2002 Vancouver Geotechnical Society Annual Symposium – Keynote Address

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Introduction

In the summer of 1998, the Province of British Columbia embarked on an ambitious undertaking; namely to plan, design and build a 21 km extension to Vancouver's Rapid Transit System (SkyTrain) in a period of only 3 ½ years. This paper describes how this was achieved.

A description of the Vancouver region is first provided, giving details of the planning context under which expansion of rapid transit is being undertaken and the governance structure that was established.

The implementation plan is then described giving details of the project's scope, budget, and schedule and the contracting strategy that was adopted.

The final section addresses the geotechnical challenges that the project met and the various engineering solutions that were adopted to meet those challenges.

Context

Vancouver Regional Transportation System

Vancouver's public transportation system covers an area of 1800 sq. km embracing a population of two million. The population has risen by an average of 8% per year since 1992 and the number of trips has increased by an average of 8% over the same period.

The number of passenger trips per year was 129 million in 2000, making it one of the most heavily used public transportation systems in North America. The transit system comprises of:

- Conventional buses, including articulated vehicles;
- Trolley buses which primarily serve the downtown Vancouver district;
- A 65 km long commuter rail line (West Coast Express) which serves communities in the north east sector and Fraser Valley beyond;
- A 29 km fully automated rapid transit rail line (SkyTrain) which connects Vancouver with Surrey in the south east of the region.

The SkyTrain Line has been a tremendous success with peak period ridership of 7,500 pass/hr/direction which is constrained only by the size of the existing fleet of 150MK I vehicles, each having a capacity of 75 persons.

The existing SkyTrain line is one of only a very few rapid transit rail systems that covers its operating costs from farebox revenues.

Planning for the Future

The basis for land use and transportation planning in the greater Vancouver area is the Livable Region Strategic Plan. This was adopted in 1995 and is based on the development of high density regional centres connected by a high speed rapid transit network.

The area has for many years determined that no urban freeways would be constructed and that the increase in person trips would be accommodated by increased public transportation use and not by an increase in road capacity. Three new rapid transit lines were identified in the 1995 plan as being essential to

the goal of achieving compact development in the Vancouver area, namely:

- New Westminster to Coquitlam
- Broadway to Lougheed
- Vancouver to Richmond

The expanded network is illustrated in Figure 1. Further studies by the then transportation authority, British Columbia Transit, determined that the New Westminster/Coquitlam and Broadway/Lougheed lines were the highest priority and further that they should be constructed using Light Rail Technology.

