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Reducing the risk of earthquake damage in Canada: Lessons from Haiti and Chile

By Paul Kovacs

November 2010

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Institute for Catastrophic Loss Reduction

The insurance companies in Canada established the Institute for Catastrophic Loss Reduction in 1997 to be a world-class centre of excellence in disaster safety. The Institute is an independent, not-for-profit research centre based in Toronto and London, at the University of Western Ontario, working to turn research into actions that enhance resilience to natural hazards. The Institute thanks Lloyd's for its ongoing support and for sponsoring this report.

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Foreword

In this report sponsored by Lloyd's, the Institute for Catastrophic Loss Reduction identifies lessons for reducing the risk of earthquake damage in Canada based upon the recent tragic events in Haiti and Chile.

Some day a large earthquake will strike Vancouver, Montreal, Ottawa or another large urban centre in Canada. Such an event has the potential to cause loss of life, property damage and economic disruption unprecedented for Canada. The tragic and contrasting experiences earlier this year in Haiti and Chile show that appropriate investments in preparedness and resilience can help prevent future earthquakes from becoming disasters.

There is a solid and growing foundation of knowledge that can be applied to improve preparedness and resilience to the threat of natural hazards. The recent events in Haiti and Chile, for example, provide important lessons for Canada and other countries vulnerable to large earthquakes.

This report identifies seven lessons for Canada, and in doing so, examines the country's state of preparedness and resilience to extreme earthquake events. There are many areas of strength in Canada's preparedness and resilience, yet there are also several areas where improvement is needed. Of particular concern is the vulnerability of public infrastructure, some concerns about the preparedness of the federal government, and the need to retrofit older homes and buildings.

In addition, there is scope to improve the dialogue between stakeholders, including public officials, business leaders and the research community. The report also highlights the important role that insurance will play to support the recovery following an earthquake and the essential contribution of research to provide a science-based foundation for action.

We hope this report will foster increased awareness about the potential impact of a major earthquake in Canada, and lead to opportunities to prevent or mitigate the risk of loss. This report seeks to strengthen the willingness to invest further in resilient buildings, infrastructure and preparedness. The best time to act is now, before a large earthquake strikes.

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Executive summary – Seven lessons for Canada

Important lessons can be learned from the tragic events this year in Haiti and Chile that can be applied to Canada to help reduce the probability that large earthquakes become catastrophes. Earthquakes can be powerful hazards. Hazards can become disasters if they strike a vulnerable community that is not prepared. Countries exposed to large earthquakes, like Canada, must invest in preparedness and resilience to reduce the risk that earthquakes will cause fatalities, property damage and economic disruption.

There are many lessons for homeowners, businesses and public officials in Canada from the tragic earthquakes in Haiti and Chile. In this report we highlight seven key lessons:

1. It is inevitable that a major earthquake will strike Canada
A number of communities in Canada have a high or moderate risk of experiencing a large earthquake, including Vancouver, Montreal, Ottawa, Victoria and Quebec City. It is essential that individuals, businesses and public officials understand the risks earthquakes pose.

2. We can help prevent earthquakes from becoming disasters
Three priorities for improving Canada's resilience to large earthquakes should include retrofitting or replacing vulnerable buildings, taking steps to reduce the threat of uncontrolled fire following an earthquake, and investment to strengthen the seismic resilience of public infrastructure. Sound investment in loss prevention can significantly reduce the need for recovery.

3. Building codes and retrofits protect lives and property
Most earthquake fatalities and extensive property damage are the result of buildings that collapse. Fortunately, modern building codes and a progressive engineering community have reduced the risk of loss for newer homes and buildings in Canada. However, investment should be made to retrofit or replace older and potentially vulnerable structures, including schools and hospitals.

4. Canada's public infrastructure is vulnerable to damage
Earthquakes in Haiti, Chile and elsewhere resulted in severe destruction of essential systems, including transportation and water systems. Public infrastructure in Canada appears highly vulnerable following decades of underinvestment, and may be severely challenged by a large earthquake. Even in the absence of a large earthquake, significant investments are required to retrofit these ageing systems to a better level of performance.

5. Effective preparedness will reduce the risk of losses
The local and provincial emergency response systems in Canada have a good record of successfully responding to natural hazards. However, Canada's system of emergency preparedness has never been tested by an event as large as a major earthquake. Moreover, there are some concerns about the preparedness of the Government of Canada to provide federal services, and support, if requested, the provincial and local response.

