DECEMBER 2009

tunnels & tunneling NORTH AMERICA

GUANGZHOU: SUBWAY CONSTRUCTION AT FULL SPEED FOR THE ASIAN GAMES.

The tunnel constructors in Guangzhou are forging ahead with a gigantic and innovative project. By 2010, they will have built around 145 kilometers of underground subway tunnels using Herrenknecht EPB Shields and Mixshields. The 16th Asian Games will be opened in the southern Chinese mega-city on November 11, 2010. By then, an efficient subway network must be available for up to 3.5 million passengers per day. Herrenknecht delivered a total of 41 EPB Shields and 6 Mixshields for the Guangzhou subway. 17 Herrenknecht TBMs are forging ahead with the new construction of Subway Line 5, and 19 machines are employed for the extension of Line 3. Here, the tunnelling teams are moving forward at rates of up to almost 50 meters per day (S-490 EPB Shield), setting the pace for Chinese metro tunnelling.

The speed of China's infrastructure construction projects is unprecedented – in particular when newly building and extending subway networks. Chinese construction companies are using a total of 112 Herrenknecht machines in eight multi-million mega cities to construct more than 300 kilometers of new tunnels.

GUANGZHOU | CHINA

PROJECT DATA

6x Mixshields, 41x EPB Shields
Diameter: 6,250mm
Cutterhead power:
40x 945kW, 6x 630kW, 1x 1,200kW
Tunnel length: around a total of 145km

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Black Holes and (No) Revelations...

So, this time last December, I was busy writing about the black cloud of the global economic meltdown hanging over us all like a harbinger of doom while we waited with bated breath to see who the first victims of the fall-out would be.

As we now know, it didn't take long for the affects to start showing, with public-private partnership projects seemingly falling apart left-right-and-center as share prices bottomed out and finance agreements collapsed.

The most daunting example at the time was the virtual overnight collapse of the Miami Port Tunnel project, when the Florida Department of Transportation (DOT) announced it was pulling the plug on its deal with the Miami Access Tunnel (MAT) consortium, due to the loss of Bouygues' equity partner Babcock & Brown.

Then came the dramas of hideously over-stretched city, county and state capital budgets, leaving officials scrambling to re-finance bonds, secure government bail-outs or finalize borrowing agreements in order to rescue their coffers from the brink of disaster.

It had just about reached the point where I was half-tempted to suggest that several DOT's consider brokering concessions with McDonalds – in an effort to boost incomes via combined fast food drive-throughs/toll booths (innovative I think) – when the Obama administration finally officially announced it would, indeed, bankroll an unprecedented raft of new infrastructure projects via the $787 billion stimulus plan.

As the promise of all that exciting federal money hung in the balance, there was an immediate surge in share prices, extending the stock market recovery, and for a short while everything looked rosey and new and optimistic.

It wasn't long however, before it became clear that many projects were still in very serious trouble. California's budget crisis saw the 4th bore of Caldecott tunnel placed on a list of 27 potential projects to be indefinitely stalled, just as the bidding process was about to get underway. Major funding shortfalls in Nevada called a halt to the Clean Water Coalition's massive System Conveyance Operation Program (SCOP) project; as well as a smaller pump station shaft contract for Southern Nevada Water Authority's Intake No 3 project. Similar funding issues forced the Detroit Water & Sewerage Department to terminate Vinci/Frontier-Kemper JV's $93.5 million Detroit River Outfall contract, just as it was mobilizing on site; and Kenny/Obayashi JV's contract for the Upper Rouge South Tunnel, even before a purchase order had been placed.

> Yes, there are a number of eagerly anticipated projects that have hit the backburners, but many of these are also now bouncing back into fruition

However, as the year has progressed, the dramas of the financial crisis have seemed to fade into the background somewhat and, particularly whilst re-reading past editions of *T&TNA* for my editorial in May's 10th Anniversary edition, it became blatantly apparent just how very healthy the North American tunneling industry actually is at present.

Yes, there are a number of eagerly anticipated projects that have hit the backburners, but many of these projects are also now bouncing back into fruition, including Miami's Port Tunnel and Caldecott's 4th bore. In addition, there is a vast amount of new work upcoming. Key projects obliviously include Seattle's large-bore Alaskan Way Viaduct Replacement, Toronto's numerous EPBM tunneling contracts and the ARC Trans-Hudson project, but there are also numerous other schemes currently under design and due out for tender next year.

So, while Tiger Woods may not be the only person in North America looking for a big black hole to climb into at the present moment, the (no) revelation is that there will be plenty of them to choose from in the next twelve months. So, here's to a most successful New Year! ■

Companies featured in this issue

tunnels & tunneling NORTH AMERICA

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Front cover

A 1.2-mile (1.9km) tunnel featuring 11 curves with 94" (2.4m) i.d. precast concrete segments was created with an Akkerman 113.5" (2.9m) EPBM. The Avenue 45 and Arroyo Drive Relief Sewer Project for the City of Los Angeles, California, was completed by contractor is Buntich Pacific JV of California. The machine is shown at a check-point site along the tunnel.

