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WHAT DO WE REALLY KNOW? A BC PERSPECTIVE

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ABSTRACT: With the increased sophistication of analysis methods and seismic parameters, many assume we know what we are doing. However, thoughtful consideration indicates we know little of what will happen when a strong earthquake hits an urban area in BC. We expect many injuries, some deaths, tens of billions of dollars' worth of damage and a recovery period that will last at least 5 years, but (1) many fail to recognize this is likely a best-case scenario and (2) while we are reducing the risk in some ways, we are increasing it in others. This overview is based on the reports of earthquakes here (1946) and other parts of the world and the types of damage that have occurred in the past.

1. Areas of Uncertainty

1.1. Seismicity

The seismicity of British Columbia (BC) is poorly known. There have been few major earthquakes and the more recent ones have been in the north where population densities are low and the fault system differs from the southern coast of B.C.. There have been a few moderate-sized quakes on Vancouver Island, but the largest of these, in 1946, has been difficult to accurately locate due to limited data. Other major earthquakes are known, but information is scant.

While the geoscientist's data, tools and methods have evolved, it is clear from the way relative design parameters have varied over the years that their ability to predict these values is still quite limited. For example, Courtenay used to have the same seismic parameters as Vancouver, then twice their value and now about 60% (NBC 1980, NBC 1985, BCBC 2012). The relative risk has not changed, only our perception. Does it make sense to give seismic parameters to two or three decimal points when they are probably not accurate to within 50%?

Perhaps it would be better to use a deterministic approach along the coast with design parameters based on a sizable crustal or in-slab earthquake and increase these locally based on the probabilistic data similar to the method used in Japan (Kawashima and Buckle 2013). It is less expensive to build in resistance at initial construction than to determine later that the design values are too low or, worse yet, get surprised by an unexpected earthquake.

1.2. Geology

Much of British Columbia's geology, while spectacular, has forced much of the transportation and utility infrastructure to be concentrated along certain routes, many of which are prone to landslides and debris torrents, the Hope-Princeton and the Lions' Bay slides being a couple of the better known events (Mathews and Monger 2005).

Major earthquakes commonly trigger such slides over a wide area both on land and underwater. In 1946, the magnitude 7.2 earthquake in Central Vancouver Island generated about 10 slumps and 17 submarine landslides (Rodgers 1980) including some that broke a number of telegraph cables and generated one small tsunami (Hodgson 1946).

On land, a major slide in the Fraser Canyon could disable one rail line and possibly the highway. This would severely impact the capacity of the rail system as these lines are currently operated on a one-way basis. Nor would it likely be easy to repair, working in an unstable area with the risk of aftershocks.

Underwater, a major earthquake in the Vancouver area, might generate slides at the edge of the Fraser River delta, Spanish Banks or a number of other locations, potentially severing some of the major high voltage cables to the Island (BC Hydro 2012) and/or generating local tsunamis.

1.3. Soils

It has been well known for many years that soils play a key role in the amount of damage that occurs (Dowrick 1977). However, while maps of susceptible soils have been compiled in the Lower Mainland, as far as the author knows, no studies have been done to delineate the expected areas of high amplification in the Lower Mainland (Clague 2015) nor to compare our soils and basin effects with those in other earthquake prone areas.

The mid-Vancouver Island earthquake in 1946 caused damage to chimneys and water pipes in Victoria and was felt in the Okanagan valley (Hodgson 1946). For the megathrust earthquake, the distance to Okanagan valley and Kamloops is similar to the distance from the 1985 earthquake to Mexico City. Would a megathrust earthquake or a large earthquake in the lower mainland cause landslides, dam failures or building damage this far inland? It will likely depend on how the geology concentrates the waves, local soil conditions (much of these valleys are susceptible post-glacial deposits) (Mathews and Monger 2005), the level of ground saturation, etc. If it did, it might delay the re-opening of routes and aid to the Lower Mainland as resources would be committed to local issues.

Another area where soils might play a large role is much of our key industrial infrastructure -- transportation, steel fabricating shops, precast yards, cement plants, warehousing, etc.-- is located on higher-risk fluvial deposits adjacent to major waterways.

1.4. Quality of Designs and Construction

While many people think we have earthquake-proof buildings, is this really the case? To ensure earthquake-resistant buildings requires three things: (1) good design, (2) quality construction and (3) adequate field reviews.

Good design does not necessarily require an engineer or architect, as some buildings inherently have a good form and in some cases quite good details. This is particularly true of some of the older wooden structures with multiple walls, etc., which often had good structural form, light weight, redundant load paths and moderate to good ductility.