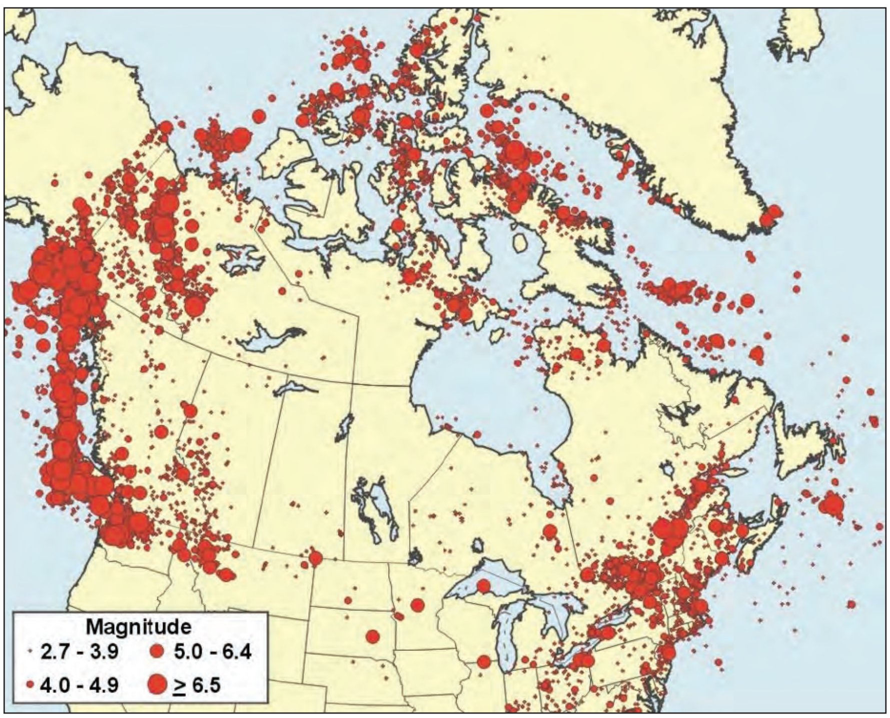
6. Canadians must understand recovery tools like insurance

The best time to plan for recovery from a major earthquake is before the event strikes. Tools like insurance and public relief are essential mechanisms to fund the recovery process. Individuals, businesses, governments and other stakeholders should take the time to understand the specific role that insurance and the other tools may play to support recovery following an earthquake.

7. Science and research provide the foundation for action

Countries vulnerable to major earthquakes, like Canada, must invest in research to enhance their knowledge of the hazard, the potential impacts, and seismic safety. Investment in science and research will provide the knowledge to support effective actions by decision makers.

Earthquakes in Canada since 1700



Source: Geological Survey of Canada, Natural Resources Canada

Disaster strikes Haiti in January

A magnitude 7.0 earthquake struck Haiti on January 12, 2010, the fifth most deadly earthquake on record.[1] The impact was catastrophic because of Haiti's extreme vulnerability. An estimated 2.5 million people experienced extreme or violent shaking. Almost nine percent of those affected were killed (222,570 people), and half (1.3 million) were forced to live in tents and other temporary shelter. There was US$8 billion in direct economic damage – a total equal to 110 percent of Haiti's annual economic production.[2]

Intensity of shaking in Port-au-Prince

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: United States Geological Survey

Tectonic summary

Haiti is located in a region prone to large earthquakes. The tectonic features of the Caribbean region are complex. The earthquake occurred in the boundary separating the Caribbean plate, which is moving eastward, and the North American plate. The earthquake struck at 4:53 pm. There was a magnitude 6.0 aftershock six minutes later, and 15 other aftershocks over the next two weeks that were a magnitude of 5.0 or greater.[3]

A tsunami warning was issued when the earthquake struck. At least 4 people were killed by a local tsunami in the Petit Paradis area, likely triggered by an underwater slide.[4] Otherwise the event did not trigger meaningful tsunami activity and the warning was soon rescinded. There were a number of landslides, particularly in the deforested areas near Port-au-Prince.

