RETC 2017 Technical Sessions

The RETC conference in San Diego will present 19 technical sessions with each session hosting the presentation of six papers. The primary focus of the technical program is to add value to the industry through examination of the most innovative practices and products currently in use. The program committee is intent on shining a light on new, novel and unusual innovations and projects. The emphasis is on real-life application of techniques as applied to real problems.

View a complete list of papers in each technical sessions below.

Monday, June 5, 2017 | 8:30 am
Pressure Face TBM I
Chairs: J. Brandt, Traylor Bros, Inc., Redondo Beach, CA
C. Painter, Parsons Brinckerhoff, Sacramento, CA

Accomplishing Extraordinary Tasks as a Machine Supplier for Metro Doha
K. Bäppler and D. Schrader, Herrenknecht AG, Germany

With the construction of the Metro Doha in the State of Qatar a vision is accomplished to establish a modern, safe, efficient and integrated public transportation network. Upon final completion of multiple phases, the network will comprise four metro lines with a length of 216km and 100 stations. Phase 1 comprises 112km of underground tunnels (56km twin tube tunnels) and a total of 21 Earth Pressure Balance Tunnel Boring (EPB) machines were deployed by the four different Joint Ventures. The project was initiated, managed and supervised by the owner Transport Authority Qatar Rail. Phase 2 of the Doha Metro will start upon the completion of Phase 1 in 2019 (Qatar Vision 2030). The owner placed full faith in the manufacturer's abilities to deliver equipment of high quality, state of the art standard within the given time frame. This paper focuses on the manufacturer's scope of delivery and on the supplier's high standards of quality in production, logistics and services. The report is completed by a chapter with remarks on the manufacturer's analysis of TBM availability on the individual tunnelling sections that completed tunnelling works.

Innovations and efficiency in urban tunneling - A case study of the Eglinton Crosstown LRT in Toronto, ON
D. Ifrim and A. Solecki, Hatch Mississauga, Ontario; I. Hassan, Metrolinx, Toronto, Ontario, Canada; P. Cott, Smith & Long, Toronto, Ontario, Canada

The Eglinton Crosstown LRT project with 10km of twin tunnels 6.5m DIA in EPB conditions is the largest infrastructure project initiated in Canadian history and is a perfect example of challenging working conditions in urban tunnelling. Working space constraints, hauling of muck, water discharge, noise and vibration limits along with "just in time" delivery of segmental lining and other materials posed a real challenge to the tunnel construction logistics. This paper discusses the project challenges and the design and contractor's innovative solutions with focus on tunnel logistics, project specific conditions restrictions and, the impact on TBM productivity and efficiency.

Wear of Cutting Tools on an EPB Tunneling Through Glacial Soils
L. Mori, E. Alavi, B. Hagan and M. DiPonio, Jay Dee Contractors, Inc., Livonia, MI

Prediction of tool life and wear for soft ground pressurized TBMs is a challenging task for contractors, machine manufactures, and designers. The issue of cutterhead inspection and maintenance in Earth Pressure Balance (EPB) tunneling can be a dangerous, time consuming, and costly process, particularly when the ground is unstable. In this case, cutterhead inspection and tool maintenance are performed under pressurized conditions or ''hyperbaric interventions''. Severe primary and secondary wear on the cutters has been seen in some of the projects in glacial soils including Seattle area. This paper discusses the experience gained regarding cutting tool wear from an EPB TBM that mined through 8.85km of glacial soils in Seattle, WA over the course of two separate tunneling projects.

Impact of conditioned soil parameters on tool wear in soft ground tunneling
M. Hedayatzadeh, Politecnico di Torino university, Italy; J. Rostami, The Pennsylvania State University, Pittsburgh, PA; D. Peila, Politecnico di Torino university, Italy

The use of mechanized shielded tunnel boring machines (TBMs), has grown rapidly in various soft ground tunneling projects. In the recent years, Earth Pressure Balance (EPB) shields have been successfully used in many tunneling projects in urban areas while the range of soil types that it can handle has expanded. One of the critical issues for successful EPB tunneling is the use of proper soil conditioning. The effects of soil abrasiveness on primary and secondary wear of tools and machine components is one of the most important aspects of soft ground tunneling, estimation and assessment of, costs, and schedule of a project. Among the parameters that can affect tool wear, soil conditioning is the most critical one that can be controlled by the operators. To assess the impact of the soil conditioning on tool wear, a new test apparatus with new propeller has been developed. Specific test procedure has been developed and many tests have been conducted. Review of the initial test results shows that soil conditioning reduces wear of tool and other machine parts. More tests are underway to evaluate the effect of soil conditioning on machine torque requirements through a parametric study.

Removal of Interfering Tiebacks in Advance in the Regional Connector Project
C. Brodbaek and D. Penrice, Mott MacDonald, Pleasanton, CA; E. Kusdogan and C. Bragard, Regional Connector Constructors (Skanska-Traylor JV), Los Angeles, CA

The Regional Connector Transit Corridor (RCTC) comprises a 1.9-mile underground light-rail project woven through downtown Los Angeles (LA). This $1-billion design-build project's reference design indicated the need for a large and intrusive open excavation, approximately 100-feet long and 30-feet wide, to remove existing tiebacks within the public right-of-way and in conflict with the RCTC bored tunnels. To minimize surface impacts, the design-build team, Regional Connector Constructor (RCC), proposed an alternative tieback removal concept comprising a vertical shaft and mined adit. This paper describes the use of Building Information Modeling as a powerful design tool to optimize the location, size and alignment of the concept and demonstrates its feasibility to the Project Owner, LA Metro, and describes the shaft and adit construction in a dense urban setting and the tieback removal process.

Port Mann Water Supply Tunnel: Lessons for the Future
G. Davidson, McMillen Jacobs Associates, Seattle, WA; F. Huber and M. Gant, Metro Vancouver, Burnaby, BC, Canada

After more than a decade of planning, design, and construction, the Port Mann Water Supply Tunnel was successfully brought into service in early 2017. The tunnel increases Metro Vancouver's (MV) capacity to meet water demand while increasing system reliability, and represents the first of several tunnel projects planned to improve seismic capacity of the system following a Maximum Credible Earthquake event. The contracting and management issues associated with delivering the project have been as complex and time consuming as some of the design and construction challenges. As well as explaining how the design and construction challenges were successfully addressed, the paper presents how Metro Vancouver approached contractor procurement through prequalification and negotiated proposal phases, presents the risk management approach and project team structure, and describes how the lessons learned on the project can be applied to future tunnel projects in the region.

Instrumentation / Monitoring
Chairs: G. Rogoff, McMillen Jacobs Associates, Pasadena, CA
M. Wone, DC Water and Sewer Authority, Alexandria, VA

Material Flow Reconciliation Risk Management for Pressurized Face Tunneling
U. Gwildis, CDM Smith, Bellevue, Washington; J. Newby, CDM Smith, Burnaby, British Columbia, Canada

Overexcavation during pressurized face tunneling is a risk factor with respect to unplanned surface deformation and damage to existing installations above the tunnel. Risk management typically includes surface and subsurface deformation monitoring of critical areas identified during planning and design. However, continuously reconciling material flows during the mining process is a risk management tool that allows recognizing and correcting causal trends before effects are observed. This paper describes the reconciliation methods for different TBM types, provides project examples from Seattle area tunnels, and discusses risk management implementation approaches involving the owner, designer, contractor, and third party asset holders.

Managing Ground Control with Earth Pressure Balance Tunneling on the Alaskan Way Viaduct Replacement Project
E. Cording, University of Illinois at Urbana-Champaign, Champaign, IL; J. Nakagawa, J. McCain, and A. Stirbys, Tutor Perini Civil West, Seattle, WA; D. Sowers Washington State Department of

Transportation, Seattle, WA; J. Vazquez, Dragados USA, Seattle, WA; C. Painter, WSP/Parsons Brinckerhoff, Seattle, WA

Washington State Route 99 (SR99) extends along Seattle's Elliott Bay waterfront on the two-level Alaskan Way Viaduct, a reinforced concrete structure built in the 1950s. The structure will be replaced by cut and cover approach structures and a single, 1.8 mile (2.8 km) long, 57.4-ft (17.5-m) tunnel accommodating a double deck structure with two-over-two traffic lanes and a breakdown lane, longitudinal ventilation ducts, and emergency passenger egress. The design-build contractor, Seattle Tunnel Partners (STP), a joint venture of Dragados USA and Tutor Perini, selected a Hitachi-Zosen earth pressure balance machine (EPBM).

DC Clean Rivers Project: Geotechnical Instrumentation Programs for Protecting Critical Infrastructures in the Nation's Capital
L. Fu, AECOM, Potomac, MD; P. Kottke, B. Murray, and S. Njoloma, McMillen Jacobs Associates, Washington, DC; R. Castro, JCK Underground; M. Wone, DC Water. Washington, DC

The District of Columbia Water and Sewer Authority (DC Water) Long Term Control Plan (LTCP) (also known as the DC Clean Rivers (DCCR) project) consists of about 14 miles (23 km) of large-diameter tunnels and deep shafts constructed in soils. A total of 15 shafts with diameters up to 149 feet (45 m) and depths up to 193 feet (59 m); three large-diameter tunnels have been constructed in three contract divisions (Divisions A, H, and P) and procurement of a fourth tunnel project (Division J) is underway. The projects of the LTCP are located in the crowded urban environments and extensive geotechnical instrumentation programs were installed to monitor performance of shaft and tunnel construction for the protection of the critical infrastructure, including DC Metro, bridges, water lines, sewers, etc. Experience gained from each project allowed the protection of structures and geotechnical instrumentation requirements to be better adapted for the follow-on projects. This paper discusses how the structure protection criteria were set and tied to the instrumentation monitoring requirements in the RFP documents of the completed divisions and the implementation of the instrumentation programs during design and construction phases. Lessons learned are also included.

