels in the Andes.

Available intermediate access adits

Where a site provides the topographic possibly of intermediate access adits then the use of TBMs is of little advantage since excavation from multiple adits can result in a similar, if not shorter, schedule with less overall risk since having multiple headings can always contribute to the overall project progress. Figure 3 shows a typical intermediate access adit in gently sloping mountainous terrain where access was possible.

Project schedule and completion

Some tunnel projects are revenue-based projects such as hydro and or mine access tunnels that demand early completion or face major penalties. These projects may mandate the use of TBMs in order to provide an overall shorter construction schedule. In some cases it may be attractive for owners to consider to pre-purchase TBMs for an earlier start of tunnel excavation rather than wait the full procurement period for a TBM (typically 12 to 16 months) after the award of contract which is one of the main disadvantages for the use of TBMs. The recent surge in projects around the world has, however, also meant a long procurement period for drill and blast equipment. The availability of used TBMs for early procurement is a key advantage for project schedule.

Minimum TBM size

One of the key issues with regards to the application of TBMs is the minimum acceptable tunnel diameter to meet both the minimum hydraulic requirements, as well as for practical construction for the effective installation of initial and final tunnel. An evaluation of the minimum acceptable TBM diameter for any long tunnel should be carried out recognizing the minimum hydraulic requirements, the maximum anticipated initial tunnel support requirements (high capacity support with shotcrete), maximum anticipated deformation/closure under weak rock conditions, minimum practical clearance requirements for effective/optimal progress based on precedent practice, and maximum final support/lining requirements. This assessment will indicate that it is prudent to oversize the TBM diameter well above the minimum hydraulic requirements and will serve as a very useful comparison to any proposals from the EPC contractors who may wish to propose TBM excavation and have not considered all the technical requirements for the project. A TBM diameter of about 4 m is considered to be practical based on the above mentioned criteria. Figure 4 shows the minimize space for the installation of heavy steel rib support for poor rock conditions for a 4.0-m TBM.

Final tunnel support and lining

The final support and lining requirements for any proposed tunnels are subject to the durability of the encountered rock conditions, as well as the performance of the initial support



Figure 4. Support installation in small TBM tunnel

installed and overall stability of the tunnels after excavation. The durability of volcanic rocks common throughout the Andes is uncertain and is of particular importance in terms of their acceptability to remain unlined/protected for long-term serviceability of the tunnels. The durability of volcanic rocks can be initially evaluated from the results of rock strength and petrographic testing, however, further durability/slaking potential testing may be appropriate if there exists rock units of low strength and suspected limited durability where zeolites and/or other vein infilling materials may be present.

The decision-making process for final support and lining for water conveyance tunnels should only be made after an appropriate time after excavation and initial support in order that the performance of the tunnels can be evaluated and the encountered rock conditions have been exposed to any possible effects of humidity. The decision-making process for final support and lining should be made by the Owner's representative during regular and routine site inspections during tunnel excavation such that instructions can be provided from the construction management team to the tunnel contractor to complete the works in a timely manner and concurrently with ongoing tunnel excavation and not at the completion of all tunnel excavation. With this approach it is necessary to have unit rates from the tunnel contractor for various forms of final support and lining. It will be necessary that shotcrete and/or concrete linings be placed over areas where low strength and/or altered/non-durable rock is encountered that can be subjected to scour/erosion. An ongoing evaluation of rock durability will be required during tunnel excavation to further assess the durability of all encountered rock units. Figure 5 shows the application of shotcrete as part of final support/lining requirements for a small size TBM tunnel for water conveyance.

The 5.7-m diameter, 11-km TBM excavated Rio Blanco diversion tunnel constructed for Codelco's El Teniente Mine in 1992 represents an interesting case history with regards to final support and lining requirements. The geology along the tunnel alignment is believed to have been andesites that were of good quality as indicated by the minimum support requirements during excavation. However, shortly after conveyance of water through



Figure 5. Final support as shotcreting

the tunnel severe problems occurred due to deterioration of the andesite rock and it was subsequently recognized that zeolites containing swelling clays were present within the andesite. Similar adverse mineralogical conditions were identified during the construction of the 45-km water transfer tunnel of the Lesotho Highlands Water Project in Southern Africa during the mid-1990's that led to the decision to place concrete lining for the entire length of the transfer tunnel. These two case histories provide an important lesson to be learned that adequate petrographic and other associated rock testing should be completed and carefully evaluated prior to construction to identify all final support and lining requirements. Significant increases to lining requirements and/or changes during construction can typically lead to major delays and cost overruns.

ADVANTAGES AND DISADVANTAGES OF TBMs

The main advantages for the use of TBMs in the Andes are as follows:

- Significantly higher and sustainable progress rates for generally good quality hard rock conditions.
- Less rock support due to less damage caused to tunnel profile.
- Long single drives where no intermediate access adits are possible in steep terrain.
- Lower ventilation requirements allowing smaller tunnels to be constructed.
- Improved health conditions for workers without exposure to blast smoke/fumes.

Where intermediate access adits are not available due to steep topographic terrain and/or environmental reasons, TBMs are the common choice.

For hydropower projects the use of TBMs for water conveyance has significant advantages due to the following:

- Improved hydraulic performance in terms of lower headlosses for circular TBM tunnels.
- Lower cost small size TBM tunnels for minimum hydraulic flows versus oversized drill and blast tunnels.
- Schedule and cost savings since no need for concrete invert.

Figure 6 shows the extensive work required associated with concrete invert for a drill and blast hydropower tunnel.

Hydraulic headloss reductions of 23 per cent and 67 per cent are typically associated with unlined TBM circular tunnels over shotcrete lined and unlined drill and blast tunnels respectively (Benson, 1986).

The main disadvantages for the use of TBMs in the Andes are as follows:

- Immediate stress relaxation and overstressing behind the cutterhead requiring early support and protection of workers.
- Limited space available for the installation of high capacity tunnel support if very poor geological conditions encountered.
- Potential squeezing of TBMs at major fault zones.
- Limited space available for pre-excavation grouting to reduce groundwater inflows.
- Long procurement time of 12 to 16 months for new TBMs or eight to nine months for used TBMs.

The advent of the McNally System™ for TBM roof support is, however, now recognized as an effective solution to allow tunnel contractors to safely support overstressed rock in deep tunnels.



Figure 6 – Concrete Invert Works for D&B Tunnel

USE OF SHIELDED TBMs

Given the typical complexity of the geology throughout many areas of the Andes it may be appropriate to consider the use of shielded TBMs in conjunction with pre-fabricated support components such as pre-cast concrete segments. This overall excavation and support approach has many benefits over a non-shielded TBM approach followed by final support where extensive sections of tunnels either need early high capacity support for stability or additional final support due to durability concerns. One-pass pre-fabricated supports are commonly used for “soft ground” or non-rock tunnels such as for metro tunnels in urban areas. Significant schedule and associated cost benefits can actually be realized by adopting a similar one-pass support approach if extensive sections are anticipated to require support.



