Canada Line Cut and Cover Tunnel Shotcrete Shoring

Vancouver, BC, Canada

By Roger W. Abbott

Driving north from the Fraser River on the 4.3 mi (7 km) corridor of Cambie Street, a main artery into downtown Vancouver, one is oblivious to the fact that up to 72 ft (22 m) below the surface is one of the largest shotcrete shoring projects in North America—that of the new rapid transit Canada Line project (Fig. 1).

Originally called the RAV line (Richmond, Airport, Vancouver) from Vancouver International Airport to Downtown Vancouver, the $2 billion (Canadian) project was completed below budget and opened on August 17, 2009, 15 weeks ahead of schedule.

The challenges were great to make the project viable. Major sanitary and storm sewers and water mains within the building envelope had to be relocated clear of the work well ahead of time (Fig. 2). Fiber-optic cable, gas, and electrical lines also required diverting. Anchors were to be installed on both sides of the trench and shoring designed accordingly to miss the services by 3 ft (0.9 m), which was a real challenge at times. Over 26,000 tensioned anchors were installed along the route. Drillers were tense, especially drilling for the first two rows where services are usually encountered. Old services that had been abandoned due to relocation were frequently hit while drilling. Surveys of old services also proved useful in identifying potential problems.

The other limiting criterion was that anchors could not encroach on neighboring private property. This created some design challenges that, at times, required some innovative solutions. Shoring wall shotcrete had a ± 1 in. (25 mm) requirement to permit the use of the contractor's collapsible box formwork.

The soil types encountered along the route varied from running sands, silty sand, sandy silt, till, rock, peat, coal, old ravine infill, and anything in-between. Soil investigations, prior to designing the line, identified one area of high water table at a large intersection where a station was also to be constructed. Several deep 5.9 in. (150 mm) Φ wells were installed and frequently monitored and modified to lower the water table some 59 ft (18 m) to permit station construction and shoring in the area under relatively dry conditions.

Major intersections were laced with services crossing the trench, which had to be supported individually to eliminate the possibility of damage. It was here, especially, that the versatility of shotcrete had a major impact. Some vertical shoring elements were installed where horizontal anchors were impossible. Small shotcrete applications were normal until structures were all tied in, with much hand digging required.

Traffic bridges, pedestrian access bridges, and service supports had to be constructed ahead of

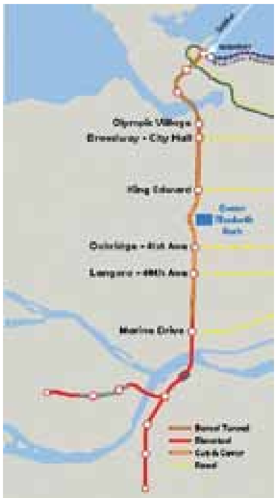


Fig. 1: The Canada Line project

Cambie Line Cut and Cover Facts

- 3.9 mi (6.2 km) of double-sided shotcrete shoring up to 70 ft (22 m) deep through a main street lined with retail and residential buildings
- 693,717 yd³ (530,000 m³) of excavation
- Approximately 19,634 yd³ (15,000 m³) 5075 psi (35 MPa) shotcrete
- 39,267 yd³ (30,000 m³) is rock at Little Mountain
- Over 1,076,000 ft² (100,000 m²) of tieback anchored shotcrete shoring and underpinning
- Over 26,000 tensioned anchors
- 153,141 yd³ (117,000 m³) concrete
- 14,330 tons (13,000 metric tonnes) of steel

Fig. 2: Service support and congestion at cross street

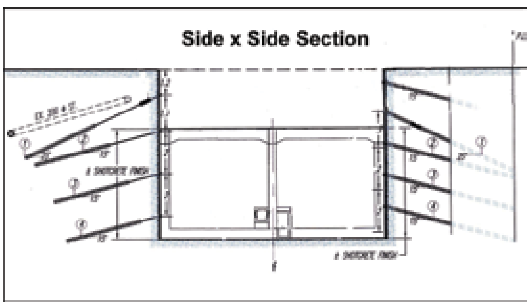


Fig. 3: Side-by-side section

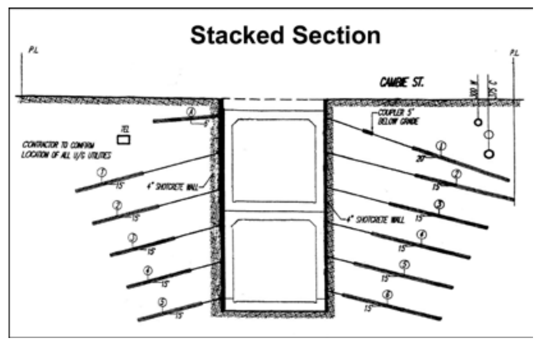


Fig. 4: Stacked section

the excavation and shoring work to provide uninterrupted traffic and pedestrian access. Through some of the sections, communications cable and fiber optics were slung along the side of the trench on hangers.