A Smart Disc Cutter Monitoring System using Cutter Instrumentation Technology
K. Mosavat, The Robbins Company, Kent, WA

Current disc cutter instrumentation technology is designed to be a conveniently mounted instrumentation package that monitors individual cutter rpm, wear, temperature, and vibration. A data logger service receives the cutter information wirelessly using low-power radio technology and displays cutter conditions in real time. With cutter instrumentation, the operator continuously monitors cutter conditions, which results in higher efficiency, lower incidence of down time, and prevents unexpected ring wear-related damage from causing further damage to bearings and hubs. Cutter instrumentation technology has been tested on Robbins' rock machines and results from previous and recent projects are presented. Design improvements for longer lifetime and increased reliability are discussed.

Shafts
Chairs: D. Metcalf, Kiewit, Omaha, NE
T. Costabile, Skanska

Dugway Storage Tunnel Ground Freezing at the Shaft DST-1 A focus study on the successful application of ground freezing around an open shaft excavation
J. Kabat, R. Bono and G. Pini, Salini-Impregilo Healy JV, Cleveland, OH; R. Sullivan, Northeast Ohio Regional Sewer District, Cleveland, OH

The Dugway Storage Tunnel (DST) is a combined sewer overflow deep tunnel project for the Northeast Ohio Regionals Sewer District (NEORSD) in Cleveland, Ohio and will provide additional storage of combined sewer flows during wet weather events reducing the number of combined sewer discharges into the environment. The tunnel alignment is approximately 2.8 miles long, excavated with single shield hard rock TBM 27 ft. diameter. The precast concrete segments with steel fibers are the finished internal lining of the tunnel with diameter 24 ft. Depths to tunnel invert generally range from 180 to 250 ft. below ground surface. The project will have a total of six shafts with internal lined diameter between 16 to 50 ft. and four adit connections between shafts and tunnel. The excavation of the DST-1 Access shaft, the project's main shaft for the tunnel operations, required specialized ground control methods to allow for the safe excavation of the shaft along with maintaining the stability of the existing Easterly Interceptor Sewer, the NEORSD's primary sewage conduit to their Easterly

Treatment Plant. This paper focuses on the Contractor's selected method of ground freezing for the control of these ground conditions and its effectiveness.

Design of the Hemphill Deep Pump Station Shafts using Blind Bore Drilling Techniques
Y. Wu, T. Jiang and J. Prada, Stantec Consulting Services Inc., Fenton, MO; B. Jones, City of Atlanta, Department of Watershed Management, Atlanta, GA

The Hemphill Pump Station, part of the City of Atlanta Raw Water Supply Program, consists of five shafts each equipped with a deep submersible pump. The shafts are approximately 420 feet deep, 9.5 feet in excavated diameter, and will be constructed from the ground surface using blind bore drilling techniques primarily in hard and abrasive metamorphic rocks. Welded steel liners will be lowered into the shafts and grouted in place. A grouting program is implemented before commencing shaft excavations to reduce the rock mass permeability and to prevent potential drilling fluid losses during shaft development. Plaxis3D is used to model the junctions between the shafts and adjacent tunnel to ensure the stability of the pillars between the shafts.

Hecla Mining Lucky Friday No. 4 Shaft Challenges and Possibilities
G. Sturgis, D. Berberick, and W. Strickland, Hecla Limited, Coeur d'Alene, ID; M. Swanson, Cementation; E. Kim and G. Walton, Colorado School of Mines, Golden, CO

Hecla Mining Company has completed sinking the No.4 Shaft. The 5.5-m (18-ft) diameter, concrete lined shaft is collared at the 4940 level of the mine and has a final mine level depth of 8620, or 2,923-m (9,590-ft) below the surface. The project has overcome numerous engineering and technical challenges including changing and squeezing ground conditions, complex logistics, and high heat conditions. Once completed, the shaft project will position the Lucky Friday Mine to potentially access over 78 million ounces of silver resources; nearly half of what has already been mined in the 70-year history of the Lucky Friday.

An Overview of the SR99 TBM Access Shaft, Seattle, WA
P. Burgmeier, Brierley Associates, East Syracuse, NY; J. Mitchell, Brierley Associates, Austin, TX; G. Hauser, Seattle Tunnel Partners Joint Venture, Seattle, WA

The SR99 bored tunnel will replace the seismically vulnerable, double-deck Alaskan Way Viaduct. "Bertha," at 57.3-ft in diameter, was, at the time, the largest EPB-TBM in the world. The TBM launched in July 2013 and stopped after mining approximately 1000-ft when it was discovered that the outer seals had been damaged. An access shaft was installed in front of the TBM to facilitate removal and repair of the cutter head assembly. Access shaft design and construction overcame difficulties including buried structures, archaeological concerns, limited site access, complex geology, adverse groundwater conditions, and proximity to the adjacent viaduct that remained in service. The project required installation of deep secant piles up to 10-ft diameter, multi-stage dewatering, structural and hydraulic grouting, structural and geotechnical modeling, and real-time instrumentation. The TBM successfully mined into the access shaft in early 2015 and the 2000-tonne cutter head was removed from the shaft via modular lift tower supported on the shaft.

Gas Control in a Vertical Boring Machine Advanced Shaft in Shale
R. Sullivan, Northeast Ohio Regional Sewer District, Cleveland, OH; M. Schafer and M. Piepenburg, MWH/MM Jv, Cleveland, OH; P. Kassouf, Triad Engineering, Cleveland, OH

Gas inflows into Cleveland, Ohio tunnels are well-documented and historically addressed with ventilation. Until recently, shafts were thought open and accessible enough to avoid gas buildup. Dugway Storage Tunnel (DST) shaft DST-7 was completed using a vertical boring machine (VBM). During shaft excavation, gas inflow rates exceeded the volume controllable with the VBM ventilation system and the VBM could not be advanced. Nearly thirty working days of delay occurred before gas levels dissipated enough to allow safe shaft entry and completion of the excavation. A case history of the shaft excavation with recommendations regarding dealing with gas impacts on future VBM-advanced shafts is provided.

Large Diameter and Deep Shafts Unique Design and Construction Challenges
R. Blanchard, Ch2m Inc., New York, NY; E. Ross, Ch2m Inc., Buenos Aires, Argentina; Harald Leiendecker, Ch2m Inc., New York, NY; Rodolfo Aradas, Ch2m Inc., Buenos Aires, Argentina

Over the past five to ten years, there has been an increasing number of underground infrastructure projects worldwide using different geometries incorporating large diameter, deep shafts into their configuration. Example projects Ch2m Inc. has direct design and construction experience with include shafts for: Blue Plains Dewatering shafts (one of five shafts) for District of Columbia Water and Sewer Authority CSO Clean Rivers Project in Washington DC and Matanza-Riachuelo Catchment Sanitation Program; La Plata River Outfall, The design, construction and critical instrumentation monitoring of such shafts brings unique challenges. These challenges can be dealt with in a number of ways, including the use of 3D structural models with a better understanding of soil structure interaction incorporated into the analyses of all loads on the shafts, with resulting savings in material and more flexibility in construction sequencing. The authors draw upon their global experience of design and construction of these large diameter and deep shafts to identify some key unique challenges, and to suggest particular ways in which they can be overcome during design and/or construction.

Grouting / Ground Modification I

Chairs: D. McMaster, Mott MacDonald, Sunol, CA
E. Fredrickson, Traylor Bros., Inc.

Cellular Backfill-A Review of Some of the Basics

R. Henn, RW Henn LLC, Centennial, CO; D. Crouthamel, McMillen Jacobs Associates, San Francisco, CA

The requirement to backfill the void or annular space between the excavation and the final lining system, associated with tunnel and shaft construction, has existed for many years. In the past the primary backfill materials used were concrete, sanded grouts, neat cement grouts or blown-in sand/pea gravel. However, starting approximately 20 years ago the use of cellular cement products has come into wide use as the backfill material of choice. This is due to its ability to flow and be pumped long distances and its relativity lower cost. However, as the use of cellular backfill has increased so have problems associated with its placement and ability to meet design goals. To help better understand and mitigate some of these problems this paper discusses approaches that designers, general contractors and specialty contracto rs should consider when utilizing cellular backfill.

Copenhagen Cityringen Project: Big Data To Manage Quality Control In Megaprojects

L. Cicinelli and V. Violo, Seli Tunneling Denmark ApS (Salini Impregilo Group), Copenhagen, Denmark; F. Stahl, Tunnelsoft; T. Gronbach, Dropbox

As Operators in the tunneling sector we are well aware of the importance of the Quality in our everyday work. Historically, "to do things right" was the informal definition of goals, but is has emerged and established as an integrated and systematic contractual requirement. We all became familiar with the words auditing, documentation, traceability (work orders, parts, working hours, etc), identificability, configuration, non-conformity management, and learned the great benefits and improved visibility around our project. Implementing the contractual requirements is challenging in terms of organizing work, resources and managing the vast reporting requirements resulting. This session shows how visionary project development, strong planning, software design, field testing and execution (the paramount PDCA, Plan, Do, Check, Act of the Quality Assurance Management Systems) is making this task more streamlined and more efficient. We will outline how an implementation aimed for the project users and workers involved rather than fulfilling mere regulatory and contractual requirements boosts project success. We will highlight the software/service our system has been integrated with: TPC Tunneling Process Control, provided by Tunnelsoft, a branch of Babendererde Engineers and the cloud service leader provider (Dropbox).

