Planning for the Recovery of the Transportation System after a Major Earthquake

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Abstract

This paper reviews the need for, and a methodology of identifying, a strategy for addressing high-risk areas related to potential earthquake damage to the transportation system. It is focused on specific conditions on Vancouver Island although there is also potential for damaging earthquakes along the entire BC coast, and in eastern Canada, principally in the Ottawa Valley/St. Lawrence areas. The methodology developed looks at potential risk sites, target locations that should be assigned a high priority for restoring access, the road network and potential detour routes that could provide immediate service should a risk site suffer failure.

The initial assumption made is that notwithstanding "design to code" and other considerations, significant damage to the transportation infrastructure will occur in a major seismic event, and that preplanning for recovery is an essential component of a successful disaster recovery plan.

The process identifies risk sites and access requirements (targets), then uses a graphic overlay technique to identify critical areas that can be used to prioritise these locations for further risk investigation, planning for restoration of service and identification of detours for use until such restoration is effective. This is a low cost, low level of effort approach to prioritizing the expenditure of limited resources in a most cost-effective manner. Following the application of this screening process, logical decisions can be made for further investigation and planning at high risk - high impact sites.

The process is illustrated by examples based on "concept" sites that highlight the principals rather than imply these sites are at high risk.

Keywords
Earthquake, Disaster Recovery, Emergency Preparedness, Bridges, Road Network Planning, Highways, Cascadia Subduction Zone.

Disclaimer:

The use of any illustration in this paper does not imply that the location/structure or feature identified is “at risk”, or does not comply with appropriate design criteria.

The illustrations are provided simply to facilitate discussion of the issues and potential actions required in a generic manner.

1 Introduction

This paper was developed out of material presented at a half-day seminar organised by the Vancouver Island section of the Canadian Institute of Transportation Engineers (CITE) in the spring of 2004. The seminar covered general concepts of Emergency Response Planning as appropriate to developing a plan for the earthquake situation, an overview of geotechnical/seismic issues and likely post-seismic event damage, and the development of a planning concept for identifying high risk areas and an appropriate response strategy. The paper focuses on the identification of potential risk sites, access targets and the planning concepts for detours.

2 Area Seismology

The coastal areas of British Columbia (BC) are categorized as “high risk” areas for seismic events. Two types of events have occurred historically, “crustal” events within the North American plate and “subduction” zone (Cascadia Subduction zone, CSZ) events along the interface between the Juan de Fuca plate and the North American Plate (Ref 1, 2). The CSZ extends from near the north end of Vancouver Island to northern California as an offshore band approximately 950km long, 60-170km wide and up to 100km deep where the offshore Juan de Fuca plate is descending under the North American Plate. Horizontal movements are approximately 5 - 10mm per year with vertical movements of 3 - 5 mm per year. This zone is "locked' with major releases of stress causing extreme seismic events (Ref 2).

In southwestern coastal BC (the ”Georgia Basin”), around 200 measurable crustal seismic events occur each year (see Ref 3 for a current listing). A small number of these are felt each year. The last recorded Cascadia subduction zone event was on January 26th 1700 at around 9pm and has been documented from geological records (buried organic materials, radio-carbon dated etc.) and written records of a tsunami from Japan. The return period for subduction events is 200-900 years. We are thus within the historic return period for these events (Ref 2). There is a "damaging" earthquake in BC roughly once every 10 years.

3 Design Criteria

The current bridge design (and building) codes use predicted ground movement intensity at the point of interest as the design criterion (Ref 4, 5). BC Ministry of Transportation uses two design events, a crustal event in the Georgia Basin of Magnitude 6.5 and a CSZ subduction event of magnitude 8.5 for structures in the Victoria area. The estimated return period for these events is 475 years. The last Cascadia subduction event (300 years ago) was estimated at Magnitude 9, and the 1946 Courtenay earthquake was Magnitude 7.3.

4 Status of the Current Facilities

Bridges designed and built since the early 1980’s are likely to be in compliance with the current structural code and thus should be relatively secure against earthquake damage at the magnitude/intensity prescribed by the code. Structures designed/built prior to 1980 may be less secure depending on their specific design details, local ground conditions etc..

Earthquake damage also includes the potential for landslides, rock falls, fill failures and soil liquefaction under specific circumstances. Many of BC’s roads were originally built as “logging roads” to standards less than those that would now be considered acceptable. Some of these roads may be susceptible to significant damage during seismic events below the current design standards.

The BC Ministry of Transportation has an ongoing seismic retrofit program addressing bridges on major (numbered) highways. Recent upgrades to Highways 1 (Trans Canada Highway, TCH) and Highway 19 on Vancouver Island provided bridges constructed to the current code.

In addition to roads, coastal BC is heavily dependent on marine ferries for access to the many smaller islands, and a number of remote communities that have no public road access. Vancouver Island itself is dependent on two major ferry routes served by two terminals on the mainland and two on Vancouver Island. Some of these ferry terminals, or their immediate access roads, may be susceptible to damage during seismic events below the current design standards.

5 Emergency Preparedness

BC has a comprehensive system of planning for response to emergency situations. This system provides uniform documentation of procedures to address situations that focuses primarily on isolated point location events, typically urban fires, chemical spills etc. It also covers wider area events including flooding and earthquakes.

These plans include identification of "Emergency Response Routes". However, these focus on protecting major facilities for use by responders to "typical" emergency situations, although in some cases they utilise facilities that are relatively immune to earthquake damage. While they form key elements in the network of required routes, they do not provide enough area coverage to suffice for recovery access and life support after a major earthquake.

The system provides a solid administrative structure to deal with emergency response to such events. However as the “normal” emergency event is generally localised (one to several blocks in extent) and may occur anywhere within a jurisdiction (generally a municipality) these plans do not provide site-specific guidance.