There were three different tunnel configurations: side-by-side in the wider sections where space would allow (Fig. 3, 6, and 7); stacked through the business section where access was smaller (Fig. 4 and 8); and a rollover section (a rollover is a transition from side-by-side to stacked) (Fig. 5 and 9). Through-traffic was maintained at all times on two of the four lanes along the entire length of Cambie Street (Fig. 10). The first section—64th to King Edward Avenue—comprised two southbound and two northbound lanes with a large grassed and treed central median. This section was where there was room to build the side-by-side structure. Trees were preserved with great care in the central median to try and eliminate any possibility of damage. Some of the flowering cherry trees and other species had been gifted to the city of Vancouver by the city of Yokohama on the occasion of the 1967 Canadian Centennial. Residents along Cambie Street created the Cambie Boulevard Heritage Society in 1994, which opposed any alteration to the wide green center median.

Configuration of the structure was:

- Side-by-side construction ..2.6 mi (4.24 km)
- Rollover transition from side by side to stacked.................................0.5 mi (0.8 km)
- Stacked construction ....0.75 mi (1.2 km)

There were five stations along the cut-and-cover portion: 49th Avenue, 41st Avenue, 25th Avenue, Broadway (9th), and Olympic station at 2nd. From this point north, the twin tunnels were bored using tunnel boring machines (TBMs) underneath False Creek waterway to the downtown Vancouver core.

Construction began in December 2005 using the anchored shoring method commonly used in Vancouver. This system differs from the soil nailing system more commonly used in the U.S. and Europe. The soil nailing system was actually created in Vancouver in 1967 by Dr. Ted Mason, a local engineer.

A silica-based grout was used, as its high early strength (5802 psi [40 MPa] in 24 hours) allowed anchors to be tested the next day, which is essential to maintain the continuity of the shoring in coordination with the excavation. All anchored shoring panels were shotcreted the same day they were excavated. With the tensioned system, far fewer anchors are used, thereby making it a more economical system. Shotcrete was nominally 4 in. (100 mm) thick throughout the normal shoring wall. In areas where service avoidance resulted in greater than normal supported height, additional reinforcing and up to 8 in. (200 mm) of shotcrete was used, sometimes with vertical shoring elements such as micro piles. The underpinning of buildings around the stations was also 6 to 8 in. (150 to 200 mm) thick shotcrete. In a few limited areas where clearance to the property line was minimal, the soil nailing method was used.

The shotcrete used was a 5076 psi (35 MPa) mixture. Reinforcing of the shoring wall was one layer of 4 x 4 in.-8/8 (102 x 102 mm–MW13.3/MW13.3) mesh with an additional layer of mesh at the anchor heads. In saturated and weaker soils, additional punching shear reinforcing was provided. A small area of the project was through rock, which was a fairly fragmented basalt. Anchors were greatly reduced in this area; and due to the uneven rock surface, which made contouring the mesh difficult, synthetic structural fibers were used at a dose of 7.25 lb/yd^3 (4.6 kg/m^3) instead of mesh with a 2 ft (600 mm) square of mesh only at the anchor head. Occasionally, silica fume was added to the mixture in tough, wet areas for additional adhesion.

Throughout the stacked section, where the width of the trench was only 17.5 ft (5.3 m) wide, drill masts were modified to fit within the trench. A modified tank drill was used in these sections; it was totally self-sufficient with its own air supply on board and didn't have hoses to drag through the mud. Drainage of the trench was very important, as Vancouver is renowned for its wet climate. Trenches were dewatered by sumps and pumps all along the route. The water was pumped to treatment plants along the route for cleansing prior to discharge into storm sewers. Various anchor types were used throughout the project

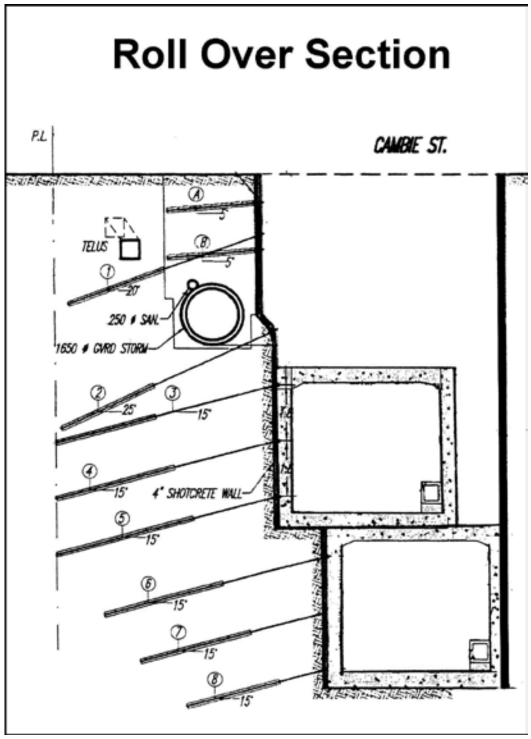


Fig. 5: Rollover section


Fig. 6: Side-by-side forms in place, with slab being prepared ahead


Fig. 7: Side-by-side forms being set


Fig. 8: Stacked section with pedestrian bridge


Fig. 9: Rollover section—start of tunnels transitioning to stacked

depending on the height of the cut. Solid-thread bar anchors were predominantly used; but in areas of pure sand and gravel, hollow grout-injected bars were used with great success. Along the very deep stacked section, areas of clay were encountered, resulting in some anchor failures. Each anchor was tested to confirm required capacity. Anchors could be redrilled or post grouted to achieve the desired capacity, leaving nothing to guess work. Every anchor that is tested is marked with a "T" for tested or "F" for fail as it is easy to lose track on a 3.7 mi (6 km) wall (refer to Fig. 7). Failed anchors were immediately replaced.