Figure 7. Rock block sampling

A key concern with the application of shielded TBMs is their greater susceptibility to squeezing and greater limitations to install flexible types of support. TBM manufacturers are, however, now incorporating greater flexibility in the design of shielded TBMs to allow for forward probing and grouting through purpose built ports within the shield and also to allow for overcutting capabilities to handle a limited amount of squeezing. The use of shielded TBMs in the Andes requires a detailed evaluation of the risks of probable weak rock and faults under high cover.

GEOTECHNICAL INVESTIGATIONS

An appropriate level of geotechnical investigations should be completed prior to the consideration of the use of TBMs. The typical tasks to be undertaken should include the following:

- Geological mapping/evaluation.
- Identification of main faults/shear zones.
- Seismic surveys at portals.
- Long horizontal drillholes at tunnel portals or into side valleys.
- Short (Hilti-type) drillholes to obtain core samples for testing.
- Rock testing for strength, petrology and abrasivity from cores and blocks.
- Evaluation of the distribution of rock quality along the tunnel alignment.

One of the most important requirements for the assessment of TBMs is the undertaking of a comprehensive rock-testing program. Rock parameters in terms of uniaxial compressive strength (UCS), tensile strength (Brazilian), as well as petrology (percentage of hard minerals) and abrasivity (Cerchar index) represent the key parameters that need to be characterized for the application of TBMs. Additional rock testing includes punch penetration, as well Drilling Rate Index (DRI) and Cutter Life Index (CLI) that are only performed at the University of Trondheim in Norway. Extremely high rock strengths (> 250 MPa) will result in slow TBM penetration rates. Conversely, low rock strengths with high rock cover can result in extensive overstressing and the

potential for rockbursts. Petrographic thin section analyses serve to define the mineral constituents and percentage of overall hard minerals (> Moh 6.5) that can also have a dramatic impact on TBM penetration. Petrographic testing will also identify the presence of rock alteration that is usually associated with a significant loss of strength. Rock abrasivity in terms of the Cerchar abrasivity Index (CAI) has become a recognized parameter that can be correlated to TBM cutter consumption and is usually related to the amount of hard mineral content. Figure 7 shows a



Figure 8. Hilti-drilling into outcrop

typical large rock block sample that was collected at high elevation as part of a hydropower project in Chile that was drilled and tested for TBM rock parameters.

In the steep terrain mountainous areas of the Andes it may not be possible to complete geotechnical drilling investigations due to access. As an alternative it is appropriate to identify representative rock block samples that can be collected and transported to a laboratory where core samples can be drilled and tested under standard procedures. The southern areas of the Andes have been subjected to glaciation where surface rock blocks are not weathered and, therefore, can be considered to be representative of deep in situ rock conditions. Another alternative to traditional deep drilling is shallow drilling of holes using a Hilti-type drilling machine into rock outcrops to obtain core samples for laboratory testing as shown in Figure 8.

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Codelco – El Teniente New Mine Level Access Tunnels, Chile

Corporacion Nacional del Cobre (Codelco) is developing the New Mine Level Project at the El Teniente Mine, currently one of the largest underground mines in the world, to maintain the level of mine production at 137,000 tpd as the block caving continues lower to the required haulage level. The El Teniente Mine has been operating since 1904 when it started as the Braden Mining Company before taken over by Kennecott Corporation and then transformed to the government of Chile in 1971. The El Teniente Mine is located approximately 85 kilometres southeast of Santiago.

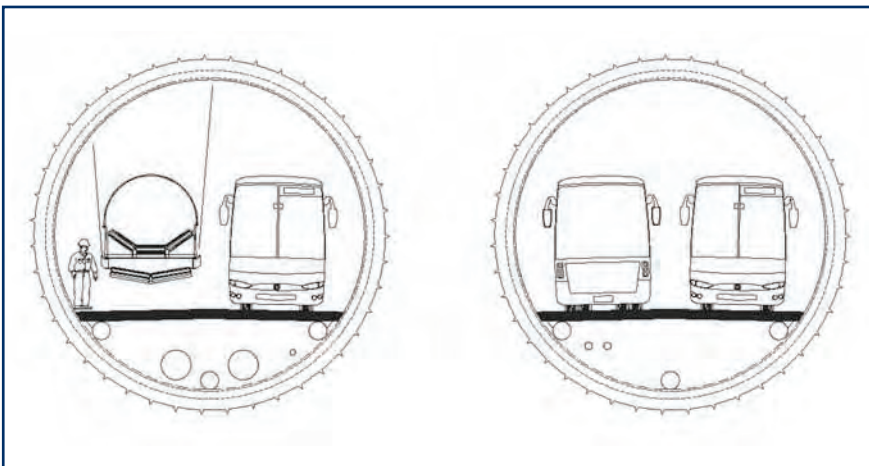
The New Mine Level project is being planned to increase the life of El Teniente by 60 years with block cave mining of a new 300-metre block below existing mine levels between elevation 1,800 metres to 2,100 metres. A significant component of the New Mine Level Project requires the construction of major access tunnels to provide access for personnel bus transportation, as well as house a large capacity (84-inch) conveyor for mine production from the new underground mining area.

It is currently planned to construct two (2) large size (approximately 10-metre) mine access tunnels over a length of about 9 kilometres and connected with cross



passages at regular intervals. The mine access tunnels are planned to be constructed starting at an open excavation portal site within the narrow Rio Coya Valley near the existing mine refinery at an elevation of about 1,500 metres. The proposed tunnels follow a northeasterly trend under increasing cover of about 1,000 metres below the Andes Mountains.

Hatch, in conjunction with tunnelling staff from Hatch Mott MacDonald, and Mott MacDonald, has been engaged as the Owner's Engineer to deliver the project under a design-build approach to a required fast-track project schedule in order to meet production startup of the new mine level. Pre-qualification of design-build teams was completed at the end of 2008, and bidding is currently underway by several international design-build teams. Contract award is currently planned in late 2009. Site works are expected to commence under an advanced contract with the construction of the starting portal in late 2009 with hand over to the tunnel contract in late 2010. The proposed large mine access tunnels may be constructed using large size TBMs to meet the overall project schedule. ●





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PROJECT DATA



S-297, S-298
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Driving power: 945kW
Tunnel length: 2,028m + 1,883m
Geology: loam, sand, silt, alluvium

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International Corporate Criminal Liability in the Workplace

By Norm Keith B.A., LL.B., CRSP, Graham Walsh B.A., LL.B., Gowlings LLP

This article is intended to assist members of the Tunnelling Association of Canada in understanding the trend towards criminal liability for health and safety in the workplace. The international regulatory community varies in its approach to prosecuting corporations and corporate actors. Some countries focus on individual liability while others focus on corporate liability. Some countries recognize no form of corporate criminal liability while others impose administrative penalties for criminal acts.¹

In recent years, there has been an increase in international pressure on many nations to implement laws and standards that incorporate various forms of corporate criminal liability. As corporate globalization

continues to afford companies headquartered in certain countries the ability to conduct business in other jurisdictions, the international community is beginning to recognize the importance of ensuring that corporations understand the laws and standards with which they must comply if they wish to avoid criminal liability.