Earthquakes by their nature are wide area events with impacts extending for potentially hundreds of kilometres from their point of origin (epicentre). In this respect they provide unique challenges including:

- Multi-jurisdictional
- Widespread infrastructure damage potentially isolating significant populations for significant time periods
- Disruption of emergency response due to infrastructure damage and failure of communication systems
- Potentially high casualties
- Potentially extreme demands on life support systems (distribution of food etc.)

The primary concern expressed regarding the current status of Emergency Response to earthquakes in BC is the apparent lack of contingency plans that identify priorities for restoration of transportation service under these conditions. Notwithstanding these concerns, the existing Emergency Response Plans provide a solid foundation for the management of response to a significant earthquake.

6 Risks and Consequences

Assessment of potential earthquake damage and the necessary planning to facilitate recovery is probabilistic rather than deterministic. We need to consider both risk and consequences:

- Risks
  - Engineering Risk
  - Probability of Occurrence of Specified Level of Damage

- Consequences
  - Effect of that Level of Damage *(or Greater)* on Infrastructure
  - Time to Recover

- Financial Risk
  - Cost of Mitigation vs. Cost of Repair, Cost of Disruption and Lost Economic Opportunity

While the probability of a major seismic event (design event) is relatively low (1 in 475 years), the consequences for the area are potentially catastrophic. In this paper we take the position that society cannot afford to build "impregnable" structures, rather that the risk is accepted and we need to plan for recovery from the consequential damage.

A Magnitude (Richter Scale) 6.5 Strait of Georgia or Magnitude 8.5 CSZ event would have a predicted Intensity (Modified Mercallii Intensity Scale) of VIII in Vancouver ("Destructive") and IX ("Ruinous") in Victoria. Intensity VIII is described as "Destructive": severe shaking. Moderate to heavy damage. Damage is slight in specially designed buildings, considerable in buildings of poor construction. Structural damage is slight to moderate to bridges and overpasses. Intensity IX is described as "Ruinous": violent shaking. Damage is considerable in specially designed buildings. Buildings shift from their foundations and partly collapse. Underground pipes are broken. Bridges and overpasses collapse. (Ref 6)

7 Potential Earthquake Damage

Potential damage can be reviewed under six major categories:

1. Bridges: Bridges may fail through several mechanisms including:

   - Bearing failure (excessive loading)
   - Relative movement (abutments shift, span falls off bearing seats)
   - Column/abutment failure (collapse due to bursting, shear etc.)
   - Ground failure (displacement of columns/abutments)

   The net result of this damage may be short term (resolvable by temporary support or realignment), or permanent failure requiring replacement with the bridge unserviceable until replaced. Time to return structures to service (at minimal levels) may vary from days to months, or if replacement of a major structure is involved, several years.

2. Buildings: Building failures, especially in "downtown" locations with taller buildings adjacent to sidewalks, have the potential to create significant disruption to the transportation system as a result of debris fields from building envelope failure or partial/total collapse of the structure.

   The results of this damage will likely be cleared from roadways within days or weeks. In addition, in these areas multiple routes generally exist providing several potential detours.

3. Fill Failures: Fill failures may be by slope failure within the fill or by failure of the underlying ground by liquefaction. Liquefaction may affect areas of low fill with little ground loading. Liquefaction is generally restricted to relatively small areas on Vancouver Island, but may affect extensive areas in major river deltas such as the Fraser River in Richmond and Delta (Greater Vancouver).

   The net result of this damage may be short term (resolvable by temporary fill), or permanent failure requiring replacement of a significant length of road with the road unserviceable until replaced. Time to return the road segment to service (at minimal levels) may vary from days to weeks.

4. Rock falls: Rock falls (or overburden failures) are a potential hazard in areas of steep natural slopes as well as in rock or overburden cuts.

   The net result of this damage may be short term (resolvable by debris removal only), or more significant requiring stabilization of a significant rock face with the road unserviceable until this is carried out. Time to return the road segment to service (at minimal levels) may vary from days to weeks.

5. Ferry Terminal Marine Structures: In many ways marine structures (principally loading ramp structures) are similar to bridges and the same considerations apply.

6. Utility Infrastructure: Overhead lines provide most of the power, telephone and cable infrastructure in BC. These may be susceptible to failure, especially power poles carrying pot style transformers. Major lines carried on timber frame or steel tower structures may be susceptible to damage by overstressing of foundations or the tower structure. A key risk is the security of the underwater electric power and natural gas lines supplying Vancouver Island from the mainland, these lines supply most of the island’s power and heating. At least one power line crosses the Fraser River delta, which is a significant known hazard for debris slumps on its seaward face. Underground utility (water, sewer and natural gas line) failures may result in point source disruption until the flow can be controlled.

   Two consequences are apparent, we will not be able to rely on electrical power for the operation of traffic signals, communications systems etc., and, roads may be blocked by downed power lines, some of which may initially be live or of unknown status, or by burst pipes undermining the roadway.

   The net result of this damage may be short term (resolvable by debris removal only), or more significant requiring reconstruction of a significant length of major power lines. Time to return the road segment to service (at minimal levels) may vary from hours to several days. In the event of a failure of one or more of the major transmission lines across the Strait of Georgia, months could elapse before they are restored.

8 Potential Earthquake Damage Examples

The following illustrations and discussion provide some insight into the scale of damage that might be expected after a "design event", or greater, earthquake. These illustrations are provided for discussion purposes only and do not imply that the locations depicted are subject to failure under any seismic event.

1. Bridges: while collapse of structures designed post 1983 is not expected in a design event, it is nevertheless a possibility for older structures, or in a greater than design event. Bridges may be freeway interchange structures (as in Figure 1) or bridges carrying a facility over a river or marine inlet. Freeway interchange structures are generally easier to deal with, while water crossings, especially if the feature is deeply incised, may be more problematic.

