# Lifelines: A Ministry of Transportation and Highways Perspective

## Turgut Ersoy

Manager, Geotechnical Engineering,
Ministry of Transportation and Highways, Victoria, British Columbia

**Abstract:** This Keynote Address provides a brief description of policies, programs and activities of the British Columbia Ministry of Transportation related to lifelines. An overview of Bridge Seismic Retrofit Program, Snow Avalanche Program and Rockwork Program is given.

## Introduction

Good morning. I am very honored to have been asked to deliver the Keynote Address for this symposium. In this presentation I will provide a brief description of the policies, programs and activities of the British Columbia Ministry of Transportation with respect to establishing and maintaining lifelines.

The Canadian Standard College Dictionary defines a lifeline as any route used for transporting vital supplies. The Webster's Dictionary defines it as a land, sea, or air route regarded as indispensable to life.

The British Columbia Ministry of Transportation and Highways is one of the first highway agencies in Canada to adopt a formal policy for Seismic Design and Rehabilitation. Since 1983 the Ministry has designed most of the new facilities to meet stringent seismic design requirements established by the American Association of State Highway Officials (AASHTO). These requirements reflected a significant evolution of both seismic risk and the response of structures to earthquakes compared to previous standards.

In 1992 a Technical Circular was issued to consider all permanent Ministry works and existing facilities for earthquake resistant design and rehabilitation. In 1994, following a major policy review initiative all updated policies were compiled into a Ministry Policy Manual, seismic design was included in the Corporate Policy section as follows:

*Policy Manual Part II* – Corporate Policy with respect to seismic design and rehabilitation:

1. Earthquake resistant design must be considered for all permanent Ministry works to the level described in the Technical Circular T-2-92 Seismic Design and Rehabilitation for Transportation Facilities.
2. The Ministry will retrofit structures that are vulnerable to unacceptable earthquake damage, subject to availability of funding.

The primary goals in establishing seismic design and rehabilitation criteria are to minimize hazard to life and to preserve important highway routes for disaster response and economic recovery after earthquakes.

The AASHTO Standard Specifications for Seismic Design do not cover suspension bridges, cable-stayed bridges, arch type and movable bridges, it also includes a statement that seismic design is usually not required for buried type structures. The British Columbia Ministry of Transportation and Highways Seismic Design Criteria applies to all permanent works including:

- Structures, underground structures, tunnels and snow sheds,
- Foundations, retaining walls, large culverts,
- Earth and rock slopes, bridge-end fills, embankments,
- Dykes and marine infrastructure.

The level of geotechnical investigation and design effort will need to be compatible with the importance classification of the facility. In the 1992 Technical Circular, Class I (important) facilities with respect to Embankments, Slopes, Dykes and Marine Infrastructure are described as the facilities performing vital functions that must remain functional following earthquakes or facilities failure of which will cause harm to inhabited adjacent area which satisfy the following criteria:

- Projected Summer Average Daily Traffic >50000 vehicles/day and height of Fill/Cut>10 metres for the South Coast (Lower Mainland) Region (height criteria is waived for embankments crossing areas with liquefaction potential.
- Height of Fill/Cut>10 m or embankments crossing areas with liquefaction potential for all other Regions.

All other permanent facilities which are not included in Class I are classified as Class II (standard) facilities.

The 1992 Technical Circular states that earthquake induced ground motions should be estimated on the basis of probabilistic analysis. All planned Class I and Class II Embankments, Bridge-End Fills, Retaining Walls Earth and Rock Slopes, Dykes and Underground Structures are required to be designed using 1 in 475 year return period earthquake induced base rock peak accelerations. For Class II Facilities, large deformations are permitted under 1 in 475 year period earthquake which could necessitate repairs and periods of closure. Ground motion parameters are to be obtained from the National Building Code of Canada or from the Pacific Geoscience Centre of the Geological Survey of Canada.

An evaluation of potential consequences of ground liquefaction is required at the preliminary design stage for all facilities. The extent of site improvement to prevent the occurrence of liquefaction for the design earthquake or other measures (including structural) that could be taken to achieve a liquefaction-resistant design are to be reviewed on a case by case basis. Structural and geotechnical design should be compatible for all facilities.

The Technical Circular also suggests that a Richter Magnitude of M7 would be appropriate to associate with the 475 year return period earthquake for the Lower Mainland (the magnitude of the design earthquake is required for the liquefaction analysis).