Copenhagen Cityringen Project: Complex Passage And Obstacle Removal Under Existing Metro Station

V. Violo and A. RaschillÃ , Seli Tunneling Denmark ApS, Copenhagen, Denmark

The Cityringen project foresees the construction of a new circular metro line in and around the city center of Copenhagen. In his 31 km drive the TBMs had to pass near or under existing infrastructure that, in some cases, were extremely sensitive in terms of allowable settlements and risk of disruption. This article describes the passage under the existing and operating Frederiksberg metro station and Frederiksberg mall.

Grouting and Ground Modification- Copenhagen Cityringen Project: Compensation and Jet Grouting as Mitigation Measures for TBM Operation under Historical Buildings

A. Raschilla and V. Violo, Seli Tunneling Denmark - Salini Impregilo group, Copenhagen, Denmark; G. Kafantaris, Copenhagen Metro Team JV - Salini Impregilo group, Copenhagen, Denmark

The Cityringen project will form a new circular line in the city centre and will consist of 21 new stations (17 + 4 transfer station) and approx. 31km of EPB twin-bored tunnels. The new tunnels passed under the historical building of Magasin du Nord, Mc Donald's and two pubs in the heart of the city with a minimum cover of about 4 m. To minimize the movements, a complex system of compensation grouting and jet grouting soil treatment was performed. A detailed action plan between the parties involved allowed coping with the critical TBMs passage successfully.

The crossing under the Alaskan Way Viaduct
E. Fernandez, Dragados, Madrid, Sapin; G. Hauser and F. Gonzalez, Dragados USA, Seattle, WA; C. Herranz, Mott MacDonald, Los Angeles, CA; A. Herten, HNTB

The 2001 Nisqually earthquake caused damages to the Alaskan Way Viaduct, (SR-99) in Seattle (WA). A bored tunnel was the solution to replace it and for that, the largest TBM ever built was manufactured in Japan. The approach for the first 1,000 feet of tunnel, running parallel to the viaduct, was to create a protected area by secant piles, jet grouting and more allowing the mega TBM to excavate in and under non engineered fill materials before crossing under the viaduct with minimal cover. This paper will describe the measures put in place to protect the Viaduct and the results of those measures.

Monday, June 5, 2017 | 1:30 pm
Hard Rock TBM
Chairs: M. Stolkin, JF Shea, Indianapolis, IN
G. Fairclough, Schiavone, Secaucus, NJ

Rockbursts in TBM Tunnels- Analysis and Counter Measures
G. Peach, Multiconsult AS, Norway; W. Dobbs, MWH; B. Ashcroft, Multiconsult AS, Norway

Twin 8.5m diameter, 10.5km long parallel headrace tunnels under overburdens of up to 1,870 m with high horizontal stresses are being excavated for the Neelum Jhelum Hydroelectric Project in northeastern Pakistan using two main beam gripper TBMs. Rockbursts presented a significant danger to personnel and equipment. Rockburst characteristics were compiled on both TBMs to create a database for future reference. Correlation of rockburst characteristics improved the ability to predict the likelihood, location, severity and number of rockburst events. This in turn allowed for optimization of rockburst counter measures including horizontal and vertical relief holes, full ring steel support spacing, shotcrete application, over cutters and alignment change.

20in Disc Cutters: A Comparison of Tool Life and Performance on Hard Rock TBMs
S. Smading, The Robbins Company, Kent, WA

Optimization of disc cutter life and penetration rate in hard rock can be one of the biggest predictors of project success. With hard rock TBMs being used today in ever more difficult conditions and longer tunnels, the question of which type of disc cutter to be used becomes critical. At one such project in Northeastern China, varying disc cutter tool steels and sizes were put to the test on a total of nine different 8.5m diameter hard rock, Main Beam TBMs from various manufacturers. The TBMs excavated sections of a vast water tunnel in similar granitic geology. This paper will look at the development of 20in disc cutters and the case for large diameter cutters, using the most recent example in China as a focus area of study. Varying advance rates, cutter life, tool steels, and challenges excavating the rock will be discussed. The paper will conclude with recommendations for optimal cutter life in TBMs destined to bore long tunnels in hard rock.

Successful Excavation of Mexico City's Emisor Poniente II Wastewater Tunnel Use of a Dual Mode, Crossover TBM in Challenging Geology
R. Gonzalez, Robbins Mexico, Mexico City, Mexico; M. Scialpi, The Robbins Company, Solon, OH

In July 2015, the launch of a dual mode, Crossover type TBM marked the start of Mexico City's next challenging wastewater project: the Tunel Emisor Poniente (TEP II). The 5.5km long tunnel travels below a mountain at depths of 170m as well as a section just 8m below residential buildings, and the geology is equally varied. Ground consists of andesite and dacite with bands of tuff and fault zones, as well as a section of soft ground at the tunnel terminus. This paper will detail the unique 8.7m diameter Crossover TBM designed for the challenging conditions, and the successful excavation of the machine through fault zones, soft ground, and more. Strategies for excavation and advance rates, and downtimes will be analyzed. As the machine can be converted from hard rock mode to EPB mode in the tunnel, the authors will also look at the conversion process and how both modes worked to excavate in widely varying geological conditions.

High Cover TBM Tunneling in the Andes Mountains A Comparative Study of Two Challenging Tunnel Projects in Chile
C. Lang, M. Belli and P. Salazar, The Robbins Company, Solon, OH

The Andes Mountain range is among the youngest and most complex in the world, geologically speaking. Tunneling projects, particularly for hydroelectric and water transfer schemes, are not new to the range but their past history has met with mixed success. Two new projects utilizing very different tunnel boring machines and excavation strategies are now providing a testing ground for modern underground construction equipment in the Chilean Andes. This paper will analyze two projects: the Alto Maipo and Los Condores Hydroelectric Projects, located approximately 100 km apart in the Andes Mountains. The two strategies being employed will be analyzed in detail, as one project is using an open-type Main Beam TBM plus extensive ground support, while the other is utilizing a Double Shield TBM and segmental lining. The authors will look at TBM performance and ground conditions encountered in the two tunnels and what effects the TBM selection and ground support strategy may have had on each tunneling operation.

Conventional Tunneling
Chairs: M. Peterman, Kiewit, Omaha, NE
D. Dorfman, Schiavone Construction Co. LLC, Warwick, NY

John Hart Generating Station Replacement Project - Underground Works: Project Update and Challenges Encountered
M. Kendall, Frontier-Kemper Constructors, Comox, BC, Canada

The Frontier-Kemper/ASL Joint Venture was formed to excavate the underground workings of the John Hart Generating Station Replacement Project in Campbell River, British Columbia. The existing surface 126 MW John Hart Generating Station originally completed in 1947 on the Campbell River, represents approximately 17% of the total generating capacity on Vancouver Island. The underground replacement project will create a more reliable, seismically robust, and environmentally friendly facility with an increased installed capacity of 132 MW. InPower BC General Partnership is a special-purpose vehicle created by SNC-Lavalin Capital Inc., and contracted by British Columbia Hydro and Power Authority (BCH) to design, build, finance and maintain the replacement power station under a 19 ¾ year public-private partnership (PPP) with BCH. The underground excavation works portion of the project is 77% complete as of the end of November 2016 and is scheduled to achieve substantial completion on or ahead of schedule by July 2017.

Sewer Tunnel Excavated Under and Adjacent to Treacherous Terrain, Including Landfills, Oil Refinery, Crowded Streets, and Significantly Contaminated Material and Utilities
R. Vakharia, LA County Sanitation District, Carson, CA; R. Paracuelles, LA County Sanitation District, Whittier, CA

The challenging 2.5 mile long, 12ft diameter, JOC shallow sewer tunnel included several horizontal and vertical curves, went under busy streets, landfills, an active oil refinery and active oil lines. Other challenges included: relocating numerous oil and utility lines, traffic control and community issues resulting in major alignment changes, encountering water and oil saturated squeezing ground, a tunnel collapse, and hitting gasoline contaminated material resulting in OSHA requiring the tunnel machine to be retrofitted and made explosion proof. Other topics include: incorporating lessons learned, the pros and cons of the tunnel machine used, and real-time web-based ground settlement monitoring.

Design and Construction of the Capitol Connector Pedestrian Tunnel
A. Stone and J. Jacoby, Stone + Howorth; M. Over and J. Schrank, McMillen Jacobs Associates

The Tennessee Capitol sits atop a limestone precipice in the heart of downtown Nashville and is home to the state senate and legislative chambers. Legislators currently access the building via the Motlow Tunnel from their offices in Legislative Plaza. With the relocation of their offices to the Cordell Hull Building, a new access for legislators to the State Capitol is required. Work for the utility and pedestrian tunnel involves extending the existing elevator shafts 50 feet down from the terminus of the Motlow Tunnel to a new access tunnel from the newly renovated Cordell Hull Building. The schedule of the entire rehabilitation project was driven by the need to relocate the legislators prior to the 2018 legislative session. This timeline required very aggressive design and construction schedules. This paper discusses design and construction challenges associated with the tunnel mining and elevator shaft extensions within the confines of this historic structure.