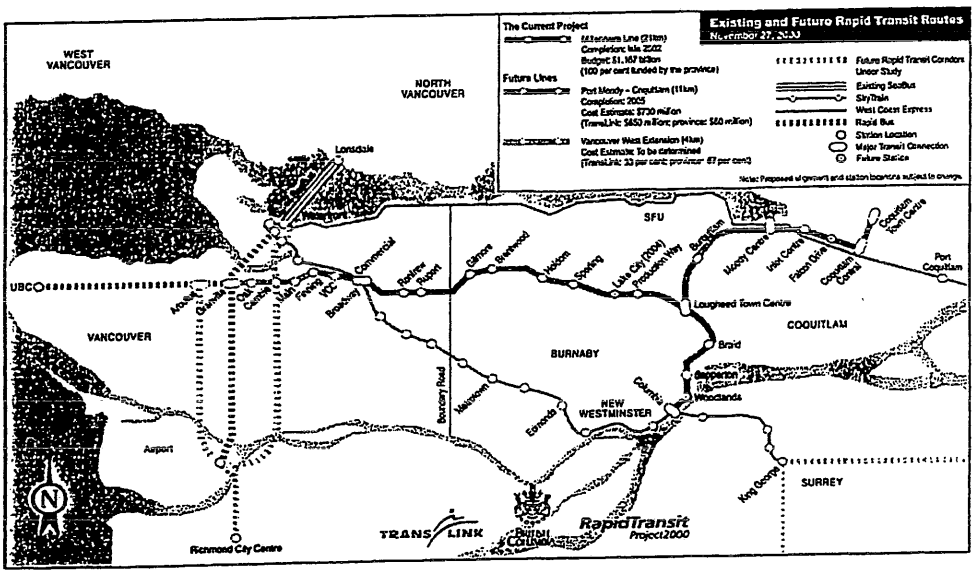

Fig. 1 – Existing and Future Rapid Transit Routes

Establishment of the Greater Vancouver Transportation Authority

Subsequent to the adoption of the Livable Region Strategic Plan, extensive negotiations took place between the Provincial and Regional Governments on issues related to governance and delivery of public transportation services in the greater Vancouver area. These culminated in agreement to transfer these responsibilities from the Province to the region and resulted in the formation of a new regional authority, the Greater Vancouver Transportation Authority (GVTA) or Translink as it was later named. The agreement also included a commitment by the Province to fund 60% of the cost of constructing the two high priority light rail rapid transit lines. These were to be completed by 2005 and the Province would manage their planning, design and construction. The Province opened a Light Rail project office in 1997 to confirm the project feasibility and budget and to develop an implementation plan for the Broadway/Lougheed and New Westminster/Coquitlam corridors.

Decision to Adopt SkyTrain Technology

Immediately after the project office was opened in 1997, the Province undertook a comparison of light rail (LRT) and SkyTrain technologies, costs and level of service.

This study concluded that SkyTrain could be build along the first leg of the Broadway to Lougheed corridor for only 8% more cost than light rail and that the level of service and ridership would be significantly higher.

Based on this information, the Province made a unilateral decision, in 1998, to change to SkyTrain technology and to deliver the first phase of the rapid transit program, defined as the Millennium Line by 2002.

Establishment of Rapid Transit Project 2000 Ltd.

The Province next turned its attention to the method of delivering the Millennium Line. After a study of the alternatives, it was determined that a single purpose body established purely to construct these two rapid transit lines would be the most efficient.

This decision was based on the following:

- The Province's responsibility for public transportation in the Greater Vancouver area would cease after construction of these two lines.
- It would not create a new bureaucracy.
- Procedures would not be constrained by existing government policies.
- It presented the least cost approach and could be wound down quickly as necessary without high cost.

Rapid Transit Project 2000 Ltd. (RTP 2000) was incorporated under the BC Company Act in 1998. The shares of the company were transferred to the Province and the Cabinet appointed a five-member Board of Directors for the Company. The Board reports directly to the Minister Responsible for Transit.

RTP 2000 is staffed through personal service agreements with local consultant companies or with individuals. Three main staff service contracts form the bulk of the organization, namely:

- Fixed Facilities Design & Construction Management – ND Lea Consultants Ltd.
- E&M Systems Design & Construction Management – SNC Lavalin Inc.
- Project Controls – RPA Group

All seconded staff form a totally integrated team that operate as a cohesive unit with each person representing RTP 2000 first.

Staffing for RTP 2000 started in mid 1998 and reached a maximum of 160 in October 2000 and is now winding down as design and construction is substantially complete.

The Millennium Line Project

Scope Of Work

Figure 2 shows the route and station locations along the Millennium Line.