Research had been published and reported in the local press anticipating that Haiti would some day experience an earthquake near Port-au-Prince that could be as strong as a magnitude 7.2.[5] There have been 11 large earthquakes in southern Haiti since 1615, but nothing in recent decades.[6] The accumulation of stress over the past 240 years indicated that a large event was expected. However, research after the earthquake indicates that considerable seismic risk remains. "The time elapsed, combined with the rate of long-term slip on the fault inferred from geodesy, suggests that this year would have been an appropriate time for the fault to slip again by about 2 m. Although this slip may indeed have occurred at depth, the uppermost 5 km of the Enriquillo-Plantain fault has remained obstinately clamped shut, and could in principle rupture at any time, generating a Mw 6.6-6.8 earthquake."[7]

Haiti was not prepared for a major earthquake

Earthquakes destroyed Port-au-Prince in 1751, and again in 1770. As a result of these disasters the local authorities forbade building with masonry and required that new buildings were to be made from wood.[8] Unfortunately these lessons about safer construction were long forgotten.

Magnitude 7.0 earthquakes are large, yet need not result in such tragic losses. Data from the U.S. Geological Survey shows that there were 148 earthquakes over the past decade stronger than the event in Haiti, yet only the remarkable magnitude 9.1 Sumatra earthquake (which triggered the Boxing Day tsunami) resulted in fatalities comparable to the Haiti event.

Haiti was not prepared. Haiti is the poorest country in the western hemisphere - 72 percent of the population survives on less than $2 per day.[9] The country has been struck recently by several large hurricanes, including more than $1 billion in damage from Fay, Gustav, Hanna and Ike in 2008.[10] Moreover, Haiti failed to impose even a minimum quality standard on construction practices. As a result, the people and buildings of Haiti were extremely vulnerable when the earthquake struck, and the impacts were catastrophic.

The performance of buildings in Haiti

Most buildings in Haiti are highly susceptible to seismic damage. The condition of the building stock unfortunately reflects the poverty in the country. There are no design standards for construction or government supervision to ensure construction quality. The vulnerability in Haiti is further increased because only 15 percent of residents own their own home and in many cases land ownership is not registered. There is a widespread practice of uncontrolled construction, with no consideration of seismic hazard by residents or public officials.

About 10 percent of the buildings in Haiti were multi-storey, almost entirely located in urban centres.[11] The taller structures that failed in January were often built with thin, unreinforced support structures and relatively heavy slab floors. These structures failed when subjected to strong shaking.

Most of the homes and other low-rise buildings in Haiti have walls built with concrete blocks, woven wood mats, bricks or rocks. These walls are typically heavy and seldom reinforced. Concrete blocks are more common in urban centres. In rural areas many homes are adobe structures built with bricks crafted from sand, clay and water mixed with sticks and straw and dried in the sun.[12] Adobe homes are affordable and extremely durable, but highly susceptible to damage from earthquakes. Perhaps 70 percent of roofs are built with light-weight materials, like tin. Most floors in urban centres are concrete and in rural areas are made of packed earth, with poor foundations to anchor the buildings.

In Port-au-Prince and the surrounding communities an estimated 105,000 homes were destroyed, and more than 208,000 were severely damaged.[13] Heavy walls of concrete blocks or earthen material were particularly vulnerable and often failed when subject to strong shaking. Most fatalities and injuries were due to collapsed buildings.

There was extensive damage to informal housing. Shanty towns on the outskirts of Port-au-Prince provided homes for people in self-constructed shelters. Perhaps two million people were living in Haiti as squatters on land they did not own. The substandard construction was extremely vulnerable to destruction from strong shaking and landslides.

Undoubtedly the loss of life and property damage was significantly increased because Haiti has no building codes, and construction standards are low.

Losses beyond severe shaking in Haiti

Vital infrastructure failed throughout the country including transportation, power, communications, schools and hospitals. The main seaport was closed when wharves collapsed into the bay and loading cranes submerged due to liquefaction-induced spreading.[14] Highway and road damage was widespread, often due to falling debris. The airport was closed for 48 hours due to damage to the control tower and cracks in the main runway. Power was lost throughout the country. Telephone and cell phone systems were down. Radio stations went off the air. More than 50 medical centres and hospitals and 1,300 schools collapsed or were damaged. Some systems were still not operating many months after the earthquake. The collapse of essential infrastructure further contributed to the losses experienced, and greatly prolonged the time required for recovery.