Figure 1 Potential Bridge Failure

2. Building Failures: in areas with buildings abutting the sidewalk, building failures will cause at least temporary disruption. In more densely developed areas (downtown Victoria, Nanaimo) the extent of the debris field will potentially be quite large with many unreinforced brick or stone structures.

Figure 2 Potential Building Failure

3. Rock falls: many roads, especially in rural areas on Vancouver Island, pass through rugged terrain where rock cuts are frequent. The hazard area may extend hundreds of meters along the facility, and many tens of meters up the slope (potentially hundreds of meters). The hazard may include overburden and vegetation as well as rock from failure of the cliff face itself. The width of the road has a significant impact on the disruption caused by a rock fall. On narrow two lane facilities a major fall may block the road for a significant time period. On wider facilities (4 lanes, full shoulders and wide median) the same event may only require a detour to the opposing lanes for the clearance period.

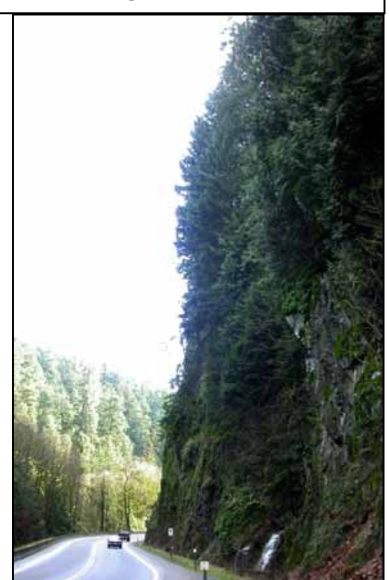

Figure 3
Potential Rockfall Hazard

4. Fill Slopes: post 1983 fill slopes (Figure 4) are generally expected to perform well. However earlier fills may have been constructed by end tipping, may contain unstable material and may already be subject to failure under "normal" conditions. Fills constructed on seismically poor ground without adequate precautions are particularly liable to failure by slippage and/or liquefaction of the underlying material (Figure 5).

Figure 4 Recently Constructed Fill Slope

Figure 5 Fill Potentially Subject to Liquefaction

5. Ferry Terminal Marine Structures: both smaller inter-island terminals and larger mainland service terminals are potentially subject to seismic damage. The Tsawwassen terminal may be particularly susceptible to damage from soil liquefaction both for the terminal structures and for the approach highway across the Fraser River delta. Smaller terminals, whilst potentially vulnerable, may be easier to repair, or, reasonable alternatives may exist by using (for example) barge services on an interim basis.

Figure 6 Ferry Terminal Marine Structures

9 The Planning Process

The objective of the planning process is to identify routes that are either relatively immune to seismic damage, or, to identify detours that can be constructed around sites where no reasonable alternative route exists. The intention is that these detour plans become an established part of the Emergency Preparedness Plans, and where appropriate, provision is made for preconstruction.

The planning process falls naturally into 6 stages:

1. Identify the access targets
2. Identify the risk sites
3. Identify clusters of targets or risks
4. Combine the access targets and risks overlays
5. Identify critical sites where alternative routes need to be researched
6. Assign priorities to these critical sites

Each of these stages can be broken down into a step-by-step process described in the following paragraphs.

1. Identify the access targets: access targets can be classified as:

   Immediate - Life and Limb (hospitals, ambulance stations etc) - required for evacuation of casualties, relocation of residents of damaged buildings, and to stabilize damaged structures. Required from Day 1 for several days.

   Life Support - Grocery Stores (as a proxy for food and other essential supplies) - required for provision of food etc. and medical aid. Required from Day 1+ for a number of weeks.

   During Recovery - a minimal network for access for reconstruction, "close to normal" essential services and ultimately return to normal lifestyles. Required from Day 1 for several months (1-2 years for some structures).

   Access targets are plotted on base mapping (Figure 7) and colour coded to identify type. The base mapping can be quite simple without a great deal of detail at this stage.

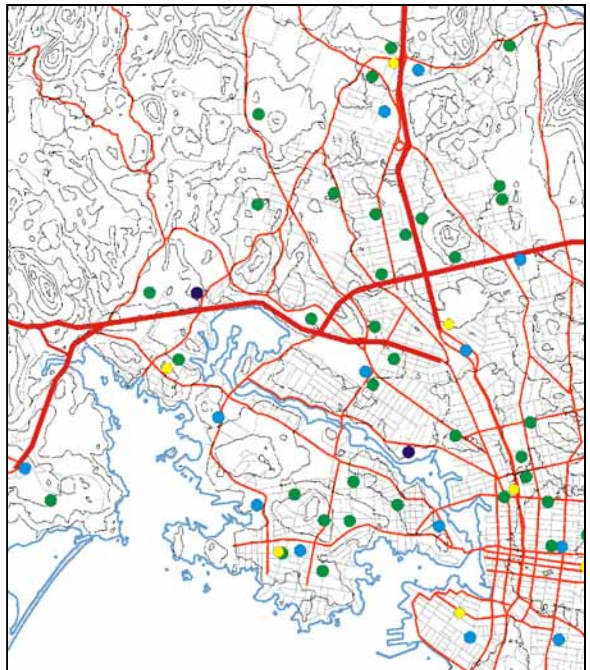

Figure 7 Access Targets

2. Identify the risk sites: the risk sites inventory can be complied from mapping, local knowledge and site review. It should initially include all potentially suspect features; bridges; fills; rock cuts; flat, waterlogged land on poor soils ("swamps"); downtown areas etc. with buildings at the sidewalk line. The major roads in the network should be highlighted.

3. Identify clusters of targets or risks: clusters such as the one illustrated on Figure 8 identify key constraint points that deserve critical attention.