Unfortunately, for larger structures, many architects neither have a good grasp of seismic design nor like making modifications to improve structural behaviour. While, in theory, engineers should push to get changes, many do not; it is poor business, so they just do their best with what they are given. However, it has been known for decades that good structural form is a key factor to good earthquake performance (Dowrick 1977). So while many of these buildings may meet the intent of the code -- life safety -- they may be damaged during a significant earthquake.

When it comes to structural design, BC relies on an honour system for design and inspection. In much of BC, building departments are concerned that the paper work is properly completed; they neither review an engineer's design nor visit the site. This is the result of Bill 71 that in essence said if a jurisdiction relies on the professionals, it is not responsible (Thorson 1991). Questioning engineers or going to site attracts liability, so these activities are discouraged (Anonymous).

This leaves the Association of Professional Engineers and Geoscientists of BC (APEGBC) to maintain high standards of engineering. While many believe APEGBC is doing a good job, the evidence I have seen is to the contrary, with engineers reluctant to report unethical behaviour or dubious work and those that do are often unsatisfied with the results (Anonymous).

So how good or bad are our structures seismically? That is both a life-and-death and a multi-billion dollar question. We know the majority of modern structures will not collapse; however, our structures may be better or worse than other jurisdictions with comparable codes. As recent evidence has shown, neither good codes nor centres of seismic excellence are guarantors of good seismic construction. In California, some schools have been built recently that did not conform to the Field Act (EERI 2012) and, in Christchurch, there was the collapse of the CTV building (Cooper, Carter and Fenwick 2012) which was designed using a modern code, but clearly was deficient in important ways.

So where do we sit? That is hard to tell. Some believe the problems are largely with the sole practioners. The problems I have noted have involved engineers from a wide range of geographic locations, firm size, educational achievement and professional designation. These problems could have been from unethical behaviour, incompetence or blind spots. The thing in common was the errors were, in the Writer's opinion, obvious.

Will these or other design deficiencies all cause collapse? No; with smaller structures snow load is a significant factor both in seismic and gravity designs. If the earthquake happens with little or no snow, there is a good chance it will not collapse. Even larger structures might not collapse, similar to the experience of damaged steel moment frames during the Northridge Earthquake (Krawinkler, Anderson, Bertero, Degenkolb, Holmes and Theil 1996). Yes, significant damage but not collapse. On the other hand, detailing oversights have been responsible for the collapse of tilt-up buildings (Adham, Tabatabi, Brooks, Brugger, Dick, Hamad, Kariotis, Nghim, Phillips, Salama, Sramek, Stanton, Wood, Cluff, Lizundia 1996).

So back to the initial question: how good or bad are our structures? Based on observations over decades and on literature reviews, I suspect worse than some jurisdictions that have formal design peer review processes, but this is difficult to know with certainty.

1.5. Weather

The weather before an earthquake can have a huge impact on the magnitude and type of risks. In the winter and spring, heavy rains and melting snow greatly increase the risk of slides and liquefaction. Spring can also see freshets on many rivers increase the risk of flooding. Later in the year, heat can produce tinder dry conditions increasing the risk of fire. These risks continue with each significant aftershock.

The weather can also challenge the recovery. In winter, our cold damp weather makes keeping people warm and dry more difficult and could also increase water damage (from leaky pipes or compromised building envelope) by delaying drying and allowing mould to take hold.

The longer dry spells of some years could make water supply a challenge in some areas, if the water system is heavily damaged.

1.6. Response Capability

We have limited emergency response capability compared to other countries, as Canada has been fortunate to have had fairly small disasters. For moderate earthquakes this is not likely to be critical, as it will be possible to muster resources from surrounding areas.

However, in the event of a very large urban or mega-thrust earthquake, unlike the US, Chile or Japan, we have (1) very limited military resources; (2) limited resources close to the affected areas to deploy quickly; and (3) limited transportation routes into and between affected areas. As well, for the mega-thrust earthquake it might be the Americans' first taste of a very powerful earthquake affecting major urban areas since 1906, so they might be scrambling with their own problems. Washington State in particular has a number of major cities on recent glacial deposits and a history of slide-prone areas.

Other key factors will be how many, how large, and when and where the major aftershocks occur.