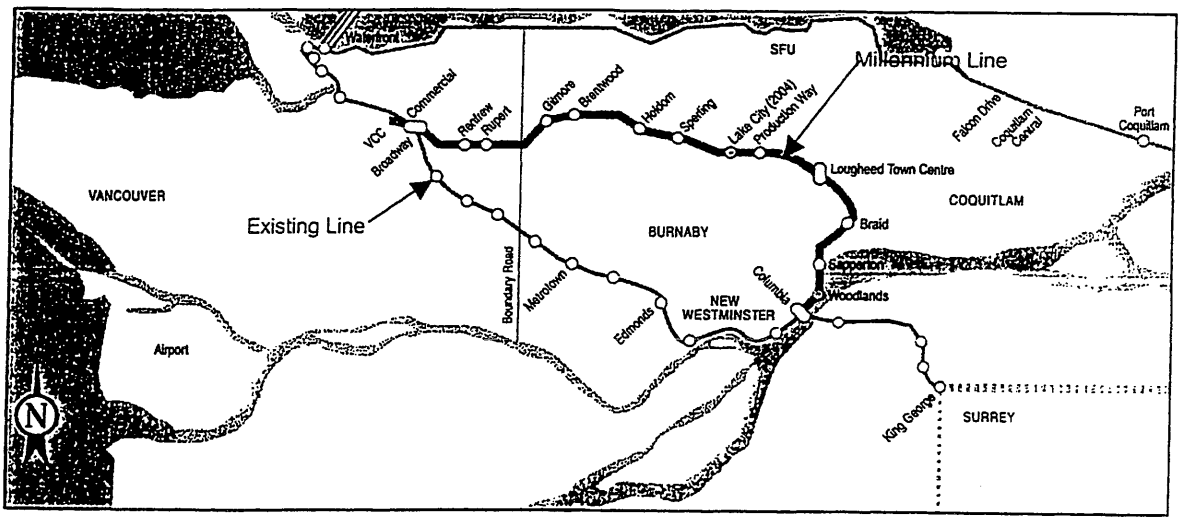

Fig. 2 – Route and Station locations along Millennium Line

The Project commences at Columbia Street in New Westminster where a junction with the existing line has been constructed. Immediately north of this junction the line enters a cut-and-cover tunnel for approximately 650 m before emerging at a portal in a steep slope that forms the western embankment of the Fraser River. The line then crosses the Canadian National Railway (CNR) and the Canadian Pacific Railway (CPR) and Burlington Northern Santa Fe Railway (BNSF) lands before crossing the Trans Canada Highway and running alongside North Road to Lougheed Town Centre. Four long span structures are included in this section to cross Front Street, Brunette Avenue, Brunette River and the Trans Canada Highway.

A complicated junction is being constructed at the Lougheed Town Centre for the future northeast line to Coquitlam. This junction incorporates nine turnouts and will permit trains to move in all directions through the junction thus allowing maximum flexibility in operations. This ability to immediately reverse trains and allow a range of movements was an option only available to a fully automated system.

Leaving Lougheed Town Centre the line proceeds west along Lougheed Highway, a major arterial roadway. The guideway is located either on the side of the roadway or in the centre of the roadway, the specific location being chosen to provide the minimum impact on adjacent land use. After running for 5 km along the Lougheed Highway, the route turns to the south side where it turns alongside the main BNSF tracks into Vancouver. It is initially elevated but changes to an at-grade configuration when it enters the Grandview Cut, a railway cutting. Commercial Station is being constructed within the Grandview Cut section and will be the major transfer station between the Millennium Line and the existing "Expo Line".

A terminal station is planned at the Vancouver Community College (VCC) just beyond the western limit of the Grandview Cut. Tail tracks will be constructed beyond VCC Station for train turnaround, and vehicle and maintenance equipment storage. Currently this section is "on hold" and the Millennium Line will be commissioned to Commercial Station.

Budget

The original project budget of $1.167 billion (CDN) was established in 1998 based on the conceptual plan for the new rapid transit line. At that time the exact siting of the route (in terms of both horizontal and vertical alignment and station locations) had yet to be determined.

This budget was adjusted in April 1999, under a new work breakdown structure, after completion of the Planning and Preliminary Engineering Phase, after proposals for the two major design/build guideway contracts had been received, and after the vehicle contract had been finalized.

The revised baseline budget, under which design and construction was controlled, is illustrated in Figure 3. The Figure also shows the forecast cost at completion as at January 2002.