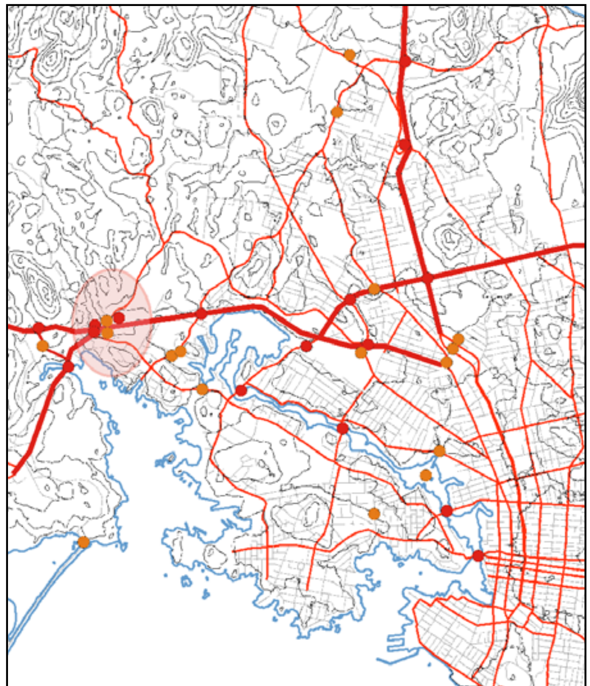

Figure 8 Risk Sites

4. Combine the access targets and risks overlays: this (shown in Figure 9) allows a visual review to eliminate targets that have "safe" access and identify those targets that are impacted by clusters or isolated risk sites.

5. Identify critical sites where alternative routes need to be researched: in Figure 9 a critical target area (major hospital, darker shading) is adjacent to a critical risk area (complex interchange/2 parallel routes, lighter shading).

6. Assign priorities to these critical sites: this last step allows us to focus on key locations based on such criteria as: degree of risk, extent of the consequences, cost and economic impacts, complexity of the solutions etc.

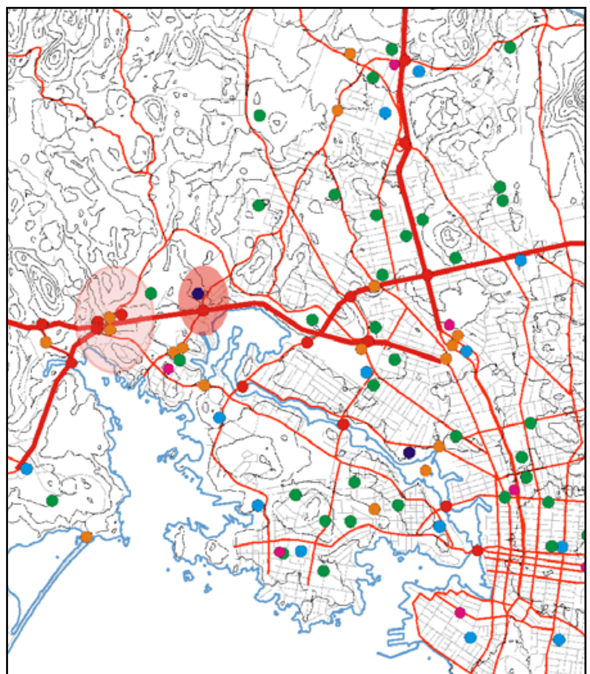

Figure 9 Combined Targets and Risks

10 Case Studies

The following case studies illustrate the process of identifying and reviewing some typical risk sites as a subset of the overall process outlined above. These examples are based on:

- **Scenario**
  - Structures are pre-1980
  - Earthquake exceeds code event
- **Options**
  - Retrofit
  - Rebuild
  - Detour

and do not imply that the locations depicted are subject to failure under any seismic event.

Case 1: Highway Interchange

In this case study a freeway interchange (half diamond, Figure 10, Panel "A") connects two parallel highways passing within approximately 2-300m of each other with a single-track railway bridge (Panel "B") between them (major bridges in red).

Figure 10 Risk Site 1

Highway 1 (TCH, Panel "C") passes through the area on the overpass; the "Old Island Highway" passes parallel to Highway 1 on the south side. The major traffic flow is along the TCH and to/from the west leg of the Old Island Highway. The east leg of the Old Island Highway has connectivity but is a low standard two-lane facility. There are a total of eight structures in the complex. To the immediate south is the upper end of a tidal inlet with precipitous rock faces down to the water. To the north is a major regional park (natural area) with "difficult" topography. There are no reasonable routes around this area.

The interchange is a critical linkage between the expanding "West Shore" area and the older parts of the community including the Downtown area, both major hospitals (one in the blue area, Panel "D") and ferry terminals.

Loss of connectivity through this area would have major economic and life safety impacts on the community. Loss of either of the major structures would compromise connectivity and likely require around two years to replace.

Since there are no reasonable alternatives around the site we explore the opportunities for detours around the area as shown in Figure 11. We have two key targets, access to the hospital and connectivity on Highway 1.

Generally we would look first for existing roads that could be used and identify the only such route first (Panel A).

However, on closer inspection we see (Panel B) that this route also has potential problems. There are two adjacent structures, one carrying the railway over Helmcken Road, the next carrying the road over a tidal creek, and then another highway interchange (red circles).

We can deal with the railway bridge, as it is a short span (<10m) structure by planning for removal of debris if it fails. We can plan for temporary use of the creek bridge with a "Bailey/Acrow" structure or temporary replacement with a culvert and rock fill.

Diamond type interchanges are simple to deal with as the structure can be replaced by use of the ramps with median crossings to replace the structure, effectively creating a sausage shaped "roundabout" (Panel C).

However, we should also look more closely at the immediate area of the primary structures. This reveals two potential detours (green) that are achievable with minor construction. To the immediate right (east) of the site there is a short stub roadway ending approximately 50m from the highway and essentially level with it. This can easily be connected to the highway. This road passes under the railway, but this structure is <10m in span and can easily be removed if it fails. To the left (west) is an adjacent road with an elevation 2-3m below the highway. This could be connected with some blasting and fill. If the minor structure on this road fails, the creek could be curvetted or bridged with a temporary structure.