The Geological Survey of Canada (GSC) is now producing a suite of new seismic hazard maps for Canada. In contrast to the 1985 maps, which gave national values for peak ground velocity and peak ground acceleration, GSC is now providing spectral acceleration values at the 1 in 475 year and 1 in 2475 year return period earthquakes for the range of periods important for common engineered structures. These spectral acceleration values are provided for most of the larger population centres in Canada. These new developments will be considered in updating the Technical Circular T-2-92. However, it is unlikely that we will adopt much higher peak ground accelerations than we are presently using.

## Seismic Retrofit Program

Since the majority of existing structures in the Ministry inventory were designed or built prior to adopting stringent new earthquake design standards, they are considered vulnerable to collapse and major damage from earthquakes until they are upgraded. A total of 470 bridges on major routes (maps of the routes will be provided during the presentation) have been identified as potential candidates for the seismic retrofit program. The retrofit work was prioritized in the following order:

- Lifeline Structures
- Disaster Response Route bridges
- Bridges on Economic Sustainability Routes
- Other Bridges

### Lifeline Structures

Lifeline structures are major structures as shown in Table 1 and Table 2. These structures are most critical to emergency response capability and post-earthquake recovery. The time required for restoring these structures to functional performance after closure would have a major economic impact.

**Table 1.** Lifeline Structures not designed to AASHTO 1983 seismic design requirements:

| | |
|---|---|
| Queensborough Bridge | Lions' Gate Bridge |
| Oak Street Bridge | Pattullo Bridge * |
| Second Narrows Iron Workers Memorial Bridge | Pitt River Bridge |
| Port Mann Bridge | Mission Bridge |
| George Massey Tunnel | Agassiz-Rosedale Bridge |
| Knight Street Bridge * | Okanagan Lake Bridge |

*Pattulo Bridge and Knight Street Bridge have been transferred to TRANSLINK.

**Table 2.** Structures designed to AASHTO 1983 seismic design requirements or better:

| | |
|---|---|
| Alex Fraser Bridge | Annacis Channel W Bridge |
| Annacis Channel E Bridge | |

### Disaster Response Route Bridges

Disaster Response Routes are corridors that must be kept open for emergency vehicle response following a major earthquake. In the Lower Mainland, the Disaster Response Routes connect all major population areas to the Abbotsford Airport.

A total of 47 bridges on Disaster Response Routes are being considered for retrofitting. A listing of bridges on Disaster Response Routes in the South Coast Region is shown in Table 3.

**Table 3.** Disaster Response Route Bridges in the Lower Mainland that were not designed to AASHTO 1983 seismic design requirements:

| | |
|---|---|
| Ioco O/H North/South | McCallum Road |
| Coquitlam River Hwy. 7 North | Lynn Creek |
| Coquitlam River Hwy. 7 South | Main Street O/P |
| Matthews U/P | Trans Canada Hwy. No. 2 U/P |
| Capilano Canyon | Lynn Valley Road O/P |
| Taylor Way O/P E/W | Seymour Creek |
| Tsawwassen O/H | Mountain Highway U/P |
| Mosquito Creek | Fern Street U/P |
| Harvey Creek | |

The listing in Table 3 does not include Pitt River Bridges and Second Narrows Iron Workers Memorial Bridge which are located on Disaster-Response routes but are classified as Lifeline structures with a higher priority. Bridges under the jurisdiction of the City of West Vancouver and B.C. Rail are also not included.

### Bridges on Economic Sustainability Routes

There are approximately 120 bridges located on or passing over Economic Sustainability Routes in the Lower Mainland and on Vancouver Island that have not been designed to the AASHTO (1983) seismic design requirements and are being considered for retrofitting.

### Other Bridges

Other Bridges are generally those remaining bridges that are less critical to emergency response capability and post-earthquake economic recovery.

### Retrofitting Levels

Superstructure retrofitting prevents the unseating of bridge superstructures by tying spans to supporting piers or abutments by means of restrainer cables and shear keys. Superstructure retrofitting is usually much less expensive than Safety retrofitting and yet can significantly reduce the risk of collapse. Therefore it provides the greatest increase in overall safety for a given expenditure.

