derground stations.

Cut-and-cover running tunnels are also shallower than TBM running tunnels, allowing for user-friendly stations. During consultation the public made it known that most were against having to use deep underground stations.

All these factors were said also to carry cost savings over deep bored tunnels and deep open cut station excavations, as well as add greater predictability, flexibility and less potential risk of delay to the limited construction program.

Nevertheless cut-and-cover construction along Cambie Street from 2nd to 64th Avenues will be a tight operation with little room available either side of the open trenches for laydown of equipment such as cranes and supplies. Blasting of volcanic rock is also scheduled to start in April 2006 to excavate a length of about five city blocks through the Little Mountain district. Most other trench excavation is by excavators through softer till and top soils and between walls supported by soil anchors, wire mesh and shotcrete. Ground water is not expected to pose significant concern in most areas. In some locations dewatering will be required.

Throughout construction InTransitBC has promised citizens and public authorities that both pedestrian and vehicle access to businesses, homes and facilities along the busy Cambie Street corridor will be maintained.

TBM tunneling

For excavation of the 2.2km of bored running tunneling in the downtown area, SNC-Lavalin/SELI JV has ordered a Lovat EPB TBM. The 6m diameter machine will work through a complex geology of sandstone and glacial till with the high probability of meeting volcanic dykes in the sandstone strata and large granitic boulders in the till. Beneath False Creek, a water level tidal range of 4m will cause a twice daily half bar fluctuation in EPB operating pressures. The machine is designed for operating pressures of up to 4 bar and a ground penetration rate of 15cm/min.

The TBM cutterhead is dressed with 17in cutters and is powered by a 1,200kW variable frequency electric drive. The machine is also equipped with a ground conditioning system for generating and injecting foam and polymer conditioning agents. A bentonite ground-loss replacement system is also included for fine control of EPB pressure.

Settlement is a concern. The bored tunnel route runs beneath city streets lined with highrise office and residential towers. Construction and supervision teams will monitor real-time ground movement readings.

En-route the TBM must negotiate tight 200m radius curves to avoid building foundations and make the alignment turn at the Davie-Granville intersection.

The TBM was ordered as a priority after the project's PPP agreement was signed in July 2005. It is scheduled to arrive on site in April 2006.

Also started early was set-up by the JV of its own segment-casting yard. The 6m o.d. tunnels are lined to a 5.3m i.d. with rings of bolted, gasketed precast concrete segments. The casting yard is in Nanaimo on Vancouver Island and segments will be barged over to False Creek.

Tunneling for both drives will progress northward from the False Creek South station box. The TBM is expected to begin its first drive in June 2006 and will operate on a 24h/day, seven day/week schedule. It will be pulled through the open boxes of the Yaletown and Robson stations with the exception of the first drive when it will mine through the Yaletown station location.

In less than four year's time, the new Canada Line will provide a major public transit link to Richmond and the south of the city. It will also offer a center-city checking facility for air travelers at the Waterfront transportation hub and a 25 minute LRT trip from Waterfront Station to the YVR airport terminal. The concentrated and intense activity to get all in operation for the November 2009 deadline and the start of the 2010 Winter Olympics is now on. ■

Seismic upgrade for Massey Tunnel

One of the world's first precast concrete sunken immersed tube tunnels is getting a facelift. From Vancouver, *T&TNA* contributor **Tonia Jurbin** reports.

The 45 year old, 2,000ft (619m) long George Massey Tunnel carries four lanes of traffic under the Fraser River to the south west of Vancouver. Built in an era when little consideration was given to seismic concerns, the tunnel is made up of six 1,150ft (350m) long precast sections in a trench underlain by almost 2,000ft (619m) of loose saturated sediments.

When discussing the seismic retrofit program for major bridges and transportation structures around Vancouver, Peter Taylor of Buckland & Taylor Limited Bridge Engineering of North Vancouver observed: "We're getting there. We haven't attached as much importance to improvement as they have in California, but since their program started they've had three major earthquakes and every earthquake shakes a little more money out of the system."

Vancouver may have some catching up to do, but with more bridges and less people than southern Californian cities, planners are forced to be more effective in how upgrade dollars are spent. "We have to do more with less", Taylor continued. "We target our upgrades to cost a maximum 30% of a replacement - which is something to be proud of." While he concedes that stiffer requirements in California do drive up the costs, he put costs into perspective by explaining that where California is currently investing $US6 billion – and counting - on replacing half of the San Francisco–Oakland Bay Bridge, the annual upgrade budget for southeast British Columbia's highway bridges (not including the Massey Tunnel) is about $US5 million.