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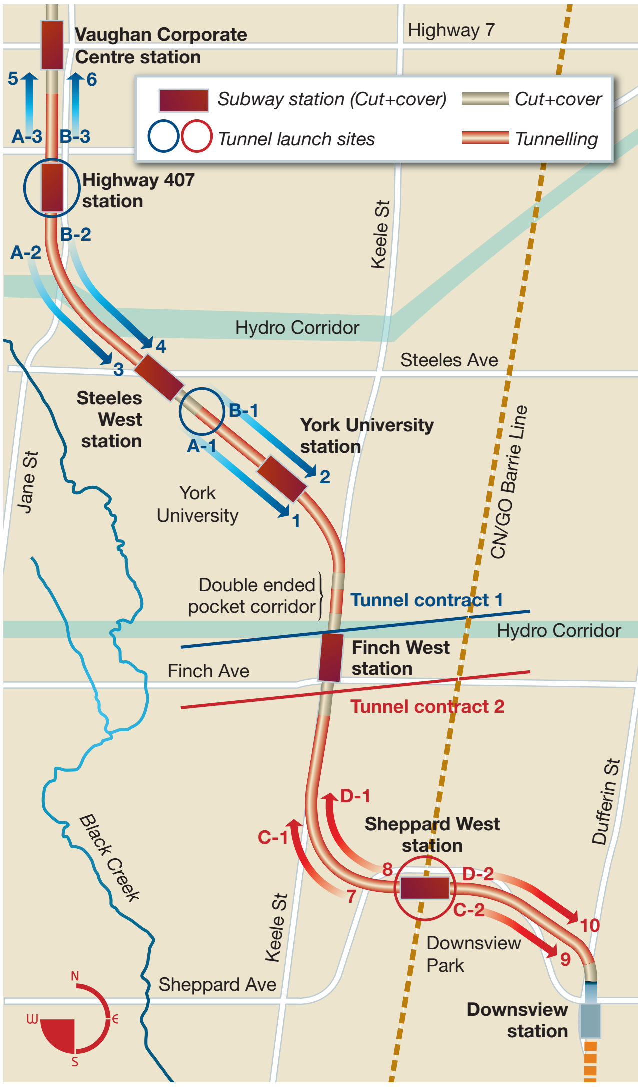

Above: Map of the project alignment, showing the twin bored tunnel contracts and EPBM drives; **Left:** Artists' impression of TYSSE's completed Sheppard West Station

TYSSE gears up for bid process

Early this month, Toronto Transit Commission (TTC) held an information session to update potential contractors on the main construction contracts for the $2.63 billion Toronto-York Spadina Subway Extension (TYSSE) that are scheduled to be tendered next year.

The TYSSE project is the first of a tranche of new transit projects that will be built in Toronto and will see the Spadina Line extended 8.6km (5.3-miles) north from Downsview Station, across the municipal boundary - a first for the city - to terminate in York Region. The extension features 6.7km (22,000ft) of twin bored EPBM tunnels; seven cross passages; six new cut and cover stations; a tail track with a cross-over structure at the northern terminal station; and a turn-back facility mid-alignment within a double-ended pocket track.

Following feedback from the industry via a number of Project Delivery Strategy workshops, held in late-2008, TTC concluded the project should adopt a Design-Bid-Build approach with six main contract packages, each valued at under $400 million. These include four contracts for the Finch West, York University, Steeles West and Vaughan Corporate Centre cut and cover stations; as well as two twin-bored tunnel contracts that each also include the construction of a station to facilitate TBM mobilization (Highway 407 Station packaged with the North tunnels and Sheppard West Station combined with the South tunnels).

There will be five secant pile/soldier pile and lagging rectangular TBM launch shafts along the alignment, with the Steeles West and Sheppard West shafts due to commence in April 2010 under early contracts. "York University Station will be the only station to be mined through," explains TTC's Supervisor for Construction, Alan Boden. "This is due to the densely built up nature of the area, which isn't conducive to the launch of a TBM." For the same reason, compensation grouting will also be required in the York University Station area, mainly due to the proximity of the Schulich Building to the south of the station. This will be the first use of the technique for tunneling induced settlement management in Toronto. "Comparisons have been drawn between TYSSE and Sheppard Subway, due to the fact that it was the last major underground project to be built by TTC," says Boden. "However, unlike Sheppard, a major challenge for TYSSE is that nearly 40% of its route lies within the zone of influence of buildings."

Yet another first for Toronto, is the recommendation for a 220m (720ft) section of SEM tunneling for the triple track portion of the Northern tunnels' double-ended turn-back facility, located just north of Finch West Station.

With three detailed design contracts for the stations awarded in September 2008, followed a month later by the award of the twin tunnels design contract, design is on schedule and has progressed to the 30%-60% level. With over 100 stakeholders involved in the project, including the four funding partners (*T&TNA*, Sept '09, p6), management of conflicting requirements has been a major challenge during design.

Pre-qualification documents for the major construction contracts are currently due to be issued from mid-January to mid-April next year, with tender documents available in June. Contract awards are expected between October and December 2010.

TTC has procured four Lovat EPBMs and the precast concrete tunnel liner rings for the project in order to reduce 'long lead time' items (*T&TNA*, Sept '09, p6). ■

Four teams vying for Alaskan Way

Washington State Department of Transport (WSDOT) recently announced the four groups that have expressed interest in bidding for Seattle's Alaskan Way Viaduct and Seawall Replacement project. The design-build teams include: Seattle Tunneling Group, which comprises SA Healy Co, Spain's FCC Construction, Parsons Transportation Group, and London-based Halcrow Inc; VTS Joint Venture, which includes French company Vinci Construction Grand Projects, Traylor Bros Inc, Skanska USA and Arup; AWV Joint Venture is composed of Kiewit Pacific, Germany's Bilfinger Berger Ingenieurbau and AECOM; Seattle Tunnel Partners includes Dragados USA, whose parent company is ACS of Spain, and HNTB Corp.

Requests for proposals are due to be issued by WSDOT in March 2010, with the final contract award expected at the end of next year. Construction of the 2-mile (3.2km) long tunnel beneath downtown Seattle is scheduled to begin in 2011. The $1.9 billion tunnel is part of an overall $4.2 billion project to replace the aging viaduct with a 54ft (16.4m) diameter deep-bore tunnel.

Mayor-elect Mike McGinn vigorously campaigned against the tunnel until the City Council voted to endorse an agreement outlining Seattle's commitment to $930 million in tunnel-related work. McGinn backed down from pledging to fight the tunnel, but has said he is still concerned about a provision in the tunnel legislation that puts Seattle property owners who "benefit" from the tunnel on the hook for cost overruns. ■

IRS digs into fraud

A New Jersey woman is accused of stealing $42 million from a tunnel workers union's benefit plans and lavishing it on a luxury lifestyle. IRS investigators and agents from the federal Department of Labor recently arrested Melissa King, 58, of Irvington. She is accused of looting three employee benefit funds for the Construction Workers Local 147 union of New York and New Jersey, which represents about 1,000 construction and tunnel workers.