Safety retrofitting is defined as the prevention of collapse during the design earthquake (an earthquake with a return period of 475 years, same as the requirement for any permanent new bridge under the current Policy). Safety retrofitting therefore provides a level of safety comparable to that of ordinary bridges designed to present codes.

Functional retrofitting is a general term for more extensive retrofitting designed to provide more assurance that the structure will remain in service after an earthquake.

For bridges whose foundations are in soils with liquefaction potential, ground improvement (e.g. densification) work against liquefaction is usually the most expensive part of retrofitting.

## RETROFIT INVESTMENT STRATEGY

### Program Phases and Costs

Phase I includes Safety Retrofitting of Lifeline Bridges and Bridges on Disaster Response Routes; Superstructure Retrofitting of other Key Bridges.
In general, work will be completed in the following order of priority:

- Complete Safety retrofitting of seven Lifeline structures in the area Vancouver to Mission (Aggassiz-Rosedale Bridge is located in Seismic Zone 3 and may be provided with Superstructure retrofitting – a final decision for this bridge has not been made at this time);
- Safety retrofitting of 40 Disaster-Response Route bridges in the Lower Mainland and on Vancouver Island (to be completed concurrently with the Lifeline Bridges);
- Superstructure/Safety retrofitting of 20 other key bridges (completed as part of major bridge rehabilitation on the Trans-Canada Highway HOV-lane project, or other bridges retrofitted prior to establishing a formal retrofit strategy.

The total cost for Phase I is estimated to be $75 million. Approximately $40 million has been invested to date. The remaining cost of $35M does not include estimated costs for Knight Street Bridge, Pattullo Bridge, and 37 other smaller bridges which are under the jurisdiction of TRANSLINK. Lions Gate Bridge and structural work at Port Mann Bridge are also not included as they are now being addressed as part of the Provincial Capital Program.

Table 4 outlines expenditures to date and estimated costs to complete Phase I.

**Table 4.** Estimated Seismic Retrofit Expenditures. Phase I ($millions)

| Category | Cost to Date | Fiscal '99 | Yet to complete | Total |
|---|---|---|---|---|
| Safety Retrofit of 7 Lifeline Bridges | $25.5 | $5.5 | $31.0* | $62.0 |
| Safety Retrofit of Bridges on Disaster Response Routes | $5.5 | $1.5 | $3.0* | $10.0 |
| Superstructure Retrofit of 20 Other Key Bridges | $2.5 | 0 | $0.5* | $3.0 |
| TOTAL | $33.5 | $7.0 | $34.5* | $75.0** |

*Cost estimates for planning purposes only, could change.
**This total does not include the value of seismic retrofit work transferred to TRANSLINK and included in the Provincial Capital Program – a combined estimated cost of $40 million.

Phase II includes Safety/Superstructure retrofitting of Economic Route Bridges, Other bridges and upgrading levels of retrofitting.

No work has yet been completed on Phase II. Table 5 outlines cost projections for Phase II. (Some tasks in Phase II will be completed concurrently with Phase I). This is to allow retrofit designs to be completed for projects in Phase II in anticipation of funding for the construction phase.

**Table 5.** Estimated Seismic Retrofit Expenditures – Phase II ($millions)

| Category | Total |
|---|---|
| Lifeline Bridges (upgrading retrofitting) | $40 |
| Economic-Sustainability Route Bridges Superstructure/Safety Retrofit | $45 |
| Superstructure Retrofit | $40 |
| Selected Bridges upgrade superstructure to safety retrofit | $10 |
| TOTAL | $135* |

* This cost estimate is for planning purposes only. Estimates are gross cost projections based on very limited cost data and are subject to change.

# OTHER PROGRAMS

In addition to Seismic Design and Rehabilitation Policy, the Ministry has similar policies for Snow Avalanche and Rockwork Programs to minimize the risk to life and to minimize closures on the lifeline system.

## Rock Slope Stabilization Program

The British Columbia Highway network traverses rugged mountainous terrain and is exposed to intermittent rockfall activity. Natural geologic processes include degradation of rock and soil and these processes result in rockfall from slopes. Rockwork is a periodic requirement in that slopes deteriorate over time due to destabilizing factors such as freeze/thaw cycles, increase in water pressures, weathering of rock and erosion. Periodic remedial work such as inspecting, scaling, minor drilling and blasting, rock bolting, meshing and shotcreting is required to minimize the risk of rockfall. Rockfall from slopes can originate from either natural slopes or man made highway rock cuts and there is a need for continuous maintenance of the highway rock slopes to reduce the risks to the travelling public and to minimize traffic disruptions.