Australia

For the most part, criminal law in Australia is governed at the state level and can vary significantly from jurisdiction to jurisdiction. However, recently Australia passed laws at the federal level providing for corporate liability in relation to inter-state offences. These newly introduced federal laws hold corporations liable for

criminal offences where “corporate culture” has encouraged or allowed the commission of offences.

Australia has not yet developed sentencing principles to adapt to these new offences² despite an Australian Law Reform Commission report³ suggesting that changes be made to the country’s corporate sentencing model to bring it in line with the British *Corporate Manslaughter and Corporate Homicide Act* which is outlined below.

The organizational liability provisions in the Australian *Criminal Code Act* are found at Part 2.5, Division 12 of this legislation in a section entitled “Corporate Criminal Responsibility.”⁴ This section provides that if an employee, agent or officer of the body corporate commits an offence within the scope of his or her employment, the physical elements of the offence are attributed to the body corporate. It also provides that intent, knowledge or recklessness becomes a fault element of an offence if the body corporate “expressly, tacitly or impliedly” authorized or permitted the commission of the offence.

To establish this element of a corporate offence, one of the following scenarios must be proven in order to establish the requisite authorization or permission: 1) The board of directors carried out or allowed the prohibited conduct; 2) Senior management engaged in or allowed the conduct; 3) The “corporate culture” of the body corporate “directed, encouraged or tolerated” the commission of the offence; or 4) The body corporate did not create and maintain a “corporate culture” that required compliance with the law.

For the purposes of the Australian *Criminal Code Act*, corporate culture means “an attitude, policy, rule, course of conduct or practice existing within the body corporate generally or in the part of the body corporate in which the relevant activities takes place.”

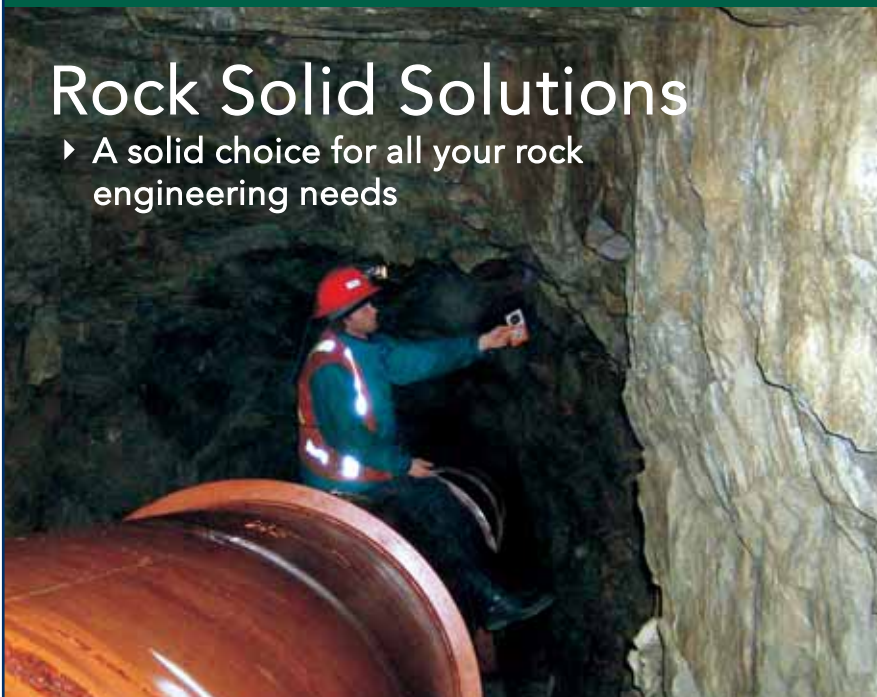
Where the fault element is negligence, meaning the corporation owed a duty of care to the public and failed to perform that

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duty, there are certain provisions that apply in situations where there is no individual that can be shown to possess requisite level of negligence. It is interesting to note that these criminal negligence provisions bear striking similarity to the majority of Canada's occupational health and safety laws which impose strict obligations on corporations to effectively implement, supervise, and communicate safety in the workplace.

New Zealand

Organizational liability for criminal acts in New Zealand is found in the *Crimes Act 1961*⁵ which applies to acts by a "person" which includes "any board, society, or company, and any other body of persons, whether incorporated or not."⁶ One notable exception is the offence of homicide, which is specifically defined as an offence that must be committed by a human being.

The leading case on this subject is *Meridian Global Fund Management Asia Ltd v Securities Commission [Meridian]*.⁷ In that case, the issue revolved around whether a corporation could be said to have had knowledge of the illegal acquisition of securities when employees, who had the authority to acquire such securities on the corporation's behalf knowingly committed the offence.

The court cited public policy reasons in its decision noting that if a corporation could not be said to possess the requisite criminal knowledge in the situation outlined above, then senior corporate managers and directing minds would be provided with substantial incentive to avoid monitoring the activities of corporate agents in order to protect the corporation from criminal liability. New Zealand, like Canada, has not yet followed the United Kingdom in the enactment of legislation creating corporate liability for manslaughter as outlined below.

United Kingdom

The United Kingdom recently passed the Corporate Manslaughter and *Corporate Homicide Act 2007* (UK) (Referred to as the *Corporate Manslaughter Act* in England and Wales and the *Corporate Homicide Act* in Scotland) [CMCHA]. Prior to the introduction of CMCHA, corporations could only be held liable if a "directing mind" of the organization had been found guilty of an offence, which would then be imputed to the organization.⁸

Under the CMCHA, corporations will be guilty of an offence when the manner in which corporate activities are managed or organized amount to a gross breach of a relevant duty of care that causes death of a person. In order for the organization to be found guilty of such an offence, the activities of a senior manager must play a substantial role in the breach.⁹ In turn, a senior manager is defined as a person who plays a significant role in making decisions about the management and organization of the corporation, or who plays an actual role in those activities.¹⁰

The CMCHA provides that organizations owe the following duties of care: 1) Duty to all employees or other persons working for the organization; 2) Duty to the public as the occupier of a premises (workplace); 3) Duty in connection with the supply of goods and services; 4) Duty in constructing or maintaining buildings; 5) Duty for infrastructure or vehicles etc. or when using plant or vehicles etc.; and 6) Duty when carrying out other activities on a commercial basis.

A gross breach of the duty of care under the act arises if the conduct "falls far below what can reasonably be expected of the organization in the circumstances."¹¹ The CMCHA works in concert with the *Health and Safety Work Act 1974* and, like in Canada, parallel prosecution under both the regulatory and criminal regimes is possible.