King owns a company that provided administrative services to the union. She is accused of siphoning off the money between 2002 and the end of 2008. She faces up to 10 years in prison if convicted of any of the charges. ■

VTC receives high-spec TBM

As *T&TNA* went to press, Las Vegas Tunnel Constructors (VTC), a joint venture of Impregilo and SA Healy, was finalizing top heading excavation of the 197ft long x 35ft high x 46ft wide (60m x 10.5m x 14m) TBM assembly chamber for Southern Nevada Water Authority's third raw water intake tunnel, at Lake Mead. Excavation of the assembly chamber is expected to be complete by February, with the first elements of the project's state-of-the-art 23.5ft (7.2m) diameter Herrenknecht Mixshield TBM due to be lowered in April.

All of the components of the 600ft (180m) long, 1,500 ton TBM are now on site, having been shipped from Germany to the Port of Long Beach, California, and delivered to site using more than 60 tractor-trailers. Once assembled, the dual-mode machine will be launched on a 15,420ft (4.7km) long drive to a new intake shaft at the bottom of Lake Mead about 600ft (182m) below the current water level. As the machine advances from hard rock into softer rock formations and water bearing silts and sands the heading has the potential of being subjected to the full 600ft (182m) hydrostatic pressure of the lake. The machine has therefore been designed to cope with maximum operating pressures of 17 bar.

Mining is due to begin in July next year and continue for 23 months. The tunnel will be lined with 2,500 pre-cast concrete rings, each formed of 5 x 6ft (1.8m) long steel rebar reinforced segments + a 6ft (1.8m) long key. The lining has been procured under a VTC purchase order from Precast Management and is currently being manufactured at a facility located about 10 miles south of Las Vegas.

Above: VTC's state-of-the-art 23.5ft diameter Herrenknecht Mixshield TBM begins to arrive on site
Left: Segment manufacture underway

VTC's $447 million Design-Build contract was awarded in March 2008. Lead designer for the JV is Arup, supported by Brierley Associates. The total current cost estimate for the entire Lake Mead Intake No 3 scheme, which encompasses five other key construction contracts, as well as planning, design, construction management, contingencies and administration is approximately $700 million.

The project is being built as a result of the worst drought to hit the region in recorded history. Lake levels have been dropping about 1% a year since 1999 and by 2012 its surface could drop below the existing Intake No 1, which currently delivers 40% of Las Vegas' water supply. ■

Breakthrough for Sacramento's UNWI

On November 18, a joint venture of Traylor Brothers and JF Shea broke through on its 3.6-mile (5.8km) long, 14ft (4.25m) diameter, Robbins EPBM drive for Sacramento's new Upper Northwest Interceptor (UNWI) more than two months ahead of schedule.

Traylor/Shea JV's $93 million contract combined the last two sections (1&2) of a wider Sacramento Regional County Sanitation District (SRCSD) scheme to relieve existing interceptor systems in the area (*T&TNA*, Sept '09, p17).

The novel PVC coated precast segmental lining used in Sacramento

The tunnel features a novel lining system never before used in the US, consisting of PVC-coated segments that are designed to minimize deterioration from corrosive sewer gasses and eliminate the need for a carrier pipe within the tunnel. Traylor/Shea Precast manufactured the 9" (230mm) thick concrete segments at its plant in Stockton utilizing a 0.6" (1.75mm) thick sheet of PVC placed in the segment mould before casting the concrete.

As the Robbins EPBM was advanced, the JV's crews installed the rings in a 5+1 arrangement and heat-sealed more than 62-miles (100km) of joints to provide an impermeable protective layer to the concrete.

The design of the UNWI 1&2 contract was carried out by URS, with Hatch Mott MacDonald providing construction management services.

When commissioned, in November next year, the UNWI will convey up to 560 million liters of wastewater per day to the New Natomas Pump Station, where it will be re-directed to an existing regional treatment facility in Elk Grove. ■

Niagara due to resume

Mining will will shortly resume on Ontario Power Generation's $1.6 billion Niagara Tunnel, which was stalled at the beginning of September when 25m (27 yards) of the tunnel's ceiling partially caved in. There were no injuries reported in the collapse, which occurred about 2km (1.2-miles) behind the TBM, and some 3.6km (2.2-miles) into the 10km (6.2-mile) long 14.4m (47ft) diameter tunnel, in an area that has experienced some of the most severe overbreak to date.

In order to mitigate delays contractor Strabag decided to bring forward a six-week TBM maintenance stop, originally scheduled for early-October, while the damage was repaired.

Before the stoppage, rock conditions had improved considerably following a change in alignment that was made late last year (*T&TNA*, Sept '08, p9).

The incident is not expected to affect the overall cost or schedule of the project. ■

Previous overbreak on the project


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Georgia's South Cobb gets into gear

The South Cobb Tunnel project, in Georgia, is the largest capital improvement project in Cobb County Water System's history. The project, which includes a 6-mile (9.7km) long, 27ft (8.2m) diameter TBM bored tunnel, will eliminate 87,000ft (26km) of aging sewer lines and provide increased long-term conveyance capacity for the region. Amanda Foley reports on current progress

Above: TBM assembly at the 40ft diameter, 270ft deep Sweetwater construction shaft

Left: Secant piles were drilled to bedrock for initial support at the Influent Pump Station with the balance of the shaft supported by rock anchors and shotcrete

The South Cobb Tunnel is part of a massive expansion project to meet the infrastructure improvement needs and growing wastewater demands of the South Cobb Water System, in Georgia. The project features a 6-mile (8.8km) long, 27ft (8.2m) diameter hard rock tunnel that, when complete, will assist in eliminating 87,000ft (26,517m) of aging sewer lines and provide increased long-term wastewater conveyance capacity for the region.

The tunnel is currently being excavated by a joint venture of JF Shea and Traylor Brothers using a 27ft (8.2m) diameter Herrenknecht TBM at depths ranging from 150ft (45m) to 400ft (120m).