Under the Rock Slope Stability Policy adopted in 1994, a systematic program of remedial rock slope stabilization is undertaken to address rockfall and slide hazards in the entire Province that are prioritized as A: high risk, B: moderate and C: low risk using a Rockfall Hazard Rating System.

The Rockfall Hazard Rating System (RHRS) was developed by the Oregon State Department of Transportation and sanctioned by the United States Federal Highway Administration. This is a system which is now in widespread use and accepted internationally as the standard system to rate highway rock slopes for the purposes of prioritizing the work required. Each slope is assessed for the potential for rockfall reaching the traveled part of the highway. The rockslope budget is then allocated to perform the work on a priority basis to the rockslopes that are considered the highest hazard.

A recent study commissioned by the Ministry has shown that the remedial rockwork performed on Highway 99 has been successful in that, over the past ten years, a rockfall reduction of more than 50 percent has been achieved.

It must be emphasized however, that the complete elimination of rockfall is not achievable and not practical even with the expenditure of vast sums of money. The hazards are not only from highway rock cuts but also from rockfall that occasionally originates from well above the highway in remote areas that would not be subject to inspection or remedial work.

## Snow Avalanche Programs

Snow avalanche related road closure times across the province vary widely depending on the severity of the winter with average closure times of 370 hours/winter. Road closures of two hours or less are now typical in an area where closure times used to last several hours or more. Information on the Ministry's Snow Avalanche Programs is listed in Table 6.

**Table 6.** B.C. Ministry of Transportation and Highways Snow avalanche programs

| Program Location | # of Paths | Kms of Hwy | Primary Control Method | AHI* | # of Staff |
|---|---|---|---|---|---|
| Bear Pass | 85 | 80 | 105mmRCL<br>Helibomb<br>Case Charge | High | 3 |
| North West Region | 90 | 500 | 105mm RCL<br>Helibomb<br>Case Charge | Mode-rate | 2 |
| Duffey Lake, Bridge River | 223 | 160 | Gaz-Ex<br>Helibomb | Mode-rate | 2 |
| Coquihalla, Fraser Canyon, Allison Pass | 222 | 400 | 105mm RCL<br>Helibomb<br>Tramway | Mode-rate | 3 |
| Thompson-Okanagan, | 250 | 2500 | Helibomb | Mode-rate | 2 |
| Selkirk Revelstoke | 265 | 350 | Helibomb | High | 5 |
| Kootenay Region | 225 | 500 | Helibomb | Mode-rate | 2 |
| Kootenay Pass | 30 | 10 | Gaz-Ex<br>105mm RCL<br>Helibomb<br>Avalauncher | High | 5 |
| Victoria | - | - | | - | 8 |
| **Totals** | **1390** | **4500** | | - | **32** |

*The Avalanche Hazard Index

The Avalanche Hazard Index is a calculated value which rates and compares avalanche hazard levels, specifically for traffic on a highway. It is calculated by considering the force and frequency of expected avalanches and the expected number of vehicles exposed to avalanche paths. AHI also considers other factors such as the number and proximity of adjacent avalanche paths, return periods of avalanche events, waiting time for traffic in hazardous situations, width of avalanche paths at highway alignment, traffic volumes and traffic speed. The AHI determines a value, which corresponds to ratings of very low, low, moderate or high.

It is interesting to note that the design and construction of foundations for Gaz-Ex exploders present challenges to geotechnical engineers due to their remote and not so readily accessible locations. Plans are currently in place to install another 6 Gaz-Ex exploders and to eliminate any further use of the recoilles rifle.

# Rehabilitation Program and Capital Program Expenditures

## Rehabilitation Program

Rehabilitation Program estimates are shown in Table 7.

**Table 7.** Rehabilitation Program Estimates

| Rehabilitation Programs | Spent last fiscal $ millions approximate | Plan for 2000/01 $ millions subject to change |
|---|---|---|
| Avalanche and Rockwork Programs | $3.6 | $8.1 |
| Bridge Rehabilitation, Replacement and Seismic Upgrade | $30 | $42 |

## Capital Program

Capital Program estimates are shown in Table 8.