Millennium Line Baseline Budget			
	June 1998 Budget Estimate	**April 20, 1999 Baseline Budget**	**January 2002 Forecast at Completion**
Guideway	328,330,000	306,611,999	379,249,632
Stations	85,220,000	93,911,975	110,423,426
Systems	162,100,000	169,265,441	229,847,501
Vehicles	108,200,000	109,447,000	110,447,000
O&M Centre	1,940,000	7,386,000	7,386,000
Design	30,899,917	47,683,644	26,458,283
Project Management	91,585,167	114,595,900	93,238,287
Insurance	5,924,584	5,900,000	4,775,798
Property	32,520,000	53,120,000	47,448,904
BC Hydro	21,080,000	15,000,000	9,991,571
PST	16,014,328	19,401,209	796,374
GST	33,336,436	27,687,659	-
Total before IDC & contingency	**917,150,432**	**970,010,827**	**1,020,062,776**
Interest During Construction	105,590,520	90,376,484	95,361,578
Contingency	143,810,000	106,163,643	51,125,646
Total accelerated	**1,166,550,952**	**1,166,550,952**	**1,166,550,000**
Percentage of fixed costs committed		**55.68%**	**97%**
Percentage of contingencies used		**26.18%**	**65%**

Fig. 3 – Budget

The overall contingency was reduced in April 1999, by CDN $37.6 million from CDN $143.8 million to CDN $106.2 million. This represented 26.18% of the contingency sum but was considered appropriate as 55.7% of the construction costs had been determined through actual contracts and fixed priced proposals.

As of January 2002, 97% of the fixed cost have been committed (to Commercial) and the contingencies stands at $51.1 million. $27 million of the contingency relates to a reduction in GST.

Schedule

Figure 4 shows the original project schedule and the revised schedule that was adopted after the requirements for CEAA approval became known.

Stage 1 completion was achieved at the end of 2001 and the Project is on schedule for Stage 2 completion in August 2002.

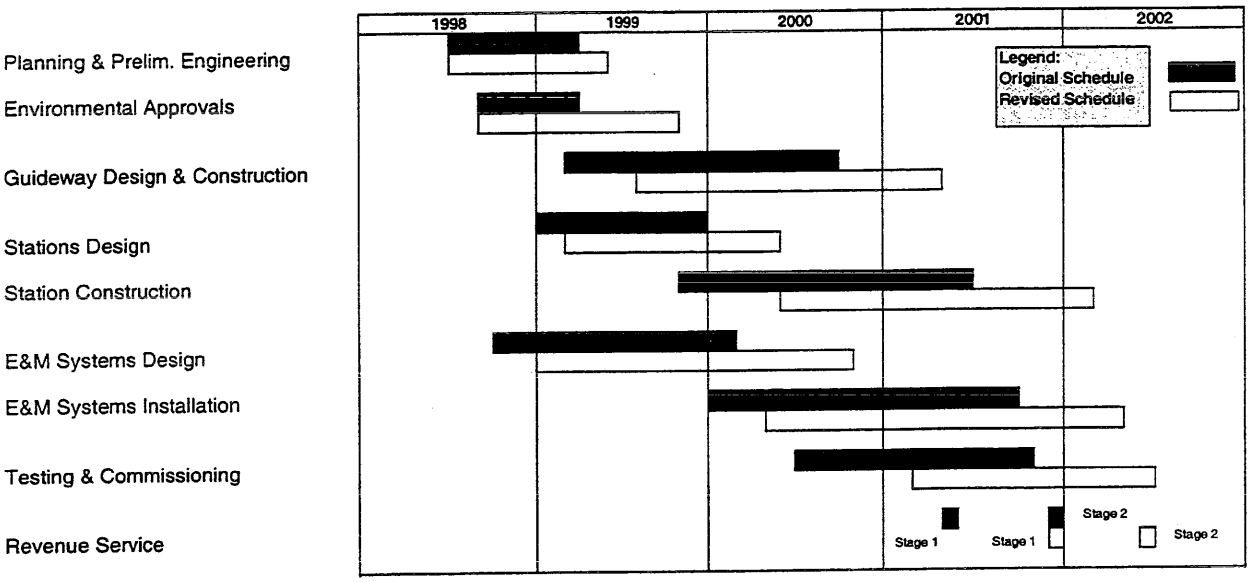

Fig. 4 - Schedule

Contracting Strategy

The project team developed a contracting strategy within the period of the Planning and Preliminary Engineering work that was aimed at limiting the risk to the Province, and at completing the work within the shortest time period possible.