2. Things that are Getting Worse

There are many things that are getting worse, including:

- More people. Basically a larger population produces more demand on all the systems, which tend to get larger and more complex.
- Denser developments. While these are absolutely necessary for a variety of reasons, they are not good for earthquake recovery as (a) apartment dwellers usually have limited food and water reserves and (b) high-rises need power and services or many of the units will be abandoned. Not many of us could walk up 6 or 7 floors with all our food and water let alone to higher floors. So after a major quake, alternative housing might be needed for tens of thousands of people.
- High land prices, technological change and stricter environmental rules have reduced the number of distribution and storage facilities. For example, on Vancouver Island major oil storage facilities in Victoria, Union Bay, Campbell River and Port McNeill have all closed -- over half the former total. Warehousing facilities have seen similar trends from many small and simple warehouses to fewer larger, highly-automated facilities. These two trends could make transporting supplies from storage to where they are needed more difficult.
- Increasing dependency on both the electrical grid and the internet. Unlike the Second World War when people stayed calm and carried on, we would find it much harder. In the 1940's most things were done manually and many factories had their own power plants. Today, most jobs use power tools or equipment. Not only do many firms lack manual backups, many of us lack the endurance to use them. While BC Hydro has taken steps to upgrade some facilities, it is still not fully prepared (Auditor General 2014).

3. Things that are Getting Better

Not all things are getting worse, and in some areas are getting better including:

- Some organizations and utilities have been upgrading their infrastructure.
- Increased heavy lift capacity of the Canadian air force. These aircraft give Canada significant capability to deliver relief supplies. The bigger problem would be getting the relief flights up and running, delivering what is needed where it is needed.
- Early warning systems. These systems use the p-wave, which arrives first but does little damage, to trigger a shut-down of some systems. Unfortunately, they give only limited warning.

4. Other Developments

Some developments could be positive, negative or both. An example of this is the port system. Advantages are (1) allowing aid to come in by sea and (2) large quantities of food awaiting shipment. Negatives are (1) increased risk of serious fires, as grain dust, etc., are highly volatile; (2) increased risk of train derailments; and (3) the impact disrupted shipments would have on the rest of the Canadian economy.

Another is better communications systems. Not only are there land lines and radios, there are cellular phones, the internet, and satellite phones. However, the population is unfamiliar with earthquakes and may either crash some of the systems with calls, tweets, selfies, etc., or overload the call centres with too much data.

5. “Black Swan” Events or Wild Cards

These are the things that normally do not occur, but if they do can turn an ordinary disaster into a catastrophe, including fire storms, flooding, civil unrest and disease. The latter two would only likely become serious if there were a breakdown in the response.

5.1. Fire storm

Famous examples of this are San Francisco 1906 and Kanto 1923. At certain times of the year, parts of the south coast are vulnerable to serious fires even without an earthquake, as fuel loads are very high and wind is common. These have been contained in the past by the fast action of fire crews extinguishing them while they are very small (Anonymous). However, in an earthquake there are often multiple ignitions (over 100 fires in Northridge) , reduced water pressure, etc., which delay the response (Scawthorn, Borden, Collier, Cowell, Harwood, Hoffman and Ward 1995).

5.2. Flooding

This occurred after the Christchurch earthquake, where the levees moved into the river channel reducing its flow capacity (Mitchell 2011). The greatest risk for BC would be a powerful shock breaching the Richmond dikes, during the spring freshet.

6. Improvements

While the worst case scenarios are catastrophic, it is unlikely the billions necessary will be spent on mitigation that may or may not be effective (Auditor General 2014). Politics dictates monies go to immediate concerns, not some risk sometime in the future (Auditor General 2014).

However, some actions are relatively inexpensive and should be taken. The earlier improvements are started the more effective and cost effective they can be. The improvements will be divided into two groups: (1) the ones with little cost (political or economic) and (2) those with higher costs. The suggestions in this latter group will not likely be adopted without some external event (e.g. a major fire) to push the change and perhaps not even then.

6.1. Lower Cost Options

6.1.1. Increasing individual disaster preparedness

It is vitally important for people to have a base level of preparedness, but it is just not there (Anonymous, Auditor General 2014). Too few people know what to do or have emergency kits. Preparedness needs to be widespread and for a sufficiently long period to allow for relief efforts to be established. The 3 day recommendation is too short for a major disaster; 7 days would be more appropriate (Henson and Johns 2011).

Perhaps events like power outages should be used to press home a simple message such as “Your power was out for x hours, how did you do? How would you do if it was out for 7 days? After an earthquake, you could be on your own for that long. Are you prepared? Water? Food? Medicines? Visit our website to learn how to prepare.”