Geotechnical Considerations for the ORBEEC Drumanard Tunnel
D. Neil, Parsons, Louisville, KY

The ORBEEC alignment required crossing the historic Drumanard property to complete the connection of I-265 between Kentucky and Indiana. The Drumanard property is listed on the National Historic Register and surface disturbance of the property is not allowed. The most viable option to overcome this obstacle required a pair of shallow three lane tunnels each approximately 1700 ft. long for the Kentucky HWY 841 approach to the proposed bridge. In order to determine the feasibility of a tunnel a limited geotechnical boring program was performed. The program included groundwater monitoring, core sampling and a small geophysical mapping program which was completed during the 2004 to 2007 time frame. These data were used for the prefeasibility study and a comprehensive test drift and underground coring program was designed and bid with the information to be used to form the geotechnical basis for a final design. For various reasons the test drift plan was abandoned and in 2011 a series of three horizontal core holes, one in each tunnel crown and one in the pillar was completed by S&ME. This data was incorporated into a comprehensive Geologic Baseline Report (GBR) and Geologic Data Report (GDR) prepared by Golder Associates. The GBR and GDR are used in the tunneling industry to present a baseline of geologic conditions a contractor may expect to encounter on a given project and used for input into planning, designing, and performing the work. Included in the GBR are the hydrogeologic conditions, the physical characteristics of the rock mass, the classification of the rock lithologic units to be excavated and the ground support requirements for initial excavation, the stress within the units, and the instrumentation requirements to monitor the reaction of the rock mass to the excavation process.

Large Span Tunnel Cavern
Chairs: D. VonPlaten, Traylor Bros., Inc., Evansville, IN
P. Kottke, McMillen Jacobs Associates, Washington, DC

Design and Construction of Indianapolis Pump Station Cavern
V. Nasri, AECOM, New York, NY; A. Varas, AECOM, Indianapolis, IN; M. Miller, Citizen Energy Group, Indianapolis, IN; J. Castillo, Southland Contracting, Indianapolis, IN

This paper presents the design and construction of a deep rock conveyance and storage tunnel and pump station cavern that was built about 70m below ground surface for the City of Indianapolis. The TBM tunnel ran nearly 13km in limestone with a finished inside diameter of 5.5m. It provided a minimum storage volume of 300 million liters of untreated excess wet weather overflow. A pump station was planned for dewatering of the tunnel and discharging the CSO flow to a surface advanced wastewater treatment facility with a firm capacity of 340 million liters per day. The pumps were located within an 18.3m wide and 24.4m high deep mined rock cavern. The project also had several deep shafts including the TBM launch/screen & grit and retrieval shafts, the pump room cavern access/discharge and equipment shafts with inside diameters ranging from 4.9m to 13.4m.

Admiralty Station, Hong Kong: Rock Excavation and Support Challenges to accommodate MTR's Two New Lines
H. Asche, Aurecon Australasia, Brisbane, Queensland, Australia; M. Bezzano, MTR Corporation Ltd, Hong Kong, China; S. Smith, Aurecon Hong Kong, Hong Kong, China; M. Wiltshire, Laing O'Rourke

Hong Kong's new South Island Line and Shatin to Central Link requires the expansion of Admiralty Station into Hong Kong's first 4 line interchange station. Already the busiest interchange station in Hong Kong, expanding this station without interrupting services involves major engineering, logistics and rock mechanics challenges. The new platforms are housed in a shallow cavern and platform tunnels immediately adjacent to the existing platforms and under major roads and high rise buildings. To facilitate connection with the existing station, the existing Island Line platform tunnel needed to be underpinned and up to 24m of rock below it removed, while keeping trains running safely above. Multi-party collaboration, interactive design and construction processes were adopted that allowed program optimization as construction progressed.

Completing the Second Avenue Subway Project, New York
J. Chua-Protacio and R. Giffen, Arup, New York, NY

Phase 1 of the Second Avenue Subway Project is due for completion in December 2016. At a cost of $4.5 billion this phase will provide 4 new stations and 2 miles of new tunnels to extend the existing Q line to the upper east side of Manhattan. Future phases will extend north into Harlem and south to the Financial District. This paper will focus on the challenges of completing and fitting out the tunnels, caverns and cut and cover structures previously constructed. The complexity of completing the platforms, mezzanines, public, back of house and ancillary structures together with interfacing with adjacent properties, utilities and third parties will be covered. In particular the lessons learned from the installation of track, escalators, elevators, architectural finishes and systems integration to a tight schedule while accommodating design changes will be covered. Particular focus will be paid to waterproofing methods used and remedial work done prior to completion.

Permanent Lining Design for Downtown Los Angeles Cavern
J. Lianides, C. Herranz, and D. Penrice, Mott MacDonald, Pleasanton, CA

Metro is constructing a light rail corridor beneath Downtown Los Angeles-The Regional Connector Transit Corridor (RCTC). To provide operational flexibility, RCTC requires a track crossover adjacent to the proposed 2nd/Broadway Station. Right of way constraints require that the crossover be constructed at relatively shallow depth using Sequential Excavation Methods (SEM), resulting in what is believed to be the largest tunneled cross section in Los Angeles. The SEM cavern permanent lining must accommodate significant ground and groundwater loads, building surcharges, and seismic events with 2,500 year return periods. Due to the complexity of the cavern geometry, dynamic time history analyses were needed to confirm the structure's seismic performance. This paper describes the numerical models required to demonstrate satisfactory performance of the permanent structure under long-term and seismic conditions.

First Large Diameter Hard Rock CSO Chamber in St. Louis
D. Frierdich and P. Pride, Metropolitan St. Louis Sewer District, St. Louis, MO; K. Nelson and C. Haynes, Black & Veatch, St. Louis, MO

The Maline Creek Tunnel (MCT) will be the first large diameter chamber to store combined sewer overflows in St. Louis. The MCT is a key feature of Project Clear, Metropolitan St. Louis Sewer District's (MSD) Long Term Control Plan to address sanitary and combined sewer overflows to local streams and rivers. Project Clear's estimated cost is greater than $4 Billion dollars making it the largest public works project to date for the state of Missouri. The MCT includes the construction of a 40ft diameter, 12.5 MGD submersible pump station, a 28ft diameter x 2,700ft long cavern, a 580ft long x 6-t lined connecting tunnel, three deaeration chambers, three intake structures, a shallow connector sewer constructed by pipe jacking, and 1,000ft of 12in to 30in diameter near surface sewers. Bids were opened on March 10, 2016. The successful bidder was SAK/Goodwin JV with a bid of $82.3 million dollars. The Engineer's Estimate was $87.7 million dollars. The project was awarded in May 2016. The contractor mobilized on site in June 2016. The project is allocated 1567 calendar days to complete the construction.

Future Tunneling
Chairs: A. Finney, CH2M Hill, Bellevue, WA
D. Sowers, Washington State Department of Transportation, Seattle, WA

Overvaal Rail Tunnel: Secring the Economic Arteries of the Rainbow Nation
J. Muir, Aurecon Hong Kong, China; H. Gouws, Aurecon Tshwane, Tshwane, South Africa

South Africa's proposed new Overvaal rail tunnel, located on the Highveld escarpment will triple the rail capacity from the coalfields to Richard's Bay. The existing Overvaal rail tunnel was built in the mid-1970s through challenging conditions and was mapped and studied by Bieniawski to develop the Rock Mass Rating (RMR) System. Beneath the escarpment point, the tunnel exhibited squeezing conditions and continuing instability at the invert means that it needs regular maintenance. A new tunnel has been designed to accommodate a double track tunnel. This paper outlines the unique design challenges for a rail tunnel in South Africa, from the unique geotechnical conditions to the challenges of retaining continuous operation of the existing tunnel during construction.

California High-Speed Rail - Design Considerations for Tunnels
S. Dubnewych and S. Klein, WSP Parsons Brinckerhoff, Los Angeles, CA; O. Alcantara, California High-Speed Rail, Sacramento, CA; N. Jain, California High-Speed Rail, Los Angeles, CA; R. Anderson, California High-Speed Rail Authority, Sacramento, CA

Construction of the proposed California High-Speed Rail system will require extensive tunneling through mountain ranges in both the north and south regions of the State. Rail alignments under consideration could require between 45 to 50 miles of tunnels that range in length from several thousand feet to over 20 miles under a cover exceeding 2,000ft at certain locations. Challenging geologic, hydrogeologic and seismic conditions are anticipated along potential tunnel routes. Geologic conditions range from unconsolidated alluvium to strong granitic rocks; tectonically sheared and deformed rock masses; high groundwater pressures and in situ stresses; and active earthquake faults. In addition, the mountain ranges exhibit environmentally sensitive areas that will have to be protected during construction. This paper discusses the design and construction challenges associated with the tunnels in this Statewide system.

Design of Atlanta Raw Water Supply Program
T. Jiang, D. Del Nero and A. Bedell, Stantec Consulting Services Inc., Atlanta, GA; B. Jones and A. Abon, City of Atlanta Department of Watershed Management, Atlanta, GA

The City of Atlanta is converting an over-a-century-old quarry into a 2.4 billion-gallon raw water storage facility. The system consists of a deep hard rock tunnel, two deep pump stations, two dropshafts and multiple connecting adits and shafts. Bored with a TBM from tunnel portal at the quarry base, the tunnel is approximately 24,000ft long, 250ft to 450ft deep, 13ft in bore diameter, and is partially concrete lined with modified contact grouting to control water infiltration/exfiltration. CFD modeling is performed for the pressurized system. Various shaft construction techniques are used, including drill & blast, blind bore drilling and raisebore drilling.