Bombardier MOU

The first consideration in developing this strategy was the development of a Memorandum of Understanding (MOU) with Bombardier Transportation.

This defined two principal contract packages, namely:

1. Vehicle Contract – Design, manufacture, testing and commissioning of 40 MK II automated vehicles.

2. E&M Systems Contract – Design, construction, testing and commissioning of all E&M systems, including: trackwork, power supply and distribution, LIM reaction rail, communications and security systems and automatic train control.

The decision to bundle all the E&M system work into one contract had a profound impact on the work required of the Owner's Project and Design Management Team as the one contract, in effect, replaced 30 supply and installation contracts that were put in place for similar, previous, SkyTrain projects.

Guideway

The principal objective in producing a design and construction philosophy for the guideway was to minimize the number of contracts and to reduce the Owner's risk as much as possible. The first decision was to adopt a design/build approach wherever possible. This recognizes that design of the guideway structure provides the greatest opportunity for innovation and that construction methodology can be the determining feature in developing the most cost effective design solution. Design/build could also deliver the guideway in the shortest possible time period, a key consideration having already agreed to bundle the E&M System work into one contract.

The following criteria were used when determining the most appropriate contracting arrangement for the fixed facilities.

Environmentally sensitive structures mean those that were subject to permit approvals for which detailed design information is required as part of the permitting process.

Criterion	Guideway	Environmentally Sensitive Structures	Stations
Many different design solutions	√	√	X (determined by architectural concept)
Design development independent of third parties	√	X (Environmental Agencies Railway Safety Act)	X (public and municipal input/review)
Little change during detailed design of E&M Systems	√	√	X (electrical room layouts, systems integration)
Costs heavily influenced by construction methodology	√	√	X
No detailed environmental permits required	√ (only if design impinged on defined riparian areas, which could not be crossed by standard spans)	X (foundations required in environmentally sensitive areas)	√
Design risk easily transferable	√	X	X
Design/Build Appropriate	YES	NO	No

Fig. 5 – Design/Build Criteria

As a result of this analysis the following implementation strategy was developed for the guideway.

- A full design/build contract for the standard elevated guideway (i.e. uniform beam section).
- A design/build contract for the underground section.
- Four conventional design/tender/construct contracts for special long span structures in environmentally sensitive areas.
- Two conventional design/tender/construct contracts for the at-grade guideway through the Grandview Cut, an environmentally sensitive area.
- A conventional design/tender/construct contract for the complex junction at Lougheed Town Centre.
- A conventional design/tender/construct contract for the tail tracks at VCC Station.

A total of two (2) design/build contracts and six (6) conventional contracts were therefore planned.

Later this reduced to two (2) design/build contracts and five (5) conventional contracts after a proposal to include three (3) of the long span structures into the standard guideway contract was accepted. (see Figure 6).

Stations

Figure 5 identifies design/build as being inappropriate for station construction. The Millennium Line stations were designed under seven design contracts each led by an architect. The designs were subject to change through the public and municipal consultation process, through development of the E&M Systems design, and through operational reviews.

The designs were thus developed to a stage that left little opportunity for savings through

innovation and construction methodology. There were therefore no perceived benefits by adopting a design/build approach.