**Table 8.** Capital Program Estimates

| Capital Plan: Includes | Spent last fiscal | Plan for 2000/01 |
|---|---|---|
| Roads/Bridges Preservation and Replacement Program, Priority Corridors Program (Vancouver Island Highway Project, Cash Creek to Rockies Project, US Border to Hwy 1, Highway 37, Nisga'a Highway), Major Highway Performance Sustaining Program and Lower Mainland Congestion Relief Programs. | $millions approximate<br>$472 | $millions subject to change<br>$418 |

# Structural and Geotechnical Research Projects and Studies in partnership with the University of British Columbia and the Industry

## Professional Partnership Program

In 1991 the University of British Columbia and the Ministry of Transportation and Highways established the Professional Partnership Program under which the Ministry supported graduate students carrying out research in subjects of importance to the Ministry.

Under this program the following projects managed by the Bridge Engineering Section have been completed

- Hybrid Evaluation System for Bridges under Consideration for Rehabilitation and Seismic Retrofitting.
- Seismic Shear Resistance of Reinforced Concrete Bridge Components.
- Performance of Welded Steel Columns to Concrete Beam Joint under Seismic Loading Conditions

The geotechnical studies managed by the Geotechnical, Materials and Pavements Section and completed are as follows:

- Evaluation of Seismic Assessment Procedures to Predict Liquefaction and Deformations
- Seismic Response of the George Massey Tunnel
- Comparative Behaviour of Geogrids in Tension and Pullout
- Comparison of Limit States Design with Working Stress Design for Shallow Foundations

The above studies were documented in thesis format and submitted by the graduate students to the University in partial fulfillment of the requirements for the degree of Master of Applied Science.

## Earthquake Engineering Research

In connection with the retrofitting of Queensborough and Oak Street Bridges a program of quasi-static cyclical load tests were conducted at the Earthquake Engineering Research Facility of the University of British Columbia. The tests were jointly funded by the Ministry and the Natural Sciences and Engineering Research Council of Canada. These tests on 0.45 scale models of the bents provided valuable data for retrofit details and resulted in considerable cost saving.

## Strong Motion Instrumentation

Force Balance Accelerometers (FBA) and Piezometers (PM) have been installed at the sites listed in Table 9 to obtain ground motion information due to earthquakes.

**Table 9.** Seismic Instrumentation Listing

| Site | Sensor type and location |
|---|---|
| Queensborough Bridge | FBA at ground level<br>FBA 12 m below ground<br>FBA at base of Pier S3<br>FBA at top of Pier S3<br>PM at 18 m below ground<br>PM at 8 m below ground |
| Massey Tunnel | FBA at ground level<br>FBA in the tunnel at 1/3 length<br>FBA in the middle of the tunnel<br>PM at 10 m below ground, south end<br>PM at 18.9 m below ground south end |
| French Creek Bridge | FBA at South Abutment<br>FBA at the base of Pier No.3<br>FBA at the North Abutment<br>FBA at the deck near the South Abutment |

## Acknowledgments

I am very grateful to my colleagues in the Ministry for their help. Particular thanks are due Mike Oliver, Peter Brett, Brock Radloff, Connie Nicoletti, David Stearns, Dr. Don Gillespie, Jack Benetto, Mike Boissoneault and Shannon Tao for sharing their work, providing useful comments and providing information.