Project background

The Cobb County Water System (CCWS) collects and treats wastewater for most areas of Cobb County. The South Cobb Tunnel project is the largest capital improvement project in the County's history and was identified in the Water System's Sewer System Master Plan, which anticipates wastewater service requirements based on population projections developed by the Atlanta Regional Commission.

The South Cobb Water Reclamation Facility, located near the Chattahoochee River, currently provides treatment for wastewater from the southern and western portions of Cobb County. Wastewater flows are conveyed to the Water Reclamation Facility through a network of interceptor sewers and pump stations.

The Sweetwater Interceptor (with pipe sizes ranging from 54" to 72" in diameter), the Sweetwater Pump Station, the Nickajack Interceptor (with pipe sizes ranging from 36" to 60" in diameter) and Nickajack Pump Station are major facilities that currently serve as the backbone of the South Cobb Basin wastewater collection system. However, these interceptors and pump stations are nearing their capacity and, based on Master Plan projections, will not support the future requirements of the service area.

Cobb County Water System therefore investigated various options to relieve the existing basin interceptors. The alternatives evaluated included the construction of shallow pipelines, deep tunnels, or a combination of the two.

Based on analysis of alternate routes, consideration of the impact of construction on the community and environment, an evaluation of geotechnical data, and a preliminary cost analysis, CCWS concluded that the construction of a deep tunnel in combination with a new Influent Pump Station, to convey wastewater from the tunnel to the existing South Cobb Water Reclamation Facility, represented the best long-term solution.

In September 2005, the Cobb County Board of Commissioners awarded a $5.5 million contract for the design of the South Cobb Tunnel and Influent Pump Station to Jordan, Jones & Goulding (JJG).

Scope and conditions

The project design entails the construction of a 29,000ft (8.8km) long hard rock TBM tunnel with a 24ft (7.3m) finished diameter. The depth of the alignment ranges from 150ft (45m) to 400ft (120m) below ground surface, with an average depth of 350ft (105m).

The scheme also includes two 40ft (14m) diameter access shafts and five intake shafts of varying diameter; the 100ft (30m) diameter x 200ft (60m) deep deep Influent Pump Station; and several drill and blast tunnels ranging from 6ft (1.8m) to 10ft (3m) in diameter, with lengths from 100ft (30m) to 3,200ft (975m), which will serve as connections to the diversion/ drop shaft structures.

The tunnel alignment runs west to east, in a shallow basin-shape, from the Sweetwater construction/access shaft to the South Cobb TBM retrieval/ access shaft, which is located near the Influent Pump Station.

In general, the geology of the Piedmont region in the greater Atlanta area consists of medium-grade metamorphic rocks that have been intruded by granitic rocks in some places. A key characteristic of the Piedmont region is the thick mantle of residual soil and partially weathered rock that overlies fresh bedrock. This mantle commonly ranges from 10ft (3m) to over 100ft (30m) thick. The soil zone typically forms the upper 60 to 80% of this weathered mantle.

Above: Shea/Traylor used a two crane pick to bring the cutterhead vertical before lowering it down the Sweetwater construction shaft

Above: **In the South Cobb Shaft (TBM exit shaft), Shea/Traylor drove a 600ft drill & blast tunnel for the Influent Pump Station connection** **Above right:** **At the end of the 400ft Starter Tunnel, Shea/Traylor used forms and shotcrete to build 'gripper walls' for the TBM launch** **Below Left:** **The 27ft dia Herrenknecht TBM enters the 'gripper section' of the starter tunnel. The TBM was moved via a Barnhart Rail system up to the point where the grippers could take over**

The transition zone forms the remainder. The soil zone consists of residual soil plus any overlying alluvium, fill, or colluvium that might be present locally. The transition zone consists of highly fractured rock that is structurally degraded by chemical weathering that penetrates deeply into the rock matrix. The bedrock zone lies beneath this mantle and consists of both fractured and solid rock.

Shaft and tunnel construction

Following the selection of Parsons/Jacobs Associates, to oversee the construction management, CCWS requested bids from pre-qualified contractors for the project's main construction contract in December 2007. With a low bid of $305 million, the contract was awarded to a joint venture of JF Shea and Traylor Brothers, on March 11, 2008.

Notice to Proceed was issued on July 14 and Shea/Traylor immediately mobilized at the Sweetwater construction shaft site. One month later a 24ft x 880ft soundwall had been erected to protect residents, the site had been graded and the 45ft (14m) diameter shaft collar installed.

By happy coincidence, Shea/Traylor was able to procure one of the two Herrenknecht hard rock TBMs used on the City of Altanta's West Side CSO project, which were the same diameter as South Cobb's TBM design. A new cutterhead was ordered and Herrenknecht USA commenced refurbishment of the machine at a nearby yard.

By early-September 2008, excavation had begun on the Sweetwater shaft and towards the end of October it had been excavated down to the bedrock transition at 140ft (42m) using steel liner plates for immediate support. The remainder of the 270ft (80m) deep shaft was then blasted using a Garder-Denver 3 boom jumbo. By December the shaft had been completed and lining operations were underway.

The 2.5ft (0.7m) thick steel reinforced concrete lining was poured upwards from the base of the shaft during an unusually cold Georgia winter. However, despite some sub-freezing days, the JV didn't miss a pour. "We had a large industrial heater that we used to channel warm air down the ventilation line and into the shaft and, regardless of the weather, we managed a 15ft (4.5m) lift every day, completing the shaft in early February," explains Shea-Traylor's Assistant Project Manager Stuart Lipofsky.

At this point, the focus of site activity switched to the drill and blast excavation of the 30ft (9m) horseshoe-shaped TBM starter tunnel and 80ft (25m) tail tunnel using a Cannon 2-boom jumbo and Caterpillar loaders. 'Gripper walls' were then constructed, using roll pipes set to grade and screeded with shotcrete, to facilitate the TBM's launch within the starter tunnel.