We have thus shown two potential routes around this key location. The process can now proceed to identify the most appropriate plan (this depends on which structures have actually failed in this complex area, all eight need to be evaluated separately and in groups). Once this is done, resources needed to accomplish the work can be documented and included in the master "Earthquake Action Plan" for the Road Authority.

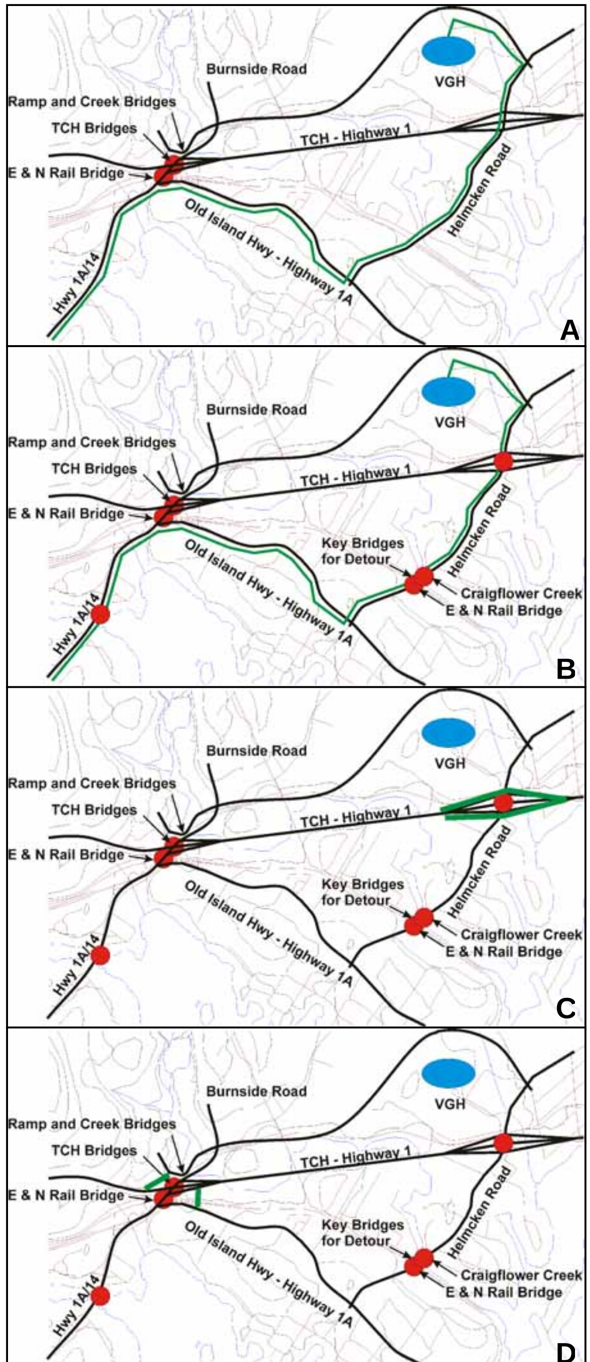

Figure 11 Detour Options Case 1

Case 2: Liquefaction Risks

In this case study (Figure 12, Panel "A") a segment of Highway 1 (Panel "B") traverses ground that is subject to liquefaction (red shading in Panel "A"). Other routes in the area also traverse risk areas. There are a number of structures (red circles in Panel "A") also in areas potentially subject to liquefaction, as well as two larger structures on good gravel foundations.

Identification of areas at risk from liquefaction will generally require site-specific geotechnical investigation. However, an initial assessment can be made visually (river deltas, "swamps", land that routinely floods, repeated settlement of roadbed etc.), and from available geotechnical mapping showing surface material classification. At the initial screening level it is desirable to be cautious and include rather than exclude areas.

In our scenario we have failure of the four structures shown in red in panel C and the associated fill on Highway 1. This closes the Highway (TCH, Highway 1) and potential alternative routes east of the Highway. The structure in Panel D is at Tzouhalem Road.

The objective in this case study is to restore Highway connectivity through the community. Contingency plans will also be required for the failure of the other two bridges noted in Panel "A".

Since the scenario failures have closed all available alternatives east of the Highway, we look to the more developed west side for alternatives. There is no realistic opportunity to construct new routes to the east as the land on this side of the Highway is primarily flood plain (alluvial delta deposits) and much of it (extending to the waterfront) is Indian Reserve.

Figure 12 Case 2 - Liquefaction

The initial alternative, illustrated in green in Figure 13 (Panel A), is the "old" highway that has three minor structures that are assessed as repairable or "safe" under these conditions (culverts).

However, the route passes though the old "downtown" area (magenta in Panel B) that has a variety of structures immediately adjacent to the sidewalk on a two-lane road (Panel C). This is judged to be an unacceptable risk so we must look for further alternatives.

The route illustrated in panel D (light green) runs adjacent to the railway and is well separated from adjacent buildings although the east-west segment rises up a steep slope. The assessment is that this is a preferable route subject to geological testing of the slope and possibly carrying out remedial work if required. The rationale for this is that the cost of the remedial work is likely to be less than seismic upgrading (or demolition and reconstruction) of the buildings along the old Highway and is easier to achieve than dealing with all the building owners.