United States

Currently the federal *Occupational Safety and Health Act*¹² ("OSHA") is the primary source of corporate criminal liability for crimes relating to health and safety in American workplaces.

The OSHA includes offences that are similar to "regulatory" or "public welfare" offences in Canada, known in the United States as misdemeanours, and more serious offences similar to those found in *Criminal Code of Canada*. Corporations may be prosecuted under the OSHA as "employers." Section 6 of the OSHA outlines the standards that must be followed by employers however; section 17 restricts the more serious prosecutions outlined above to those employers convicted of having

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“wilfully violated” an OSHA standard resulting in the death of a worker.¹³

As outlined above, corporations in the United States are held “vicariously liable” through the actions of the corporate directing minds and those employees who act to advance the corporate interests. So restricted has the use of the most serious penalties allowed under the OSHA that only eight prosecutions have resulted in the imposition of imprisonment.¹⁴

Individual American states also play a limited role in regulating corporations in the management of health and safety in the workplace. However, state laws relating to health and safety violations are very limited and such laws vary widely from state to state with some providing a variety of sanctions for corporations while others rely solely on regular criminal sanctions for individuals, such as criminal negligence laws, to regulate corporate entities through directing minds.

As outlined above, the United States, as of yet, has not enacted a comprehensive system of laws that are specifically designed to hold corporations and other organizations criminally liable for management decisions that result in criminal offences. However, as demonstrated through the OSHA, there are situations in which a corporation may be subject to serious penal sanctions.

Japan

Generally, criminal liability for corporations does not exist under Japanese law. The Japanese Penal Code contains no provision for corporate criminal liability.¹⁵ On the other hand, Japan does have in place a process of corporate liability that operates in parallel to the liability incurred by natural persons. Under this system, when a natural person commits a crime, the corporation will be liable for fine if that person is an agent of a corporation, or if that person is an employee and the corporation is negligent in supervising that employee.

Unlike circumstances in the United States or the United Kingdom, there is no consideration of whether the employee was acting as the mind of the corporation or for the benefit of the corporation.¹⁶

European civil law jurisdictions (EU)

Corporate criminal liability does not exist as a concept in some EU jurisdictions such as Bulgaria, Luxembourg, and Slovakia. In other jurisdictions such as Germany, Greece, Hungary and Sweden, corporations face regulatory sanctions for the criminal acts of their employees.

In Finland, corporate criminal liability came about in 1995. It is borne of acts by management or decision makers and the corporation may be subject to fines

whether the natural person carrying out the acts can be identified or not. A corporation can also attract liability if an agent, employee, manager or person taking informal instruction from a representative of the corporation acts in a manner that benefits the corporation. In a sense, the liability resembles a mixture of the identification theory favoured in commonwealth countries and the vicarious liability approach favoured in the United States.¹⁷ Prosecutors have discretion as to whether to bring charges against the corporation. It must be noted that legal persons have been subject to criminal liability very rarely.

Criminal corporate liability was introduced in Austria in 2005. It covers acts by employees and decision-makers however, contractors and agents are arguably not covered. The offending act must be for the benefit of the entity or in breach of the entity’s duties. It may require intent, i.e. *mens rea* on the part of the decision maker. Finally, liability may be incurred due to negligence stemming from the organizational culture of the corporation.¹⁸



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In Belgium, criminal liability for corporations was introduced in 1999. It covers acts for the benefit of the corporation or offenses on behalf of the corporation.¹⁹ In Denmark, corporate criminal liability was introduced into law in 1996. It covers acts by anyone connected with the legal person acting negligently or with intent, within the legal person. In Iceland, corporate criminal liability may attach to the acts of any natural person acting on the corporation's behalf, even if the natural person cannot be identified.²⁰

Summary and conclusion

In summary, the international legal community is moving towards more regulation and criminalization of workplace health and safety. Employers in the tunnelling industry who do work outside of Canada need to have awareness of the trends. They also need to have an effective health and safety policy and program to manage workplace risk. The key elements of an effective health and safety management system will be the subject of our next article. ●

¹ Allens Arthur Robinson for the United Nations Special Representative of the Secretary General on Human Rights and Business. 'Corporate Culture' as a Basis for the Criminal Liability of Corporations. February 2008 at 4.

² *ibid* at 10. 3 Australian Law Reform Commission, Report 103 (2006), by Professor David Weisbrot, Brian Opeskin, Les McCrimmon "Same Crime, Same Time: Sentencing of Federal Offenders," online: Australian Law Reform Commission <<http://www.austlii.edu.au/au/other/alrc/publications/reports/103/>>

⁴ *Criminal Code Act 1995* (Cth) s.12.3 – s.12.6.

⁵ *Crimes Act 1961*, 1961 (N. Z.), No. 43, s. 2 (1).

⁶ *Ibid.* at s. 2 (1).

⁷ [1995] 2 AC 500 PC. [*Meridian*]

⁸ *Corporate Manslaughter and Corporate Homicide Act 2007* Explanatory notes. Found on the website of the government of the UK.

⁹ *Corporate Manslaughter and Homicide Act 2007* Chapter 19 s.1 (1), (2), (3).

¹⁰ *ibid* at s.1(4)(c) (i)(ii)

¹¹ *ibid* at s.1(4)(b), i.e. a breach of duty of care by an organization is a "gross" breach if the conduct alleged to the amount to a breach of that duty falls far below what can reasonably be expected of the organization in the circumstances.

¹² *Occupational Safety and Health Act*, 29 U.S.C. §§ 651 – 678.

¹³ *Ibid.* at s. 17(e).

¹⁴ www.pbs.org. *frontline* a dangerous business: osha: criminal prosecutions of workplace fatalities.

¹⁵ Keiho [Penal Code], Act No. 45 of 1907, Art. XXXX, No XXX-XXX.

¹⁶ *Supra* note 1 at 44.

¹⁷ *Supra* note 1 at 39

¹⁸ *Supra* note 1 at 47.

¹⁹ *Supra* note 1 at 48.

²⁰ *Supra* note 1 at 53, 54.

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Tunnelling Under the Great Lakes – Historic Perspective

By Boro Lukajic and Bill Cushing, formerly, Ontario Hydro, Toronto

In the late 1970s and early 1980s, Ontario Hydro constructed several major tunnelling projects under Lake Ontario and Lake Huron. Large diameter tunnels were driven through a variety of rock conditions, ranging from open-wet to completely dry (highly stressed ground). This combined with the design and operational requirements, had a major influence on construction approach, which ranged from continuous grouting to control water seepage, to a special excavation and lining sequence to accommodate time-dependent deformations. This historic perspective reflects on the construction aspects of cooling water tunnels located at Bruce B and Darlington A nuclear generating stations. Concrete lined intake tunnels up to 193 m³/sec flow capacity, averaging 9 metres in diameter, were constructed at each site to form a part of the stations' cooling water system.