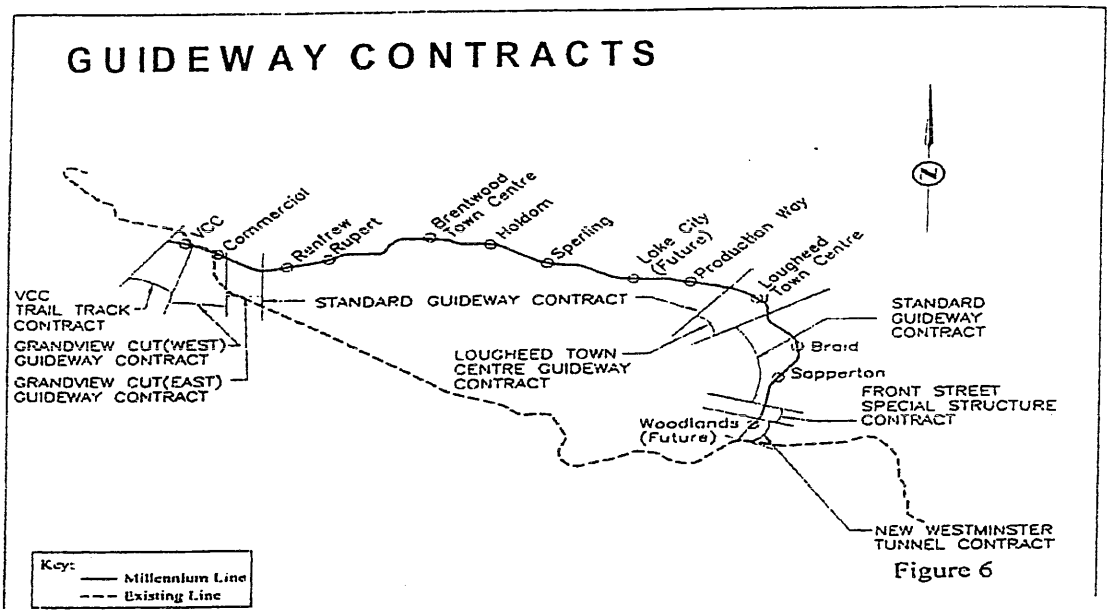

Fig. 6 – Guideway Contracts

Geotechnical Challenges/Solutions

The following describes the geotechnical conditions along the route, the particular challenges that these ground conditions presented and the solutions that the designers adopted.

New Westminster Tunnel

The ground conditions along the length of the tunnel comprised of tills with intertill sediments overlaid by surficial materials comprising of fills, raised beach gravel deposits and glacio-marine deposits.

The tunnel was constructed by the cut-and-cover method with the principal challenge relating to the temporary excavation support system. The Contractor Walter/BFC chose to adopt a shotcrete and anchor method which worked very successfully. Goundwater control, which had been a problem on past tunnel excavations in New Westminster did not present much of a problem. Wellpoints were installed on the upside of the excavation but did not prove to be particularly effective and most of the groundwater was controlled from within the excavation.

The north portal of the tunnel is located in a very steep slope within a congested site between the CN Rail track and Columbia Street. The portal walls were designed using permanent ground anchors whilst steel pipe piles were installed to support the abutment for the elevated guideway onto which the Guideway transitions through the portal area.

This contract was delivered through the design/built process and proved to be, probably, the most successful contract on the whole project.

Front Street Special Structure

Ground Conditions

This is a three span trapezoidal box structure with a maximum span of 90M.

At its southern end the structure sits on the till that forms the steep embankment above the river. At its northern limit the structure is directly on the river bank which comprises of silt, sand and gravel fills of variable density overlaying the Vashon till.

Foundations

Single caissons were adopted as the foundation of choice for this structure. One of these foundations is located on the bank of the Fraser River and incorporates a tie-back retaining structure to protect from possible liquefaction during a seismic event.

Front Street to Lougheed Mall

Ground Conditions

The first section of this segment runs along the bank of the Fraser River. The ground here comprised of sand and gravel fills overlaying very dense silty and gravelly sand (till-like).

As the alignment moved further north a deep layer of peat and normally consolidated silts was encountered.

Where the alignment parallels the Trans Canada Highway the ground conditions change with the natural silts generally consisting of raised beach deposits including fine sands and silts with lenses and interbeds of gravelly sand. These natural soils are overlaid with fill materials used to form the Trans Canada Highway.

The final length of this segment is along North Road where the ground generally consists of unconsolidated sands and gravels overlying glacial till.

Foundations

This was the first section of the design/build contract for the standard elevated Guideway and which was undertaken by SAR Transit.

The contractor adopted single large diameter (2.4M) caissons as the foundation for each column.

These were typically installed by inserting a permanent lining through the overlying loose soils and augery directly into the underlying tills.