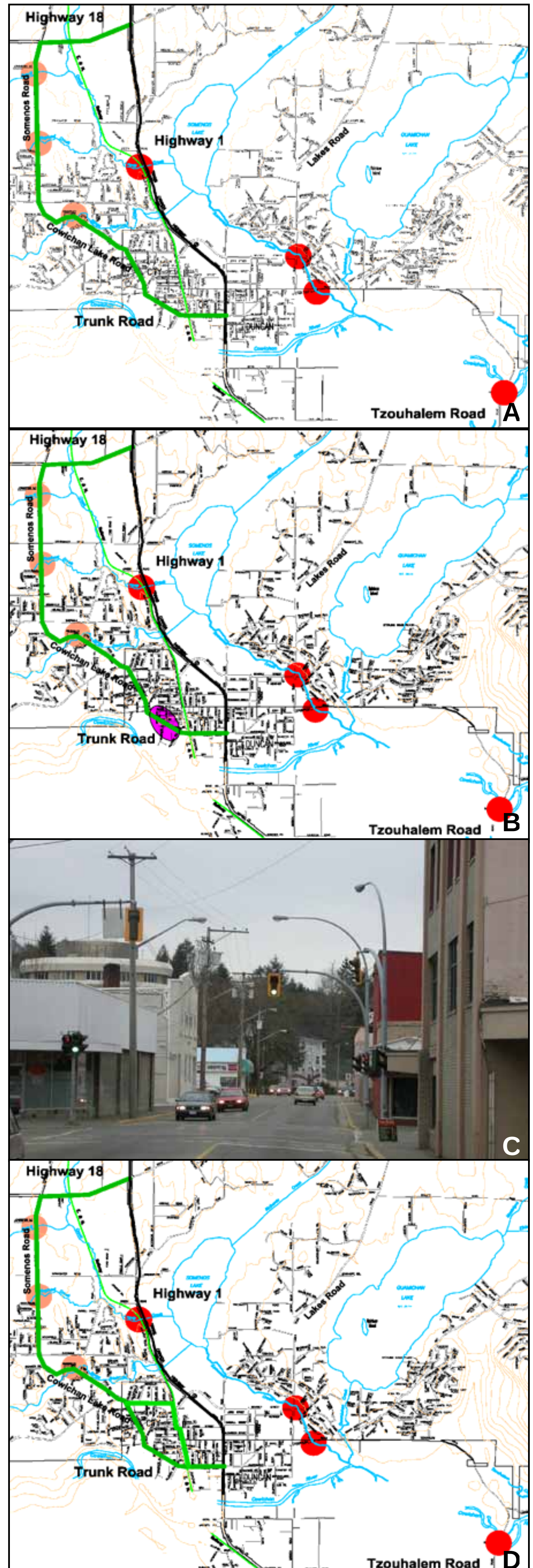

Figure 13 Case 2 - Detours

Case 3: Multiple Risks - Multiple Routes

In this case study we explore the next steps of going from individual sites to constructing a network of routes that can avoid risk sites and service multiple access targets. Our objective in this case study is to provide access to/from the south to the two identified ferry terminals (Figure 14 Panel "A"). Highway 19A was functionally replaced by Highway 19 for through traffic, and a significant amount of internal traffic, but remains an essential artery. Highway 1 (TCH) enters the area from the south to the 2nd ferry terminal that is one of the major Island/Mainland route terminals.

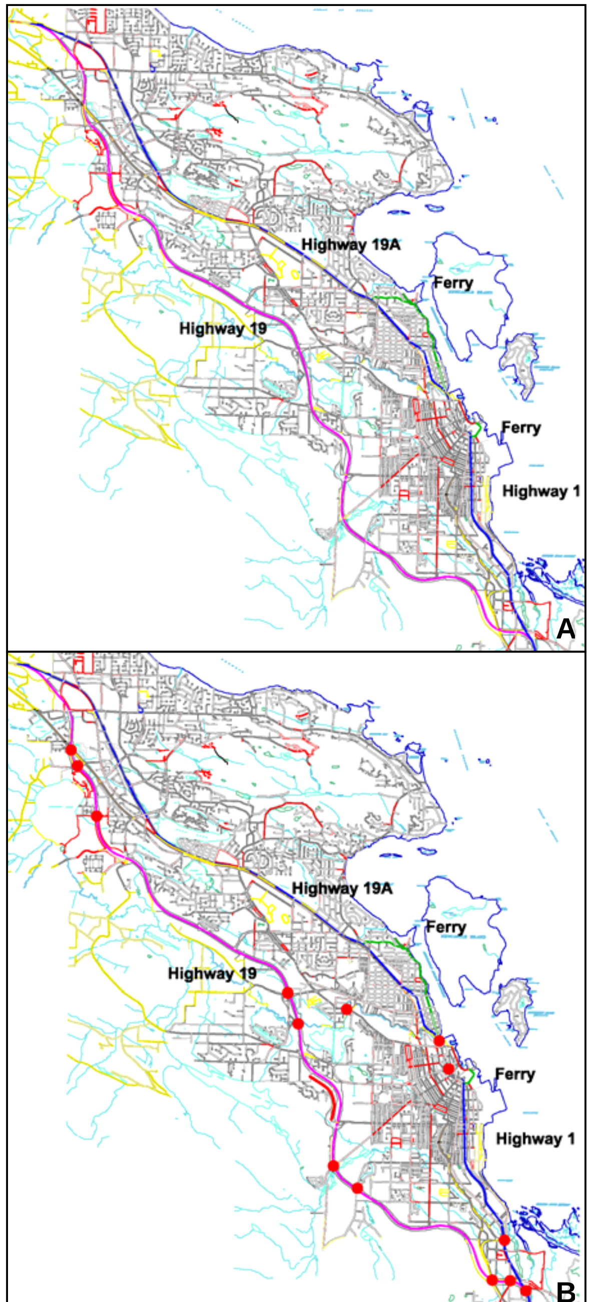

Figure 14 Case 3 - Multiple Routes

The identified risk sites include (Panel B):

- 9 Bridges on the Parkway (Highway 19)
- 3 Bridges on Highway 1
- 1 Interchange Bridge Hwy 1/19
- 1 Bridge on Bowen Road
- Rock fall Area on Parkway

The bridges on Highway 19 include several with no practicable alternative as they are over deeply incised creeks and a rail line at the bottom of a steep slope. The rock fall area also has no immediate detour route as it is located on a steep side hill. The road network of the community does not provide good north/south connectivity due to both the road layout and natural barriers. There is no practicable route around the community with the Strait of Georgia to the east and the Vancouver Island Mountains to the west.