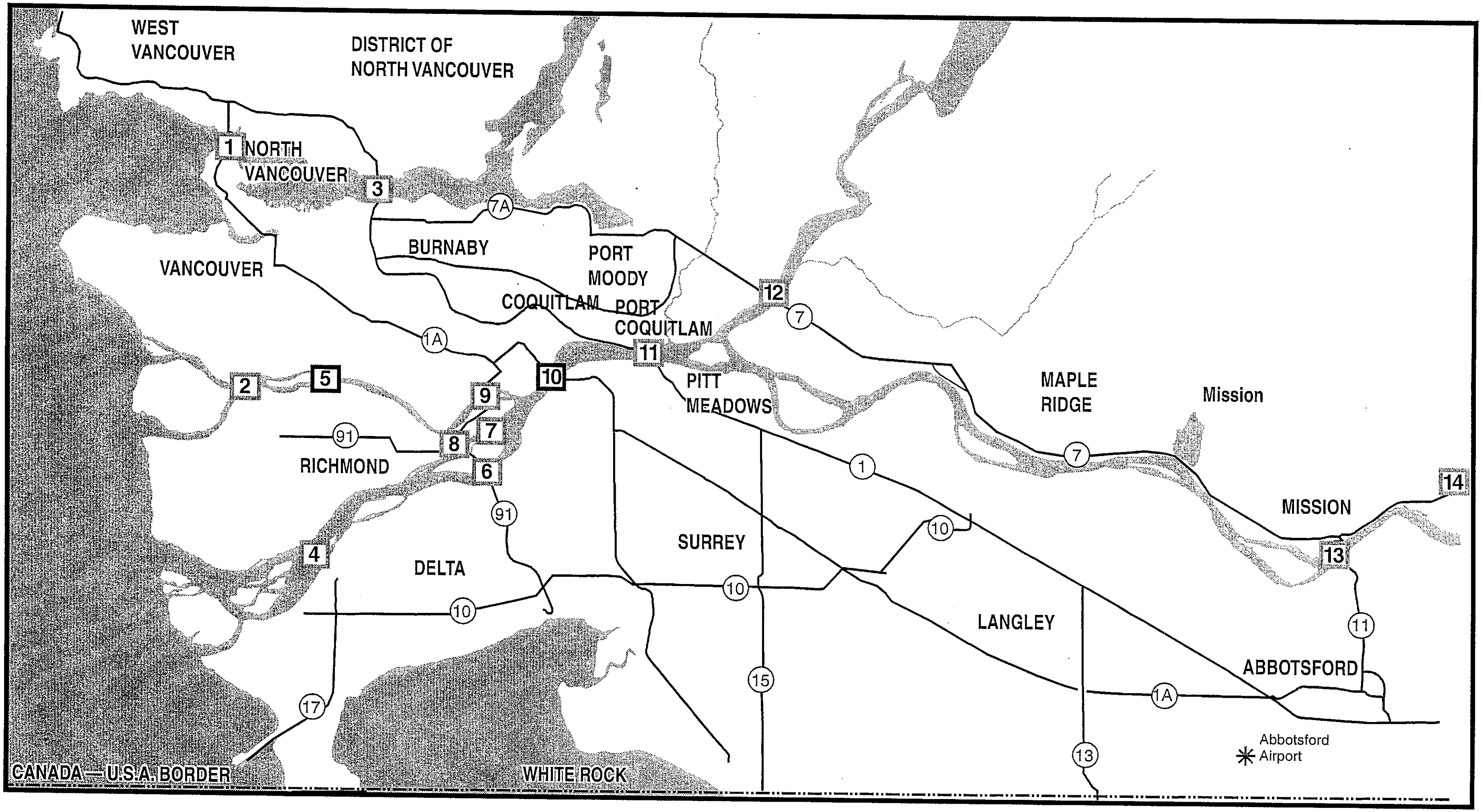
## References

British Columbia Ministry of Transportation and Highways, *Ministry Policy Manual,* March 1994.

Boissoneault, M. 1998. Meeting the Challenge of Size and Diversity, Snow Avalanche Programs of the British Columbia Ministry of Transportation and Highways, The *Avalanche Review,* Autumn 1998, Alta, Utah, USA

Latandresse, V and Ventura, C. *Strong Motion Instrumentation Report,* Project 96-001 Report to B.C. Ministry of Transportation and Highways, UBC Earthquake Engineering Research Lab, 1997.

# Lower Mainland
Life Line Structures




7 Life Line Structure (Provincial)

5 Life Line Structure (TransLink)

## Life Line Structures

1. Lions Gate Bridge
2. Oak Street Bridge
3. Second Narrows Bridges
4. George Massey Tunnel/Dease
5. Knight Street Bridge (TransLink)*
6. Alex Fraser Bridge
7. Annacis Channel East
8. Annacis Channel West
9. Queensborough
10. Patullo Bridge (TransLink)*
11. Port Mann Bridge
12. Pitt River Bridge
13. Mission Bridge
14. Agassiz-Rosedale Bridge
15. Okanagan Bridge – Region 2

** Transferred to GVTA (TransLink) April 1999*

Figure 1

1724 - 4-1c (00/02/10)