Upgrading of the region's bridges and the George Massey Tunnel is vital as they are designated lifeline structures on Vancouver's Disaster Response Route (DRR). Vancouver is the first city to develop a network of land and water transportation routes that will be open to emergency vehicles only in any post disaster situation. As a result, every vulnerable component on every DRR - whether it is maintained by the City of Vancouver, Ministry of Transportation, or TransLink - has been, or will be upgraded.

"The George Massey Tunnel upgrade is certainly the most costly and technically challenging of all the retro-

Left: Crews prepare the main joint between tunnel sections for structural repair and strengthening

fits", explained Allan Galambos, Manager of Bridge and Structural Engineering, South Coast Region, Ministry of Transportation in British Columbia. "With little precedence for seismic retrofits of sunken tunnels, we designed a program of about $US16.8 million structural repair and a projected $US15 million for future geotechnical work." This 2002 estimate is now expected to be considerably higher.

Though the quality of the Massey Tunnel precast concrete is still good, there is only about half the reinforcing that would be used today. This makes the structure incapable of handling any relative movement.

Above: Additional re-bar installed to the roof of the air duct

Above: Butterfly joints span a sunken tube section joint

The plan for the structural upgrade was to add reinforcement to ensure that an earthquake would induce many well distributed cracks as opposed to a few large ones.

The biggest challenge was finding space where to add steel. Taylor explained: "We had to pack in steel wherever we could. It is really very tight. Trucks already scrape the ceiling so we can only reinforce the ceiling corners, the floor and the walls." Steel was also placed in the wind tubes and the air ducts.

The original joints between the concrete sections were formed by welding the embedded reinforcement together and encapsulating the welds in concrete. These are now reinforced by spanning them with 8.2ft long, three quarter inch (2.5m x 20mm) steel 'butterfly joints'. The butterfly joints as well as structural repairs and additional re-bar is encased in a poly fiber reinforced shotcrete finish.

Unfortunately, as is often the case with rehabilitative work, once crews started to peel away at the structure unanticipated challenges were discovered. Concrete in the air ducts was delaminated and had to be removed. Conflicts between the structural reinforcement steel and the proposed doweling to key new layers of concrete also caused delays.

To get the project back on track, prime contractor Kenaidan Contracting Ltd of Mississauga, Ontario brought in more staff and lengthened the working week.

Above: Reinforcing steel added to the floor of the air duct

Having started its $18.6 million structural repair contract in September 2004, Kenaidan is completing work on the first tube and will move into the second traffic tube and air duct over the next six months completing the contract about six months beyond schedule.

One traffic tube has remained open throughout the works with the tube under structural repair closed from 11pm to 5.30am, 7 days a week.

Once the structural upgrades are complete the tunnel will be able to withstand the rigors of a separate contract to complete geotechnical upgrade. Earlier concerns of the tunnel floating during an earthquake resulted in rock and concrete being placed over the tunnel, which add to the challenge of underwater ground improvement. The plan is to improve by densifying a 50ft (15.25m) wide strip along both sides of the tunnel (65ft wide near the river bank) and to 30–45ft (9-13.7m) below the mudline using stone columns or timber piles. Grid spacing would be refined during construction as the riverbed is not flat and scour holes could cause lateral spreading during the densification, possibly causing the tunnel to shift horizontally. Other measures to prevent movement include careful monitoring, and alternating the densification between both sides of the tunnel.

Because of the delays and increased costs of the structural rehabilitation contract, and also changes in the Canadian building code that are yet to be adopted into the British Columbia code, the geotechnical upgrade will be re-evaluated, and possibly redesigned before it is offered for tender in March 2007 at the earliest.

Galambos' wish list is modest. "We are going to get what we want eventually, obviously the faster you do your upgrades the more you cut down the risk before the earthquake hits. However funding is limited and using all of the money for seismic upgrades takes funds away from deteriorating structures elsewhere. Our program considers public safety as well as the ability of the lower mainland to function economically post disaster. We know that closing any structure has a huge impact on the region. A highway component failure would cause a standstill. All things considered, I'm happy with the current level of funding, especially given the competing projects such as Vancouver's hosting of the Winter Olympic Games in 2010." ■