Meanwhile, a collar had been installed and excavation commenced on the project's other 40ft i.d. construction/access shaft at the South Cobb site. Secant piles were also being drilled to bedrock to provide initial ground support for the nearby Influent Pump Station (IPS) shaft. Once excavated, the drill and shoot balance of the 200ft (60m) deep IPS shaft, was excavated using Furakawa drills and supported with rock anchors and shotcrete.

"There is a shear zone that cuts through the site very sharply," explains Lipofsky. "There was some concern about this in relation to the IPS shaft, so we installed some very long 20ft (6m) to 65ft (20m) tensioned rock bolts to ensure stability." The IPS was finished a month ahead of schedule, in June this year and lining works are now ongoing.

By June, the starter and tail tunnels at the Sweetwater Shaft were also complete and the majority of the components of the 27ft (8.2m) diameter TBM had arrived on site. Following a three month assembly period, the TBM pushed off on September 1st.

Current progress

Now three months into the drive, Shea/Traylor has advanced 4,940ft (1505m) and was expecting to achieve its first mile as *T&TNA* went to press. "It took us about a month to get up to speed," says Lipofsky. "Despite a couple of zones of very hard rock we are averaging good penetration rates, about 2" (40-50mm) per minute, with a best day of 180ft (55m).

The project's hard and highly abrasive geology was always a major consideration for TBM operation. The JV is working a five-day week, with a maintenance shift for cutterhead inspection during the day and two night mining shifts. "So far we have changed over 200 cutters," explains Lipofsky. "But of course it all depends on the rock, one day we may only change one or two cutters, another day it can be as many as 20."

Discussing future challenges that lie ahead on the drive, Lipofsky explains that there is the potential for flushing groundwater flows of up to 1200g/min. "We are mining downhill, so it is definitely a concern. But we have a number of pumps on standby in case we do encounter such volumes. To date inflows have been negligible."

The majority of the tunnel is being supported using 10ft (3m) CT bolts and wire mesh. However, the last mile of the tunnel alignment is expected to be in much blockier ground, which could prove to slow progress rates and require the addition of steel rings to the immediate support. Ultimately, 75% of the main tunnel will have a 1.5ft (1m) thick cast in-situ concrete liner. This will be cast using refurbished Everest forms.

The 1400ft (425m) long Sweetwater and 3400ft (1,035m) long Nickajack drill and blast connection tunnels, which are also now under construction, will have a 78" fiber reinforced pipe installed before they are backfilled with cellular concrete.

With an original estimate of 30 months for the TBM drive, South Cobb is already slightly ahead of schedule and currently on track for early completion. "The project is off to a great start," says Judy Jones, CCWS's Engineering & Records Division Manager, "and we are really pleased with the excellent working relationship that the project team has developed."

T&TNA looks forward to following the project's progress in the year to come. ■

Acknowledgments

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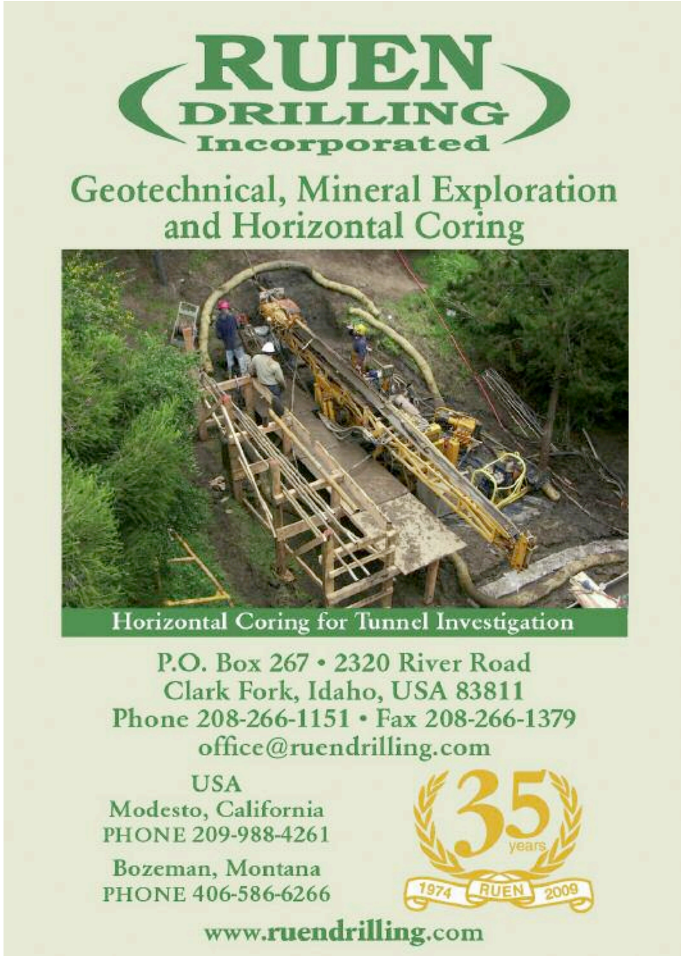
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Practical precast ring selection

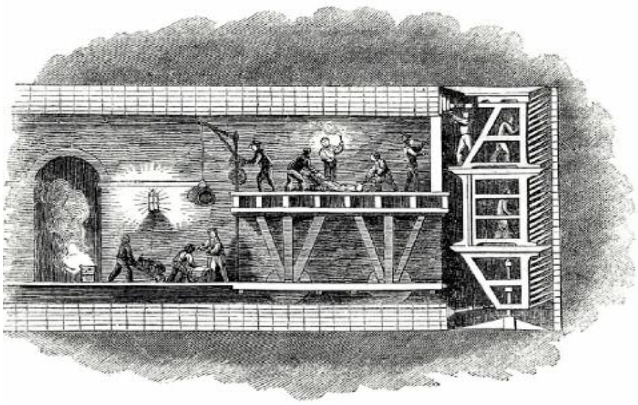
Steve Skelhorn and Laura McNally, of McNally Construction Inc, look at the history of precast segmental liner rings and the criteria for ring selection, including general ring geometry, segment geometry, ring taper and ring width

Tunnels have been under construction throughout the history of man, with the first tunnels built in prehistoric times, probably as a means of enlarging cave dwellings. Ancient Babylonians, circa 2180 BC, constructed the first recorded tunnel under the river Euphrates. Used to connect the Royal Palace with the temple, the tunnel involved the use of copper tools and reed drills and removed rock using fire and rock quenching, often using wine rather than water to quench and spall the rock. Technically this was not the first sub aqueous tunnel as the entire river was diverted out of the way prior to tunnelling; presumably budget and schedules were not of major concern in those days.