As the project got rolling and new areas with relocated services became available, the number of crews was increased to cope with the hectic pace of construction. Up to seven crews were working along the line on any given day. The procedure was:

Day 1: Excavate leaving a safe berm;
Day 2: Drill anchors though the berm;
Day 3: Cut and shotcrete first set of alternating panels;
Day 4: Tension previous day's anchors, cut, and shotcrete; and
Day 5: Tension last day's anchors and cut berm for the next level.

The process was repeated layer by layer.

Once at grade, the base slab was poured and the rolling formwork was set. There were four sets of 65.6 ft (20 m) long box forms that were cycled every 3 days (Fig. 8 and 9).

Shoring crews could see the advancing forming army and knew they had to act fast to get ahead. Survey control was by plumbing down from pre-surveyed control points, and with the tight tolerances, it was imperative to maintain accuracy of the vertical shotcrete wall. Waterproofing membrane was attached to the shotcrete wall in 3.3 ft (1 m) wide strips at the wall joints prior to pouring the concrete. This did not stop leaking entirely, however, and remedial grouting was performed on the soffits. In other areas, the minimal water ingress was merely collected in drainage channels at the edges of the structure and pumped out at the stations.

At the deepest stacked section (69 ft [21 m]) there were 11 rows of anchors. Looking up from the bottom of a narrow 17.4 ft (5.3 m) wide trench is quite an experience and calls for absolute faith in the designer.

Excavation of a 65.6 ft (20 m) deep by 17.4 ft (5.3 m) wide trench in the middle of active traffic and pedestrians presented a challenge (Fig. 11 and 12). Flaggers kept the traffic moving as fast as

Fig. 10: Buses can be seen passing on the right

Fig. 11: Long stick backhoe, fitted with camera on underside of the boom. Monitor is in the cab

Fig. 12: Camera to assist operator's vision of bucket

possible. Coordination was required during shotcreting to prevent blocking access for concrete trucks. Excavated material was recycled or loaded onto barges for ocean dumping at a federal government-approved dumping ground.

The same system of shoring was used for the five stations along the Cambie portion of the line, as they are all below grade. Some stations adjacent to existing buildings necessitated underpinning to shore up existing adjacent structures (Fig. 13).

Shoring was completed in July 2008 and the line opened 15 weeks ahead of schedule in August 2009 with up to 82,500 users daily in the first 6 weeks of operation.

For the designers, managers, and operators of the project for the next 35 years, it was a remarkable feat to overcome the major challenges this project presented, let alone to complete it on time and within budget. It is an example of what can be accomplished with the cooperation of all concerned and the team effort of all involved with the project. Decisions had to be, and were, made in a very timely fashion.

Visitors to the 2010 Olympic winter games, which commence on February 12 and end on March 21, will be the beneficiaries of this remarkable project, with direct links to the venues around Vancouver, Richmond, and the airport (Fig. 14).

Vancouver has aptly been called the "Shotcrete Shoring Capital of the World" because since the late 1960s, every building has been required to have a certain ratio of parking places per tenant. In 2005, Vancouver's density eclipsed that of Manhattan as North America's high-density residential area. Nearly all of the 85,000 downtown residents live in sleek high-rise towers filling the Vancouver skyline, most with up to eight levels of underground parking. The Pacific Centre Shopping Mall is completely underground in the center of downtown and extends four city blocks. Shotcrete shoring has been the excavation support system for the majority of these structures, as there is just not enough room to slope excavations. The flexibility of the shotcrete system has allowed successful completion of challenging projects, especially excavations along the waterfront where old rip rap berms, water ingress, and even buried locomotives have added to the challenge.

Fig. 13: Broadway Station: Note temporary bridge for vehicular traffic, which accommodated two lanes east and two lanes west along Broadway

Fig. 14: One of five completed Cambie Street stations

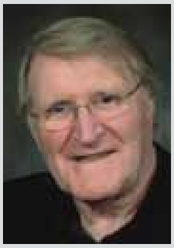
Canada Line Project

Owner/Operator
SNC-Lavalin

General Contractor
Cambie Street Constructors Ltd.

Shoring Contractors
Abbott Shoring & Foundations Ltd.
(49th to 2nd Avenue)
Southwest Contracting Ltd.
(64th to 49th Avenue)

Shoring Design
GeoPacific Consultants Ltd.



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