Tunnel components

A longitudinal section common to both Darlington and Bruce intake tunnels is illustrated in Figure 1. The outlet transition is, approximately, a 25-metre long section between the tunnel and the forebay. The outlet ramp slopes down at a grade of 14 per cent from the outlet transition to the horizontal tunnel. A near horizontal tunnel having a grade of 0.25 per cent slopes up from the outlet ramp to the intake shaft. The tunnel has vertical sidewalls and an arched roof. A circular vertical shaft having a diameter of approx 9.5 metres was excavated first, leaving in place a rock plug 14 metres thick at the top of the shaft. After tunnel flooding, the upper portion of the plug was blasted and removed by marine operation, while the lower 4-metre-thick plug was blasted and allowed to slump into the sump at the base of the shaft.

Design criteria

The primary design consideration for the cooling water tunnels at both stations was that the tunnels should be aligned to

minimize their length, while also satisfying hydraulic and geotechnical requirements. The selection of the length and horizon of the tunnels was based on the criteria that:

- The intake shaft be located at a sufficient depth (minimum 15 metres) to ensure an adequate and consistent supply of cool water and prevent ice clogging of the intake structure.
- An adequate distance between the intake and the discharge structure be maintained so that recirculation of heated water is avoided.
- The tunnels be placed within a massive rock unit requiring only minimal rock support and normal construction methods.

Tunnel support and lining

In designing the rock support the main consideration was given to the tunnel span and its orientation relative to rock structure. Temporary support, consisting of a pattern of ungrouted bolts 2.5 metres long at 1.5-metre spacing and wire mesh was required during the construction period in normal tunnel sections. The enlarged portions, such as the intake transitions and elbows, required permanent rock support consisting of grouted rock bolts and shotcrete.

The final concrete lining was installed to reduce hydraulic head losses and to maintain the integrity of the rock structure during operation, thereby limiting the risk of raveling.

Bruce Tunnel

The Bruce Nuclear Power Development is located on the east shore of Lake Huron, 300 kilometres northwest of the city of Toronto, Ont., at that time one of the largest energy complexes in the world. An 8.7-metre diameter, 900-metre long tunnel was excavated beneath the lake. The main portion of the tunnel was positioned within the bedded limestone of the Detroit River Formation. A 12-metre-thick rock cover above the tunnel consisted

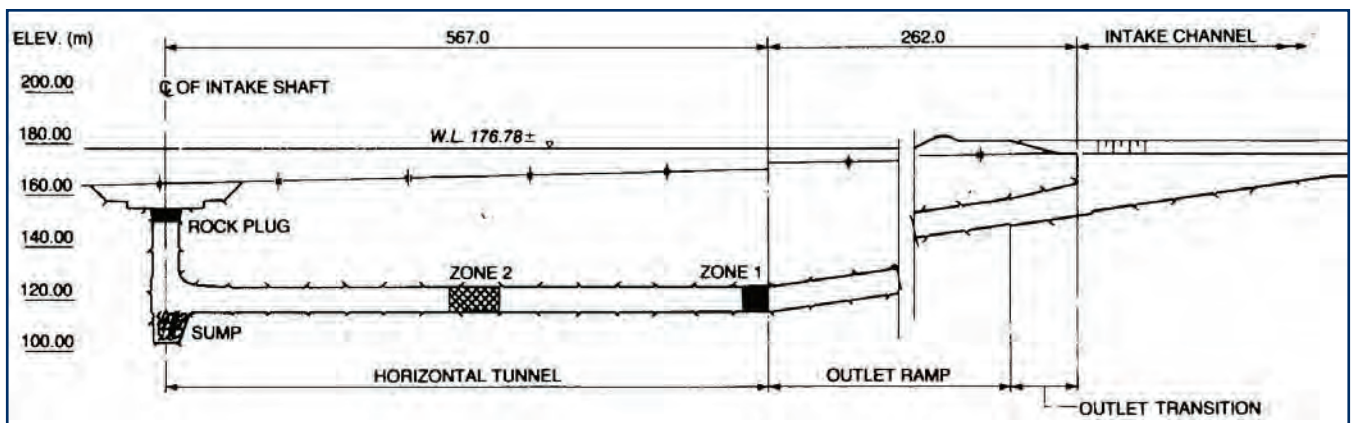


Figure 1. Tunnel profile



Figure 2. High-pressure water inflows in tunnel

of a series of dolomite beds of variable thickness and quality. The results of water pressure testing indicated that open wet rock conditions would be encountered at various depths to well below the tunnel grade requiring probe drilling and grouting. It was estimated that one-third of the excavation time would be spent on water control. An 11-m³/min inflow was estimated for bidding purposes. The tunnel was excavated by full-face blasting rounds combined with grouting. Normally, the excavation cycle consisted of grouting a minimum of 30 metres beyond the tunnel face, to

control seepage followed by excavating for 24 metres. A total of 49 grout cycles were required to grout the entire tunnel length. Each grouting cycle consisted of 15 to 46 grout holes, depending on local conditions. This operation resulted in a total of 40,000 metres of probe and grout hole drilling and injection of 5,300 m³ of cement grout. Water seepage was minimized by grouting, while excess water was pumped from the tunnel via a weir box to the ground surface. Progressive estimates of the potential water seepage indicated a cumulative total of 112 m³/min for the full tunnel length. Pressure grouting reduced this seepage by about 93 per cent, to 8 l/min per metre of tunnel.

Unusual ground conditions developed when tunnelling encountered an open, high pressure, water bearing feature at the bottom of the decline ramp. Attempts to grout this zone proved unsuccessful. After a review and evaluation of the exploratory findings, grouting attempts, and assessment of the hydraulic requirements, it was decided that it would be more economical and safer to divert the tunnel around this zone rather than mine through this feature. Supplementary work associated with the diversion consisted of additional probe drilling, grouting, staged excavation and rock support.

Second, unusual condition occurred in the mid-portion of the tunnel when an inflow of 17 m³/min developed. The inflow caused the erosion of 30 m³ of brecciated material into the tunnel. Remedial measures to control the flow consisted of constructing a 4.5-metre thick concrete bulkhead, placed directly against the



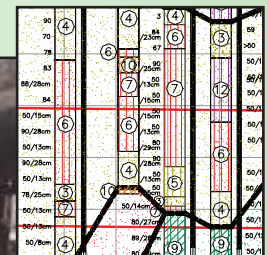
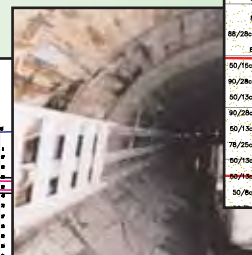
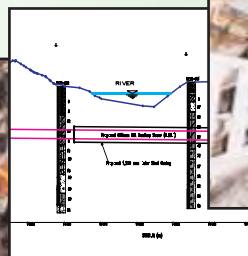
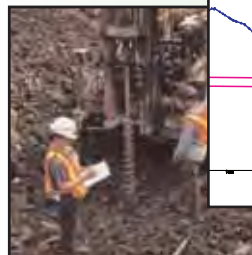
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Figure 3. View of tunnel at Darlington

tunnel face. A grout cut-off wall extending a full 360 degrees around the tunnel and a grout cone was made to consolidate the surrounding rock. Final grouting of the major flow was done through a 300-millimetre pipe installed through the concrete, directly into the flow zone. A total of 240 m³ of grout was required to seal this open zone.