These early tunnels were driven through sound rock and required no lining. As tunnelling began to be completed in more challenging conditions various types of support systems were developed, including segmental liners and simple rib and lagging liners.

Early segmental linings

Early tunnel lining materials consisted of brick or masonry blocks. The first tunnel across the River Thames (London, UK) was the Rotherhithe tunnel, constructed by Marc Brunel between 1825 and 1841, the tunnel demonstrated the first use of a shield and was lined with brick masonry.



Left: **Brunel's Thames Tunnel**

The Simplon tunnel, built at the turn of the 20th Century, required a masonry liner of up to 10ft (3m) thick to safeguard against rock bursts. The 12-mile (19km) long tunnel reached maximum cover of 7000ft (2,133m) as it passed under the Swiss Alps.

As tunnelling methods developed, so did the type of lining, allowing tunnels to be built through increasingly more challenging ground. In 1869, Peter Barlow and James Greathead, pioneered the shield and the segmental liner. The "Greathead Shield" used for the second Thames tunnel was so successful, its design remained unaltered for almost 75 years.

Right: **An SGI escalator shaft**

Erecting the segments

The Shield allowed the erection of precast segments as a support system. These were cast iron rings, consisting of up to 10 segments per ring. The liners were so successful that they were used to construct the majority of London's Underground between 1854 and 1906.

Cast iron segmental liners, or spherical graphite iron (SGI) are still used today. Casting tolerance combined with machined faces allows intricate shapes to be formed and many of the Underground's escalator shafts were constructed this way.

Precast concrete liners

Since the 1960's, concrete liners have been used in many small diameter tunnels in Europe. The liners were designed to be built by hand and consequently the segment width was restricted to around 600mm due to weight. These generally formed the primary liner with a secondary liner consisting of in-situ concrete or infill panels.

With the development of TBMs came the introduction of mechanical ring erectors, which eliminated size constraints related to segment weight This allowed

Above: **Standard bolted segmental liner**

Above: **Wedge block liner**

design of a solid (non-paneled) ring that was sufficient for use as a final lining, leading to a one pass tunnelling approach. Ring widths could also be increased and consequently standard rings of up to 1m in width became available.

Individual segments are normally constructed using bolted connections. There are some exceptions to this, notably, in the case of wedge block linings, segments are expanded against the ground with the installation of a tapered key that compresses the ring negating the need for bolts. This type of liner is only suitable in stable ground.

Waterproofing of the constructed tunnel was always an issue, as achieving an effective seal between the segments was difficult. Initial ring designs incorporated tarred yarn (tar impregnated hemp rope) between each of the segments to temporarily seal the gap between adjacent segments and retain backfill grout. The joints between segments were sealed with a caulking compound after completion of the tunnel, which increased the overall project schedule. Over time, the yarn was substituted with a permanent hydrophilic gasket. This was set into a groove cast into the ring. These proved partly successful, but many clients still demanded secondary caulking.

Ring geometry at this stage consisted of a number of parallel segments, two top segments (segments either side of the key) and a key segment. Keys were often parallel sided consisting of a rectangular keystone about 150mm wide. Construction required the two top plates to be physically lifted to allow the key to be installed. This was fine in good ground with hand built rings, but was not practical for mechanised tunnelling.

Subsequently the parallel key was replaced with a trapezoidal shaped key, which allowed a machine ram to push the key into place. An added advantage of this approach was that the gaskets were not in contact until the key was slid into place, and gasket tear-out was greatly reduced.

The trapezoidal ring

In the early 1980's, designers and contractors began to experiment with trapezoidal segments. The change was driven by the need to improve water-tightness of the lining and the substitution of rubber gaskets for previously used hydrophilic gaskets. With a rubber gasket, there was a need to slide each segment into place before contact was made. This was not possible with parallel segments, where it was necessary for the TBM erector to compress the radial gaskets to align the bolt holes. With trapezoidal segments, the gasket does not make contact until the bolts holes are aligned.

The initial trapezoidal ring consisted of six identical trapezoidal segments. These could essentially be thought of as three keys and three counter keys. One of the disadvantages of this type was in the building of the ring. Starting with a counter key segment, the build sequence required a "key" segment to be built on either side of the key before installing the other two counter keys. This resulted in difficulty compressing all the gaskets and ensuring water tightness of the liner.

Bolting of the rings was also an issue. One pass rings had bolted connections for the radial and circumferential joints. To make this practical, bolt pockets with curved holes were provided in each segment and curved "banana bolts" were used for the connection. These were effective; however, to provide sufficient clearance for the threaded section it was necessary to oversize the hole. This inevitably led to movement of the segments, an increase in lipping of the joints, and overall liner quality concerns.

Over the course of several projects the system advanced, culminating in the modern universal ring used today.