The principal challenges encountered related to obstructions, boulders or timber in the fills and boulders and water bearing lenses in the lower bearing strata. Very few holes could be totally sealed simply through installation of the casing in the upper fills.

First attempts at sealing the caisson bore involved the use of polymer muds. The use of polymer muds was later abandoned due to its perceived inaffectiveness.

Full length temporary casings were installed in areas where the integrity of the bore could not be maintained.

Once the caisson excavation had reached its design elevation the base was cleaned with a special bucket, the reinforcing cage was lowered into place and concrete poured by tremie.

The variable nature of the ground along the route is evidenced by the time taken to install each caisson which varied from 2 days to 3 weeks.

The disposal of excavated materials, drilling fluids, and concrete laitance presents particular challenges in today's world. The polymer muds required a large mobile settlement tank and all soil sludge, laitance and other such contaminates had to be removed by vacuum truck to settlement basins.

Even with all the precautions in place there were very minor spills into local watercourses.

After some initial concern related to possible soil inclusion in the caisson shaft the contractor installed arrays of PVC pipes which were used to undertaken ultrasonic tests of the integrity of the concrete.

The contractor instituted a detailed quality control and assurance program covering the installation of the caissons, supported by a detailed inspection and test plan.

Any problems were properly analyzed and remedial works determined. These ranged from soil grouting at the tip and/or shaft to, in one case, a complete removal.

Lougheed Mall Guideway

Special structures were designed for the complex interchange arrangements at Lougheed Mall.

Initially all the foundations for these structures were designed as large diameter caissons but a number were later changed to simple spread footings after problems with boulders and sloughing ground were encountered within the excavated bore.

Lougheed Mall to Grandview Cut

The ground conditions along this segment of the alignment varied vary much as the segment from Front Street to Lougheed.

Particularly difficult ground was encountered where the alignment is close to Still Creek at Kensington and at Gilmore. Deep peat deposits occur in these areas.

Single large diameter caissons were the foundations of choice with the same construction methods as described above.

The contractor did change to simple spread footings in the Willingdon and Grandview Cut areas where good ground exists very close to the surface.

Grandview Cut

The Guideway through the Grandview Cut in Vancouver is supported on a bench formed in the side of the cut.

The outside portion of the bench is formed by a mechanically stabilized earth (MSE) wall using concrete facing panels with architectural treatment.

The rear portion of the bench was formed by excavating into the bank and supporting the excavated face with shotcrete and soil anchors.

Precast concrete bins have been placed and attached to the face of the shotcrete into which growing medium has been placed. Ivy and similar shrubs have been planted into the growing medium and will ultimately transform this cut into a "green wall".

Installation of the lower MSE went very smoothly but significant problems were encountered with the upper excavation and shotcrete and anchor supports. The material was not as competent as forecast and large slab failures were experienced as the excavation proceeded. Extensive revisions were necessary to wall designs as excavation proceeded.

In truth, the designs had been too ambitious focusing more on the retention of existing vegetation than on practical geotechnical solutions. The existing slope was heavily covered in trees and shrubs preventing a comprehensive survey of the existing surface and subsurface conditions. Once cleared the conditions were found to be much different that assumed with numerous gullies and irregularities that could not be have been foreseen. It had been planned to retain at least 25% of the existing vegetation. In practice, one tree remains.

The loss of vegetation will be fully compensated for with new planting under commitments made in the project's environmental assessment.

Role of the Geotechnical Engineer

Division of Responsibilities

Geotechnical Engineering services, on projects such as this, can be simply divided into three components, namely:

- Site investigation;
- Foundation design; and
- Construction inspection.

On small conventional design/tender/construct contracts a single geotechnical engineer is employed to cover all three phases.

Large, multi-contract projects, however, present opportunities for a division of responsibility both within each component and between each component. The potential variations are further compounded when a combination of procurement methodologies are adopted, particularly when design/build strategies are used.

Pressure to "spread the work around" also exists.