Darlington Tunnels

The Darlington nuclear station is located on the north shore of Lake Ontario, approximately 60 kilometres east of Toronto. A cooling water flow is conveyed into the station via a 1,000-metre long intake tunnel and discharged into the lake through a tunnel and series of vertical diffusers extending approximately 1,800 metres offshore. Both tunnels were excavated through the massive, thickly bedded Lindsay Limestone. The tunnels were excavated employing the full-face blasting method. In contrast to Bruce Tunnel, as a result of high horizontal stress causing rock joints to remain tightly closed, an observation in both tunnels was the lack of water inflow. Because of these conditions expected tunnelling rates were achieved throughout construction in both tunnels. Because of high stress environment, a comprehensive rock mechanics program was carried out in both tunnels to determine the time delay required between excavation and installation of concrete lining. A waiting period of 90 days was built into the construction schedule to allow for time-dependent deformation as a result of stress relief (Ref. 1, K.Y. Lo and B. Lukajic 1984). The free swell tests on rock cores indicated a variable swelling potential in the horizontal direction, depending on the amount of shaly interbeds. This phenomenon was, therefore, considered to be significant in the design with respect to the safe performance of the tunnel lining.

Summary

1. An important consideration at the Bruce site was the control of water seepage into the excavations. The pre-construction estimate of seepage and mining time proved to be valid. Most



Figure 4. Forebay walls excavated by use of presplit blasting at Darlington

importantly, the cement grouting programs were successful in reducing the seepage into the excavations by over 90 per cent.

2. In contrast to Bruce site, completely dry tunnelling conditions were encountered at Darlington site as a result of in situ stress condition. The specified 90-day waiting period appeared to be sufficient, initially. However, a rock mechanics monitoring conducted during construction confirmed that this period could be safely reduced to 70 days.

Acknowledgements

1. Bruce B tunnel was constructed between May 1978 and November 1979, by S. McNally & Sons Ltd., Hamilton, Ont., with his subcontractor Redpath Construction from North Bay, Ont.
2. Darlington tunnels were constructed between 1982 and 1986, by Spino Construction from Montreal, Que.

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- Lo, K.Y. and Lukajic, B. 1984. Predicted and Measured Stresses and Displacements around the Darlington Intake Tunnel. *Canadian Geotechnical Journal*, Vol. 21. Number 1, pages 147-165.
- Boro Lukajic and Bill Cushing, Ontario Hydro Recent Tunnelling Experience, *Tunnels and Water*, Proceedings of the International Congress on Tunnels and Water, Madrid, June 1988.
- Boro Lukajic and Dan Dupak, Design and Construction of Darlington Cooling Water Discharge Tunnel, *International Congress on Large Underground Openings*, Florence, Italy, 1986. ●

McNally System Effective at Olmos

By Mike McNally, McNally Engineering Corp

TBM excavation at the Olmos Water Diversion Project in Peru has been under way by Odebrecht of Brazil using an open main beam Robbins 5.3-metre diameter high powered TBM since February 2007 for the 13.8-kilometre drive. The TBM was assembled and launched from an underground chamber excavate at the end of a tunnel that was constructed previously during an earlier stage of the project. Geology along the drive comprises a mix of volcanic, granitic and argillite rocks under a maximum cover of 2,000 metres.

An initial TBM progress of about 15 m/day was achieved during the early stages of tunnel construction. However, when rock cover approached 1,500 metres, significant overstressing with slabbing and spalling occurred, which resulted in TBM progress dramatically reduced to about 8 m/day.

In April 2008, the McNally System™ was

introduced to TBM excavation operations resulting in TBM progress increasing significantly to about 20 m/day. The McNally System™ allows for the early installation tunnel support concurrent with TBM excavation to address overstressing ground and thoroughly contain slabbing and blocks from falling onto the TBM. The McNally System™ comprises a series of tubes arranged in an arc similar to the shape of the tunnel. Slats of wood or steel are fed into these tubes and extruded longitudinally along the tunnel. A detailed explanation of the system can be accessed via US Patent 64668000 available online.

Timber/wood can be used as part of the shielded support system for tunnels that will be concrete lined after excavation. However, for unlined tunnels, such as for water conveyance, the system should ideally be comprised of steel components that will not be subject to early corrosion.

The McNally System™ is trademarked and patented property of C&M McNally Engineering Corporation. The system is available for use by tunnelling contractors through approval from Mike McNally (mmcnally@mcnally.ca) The McNally System™ has now become internationally recognized as an effective TBM tunnel support system. ●



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Aurora, Ontario, Canada

An Innovative Water Cut-off Solution for a Hard Rock Tunnel

By Vreneli Wall, Marketing Co-ordinator, Multiurethanes Ltd.

Hard rock tunnels present a unique set of challenges, especially when constructed through water-bearing fractured ground conditions. A large tunnelling contractor found itself in a difficult situation with a large flowing water leak in a new rock tunnel 20 metres underground. The tunnelling crew was experienced in managing small water leaks through the use of conventional cement grouting and chemical grouting methods. This particular situation, however, was more complex and required assistance from the experienced grouting specialists at Multiurethanes.

During tunnel construction, localized areas of bad ground conditions were encountered, characterized by heavily fractured rock. Conventional cement grouting was used by the tunnelling contractor to control water inflows in some of these areas. Typical solutions to water infiltration involves multiple hole grouting where several holes are drilled

to intersect the water-bearing fracture and the leaks are cut off by cement grout injection.

An evaluation of the particular site conditions by the Multiurethanes' crew determined that debris and broken ground made it impossible to accurately identify the primary water-bearing fracture, as experienced by the tunnelling crew, when initial injections were washed out by the large water inflow. An innovative solution involving chemical grouting through single grout hole injection while isolating and identifying nearby localized leaks, was successfully implemented.

The specialized nature of the water cut-off grouting work required a combination

of materials, equipment and experience, including Multiurethanes Universal Resin, a pneumatic chemical pump and skilled grouting techniques performed by experienced Multiurethanes technicians. One member of the grouting crew focused on mixing and pumping the material while the other members identified and sealed nearby localized leaks as the grouting process was underway. This tedious process was systematically undertaken until the water inflow gradually stopped and the tunnel became dry.

The secret to this successful water cut-off project was the application of appropriate grouting techniques, equipment and materials for the existing site conditions. After conventional cement



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Grout plugs are installed to allow high pressure injection of Multiurethanes Universal Resin.