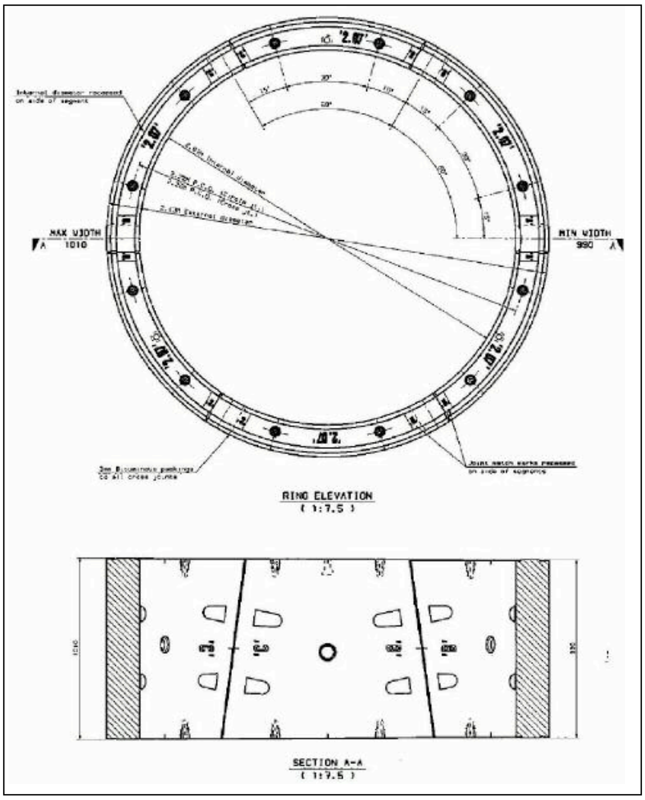
Tapered ring

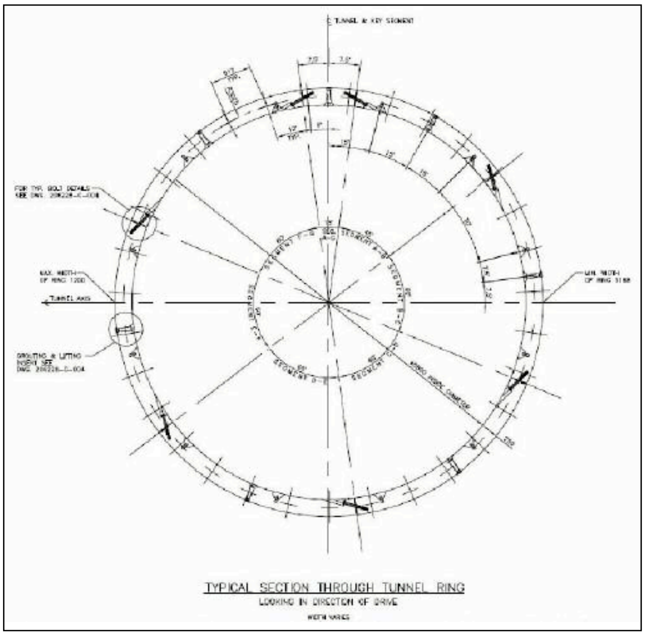
One of the issues with any segmental ring is negotiating curves. With a non-tapered ring, it was necessary to pack the longitudinal joints. This would accommodate curves in the tunnel; however it created ring build quality problems. When a parallel ring is packed on one edge, the ring loses its plane; for example, if the left side of a ring is packed the sides of the ring will project further forward than the mean of the top and bottom. Within a segmental ring, this causes a geometrical shift and the ring looses it circularity. This in turn makes it harder to build subsequent rings.

To counteract this, extensive surveys and checks were required during and after construction to allow appropriate adjustments through packing of the rings. A tunnel engineer would typically carry out a series of checks as detailed below:

- Check the laser orientation and record the position of the TBM.
- Extend "square marks" along the tunnel wall by measuring forward from previous marks with periodic checks using an

Below: **A trapezoidal segment layout**





optical square from the laser or by means of a 90° eyepiece from the theodolite.

- Measure the square of the ring relative to the theoretical alignment. This would be done by using a square mark for the horizontal lead and by means of a plumb bob for the vertical.
- Measure the ring build diameter both horizontally and vertically to determine the circularity.
- Measure the plane on the ring by means of a horizontal straight edge combined with a plumb bob.
- Calculate the theoretical leads and advise the lead miner of the packing required to steer the ring and mitigate plane issues.

This was obviously a lengthy procedure and required a full time engineer at the TBM. In addition, any packing to the joints would introduce a weak point in the gasket system and could lead to leaks and the need for additional waterproofing later on.

The tapered ring was developed using a standard ring with a single key, and introducing a taper to the ring width. Tapers varied but were generally between 10mm to 20mm. A nominal 1m wide ring with a 20mm taper would therefore consist of segments ranging in width from 990mm to 1010mm; the tunnel could now be steered by directing the taper in the desired direction, while maintaining the plane of the rings.

With a tapered ring, the geometry of each individual segment is different. This introduces complexity in casting, with individual moulds required for each segment. The tapered trapezoidal ring mitigates this issue to some degree. With all the segments trapezoidal, this ring consists of three pairs of identical segments.

Ring building typically starts with a segment in the invert and ends with the final plate or key placed above spring line. With a tapered ring, the required alignment of the taper is determined at the end of each mining cycle by measuring the gap between the last ring built and the TBM. It is not possible to determine the orientation until the TBM has completed mining, as it is dependent on TBM steering.

A build sequence starting in the invert was driven by the method of operating the TBM segment erectors, combined with most owners specifying that the key needed to be built above spring line. The origin of this requirement is not really clear; however, discussions with the industry have found that it was thought to provide better build quality. Subsequent projects with the key built anywhere around the circle have disproved this assumption. It should be noted that in the case of a full trapezoidal ring there are actually three keys, so this requirement does not apply.

Left top: Tapered ring on the Sheppard Subway, Toronto
Left bottom: Tapered precast liner design – Edmonton SLRT

A key issue with restricting placement of the key segment to above spring line is the impact on delivery of segments to the TBM. This is a greater issue with small diameter tunnels, where there is generally insufficient clearance to rearrange the segments within the machine in order to provide the segment with the required taper to start the ring build. Consequently the delivery order of segments is critical but in many cases is not practical to make adjustments during operation without causing delays due to the length of the tunnel drive.