In our scenario we are assuming that one (or more) of the risk sites on Highway 1 has failed and that traffic is to be detoured. The consequences of additional failures of risk sites on Highway 1 are reviewed in this case study.

Detour 1: the Cedar Interchange is a semi-direct layout with free flow on Highway 1 to 19, but a signal under the Highway 19 northbound overpass for other movements. This means there is no ramp system as in a diamond interchange (see case 1). Due to the topography there is no alternative route to the west. To the east there is an old road the continuity of which has been broken at "U" (Figure 15, Panel A) by a new access road to the third ferry terminal. This road, with a temporary intersection at "U" (green line) is likely to be the best option for north/south continuity. For access to Highway 19, with the overpass failed, the only alternative route is to use the southbound ramp as a two-direction ramp.

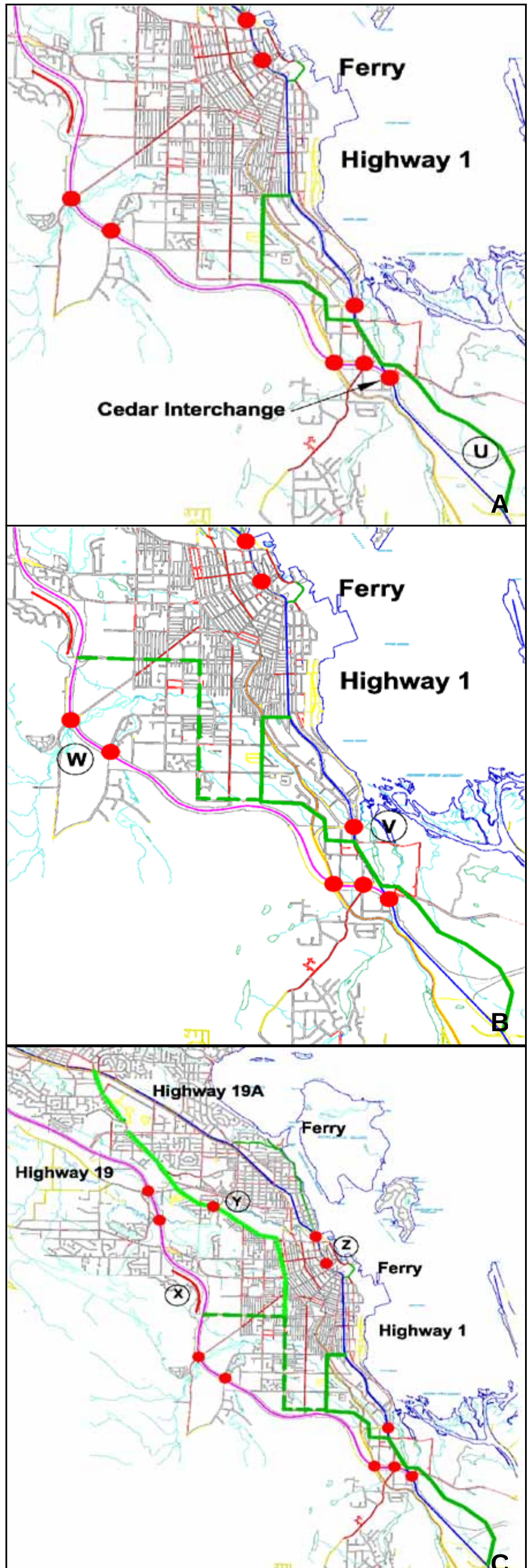

Figure 15 Case 3 Detours

Detour 2: if the rail underpass at "V" in Panel B has also failed an alternate route using the local street system is available (dark green line in panel A). This route provides continuity towards the ferry terminals on Highway 1.

Detour 3: if either of the structures at "W" in Panel B has failed, there is no local detour. The route identified in Panel B in dashed green uses the local street system to reach Highway 19 again.

Detour 4: if the rock face "X" or structures north of it on Highway 19 have failed, the available detour as shown in light green in Panel "C" is available. The minor structure at "Y" is deemed unlikely to fail, or can be easily repaired (large culvert). This restores continuity to Highway 19A as an alternative to Highway 19 for failure of any structures further north (see Figure 14), or for failure of the two structures at "Z".

As this is a heavily developed urban street system we have additional considerations to failure of structures that include: traffic control; signals (is power available); capacity is likely to be significantly reduced; localized debris, power lines down require clearing etc.. These routes become high priority for clearing – do they match emergency response routes?

Case Study 4 - Rural Areas

This case study is based on a project carried out by Richard James & Associates for the Islands Trust in 2002/2003. The project objective was to identify alternate routes to connect isolated pockets of development on Gabriola Island in the event of any of a number of situations including forest fires, rock falls, large-scale tree blow-downs, or earthquake. The intention was to identify routes that could be preserved and maintained for emergency access to fight fires, for evacuation or as temporary detours during reconstruction. As such, this study illustrates the broader use of the planning concepts discussed in this paper.

Gabriola Island is located in the Gulf Islands east of Victoria. It is approximately 25 km long by 2 to 3 km wide and has only one continuous public road, on the west side, along its length. The island consists primarily of a precipitous rock "backbone" with development generally along or near the shorelines.

Figure 16 Panel "A" identifies typical features including:

- Main road - red
- Existing local roads - blue
- Existing logging roads - green
- Rockfall hazard areas - magenta

Using aerial photography, mapping (1:20,000, 20m contour), local input from the Island's Transportation Committee, and site investigation which consisted of hiking many of the potential routes on a brilliant fall day, potential links between the public road on the west side (red) and the local and logging road systems on the east side were identified and the most feasible routes selected. One such cross-link is shown in blue on Panel "B".