Flowing water makes tunnelling work very difficult. Multiurethanes has the experience and technical support to resolve challenging water cut-off situations.

grouting injections had washed out, it became clear that an experienced grouting approach, including patience instead of brute force, would win this battle. It's how you do the job – not how

much pressure you use – that leads to a successful conclusion!

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Edmonton SLRT.2 Water Inflows Solved by Grouting Specialists from Multiurethanes

By Vreneli Wall, Marketing Co-ordinator, Multiurethanes Ltd.

An extension of the South Light Rail Transit (SLRT) system for the City of Edmonton was completed by a tunnelling contractor in 2004. The twin tunnel extension brought the SLRT from 6 metres below grade up to street level to extend the SLRT system to the south side of the city.

Design challenges associated with SLRT twin tunnel extension included strict settlement control due to sensitive structures (including University of Alberta and adjacent hospital structures) and tight radius curves due to alignment requirements. The ground conditions were soft, silty sands with a high water table that increased drastically during spring thaw. Precast gasketed tunnel segments were installed to provide final twin tunnel diameters of 10 metres each.

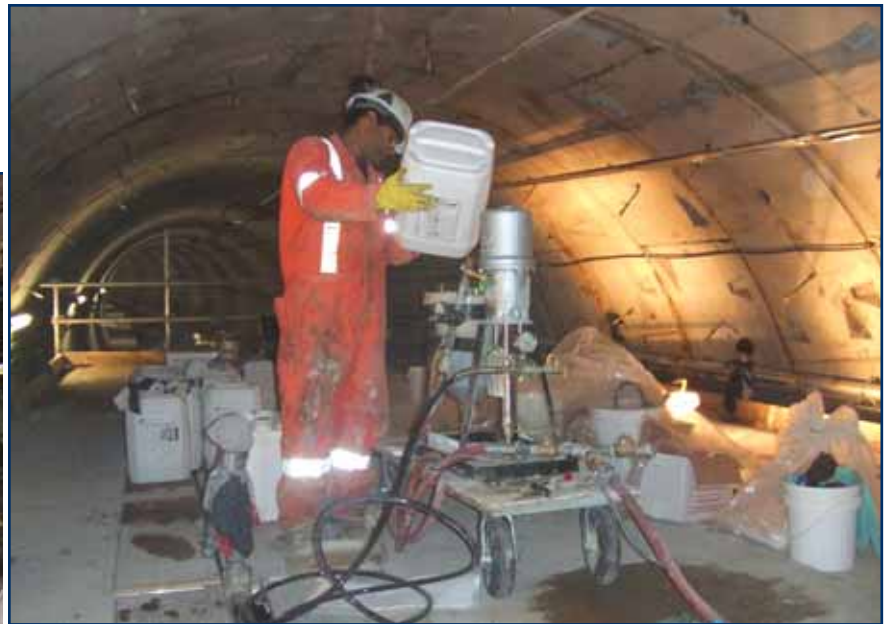
From completion of tunnel construction to 2007, various water leaks occurred between the precast segments, from grout

ports, as well as at the interface of the twin tunnels and the underground SLRT station bulkhead. Local contractors performed regular maintenance procedures on behalf of the tunnelling contractor with limited success. Injection of polyurethane resin was used at various locations throughout the entire length of the tunnel. This method succeeded for most of the twin tunnels except for the final 15 metres where the tunnels interfaced with the underground station. This section experienced higher water inflows compared to any other location in the tunnel, compounded by a high water table level at this location.

The tunnel contractor retained Multiurethanes, a full-service engineering

firm specializing in difficult and challenging water inflow and soil stabilization projects, to deliver a final resolution to these troublesome water inflow problems. Multiurethanes mobilized two grouting crews (with four technicians per crew) to troubleshoot the situation during two weekend SLRT system shutdowns (one tunnel per weekend) from Friday night to Sunday night.

Two chemical grouting methods were used to stop the water inflows; precise injections into the most problematic areas (i.e., tunnel/station interface and grout ports) and wide spread injection to deal with the leaking joints of the precast segments. The second method (overcoming water inflows at the tunnel



A pneumatic chemical pump is used to mix and deliver grouting material.

Multiurethanes universal resin is injected into grout ports through the precast tunnel segments as well as the bulk head at the tunnel-station interface (as shown in the background).



Technical grouting requires experience. Multiurethanes technicians can provide training for your team on grouting fundamentals.



Multiurethanes Universal Resin is used to stabilize soil and cut off water flowing from leaking joints of precast tunnel segments.

segment joints) involved an advanced grouting application for sand stabilization and water cut-off using Multiurethanes Universal Resin. Both methods were successful due to the knowledge of chemical grout application techniques and the use of appropriate grouting equipment

for the site conditions. Experienced project planning and technical expertise of the Multiurethanes' crew, successfully completed the project on behalf of the tunnelling contractor within the time constraints set by the SLRT system. High-volume, high-pressure water

inflows are routinely resolved by Multiurethanes' grouting crews. For innovative solutions, material selection advice and technical support, call us anytime at 1-800-663-6633 or in an emergency call 416-254-5212. We're here to help! ●

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Wastewater Treatment Plant Outfall Tunnels Under Lake Ontario

The Clarkson Wastewater Treatment Plant is currently undergoing an expansion to keep up with growth in the Region of Peel, west of Toronto, in Ontario. As part of the expansion, a new outfall was designed by R.V. Anderson Associates Limited to convey treated effluent to Lake Ontario, and is required to address the increase to the plant's overall effluent capacity.

The original outfall concept envisioned a marine pipeline laid in a trench blasted into the lakebed. Ultimately, an alternative tunnelling approach was chosen for its significant benefits, which included reducing the length of the construction schedule, expediting approvals requirements with respect to fisheries issues, reducing costs, and the elimination of environmental disturbances due to trench blasting.

The new outfall tunnel currently under construction has a finished diameter of 3 metres (the bore diameter is 3.6 metres) with an overall length of 2,190 metres –

1,900 metres of which is under the lake. A vertical shaft, located at the southern end of the plant, conveys flows from the plant into the outfall tunnel. It is 12 metres in diameter and 47 metres deep. The outfall shaft and tunnel are also used to achieve disinfection contact times.

The tunnel and effluent diffuser design anticipated the timing and technical issues related to the connections between the lakebed and the tunnel. The marine construction was scheduled so it could be completed prior to the arrival of the tunnel bore at the interconnection points.

A diver access shaft, providing access to the tunnel, is located approximately 1.4 kilometres out into the lake. It is 1,050 mm in diameter and 20 metres deep. This access shaft was the first element of marine construction to be completed and is located directly above the bisulphite injection point in the tunnel.

At the end of the outfall there are 18- to



450-millimetre-diameter diffuser shafts spaced at 12-metre centres along the tunnel that connect to the lakebed. The diffuser nozzles are located at a depth of 19 metres and are designed to accelerate the flow of the effluent to promote its dispersion into the lake. The diffusers were constructed by drilling 750-millimetre diameter holes 12 metres into the lakebed bedrock. Stainless steel casings were placed into the drilled holes and the annular space was grouted.