Annacis Island Wastewater Treatment Plant Tunneled Outfall System
J. Newby and K. Pathirage, CDM Smith Canada, Burnaby, BC, Canada; K. Massé, Metro Vancouver, Burnaby, BC, Canada

Expansion to Metro Vancouver's Annacis Island Wastewater Treatment Plant (WWTP) in Delta, British Columbia will require a new 4.2 m ID tunneled effluent outfall system, including three shafts and multiple tunnel drives, extending into the Fraser River. Within Annacis Island, the conveyance tunnels will be located near the base of a 35 to 40 m alluvial sand deposit. The tunnel will terminate about 25 m beneath the river at a riser shaft connected to a near surface diffuser pipeline, risers, and ports. This paper addresses the overall project, which will begin construction in 2018, and challenges associated with the project.

Delivery of the Design, Environmental Statement, Engineering Construction Management for the UK's New High Speed Railway for 21st Century
C. Rawlings, CH2M/High Speed Two (HS2) Ltd, London, UK; N. Rabadia and M. Howard, High Speed Two (HS2) Ltd; R. Sturt, Arup; D. Soper, Birmingham Centre for Railway Research & Education; A. Vardy, Dundee Tunnel Research

High Speed Two (HS2) is a new $67billion (£56 billion) high speed railway which will form a "spine" of a reshaped rail network providing an engine for growth and connecting eight out of the top ten regions within Great Britain. There are about 64km of twin bore and 8km of twin cell cut-and-cover tunnels. Principles of Systems Engineering (International Council on Systems Engineering (INCOSE)) have been incorporated to drive processes and approaches to underground structure design & construction. In addition, HS2 Ltd established an efficiency challenge programme specifically tasked with generating savings for the project through updating and refining existing standards/guidance documents in geotechnical engineering and underground construction. This paper describes aspects of the design, engineering & construction management and environmental aspects to ensure high quality and cost effective underground structures for this innovative high speed railway including HS2's approach to tunnel porous portal designs for the various HS2 underground structures.

Planning and Design of the New Ashbridges Bay Treatment Plant Outfall for the City of Toronto
G. Kramer, Hatch, Mississauga, ON, Canada; D. Ross, CH2M Canada, Toronto, ON, Canada; F. Duckett, W.F. Baird and Associates, Oakville, ON, Canada; J. Kempa-Teper, City of Toronto, Toronto, ON, Canada

The Ashbridges Bay Treatment Plant (ABTP) Outfall project by the City of Toronto involves construction of a new tunneled outfall that will convey treated effluent (water) from the ABTP into Lake Ontario. This new outfall will be built to allow cessation of operations of the existing outfall which is reaching the end of its service life and has limited hydraulic capacity. Outfall construction will include mining a 3,500 m long, 7 m internal diameter tunnel through rock beneath the lakebed. The project will initiate at an 85 m deep, 14 m internal diameter onshore shaft, to be constructed adjacent to the shoreline and downstream of the future UV Effluent Disinfection Facility. Treated effluent will flow by gravity from the plant through connecting conduits to the shaft and tunnel out into the lake. Vertical in-line risers will be constructed along the last 1,000 m of tunnel to connect the tunnel and convey flows to the lake. Tunnelling operations will be supported from the onsite shaft and the risers will be drilled from over-water barges. The investigations and design phase of the project work is planned through the end of 2017, tendering in Q1/Q2 of 2018 and construction starting in the third quarter of 2018 and extending to the end of 2023. The paper presents the planning and design of the project including discussions of challenges such as optimization of the risers, meeting regulatory requirements, addressing underground construction in rock known to exhibit time dependent behavior and riser construction up to 48 m in length through 38 m deep soft ground lakebed deposits overlying the bedrock.

Planning of the San Francisco Public Utilities Commission's Channel Tunnel

R. J. Caulfield, Jacobs Engineering, San Francisco, CA; A. Hamid, Stantec/MWH Global, Walnut Creek, CA; M. Wong, San Francisco Public Utilities Commission, San Francisco, CA

The proposed Channel Tunnel is a critical component of the San Francisco Public Utilities Commission's Central Bayside System Improvements Project (CBSIP), which is a key element of a $6.9-billion Sewer System Improvement Program to upgrade their aging and seismically vulnerable wastewater facilities. The tunnel will provide gravity conveyance and storage of combined sewage flows from the northeast sector of San Francisco to the Southeast Water Pollution Control Plant for treatment. The tunnel will be approximately 1.7 miles long and 24 feet in internal diameter. It will utilize a single-pass precast concrete segmental lining system. Tunneling challenges include excavating with pressurized face TBM technology through highly variable ground conditions including Franciscan Complex (rock and mélange), clayey/silty sands, stiff to hard clay (Old Bay Clay) and mixed-face conditions.

Tuesday, June 6, 2017 | 1:30 pm
Tunnel Lining I
Chairs: J. Clare, Mott MacDonald, Seattle, WA
R. Gomez, Gomez International, Inc., Casa Grande, AZ

Load Bearing Capacity of Fiber Reinforced Concrete Tunnel Linings under Combined Moment-Normal Force Loading Conditions

A. Nitschke, Shannon & Wilson, Tysons Corner, VA; E. Bernard, Technologies in Structural Engineering, Sydney, Australia

Fiber Reinforced Concrete (FRC) tunnel linings in soft-ground tunnels are typically designed as a two-dimensional beam structure under combined moment-normal force loading conditions. Structural design concepts for unreinforced or bar reinforced concrete are used by amending the stress-strain-relationship on the tension side, using data obtained from beam tests. By computing an equilibrium between the resulting forces from the stress distribution over the height of the beam with external forces, moment-normal force interaction diagrams for FRC are developed. The moment-normal force pairs from the tunnel lining are then compared with the bearing capacity of the material using the interaction diagram to determine if capacity is adequate. This paper will describe this approach in detail, highlight some specific failure modes and highlight its weakness, namely that the full potential of FRC remains under-utilized. In addition, the concept is amended by introducing a concept of "plastic hinges" in the tunnel lining that allows the designer to take full advantage of the elasto-plastic failure characteristics of FRC.

Engineered and Safe Approach to Tunnel Segment Lining Installation with Dowelled-In Connectors on the First TBM Tunnel in Qatar

F. Bernardeau and J. Stypulkowski, CDM Smith, Doha, Qatar

Abu Hamour (Musaimeer) Surface & Ground Water Drainage Tunnel-Phase I (AHSO) is a 9.5k m long, 3.7 m ID storm water tunnel which was successfully and safely completed using circumferential dowelled-in connectors and guidance rods. The approach assured precise, safely sequenced and engineered radial segment fastening. The installation was designed with safety in mind. However, precision and quality assurance were the key requirements to assure that no newly or previously installed segments were not free standing during segment and ring installation process.

Design of Steel Fiber-Reinforced Concrete Segmental Lining for South Hartford CSO Tunnel
M.Bakhshi and V. Nasri, AECOM, New York, NY

The South Hartford Conveyance and Storage Tunnel (SHCST) as a major component of the Hartford Metropolitan District's Clean Water Project is intended to capture and store Combined Sewer Overflows (CSO) from the southern portion of Hartford and Sanitary Sewer Overflows (SSO) from West Hartford and Newington. The 20 ft-diameter, 21,800 ft-long bored tunnel will be excavated in shale, siltstone and basalt through several fault zones with high groundwater pressures up to 9.6 bars. This paper discusses the implementation of the results of the geotechnical discontinuum analyses on the structural design of the tunnel segments for final service stage design as well as other critical load cases occurring during the segment production and transient stages. For the first time in North America, double hooked-end steel fibers (Dramix 4D) were designed for reinforcement. This new type of steel fiber satisfies the serviceability requirements by limiting time-dependent effects of creep on crack opening and more significantly satisfies ductility requirements by providing an ultimate bending moment higher than the cracking bending moment.

Final Lining Design of the Ohio River Bridges East End Crossing Tunnel
W. Chen, M. Shaikh and S. Narasimharajan, Jacobs Engineering, New York, NY; C. Uhring, Walsh Vinci Construction Join Venture

The Ohio River Bridges East End Crossing Tunnel is the largest twin tube highway tunnel in the US, 55-ft wide by 30-ft tall, constructed by sequential excavation method. Geologic units along the tunnel profile include karstic limestone, shale, and dolomite. Tunnel final lining support types were predetermined during early design phase and confirmed or adjusted/redesigned based on actual ground condition mapped in the field. This paper presents rationales in selecting the tunnel final lining design approaches, its associated rock load and groundwater load derivations, design details to meet service life requirement, and lining support type selection process during construction.

Construction Logistics for East Side Access-A Study from Queens to Manhattan
S. Lo Grasso, Mott MacDonald, New York; R. Adames and L. Jacobs, Frontier-Kemper Constructors, Inc., New York, NY

This paper describes the logistical challenges that were encountered during the construction of East Side Access (ESA) CM006 (Manhattan North Structures). While the daily logistics of transporting materials, personnel and concrete throughout the construction site may seem mundane (given the sheer enormity of ESA), this is a critical operation that directly impacts the project schedule. Coordinating the delivery of the necessary materials is a complex endeavor, given the high demand, the dense urban setting and the large geographical scope of the project. The specific delivery system for concrete and other materials to the tunnel site will be discussed in detail in this paper.

Cost-effective seismic station-tunnel connections on Westside Subway Extension Section 1
A. Harding and H. Nofal, CH2M, Santa Ana, CA

When designing metro systems for strong seismic motions there is a wealth of information on the design of both conventional bored tunnels and cut and cover structures like stations. However, there is very little literature treating the connection between the two. This paper describes how the closed form solutions often used to approximate the longitudinal soil-structure behavior can underestimate the movements at connections, and how these shortcomings were overcome in the Westside Subway Phase 1 project in Los Angeles. With reference to previous projects in the LA area, some useful conclusions for future designs are drawn, including how larger displacements can be allowed for in commonly used details with negligible impact on their cost.