Most of the fatalities and property damage in Haiti were due to strong shaking of poorly built structures. Secondary hazards that added to the losses were soil liquefaction and landslides, compounded by poor disaster response. Liquefaction occurs when strong shaking triggers a temporary loss in the load-bearing capacity of soils. The port facilities in Port-au-Prince and some other areas of the city experienced damage greater than otherwise would have been expected due to soft soils. Steep slopes and long-term deforestation made the southern parts of Port-au-Prince more vulnerable to earthquake-triggered landslides, resulting in high concentrations of building damage. Tsunami warnings were issued immediately following the earthquake but were quickly canceled. The town of Petit Paradis experienced a localized tsunami, but the Haiti earthquake and aftershocks did not trigger large tsunamis.

The January earthquake resulted in a breakdown of social order, and the World Bank noted "the earthquake decimated the government's operational capacity."[15] Emergency response was delayed and inconsistent across the affected region. For several days it was unclear who was in charge of the relief efforts. Thousands of bodies were buried in mass graves. Tens of thousands slept outside with little or no shelter because they were fearful of aftershocks. Treatment for the injured was delayed or not available because of damage to hospitals, lack of supplies, and fear that buildings were unsafe.

The response to the earthquake in Haiti was chaotic and compounded the tragedy. It will be many years before Haiti recovers even to the poor state of economic and social health that was in place before the earthquake. Indeed, "nine months have passed since the disastrous earthquake in January 2010, but the state of emergency in Haiti has not ended. Refugee camps are still prevalent, and acceptable levels of security are still a distant dream, particularly for women."[16]

Financing the recovery

Haiti's recovery from the January earthquake will be financed primarily through international post-event disaster relief. The United Nations donor conference in March secured $5.3 billion in pledges to help Haiti recover.[17] Few property owners in Haiti purchased private insurance cover, so insurance will play a very small role in financing the recovery, paying perhaps $150 million in claims.[18] Immediately after the earthquake struck, the Caribbean Catastrophe Risk Insurance Facility paid $8 million to the Government of Haiti, twenty times Haiti's premium, to prefund the initial response to the disaster. Members of the Facility are re-examining this program as "the small size of that payout relative to the levels of destruction highlights the need for increased levels of coverage… (to) provide a springboard to more rapid and comprehensive recovery."[19]

Disaster strikes Chile in February

A magnitude 8.8 earthquake struck Chile on February 27, 2010.[20] This was the fifth strongest earthquake ever recorded. The energy released was 500 times greater than the Haiti earthquake. More than 12.5 million people experienced severe or violent shaking, or were affected by the resulting tsunami. The Chilean government has identified 432 people that were killed by the earthquake and continues to investigate 98 other deaths where the earthquake appears to have been the cause.[21] The subsequent tsunami was responsible for 124 of the total deaths.[22] Direct economic damage could reach US$30 billion, or 18 percent of Chile's annual production.[23] The adverse impact on Chile of this large earthquake was significantly reduced because of the investment in preparedness and resilience, and stands in stark contrast to the experience in Haiti.

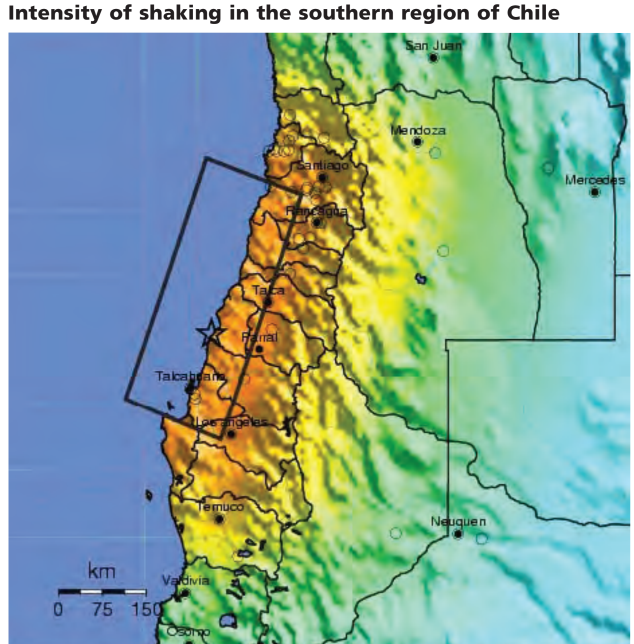
Tectonic summary

Chile is one of the most seismically active places in the world. The Nazca plate is moving beneath South America. Many times each year earthquakes occur at the boundary where the plates meet or within a plate, and occasionally these events can be large. In addition, every few decades the region experiences megathrust subduction events, like the January event, where there is a sudden movement over a large area.