During the design phase it was apparent that placement of concrete for the tunnel lining was a critical element of the project because most of the tunnel was too distant from the shaft to pump concrete. The contractor, C&M McNally Engineering Corp., developed a unique concrete delivery system that consisted of belly dump hopper cars, a moveable ramp system and a portable concrete remixing and pumping facility.

Retarded concrete is delivered down the shaft into the waiting train and transported out to the lining operation where the cars ascend a mobile ramp and empty the concrete into the underlying remixing/pumping facility. Super plasticizing chemicals are added and the concrete is remixing and pumped into the telescopic steel forms.

This tunnelling project has benefited from the willingness of the client, contractors and engineering team, to work together to generate and implement innovative solutions to the project's technical requirements. ●

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\$500 million capital sewage project for planned tendering in 2009



The York Durham Sewage System (YDSS) is a state-of-the-art wastewater collection system within the Great Lakes basin. Initial phases of the YDSS were constructed by the Province of Ontario in the late 1970s and early 1980s in response to a 1965 decision that no additional sewage treatment plants could be built on the Humber, Don and Rouge Rivers.

The YDSS complements the Canada-Ontario Agreement respecting the Great Lakes Basin ecosystem. What evolved was one of, if not the most environmentally respectful sewage systems in the entire Great Lakes Basin. York Region is justifiably proud of its reputation as a leader of providing quality infrastructure to our growing communities and protecting our environment.

Southeast Collector Trunk Sewer (\$500 million infrastructure project) *Scheduled Completion – December 2012*

The proposed Southeast Collector (SeC) Trunk Sewer is an integral component of the overall YDSS trunk sewer system. It moves wastewater from communities throughout York Region, as well as the communities of Pickering and Ajax in Durham Region to the Duffin Creek Water Pollution Control Plant (WPCP) in Pickering, Ontario. The portion of the SeC within Durham Region is co-owned by the Regions of York and Durham, who are co-proponents on this project. The SeC Trunk Sewer is a critical component of servicing approved future growth in York Region, up to 1.5 million and beyond, and must be completed on time in December 2012.

Key aspects of this critical project include York Region's early procurement of four earth pressure balance tunnel boring machines and project materials including the supply of segmental liners.



Project Details

- 15 kilometres of 3 m (inside) diameter sewer
- Depth of sewer ranges between 10 and 40 metres
- Geotechnical - Newmarket Till
- 15 shafts including maintenance and working shafts
- Odour control and metering facility
- Corrosion control facility
- Two baffle drop shafts - up to 30m
- SCADA controlled flow control gates

Project Timelines

- Fall 2008 - Individual Environmental Assessment (IEA) filing with Ministry of the Environment
- Throughout 2009 – Procurement of equipment and liner materials
- Mid-2009 – Expected approval of IEA
- Spring 2009 – Prequalification of contractors
- Winter 2009 – Detailed design approvals
- Winter 2009 – Two construction packages to run concurrently
- 2010 – 2012 – Construction period for Southeast Collector Trunk Sewer

For further information on this project, please contact
Wayne Green, Senior Project Manager
905 830-4444 ext. 5049 | wayne.green@york.ca

Visit our website www.york.ca for more details.

In Memorium



**Sir Alan Muir Wood
(1921-2009)**

At 87, Sir Alan had enjoyed a long and distinguished career as one of the world's leading professional engineers and, subsequently, as a leading statesman of our industry.

Right up to the last, his passion for his chosen expertise and

speciality was at the fore. In December 2008, he was on the podium giving a presentation to the British Tunnelling Society – a society within the UK's Institution of Civil Engineers (ICE) of which he was the 113th president (1977-78) – and a society he not only promoted, but was the second chairman (1973-74) after the founding chairman, Sir Harold Harding, the 99th president (1963-64) of the ICE.

Sir Alan is most well known to the international community as an initiator, as well as the first President and the Honorary Live President, thereafter, of the International Tunnelling Association (ITA), a group of 54 member nations that meets annually at its general assembly. The ITA is also a recognized NGO (non-governmental organization) of the United Nations.

From its beginnings in 1974, Sir Alan remained ardently committed to the operation, growth, and work of the Association, giving his last presentation to the gathered delegation at the World Congress in 2002 in Sydney, Australia.

It was at the BTS in December that Sir Alan told TunnelTalk that he was not well, suffering with sclerosis of the lung, which had manifested itself only recently and could be traced back to his days as a young man in the Royal Navy when asbestos was used prolifically as an insulating material. He admitted that it had been a great effort to make it to the meeting, but that "it was very important to be here. This is a very important topic. I feel it is the crux of all successful tunnelling projects and the root of all those that experience failures. We must get it right."

Sir Alan was known internationally as a senior engineer with the Halcrow Group in the UK head offices, retiring as senior partner in 1984, and remaining a consultant to the firm into his retirement. Sir Alan is the author of many books on engineering and tunnelling and lecturer to many international schools and universities of engineering.

His opinions on practical tunnel design and construction were often contrary to a wider school of thought and in recent years he devoted his attention to the interconnection between the designer and the contractor.



**Tor Brekke
(1934-2009)**

Tor L. Brekke, renowned tunnelling expert and U.C. Berkeley professor emeritus, passed away on March 6, 2009, at his home in Berkeley, Calif.

Born March 3, 1934, this Norwegian immigrant exemplified the American dream. A Bohemian

Club member, he enjoyed life to the fullest and showered those around him with love and respect.

As a professional engineer, Dr. Brekke influenced projects in many countries of the world and most major tunnelling projects in the United States, impacting on hydropower plants,

dams, highways, railroads, and mining projects. As an educator, he considered his greatest achievement to be the accomplishments of his students.

A past chairman of the U.S. National Committee of Tunnelling Technology, Tor was a member of the Norwegian Academy of Sciences and the Royal Swedish Academy of Sciences. He authored or co-authored more than 85 publications and in 2008, was recipient of the Outstanding Educator of the Year Award presented by the U.S. Underground Construction Association.

His professional success was only surpassed by his kindness as a husband, father and grandfather. He is survived by his wife Joyce, sons Tor and Gunnar, daughter-in-law Carolina, and grandchildren Naomi and Monica, all of whom adored him.



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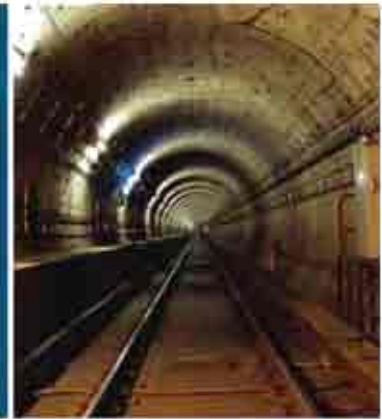


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