Stations, Cross Passages

Chairs: N. Long, Jay Dee Contractors, Northlink, WA
S. Maggipinto, Schiavone Construction Co. LLC, Secaucus, NJ

Cross Passage Mining Using Different Supports in Different Grounds
S. Akai, K. Yamauchi, H. Kawasaki and D. Liebno, Obayashi USA; G. Venturini, SWS Canada

Cross Passage (CP) mining is a unique form of excavation and there are many ways to skin a cat. In conjunction with the ground improvement such as dewatering, jet grouting, ground freezing and compressed air, different types of initial support can be applied to maintain safe mining. Particularly, CP mining heavily relies on ground conditions and ground improvements therefore the initial support has to be designed accordingly. Through the course of the Project, eight cross passages were excavated along the 6.4 km of twin bored tunnel. Each cross passage had unique ground conditions and different ground support systems were applied at each CP. This paper summarizes our approach on a case by case basis and includes our lessons learned.

Systematic Crosspassage Design and Construction Planning for Transit Tunnels
P. Chou and Y. Shi, Parsons, Pasadena, CA; M. Burdick and P. Nicholson, Skanska Taylor Shea Joint Venture, Los Angeles, CA

Long transit tunnels are becoming popular in California's metropolitan areas. Due to their lengths, many crosspassages (CP) are required between twin bored tunnels through urban areas in gassy, tar-rich, and seismically active ground. The considerable number of CP, along with varying operating functions, heterogeneous ground conditions (including mixed face) and limited space create a unique design and construction planning challenge. This paper presents a practical, systematic design and planning approach for long tunnels. The paper covers critical aspects of CP design: geological setting, constructability, functionality, system layout and life-safety. This paper discusses key features of the design and construction planning necessary for long transit tunnel CPs, and presents recommendations for an effective CP planning solution including the use of Building Information Modeling (BIM).

Station Excavation and TBM Tunnel on Los Angeles Crenshaw Project
R. Chen, J. Salai and B. Schatz, J. F. Shea Construction, Los Angeles, CA

The LA Metro Crenshaw/LAX Corridor project is 8 miles of light rail which includes three underground cut and cover stations and one mile of twin tunnels. Support of excavation for the underground stations included various methods, such as drilled soldier piles, cutter soil mix wall, and jet grout. Tunnels were excavated by EPBM. Precast sixsegment universal rings with 5.47m (18.83ft) inside diameter were erected after each 1.52m (5ft) of TBM advance. Efforts made by owner and design-built team turns the project into a big success, although there were many of challenges during construction.

Third Street Light Rail Phase 2, Central Subway Stations, San Francisco, CA-Utilization of Multiple Foundation Techniques
A. Neumann, K. Bolton and J. Bean, Bencor Global Inc., Frisco, TX

In October 2013, Bencor Global (a Keller Company) was awarded a subcontract by the successful prime contractor, Tutor-Perini Corporation, to perform key elements of the construction of the support of excavation system to facilitate the installation of underground subway stations for the project owned by the San Francisco Municipal Transportation Agency. The Central Subway (Contract 1300) is the second phase of San Francisco's Third Street Light Rail Program. It is a 2.74km extension that will expand light rail service within the city, improve regional connections to Caltrain, BART, Muni Metro, and provide an alternate transportation option to congested vehicular surface traffic. The key elements of this project included the utilization of three different advanced foundation techniques using diaphragm walls, compensation grouting and jet grouting at the new Chinatown Station, Yerba Buena/Moscone Station and the Union Market Street Station. This paper will discuss the complexities associated with the planning and performance of geotechnical construction work in the heart of downtown San Francisco within densely populated neighborhoods and complex underground utility systems. It will also highlight the logistics associated with coordinating key elements of a complex foundation system and the benefits of utilizing one geotechnical contractor to perform all three elements on the project.

Risk Reduction, Management and Mitigation from experience based learning during construction of Cross-Passages, Seattle, Washington
S. Pyakurel, W. Klary, and V. Gall, Gall Zeidler Consultants, Ashburn, VA; N. Long, Jay Dee Contractors, Inc., Seattle, WA; A. Pooley, Jacobs Engineering Group

Cross passages are critical elements in transit and highway tunnels, providing a means of safe emergency egress between adjacent running tunnels. Although usually short in length, they are often technically challenging and can pose significant construction risks. Two recent projects in Seattle-Sound Transit's University Link Light Rail Contract U230 and Northgate Link Extension Contract N125-involved cross-passage construction between twin single-track Metrorail tunnels. This paper

describes risk reduction, mitigation and management experience gained from the U230 and N125 contracts during construction of cross passages. Specific emphasis is given to challenges associated with excavation in glacial deposits under high ground water pressure and the ground improvement measures implemented, which included dewatering, grouting and ground freezing.

Closing the Gap for Bogotá River Sanitation System Tunnels (Columbia)
M. Gilbert, CDM Smith, Boston, MA; H. Suarez, CDM Smith, Bogotá; M. Khwaja, CDM Smith, Boston, MA

Located within challenging terrain, the Interceptor Tunjuelo-Canoas (ITC) (4.2 m) and the Emergency (3.2 m) tunnels form 11 km of underground conduits of the Bogotá River sanitation system. Vertically offset, the tunnels were to be connected via a pump station; logistical and contractual challenges resulted in a two year construction delay. CDM Smith, subsequently retained by the owner, Empresa de Acueducto de Bogota (Owner), designed the interconnection as a vortex drop-shaft structure. This paper documents project and geotechnical synopsis; novel approach to vortex chamber construction through layered claystone and sandstone geology, without utilizing working shafts; and, modifications to the segmentally lined tunnels.

Grouting / Ground Modification II
Chairs: A. Curry, Moretrench, Rockaway, NJ
J. Nakagawa, Tutor-Perini, Seattle, WA

Leak Mitigation Grouting for New York Subway Tunnels
P. Gancarz, J. Minturn, N. Grobler and D. Van Dyk, Sovereign-Thyssen L.P., New York, NY

Groundwater intrusion into tunnels is a severe challenge encountered by contractors and owners. Significant cost over the tunnel's lifetime illustrates the pivotal role of dewatering and leak mitigation. Polymer-based emulsion grouts have provided permanent cutoff barriers in dams, mines and tunnels for over forty years. Our study addresses the failure of membrane waterproofing systems in mitigating groundwater infiltration, illustrates the technology, performance and material characteristics of polymer emulsions, and how its application to water cutoff grouting compares with available cementitious and resinous systems. Case histories into the use of polymer emulsions for tunnel rehabilitation in New York will be provided.

Complex Inner-city Tunnel Excavation by means of the New Austrian Tunnel Method in Combination with a Hyperbaric Atmosphere
T. Wechner, BeMo Tunnelling GmbH, Innsbruck, Austria

The Tunnel Karl-Friedrich-Strasse is located directly in the city of Karlsruhe (Germany) and is being excavated using the New Austrian Tunneling Method. The total length of the tunnel is 250 meters. 40 meters will be a highly complex tie-in structure with a cross section of 180mÂ². Due to the inner-city location and the very high water table the chosen construction method was to excavate the tunnel in a hyperbaric atmosphere of circa 1.0 bar. This document describes the extraordinary challenges of NATM Tunnel in an urban area in combination with hyperbaric atmosphere.

Geologically Targeted Pre-Excavation Grouting on WestConnex M5 Tunnel, Sydney, Australia
U. Pelz and J. Casado, CDS Joint Venture, Mascot, NSW, Australia; H. Asche and J. Raymer, Aurecon Jacobs New M5 Joint Venture, Mascot, NSW, Australia; D. Crouthamel, McMillen Jacobs Associates, San Francisco, CA; S. Fidler, Golder Associates Pty Ltd, MIton, QLD, Australia

The WestConnex M5 motorway includes deep bedrock tunnels 70 m deep to pass under a 40 m deep paleochannel. Beneath the paleochannel, the rock contains large, systematic fractures caused by valleyfloor thrusting and a regional wrench-fault system. Pre-excavation grouting from the surface and underground will be used to control groundwater inflows to the tunnel. The surface phase uses an acoustic televiewer to geologically target each grout stage and find the optimal place to set the packer. This reduces the potential for bypass and allows higher pressures and volumes to be used, thus reducing cost by reducing the number of grout holes. The surface program creates the foundation for the underground program, which uses high-pressures and ultrafine cement to provide the final sealing of rock mass.

A Proactive Approach to Tieback Anchor De-tensioning
S. Peterfreund and G. Finn, McMillen Jacobs Associates, Seattle, WA

For urban underground development involving tieback anchor excavation support walls, authorities having jurisdiction usually require tiebacks to be de-tensioned before project completion. De-tensioning typically involves the construction of block outs in the permanent concrete basement walls, which are labor intensive to install and backfill, and tend to interrupt the continuity of the basement's waterproofing system. This paper presents a tieback de-tensioning approach that is integrated into the design of the excavation support system: one that maintains the integrity of the waterproofing system and eliminates the need to sequence de-tensioning activities with basement build-out.