6.1.2. Increasing community disaster preparedness

The auditor general’s report notes a number of actions that should be taken, but an additional one is the need to get more of our intermediate and senior responders first-hand field experience. While some staff from the Ministry of Transportation, Provincial Emergency Program, non-governmental agencies and local communities (Henson and Johns 2011) have visited disaster sites, more need this sort of on-site field training. Some lessons from these trips have been that many tasks were not anticipated, heads of departments are taken up with public relations, need for structural inspectors, and the need for larger scale exercises (Henson and Johns 2011).

6.1.3. FM chip in smart phones

The FM chip in smart phones allows users to listen to FM radio without using the internet; however, on most phones it is disabled by the carriers. Not only would this allow dissemination of information if the cellular towers or internet are damaged, its use greatly extends battery life (Smulyan 2015). Government should require carriers to enable this chip and phones should be fully operational at the time of purchase.

6.1.4. Building robust systems

Some improvements have been done in this area but more needs to be done with key infrastructure, particularly water, sewage, bridges, fire fighting, gas lines and medical facilities (incl. veterinary).

Specific low cost suggestions include:

- gas isolation valves. Surprisingly some of the new plastic gas lines have very few isolation valves; instead workers excavate the line and pinch it to stop the flow (Anonymous). While this may be adequate in normal times, it is not after an earthquake.
- small fire-fighting boats. These can be trailered and launched near the site. It makes sense to fight as many of the fires with local water rather than rely on mains that may be damaged. Some communities already have these.
- backup water systems. Drinking water could be critically important after an earthquake, there needs to be backup plans in place to get a few days of supply for the community.
- Plan and keep key facilities on good soils where possible.

6.1.5. Better structures

Structures are not likely to get better under the current system nor the proposals from APEGBC. For example, a recent proposal from APEGBC is to have engineering licenses accepted across the country. While convenient for some engineers, this does nothing to protect the public. I recently reviewed an out-of-province engineer's calculations that were full of basic errors.

Some suggestions that might be effective include:

- Use a combined deterministic and probabilistic approach for seismic forces.
- Require all failures or near failures be reported to a central body. This might give some insight to problem areas in design and construction.
- Select engineers based on ability, not price. Increasingly engineers are being selected based on price with little regard to their experience or quality of their work.
- Non-structural seismic design should be done by an engineer hired by the owner. Hiring through the contractor is hit-and-miss at best and non-structural is more important than many people think. It is often responsible for the largest dollar value of damage, many of the fires, and has shut down critical facilities (EERI 1994).
- Hold harmless building inspectors for questioning designs or visiting the site. An extra set of eyes is valuable and might get some engineers to take their obligations for design and field reviews more seriously.
- Have independent random or partial reviews of designs submitted. Not only does this provide some incentive against poor design it also highlights areas of confusion or ignorance.
- Have an independent, open and competent review of APEGBC's handling of complaints. Government too often delegates power to self-governing bodies and then ignores them. APEGBC'S handling of the Writer's written complaints have been flawed, in my opinion, but I am not alone in this opinion and concern (Anonymous).

6.2. Higher Cost Options

6.2.1. Planning

Truly long-term planning is required, including the phasing out of population growth. This will be highly controversial as growth has been a constant since the arrival of the Europeans. However, rapid global growth has only occurred for the last 200 years (World Almanac 2014), so it is the anomaly in human history, not the norm. Neither the planet nor BC is getting any bigger, so at some point both population and consumption must stop growing. The risk from earthquake is just another reason for curtailing development earlier.

6.2.2. Restrict Building Areas

6.2.3. Limiting new construction and reconstruction to lower risk areas. This concept has been pioneered by the Swiss after a series of expensive natural disasters (Environment 2007). They are mapping all potential risk areas (flood, earthquake, avalanche, etc.) and limiting construction and rebuilding to safer areas. In BC, our efforts have been uncoordinated. There are some restrictions based on slope stability and flooding, but not other hazards. The province should expand the criteria and undertake this work to provide a more consistent approach over the entire province. Given the Lower Mainland's key place in the BC economy, and its rapid growth, it should be one of the first areas considered.

7. In Conclusion

The problems highlighted and others not noted have all happened during earthquakes, but not all together. The combination of what will happen is a function of our actions and factors beyond our control. Some risks must just be accepted. However, we are still failing to implement many basic and inexpensive precautions in both prevention and ensuring a reasonably strong response. The time for action is now.

8. Acknowledgements

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