The Owner has to give careful consideration to the division of work under such scenarios while the Geotechnical Engineers have to carefully consider their involvement from both the ethical and business perspectives.

Fig.-7 shows the division of responsibilities as they evolved for the Millennium Line Project.

The design/build approach for the two principal contracts raised particular business concerns for geotechnical engineering companies. Bigger financial returns were likely from providing services to the design/builder. Firms were faced with the decision as to whether they should decline early opportunities for investigation and preliminary engineering work in the expectation of greater returns for final design services.

Faced with this dilemma RTP2000 declared that firms providing investigation and preliminary engineering services would not be barred from joining design/build teams.

In the event this did not cause any problems but the potential did exist for firms to be party to claims against themselves. Such arrangements will require particular review on future projects where alternative procurement methods like design/build and public/private partnerships are involved.

	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
	New Westminster Tunnel	Tunnel to Braid	Braid to Lougheed	Lougheed Mall	Lougheed to Grandview Cut	Grandview Cut
Investigations	Klohn-Crippen	Klohn-Crippen	Knight-Piesold	Golder	Golder	Golder
Foundation Design Owners Engineer	Klohn-Crippen (Preliminary)	–	–	Thurber	–	East – Bruce West – Thurber
Foundation Design Contractors Engineer	Klohn-Crippen	EBA	EBA	–	EBA	–
Inspection Contractor	Klohn-Crippen	EBA	EBA	–	EBA	–
Inspections Owner	–	–	–	Thurber	–	Bruce/Thurber
Contract Type	Design/Build	Design/Build	Design/Build	Design/Tender/Construct	Design/Build	Design/Tender/Construct

Note: Stations, Front Street Structure and Grandview Cut West Excluded

Fig.-7 Geotechnical Services Providers

Risk Mitigation

Claims are part of the construction process and geotechnical conditions provide fertile ground for such claims.

Geotechnical engineers and, in particular, Owners need to pay more attention to procedures that will eliminate the opportunity for geotechnical disputes.

In the contractor's eyes, the ground is either "too hard" or "too soft" but rarely to the consistency that could have been reasonably foreseen.

Appropriate risk assessments should be undertaken of all designs comparing the geotechnical reports against the proposed construction techniques.

Particular issues faced during construction of the Millennium Line were:

- Presence of boulders in till;
- Presence of water bearing sand lenses in till; and
- Slope failures in the Grandview Cut.

The first measure to mitigate geotechnical risk is to ensure that the appropriate level of investigation and testing is carried out. Too often Owners cannot find money for more site investigations but can always find money to settle claims for "changed ground conditions".

Secondly, geotechnical engineers must precisely understand the financial impact of any change in assumed ground conditions of the proposed method of construction. A risk assessment should be undertaken and further work done where the consequence of change could be dramatic.

Finally, the conditions of contract should be moving towards a more equitable sharing of the risk possibly through more use of Geotechnical Baseline Reports where interpretation is made and the basis on which the tenders are prepared is clearly stated. Disputes are reduced under such arrangements as arguments as to what could reasonably be expected are removed. However, while contractors will reasonably seek reimbursement if conditions are worse they are reluctant to provide credits if conditions are better.

The equitable management and allocation of risk with respect to ground conditions is an important consideration in project planning and one which does not usually get the attention it deserves.

Summary

The announcement in 1998 to translate a felt pen line on a street map, into a fully operational fully automated rapid transit system in just four years presented a challenge that some said could not be achieved.

This was particularly challenging given the unilateral declaration and the hostility this produced with the regional and municipal governments through which the system runs.

Similar projects in North America, started well before the Millennium Line, are far from complete.

Even if you believe that the project is not the right solution for the public transportation needs of the region, you cannot deny that its completion, or schedule, and under budget is a major achievement of which we all should be proud.

Every one deserves credit for this success. The construction workers, in particular, have shown their skills, and their productivity is second to none. And, finally, British Columbia engineers, of all disciplines, have shown that the necessary skills and experience required to deliver major projects on time and on budget reside right here.

This is a message worth repeating as we finalize our bid for the 2010 Winter Olympics.