Ground Freezing for Tunnel, Shafts, and Adits
J. Sopko and A. Curry, Moretrench American Corporation, Rockaway, NJ; B. Messina, Skanska USA Civil, Queens, NY; S. Njoloma, McMillen Jacobs Associates

Construction of a 0.81km long, 6.1m diameter sewer tunnel, a component of D.C. Water's Clean River Project required construction of three drop shafts and connecting adits. The location of these three shafts and adits was complicated by their locations in a populated suburban neighborhood. Ground freezing from the surface was selected as the method to provide temporary earth support and groundwater control during construction. The ground freezing option was not only the most technically appropriate method, it provided significant advantages to accommodating the citizens in the neighborhood. Not only did the drilling and installation process provide a minimal equipment footprint at each site and reduce cuttings and spoils, but the refrigeration plants were located at a remote location reducing noise levels during the freezing process and construction. This paper discusses the design and implementation process of this complex freezing system that included drilling refrigeration pipes at complex angles in order to minimize traffic interruption and avoid utilities. Additionally, horizontal freeze pipes were drilled under 3 bars of pressure from the EPB tunnel in order to ensure that the adit connections were sufficiently frozen. The intricate cooling system extended over half a mile on both the surface and underground tunnel with instrumentation and monitoring along all points.

Exposing Young Engineers to Multiple Facets of Tunneling
J. Brandt, Traylor Bros., Inc., Redondo Beach, CA; E. Kusdogan, Traylor Bros., Inc., Los Angeles, CA; N. Tabor, Traylor Bros., Inc., Washington, DC; D. Tew, Traylor Bros., Inc., Alexandria, VA

Firsthand experience is best suited to expose and train new engineers in unfamiliar tunneling methods. This paper illustrates the advantage of how hands-on training through the collaboration of different, non-competing companies can be advantageous in preparing young engineers for the challenges of technical leadership positions. To further broaden their engineering background, four engineers were temporarily placed internationally with a partner company on two existing projects, the Neubau Zierenberg Tunnel and Tunnel Karl-Friedrich-Strasse. The experiences gained have been indispensable in implementing the Sequential Excavation Method and the New Austrian Tunneling Method on their projects, increased exposure to the variety of toolbox selection methods, as well as shown the differences with foreign client-contractor relationships.

Trenchless Tunneling

Chairs: J. McCain, Tutor-Perini, Seattle, WA
R. Taylor, Traylor Bros., Inc., New York, NY

Paradise Raw Water Intake-Fighting the Green River
N. Joens and Matt Roberts, Kiewit Infrastructure Co., Omaha, NE

The TVA Paradise Combined Cycle Project included a Raw Water Intake structure designed to pull water from the nearby Green River in Paradise, Kentucky. The original plan was to sink a 100-foot-deep shaft into rock, and drive a microtunnel into the bottom of a cofferdam located 335 feet away in the river. Heavy rainfalls and fluctuating river elevations delayed progress of the cofferdam, forcing a change to the design. It was decided to eliminate the need for the cofferdam by raising the elevation of the tunnel into soft ground, and performing a wet retrieval in the river. This paper will walk through the decisions that led to the original design, the change and the outcome.

Dugway South CSO Relief and Conveyance Sewer, A Critical Connector
D. Mast, AECOM, Cleveland, OH; K. Buxton, Northeast Ohio Regional Sewer District, Cleveland, OH; A. Foote, AECOM, Cleveland, OH; I. Halim, AECOM, Chelmsford, MA; A. Schreiber, Northeast Ohio Regional Sewer District, Cleveland, OH

The Dugway South Relief and Consolidation Sewer is a critical component of the NEORSD Easterly CSO control system in Cleveland, Ohio, connecting four (4) other CSO tunnels in a dense urban neighborhood. Design and construction challenges included: previously fixed pipe elevations necessitated both soft ground and rock tunneling on the same alignment, underground hydraulic structures in poor ground conditions, tunneling beneath a critical unreinforced concrete box culvert built in the 1910's, contract constraints necessary for coordination with adjacent CSO contracts, and potentially gassy ground. The flexible bid documents allowed for a variety of construction means and methods, improving bids.

Long-Distance Microtunnelling at Toronto Pearson International Airport
R. Ofori, J. Schreiner and M. Gelinas Hatch Corporation, Burlington, Ontario, Canada; A. Puri, The Regional Municipality of Peel, Brampton, Ontario, Canada; W. Trisi and J. Mulville CRS Tunnelling Inc., Oakville, Ontario, Canada

Identified as the last link in the twinning of Peel Region's East Trunk Sewer, the Etobicoke Creek Trunk Sanitary Sewer Twinning project was initiated to service future development in the sewershed. The project involved long-distance microtunnelling below operating surfaces that included a runway, two taxiways and access roadways at Canada's busiest airport, Toronto Pearson International Airport (TPIA). This paper discusses the challenges overcome in completing this project including working within TPIA's restricted "airside" environment, long-distance pipe jacking in mixed-ground conditions, providing for tunnel face access under hyperbaric conditions and minimizing tunnelling impacts to airport operations during construction.

Upper Limit Microtunneling Application to Meet Dam Safety and Operational Longevity
B. Marquis, McMillen Jacobs Associates, Burlington, MA; E. Knight, Gannett Fleming Hazen Joint Venture, New York, NY; E. Chase and J. Vickers, NYC Environmental Protection, New York, NY; J. Arciszewski, Southland Renda Joint Venture, Gilboa, NY

Gilboa Dam in upstate New York impounds Schoharie Creek, forming Schoharie Reservoir-a part of NYC's water supply system. To ensure the dam's long-term performance and reliability, a Low-Level Outlet (LLO) is being constructed to facilitate reservoir draining to meet conservation releases. It consists of two 9-foot-diameter tunnels (water leg and land leg) totaling 2,160 linear feet, terminating at a new chamber releasing water to the Creek downstream. Excavation is by microtunnel boring machine (MTBM). The land leg tunnel terminates downstream while the water leg tunnel upstream, and penetrates into a coffer dam at the reservoir bottom elevation 977 (-153 feet). This paper presents LLO microtunneling design considerations and construction methods.

Microtunneling in Georgian Bay Shale - Rebecca Trunk Wastewater Main, Oakville, Ontario
P. Headland, Aldea Services LLC, Frederick, MD; G. Fabian, Aldea Services LLC, Columbus, OH; R. Ali, Aldea Engineering Services Ltd, Toronto, ON, Canada; K. Mohammed, Cole Engineering Group Ltd, Toronto, ON, Canada; M. Bajor, Halton Region, Toronto, ON, Canada

The Rebecca Trunk Wastewater Main Construction project comprises 4.05km (13,287 ft.) of microtunnel (MTBM) construction including a total of 14 microtunnel drives (12 rock drives & 2 mixed face drives) varying in length from 165 m (540 ft.) to 403 m (1,325 ft.) located in Oakville, Ontario. Twelve of the drives are curved in part based upon requirements to limit impacts to existing utilities, protected trees, and existing structures, minimize easement requirements, maximize clearance beneath environmentally sensitive creeks, and connection locations required to decommission existing pumping stations. The rock drives are located primarily within the Georgian Bay Formation (Upper Ordovician) which comprise shales with interbedded Siltstone and Limestone ("hard layers"). The mixed face drives comprised of Georgian Bay Formation and Glacial Till. All drives are below the water table. Design considerations include provisions for swelling Shale, interbedded Limestone & Siltstone ("hard layers") within the softer Shale, high horizontal stress, areas of limited ground cover (less than 0.4 MTBM diameters), curved and composite curved alignments (minimum radius of 430m/1,410ft), and pipe requirements including provision for grout ports (for lubrication during jacking and grouting after jacking), and watertight gaskets. Construction requirements include a continuous lubrication system, an automated guidance system; and an MTBM equipped with rear loading cutters, a crushing chamber, and a minimum required overcut. The paper presents the design approach taken and the requirements placed within the Contract Documents for the project. Construction commenced in December 2015.

Wednesday, June 7, 2017 | 8:30 am
Tunnel Rehabilitation
Chairs: P. Ciuffarin, Frontier-Kemper
S. Firth, CH2M Hill

Sumner Tunnel Rehabilitation
S. Quinn, WSP Parsons Brinckerhoff, Boston, MA; J. Rigney, MassDOT Highway Division, Boston, MA

First opened to traffic in 1934, the Sumner Tunnel currently carries traffic travelling from East Boston to Boston under the Boston Harbor. It was constructed using cut and cover construction techniques near the portals. Between the cut and cover sections the tunnel was bored/shield-driven to form a 31-ft diameter tube using steel liner plates to support the ground and later reinforced with concrete. Given the age and constant use, the Sumner Tunnel concrete liner, invert slab, ventilation system, electrical system and drainage system are in dire need of repair and upgrading. MassDOT contracted with WSP | Parsons Brinckerhoff to prepare construction documents for a complete "gut renovation" and upgrade.

The Arlberg Tunnel Project-a Milestone in the Austrian Efforts to increase Safety of the Road Tunnel Network
M. Hoellrigl and N. Fuegenschuh, BeMo Tunnelling GmbH, Innsbruck, Austria; C. Wanker, ASFINAG Bau Management GmbH, Austria

The Arlberg Road Tunnel with a length of almost 14 kilometers is both, the longest road tunnel in Austria as well as the most important east to west connection between Tyrol and Vorarlberg. Built between 1974 and 1978 and after being in service for almost 40 years the tunnel is currently undergoing a major renovation program. This includes construction of additional emergency bays, emergency galleries, caverns for new electrical equipment and a complete replacement of the electromechanical equipment.