Universal ring

Modern tapered segmental rings have mitigated many of the early issues. They generally consist of two trapezoidal key segments and a number of rhomboid side segments (normally between 4 and 6) to make the full ring. The usual configuration is for the keys, referred to as a key and counter key, to be opposite one another within the ring (i.e. 180°). Ring erection commences with the key, follows with placement of two (or three, depending on design) rhomboid segments on either side, and finishes with the counter key. Some projects have been carried out with the two keys adjacent to one another in the ring; however, this configuration restricts the building process to one direction only. In this case, ring building must start with the counter key, and work sequentially around the circle, ending with the key. For a ring design with the key to the right of counter key, the build will always need to be carried out in a counter clockwise direction. A consequence of this approach is that, with the erector always acting on the same direction, it can introduce a roll to the tunnel.

A universal ring has the great advantage that the build process always starts with the same segment (the counter key) for all rings. Depending upon the required orientation of the ring taper, this segment may be built anywhere around the circle. Taking advantage of this factor, it has been possible to reduce the key size, which increases ease of construction. It also reduces the recoil distance required and, consequently, the TBM ram stroke and tail can length.

Modern rings have replaced the old style "banana bolts" with straight spear bolts that screw in to cast-in plastic inserts and have

Right: The Universal ring

introduced the option of using dowels for longitudinal joints. These changes have greatly improved the build quality and ease of construction of the liner. Other advancements, such as double gasketed systems and hydrophilic gaskets for use in extreme water head areas have also improved final quality.

Ring selection

There are several criteria to consider when selecting the optimum ring configuration. A review of recent tunnel projects will reveal many variations of the universal ring are being used. This section provides a discussion on the key factors to be considered. It is important to note that there are no right and wrong choices, and many decisions will be a matter of preference.

Ring width - (Width of the segments along the tunnel)

The optimum ring width is the subject of much debate. Logically, the wider each ring, the more production will be achieved for a set number of rings in a shift. As tunneling is generally cyclic, this is an important factor, especially as tunnel length increases. Additionally, by increasing the width, the total number of rings required for the tunnel is reduced. This can be an important factor if the ring joints and bolt pockets are to be patched ultimately.

The ring width affects the design of the TBM and tunneling system in a couple of ways. First, the design of the TBM, such as tail can length and clearance through the trailing gear must be considered. Back up equipment to accommodate the ring width and resultant excavated material per cycle is impacted – such as muck handling equipment and grout quantities. The width also directly affects the taper required to navigate curves; as ring width increases, amount of taper required to achieve the same curve radius increases.

There is no definitive consensus on an ideal ring width, however, analysis of projects to date suggests an optimum width of between 30% to 40% of the finished diameter.

Ring taper

The taper is generally determined by a combination of the tunnel alignment and width of ring. The ring taper and ring width should always be considered together. The minimum curve radius on the project will dictate the taper of the rings required. As a rule of thumb, it is preferable to incorporate a taper equaling twice the calculated taper required to negotiate the tightest curve, to allow for steering adjustments. There are issues with providing too much taper including build problems within the tail can and a tendency for adjacent rings to move sideways as thrust imposed producing lipping between rings. As the positioning of the segments within a completed ring is incremental, a compromise must always be met to position the segments in the best-fit orientation. One solution is to provide standard tapers with shorter rings for the curve.

One of the factors to consider is where on the circle the taper should be. This is not of major importance but for simplicity in ring selection, it is suggested that the widest part of the ring should be the counter key (first segment built). This has advantages in ring selection and also means the key is the narrowest segment, assisting in placement.

End purpose – Type of concrete – finish/durability

Many clients are now seeking more durable products, with longer design life. For sanitary sewers, some owners are now specifying secondary linings for corrosion protection. In lieu of installing a separate pipe within the completed tunnel, several methods, such as spray on linings or secondary PVC membranes have been tried with varying degrees of success. Any secondary lining will extend the schedule and negates one of the advantages of a one pass lining. Recent developments in sulphate resistant concrete and polymer concrete provide an alternative, as well as fundamental system designs providing improved ventilation. For tunnels that do require a secondary lining, minimizing the number of bolt pockets and mitigating steps and lips is a must.

Another consideration is the use of steel fibre reinforcement. The majority of concrete segments cast to date have used a traditional steel reinforcement

Above: Segment storage in Toronto, Ontario

cage. Modern developments with steel fibres have allowed the deletion of this cage, which reduces segment manufacturing costs, improves durability, and mitigates the potential for damage during handling.

Constructability

There have always been concerns with commencing the ring build above spring line. For this reason, some people have elected to provide left and right rings with opposite taper orientation, or rings that can be rotated within the TBM. The latter option is only possible with a standard universal ring with a key and counter key that are the same size. Although these systems do increase the odds that the first segment will be in the invert, it does not guarantee it, and can lead to other issues. Increasing the number of variables in the ring build process does increase the possibility of human error and potential for ring build quality problems as a result of improper ring orientation.

Ring building

Modern universal rings make ring building simple compared to the early systems. Liners are built to follow the TBM, reducing the number of measurements and calculations required. In the early days of the tapered ring, tunnel engineers continued with their extensive measurement and checking regimes, however it very quickly became apparent that most of these were unnecessary.

The method of installation now requires a check of the gap between the segment and the tail can. The maximum taper width is then placed at that location.

Improvements in guidance systems have also simplified the process, especially the addition of ring placement software, which allows placement of the next segment to be determined at the push of a button.

The ring plane, square and circularity are now generally less important and in some cases are not measured. Improvements in tolerances of segment casting, bolting systems, TBM erector systems and guidance systems have all contributed to creating a better-finished product.

Conclusions

At this stage there are no hard and fast conclusions when it comes to the optimum ring; however, the Authors consider the universal ring to be the ideal lining system for modern tunneling. Extensive research into modern systems would provide more insight, but current systems are advancing at such a rate that such a study may be outdated before it was completed. Future developments on TBM design, concrete materials, casting techniques and automated build systems will inevitably develop things further, and exciting advances such as extruded liners, laser guided erectors, expandable liners for EPB tunnels and polymer concrete segments are on the horizon. ■

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Bibliography

British Transport Museum – London England

London Under London – A subterranean guide – Trench / Hillman