Road standards on the logging road system varied from quite overgrown and eroded to straight, serviceable segments (Panel "C") and in some cases paved roads that were constructed for failed sub-division projects.

For this project there was a defined process to ensure protection of the routes: identify the routes on the Official Community Plan (OCP), then protect the routes and require maintenance through covenants at the time of subdivision or rezoning. This process may be appropriate for smaller and remote communities and in rural areas.

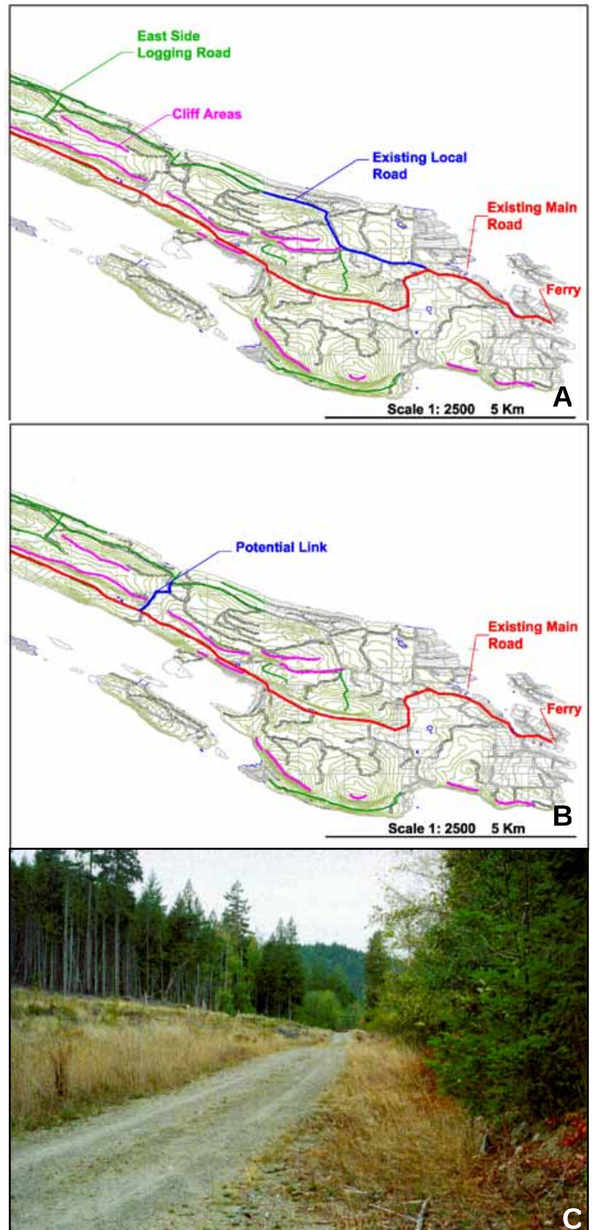

Figure 16 Case 4 Rural Area

11 Other Considerations

Remote Communities: these present special challenges, they typically have only one road access, which is through adverse terrain, detours are difficult or impractical to construct, and typically have "logging road" construction with side-hill cut/fill situations. Typically structures will be of low quality, but may have high load limits. Cost of improvements vs. "benefits" is a major issue.

Coastal Communities: along BC's coast, and on some inland lakes, there are a number of "Water Access Only" communities that have no road access. In these cases marine access is the normal mode of transportation and would continue, with emphasis on the integrity of the wharfs. Marine access is also a viable alternative for coastal communities with a low standard or high-risk road access, or where the cost of upgrading the access is prohibitive. Again, integrity of the wharfs is critical.

Additional Risks for coastal communities would include Tsunami damage to facilities (Port Alberni suffered extensive damage from a major seismic event in Anchorage, Alaska in 1964), and from uplift or drop of the coast seabed, which may result from a subduction zone event.

Road Condition Considerations: in addition to planning detours, we need to include provision for issues such as: removal of debris, clearance and replacement of downed hydro & telephone poles/lines etc., traffic signal masts, building debris, repair of culverts, pipelines (water/sewer, gas etc.).

12 Conclusion

Because of the potential scale of earthquake damage, we need a priority plan for restoring access. (The management plan is in the emergency response plans). In this paper we have identified a planning process for this that includes the following steps:

1 Collect Data
- Identify Risks
- Identify Access Targets
- Identify Detours

2 Prioritize
- Importance in Network – System Issues
- Degree of Risk (Seismic, Design)
- Cost (Retrofit, Replace, Detour)

3 Actions
- Retrofit
- Rebuild
- Detours

We can then:

1. Assign priorities
   - Based on importance in the network
   - Based on risk conditions

2. Investigate high priority sites
   - Geotechnical
   - Structural

3. Develop mitigation measures – individual risk locations
   - Rebuild
   - Strengthen
   - Detour plans

4. Develop a roadway clearance priority plan

5. Develop or modify design standards for new projects
   - Alternative access to development
   - Seismic design standards for critical locations

5. Document the plan
   - Detour routes
   - Priority plan for clearing debris
   - Priority retrofit requirements

6. Make the plan known to staff
   - Staff deployment plan - including manage external resources
   - Resources deployment plan
   - Available external resources

7. Plan identifies risks and alternatives
   - You have the knowledge
   - We have identified some tools
   - Develop and use the plans

13 References

1. National Research Council, Pacific Geoscience Centre website at: http://www.pgc.nrcan.gc.ca/seismo/table.htm
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4. Canadian Highway Bridge Design Code, CSA-S6-00, Canadian Standards Association, 5060 Spectrum Way, Mississauga, Ontario, L4W 5N6
5. NRC (1995). "National Building Code of Canada", National Research Council of Canada, Ottawa, ON
6. National Research Council, Pacific Geoscience Centre website at: http://www.pgc.nrcan.gc.ca/seismo/eqinfo/intensty.htm.