Large Diameter Sliplining Under Extreme Conditions- Rehabilitating the Oakland-Macomb Interceptor While Maintaining Service to 830,000 Customers
C. Rozelle and A. Mekkaoui, Jay Dee Contractors, Inc., Livonia, MI; F. Klingler, FK Engineering Assoc.; S. Sachidanandan, NTH Consultants, Ltd.; S. Lockhart, Office of the Oakland County Water Resources Commissioner

The Oakland Macomb Interceptor Drain (OMID) serves 830,000 residents in Macomb and Oakland Counties, providing sanitary sewer service to large portions of the northern suburbs of Detroit. The sewer has had multiple failures since its construction in the 1970s and was in need of major repairs. The contracts preceding Contract 4 involved constructing flow control facilities and interceptor repairs for preparation of sliplining. OMID Contract 4 was comprised of sliplining four runs of large diameter interceptor over 11 miles. The sliplining lengths in PCI-5, PCI-6, PCI-7 and PCI-8 were approximately 14,760 linear feet (LF), 3,300 LF, 3200 LF, and 4,200 LF, respectively, and the finish pipe diameter ranged from 8-foot to 10-foot internal diameter (ID). The annulus was filled with over 30,000 cubic yards (CY) of cellular grout. Jay Dee Contractors (JDC) had to overcome many challenges during this project which included: flow control management, long travel distances with pipe, difficult tunnel geometry, and logistics of working in a live sewer. This paper presents a brief history of the interceptor and the design process, followed by a review of the methods JDC used to overcome the unique challenges.

SEM / NATM
Chairs: B. Messina, Skanska, Elmhurst, NY
J. Jonasen, Traylor Bros., Inc., Evansville, IN

Steep inclined SEM Excavation-The "Uphill Machine" - at London Crossrail Development and application of a safe excavation system in soft ground
R. Antretter, BeMo Tunnelling GmbH, Innsbruck, Austria

Escalator tunnels for passenger station access are usually built applying declined excavation method in order to avoid excavated material from falling down along the excavated section putting individuals and plant in danger. If this method cannot be executed due to geometric or contractual restrictions a challenging situation is encountered. This was the case at the Whitechapel and Liverpool station sites at London's Crossrail, contract C510. This paper describes development of the basic idea, initial

layout, final design and practical application of a mechanised uphill excavation and support system. The machine was used for excavation of multiple inclined tunnels with a 30-degree gradient.

Downtown Bellevue Tunnel-Concept Optimization through Team Collaboration
D. Penrice and H. Yang, Mott MacDonald, Pleasanton, CA; C. Frederick, Sound Transit, Seattle, WA; J. Coibion, Atkinson Construction

The Downtown Bellevue Tunnel (DBT) is a key component of Sound Transit's East Link Project-a $3.7 billion, 14-mile light rail extension connecting Seattle with the cities of Bellevue and Redmond. The DBT construction contract was awarded to Atkinson Construction in the Fall of 2015. Subsequently, at the request of Sound Transit, the Contractor was asked to provide recommendations for reducing the DBT construction schedule by 3 months, to mitigate a delay in right-of-way acquisition and provide flexibility on an adjacent contract. This paper discusses the collaborative process involving Owner, Contractor and Engineer that supported the evaluation and implementation of the Contractor-generated proposals-including revisions to the prescriptively designed SEM excavation sequence, and elimination of pipe canopy, to accommodate the revised project schedule demands.

Comparative Application of NATM, TBM and RBM Technologies
P. Véliz and P.Diaz, PEK Teknep Overseas Engenharia S. A., Rio de Janeiro, Brazil

Last expansion of Rio de Janeiro subway began in 2010 aiming the 2016 Olympics. The project included seven underground stations and 17 km tunnels. Biotite-gneiss, augen gneiss, weathered rock, marine sands, soils and urban material were excavated. NATM, TBM and RBM technologies were applied to each ground type and urban condition. Innovative methods of excavation associated to last generation electronic blasting, ground control, roof support, instrumentation in surface and underground environments were some of the most challenging tasks. Almost all the current underground construction methods were applied resulting in a very valuable experience. This paper outlines strategic guidelines for assessment in subway construction in densely populated areas and variable rock conditions. It also describes the main elements of design with respect to project requirements.

Sequential Excavation Method with Ground Freezing for DC Water's First Street Tunnel
I. Hee and W. Bracken, Skanska USA Civil; H. Cordes, WSP Parsons Brinckerhoff; S. Njoloma, McMillen Jacobs Associates

Mined tunnel excavation for DC Water's First Street Tunnel project in an urban residential neighborhood with complex ground conditions; required the utilization of ground improvement with ground freezing. A total of three connection tunnels (adits) of different size and geometry have been constructed between deep drop shafts and the main tunnel, which was excavated by Tunnel Boring Machine. This paper is focused on the adit design challenges and contractor's means and methods to successfully deliver this project. The application of vertical ground freezing required innovative construction sequencing, unique solutions to maintain the freeze during excavation, and deliberate equipment selection. Lessons learned from the design through construction are provided.

Difficult Ground
Chairs: G. Hauser, Dragados USA, Seattle, WA
R. Marshall, Frontier-Kemper, Canyon County, CA

Design of the Fort Wayne CSO Tunnel through Complex/Wet Rock
A. Sivaram and M. Bradford, Black & Veatch, Fort Wayne, IN; T. Short, Fort Wayne Utilities, Fort Wayne IN

The Three Rivers Protection and Overflow Reduction Tunnel (3RPORT) is a critical component of Fort Wayne's Long Term Control Plan to reduce the volume of CSO entering the waterways of Fort Wayne, Indiana. The project consists of 24,580ft (7,500m) of 16ft (4.9m) finished diameter deep rock tunnel, nine drop structures, TBM launch and retrieval shafts, a 30mgd (113,500m3/day) deep dewatering pump station, and associated deaeration chambers, adits, and near surface infrastructure. The local geology consists of horizontally bedded dolomite interbedded with chert and fractured dolomitic bank reef formations with artesian groundwater. Key considerations in the tunnel design will be presented including planned groundwater mitigation strategies for construction, which is scheduled to start in early 2017.

Rondout West Branch Bypass Tunnel - TBM Boring in Hard Rock Against High Water Pressure and High Water Inflows Beneath the Hudson River in New York

D. Terbovic, The Robbins Company, Kent, WA; M. Scialpi, The Robbins Company; Solon, OH

A single shield hard rock tunnel boring machine is set to bore in hard rock, high water inflows and high water pressure in New York State. To overcome the difficult conditions the TBM is designed to handle 2500 gpm water inflows and seal against 30 bar of pressure. The TBM will bore a tunnel to replace a damaged portion of the Delaware Aqueduct that supplies half the raw water to New York City. The 2.5 mile bypass tunnel passes beneath the Hudson River with geology consisting of shale and limestone. Due to the high water pressure and inflows the TBM was designed with new sealing systems for the main bearing and to close the TBM off if high water inflows are encountered. The TBM is to be equipped with two dewatering systems and multiple drilling and grouting systems for pre excavation grouting and segmental lining backfill. Systematic drilling and grouting procedures specific to the project were developed and incorporated into the TBM and backup design to ensure that the TBM can handle the extremely difficult ground conditions of the project.

Innovations on West Trunk Sewer Contract 2

J. Hurt, Arup, New York, NY; J. Riechers, Herrenknecht Formwork Technology GmbH, Schwanau, Germany; M. Ghasemi and T. DiMillo, Technicore Underground, Newmarket, ON, Canada; V. DiMillo, Ewing Fabricators, Newmarket, ON, Canada; A. Puri, Region of Peel, Brampton, ON, Canada

Construction of Contract 2 for the twinning of the West Trunk sewer tunnel for the Region of Peel in the City of Mississauga consists of approximately 3,800m (12,500ft) of 3.0m (10ft) diameter trunk sanitary sewer. The new sewer is being constructed by tunneling using two EPB machines and installing precast concrete segments as the final liner. Two significant innovations are included in the construction of the tunnel. The first is due to the tunnel being constructed in the Georgian Bay Shale, which is known to exhibit time dependent deformation (TDD) after excavation. The forces generated by TDD are significant and are typically dealt within tunnels by delaying the installation of the final lining to allow unrestrained swelling to occur, or by use of a compressible material outside the tunnel lining. For the precast concrete segments, which are installed immediately behind the TBM a compressible grout was developed to accommodate the TDD. The second innovation is the use of Herrenknecht Combisegments® over a 250m length of the tunnel where a corrosion resistant lining was specified in the contract. This paper discusses the development and use of these innovations.

Tunneling through the Fault Zone at West Trunk

B. Khorshidi, A. Ramezani, and N. Crawford, McNally Construction Inc., Hamilton, ON, Canada

The majority of the West Trunk sewer twinning project is aligned along Erin Mills Parkway in Mississauga, Ontario. The tunnel was expected to be driven through the Georgian Bay Formation's blue-grey shale and so the primary tunnel rock support was limited to steel channel arches, timber lagging, and rock bolts. This is overlain by the Queenston Formation's typically weaker brownish-red shale with soil above that which consists of top soil, fill material, and cohesive and granular deposits depending on the borehole. The final lining is 2.4m i.d. cast in place concrete. The Robbins 3.023m main-beam TBM was launched from a 22m deep shaft, S5, approximately 1km south of Mississauga's highway 403. Within approximately 575m the TBM encountered the first fault zone. Dewatering was commenced and full steel sets were employed behind the TBM's limited roof shield to support the ground. Probe drilling and grouting were used to stabilize the roof ahead of the TBM. The overall length of the fault zone was approximately 20m. A second fault zone was found approximately 1.5km from the launch shaft and 800m short of the next 36m deep shaft S6. Again, grouting and steel sets were used to control and support the ground. The overall length of the second fault zone was approximately 60m.

(End)