In 1922, the northern region of the boundary generated a magnitude 8.5 subduction earthquake. In 1960, the southern region of Chile experienced a violent 9.5 magnitude earthquake, the most powerful ever recorded. In February 2010, the central region ruptured. Research on strain rates suggested considerable risk given the absence of a strong earthquake in the region since 1835. In 2009, Ruegg *et al*. warned about the potential for a magnitude 8 to 8.5 earthquake in the area.[24]

A magnitude 8.8 earthquake struck the central, southern region of Chile on Saturday, February 27 at 3:34 am. More than 300 aftershocks greater than magnitude 5.0 were recorded over the next two months, including 21 stronger than magnitude 6.0.[25] These earthquakes were strongly felt over a large area with a population of 12.5 million people, or about 75 percent of Chile's population. Tsunami warnings were issued affecting hundreds of millions of people around the Pacific Ocean. There was extensive earthquake and tsunami damage in Chile and minor tsunami damage in locations as distant as Japan and the United States.

Intensity of shaking in the southern region of Chile



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
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INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: United States Geological Survey

The February 2010 earthquake was shallow, at a depth of 35 kilometres. The rupture extended over nearly 500 kilometres, resulting in a great release of energy. The last time this part of Chile experienced a subduction earthquake was in 1835, as reported during a visit from Charles Darwin onboard the Beagle.[26].

The performance of buildings in Chile

Chile has been working to build its resilience against large earthquakes since the Talca earthquake in 1928. This is evident in the country's first building code in the 1930s, and revisions to the code in 1949, 1972 and the 1990s following large earthquakes.[27]

Most homes built in Chile since the 1970s were wood frame or reinforced masonry. These homes experienced little if any damage following the earthquake this year, despite the severity of the shaking. However, significant damage was experienced in many older, adobe structures, known for poor seismic performance. Also some informal wood homes were built directly in flood plans and washed away by the tsunami, while reinforced masonry buildings survived the tsunami with minor structural damage. The Government of Chile estimates that 81,444 houses were destroyed, 108,914 were severely damaged, while 179,693 sustained minor damage.[28]

Most of the larger buildings in Chile performed well. The Earthquake Engineering Research Institute reports that 50 multi-storey reinforced concrete buildings were severely damaged and will need to be demolished, while four buildings collapsed.[29] Any poor performance of newer structures appears to be the result of oversights in the design process, perhaps failing to anticipate the effects of soft soil deposits, or due to construction deficiencies. Building codes in Chile largely reflect current international engineering and design knowledge about seismic safety. The codes are widely applied by the construction industry and generally enforced by public officials.

Most modern structures performed well, and in many cases experienced no damage from this very large earthquake, while older buildings nearby may have been destroyed. A number of designs are common for the building of multi-storey structures in Chile including reinforced concrete and steel construction. These engineered structures are more resilient to earthquakes.

Losses beyond severe shaking in Chile

The earthquake triggered a tsunami that caused damage over much of Chile's coastline. A warning was immediately issued to nations around the Pacific Ocean, but all of the tsunami fatalities and most of the damage was experienced in Chile. "Few coastal residents died in the tsunami because of a high level of tsunami awareness."[30] Most of the tsunami fatalities involved weekend campers on an island accessible only by boat, with no high ground and little protection. The tsunami also destroyed 1500 homes and several bridges on highways near the coast.

The earthquake caused disruption for transportation, power, communications, water and sewage systems. Santiago international airport was closed for 24 hours due to non-structural damage to the terminal, while the airport in Concepción was closed after the tsunami washed over the runway. The subway and bus system in Santiago was closed for two days.

Several ports experienced extensive damage. Many roads buckled or were blocked by debris and 200 bridges were damaged, including 20 with collapsed spans. Highways experienced significant damage. More than two million people experienced power outages, yet within five days electricity was restored to most of the country as the main power grids did not experience extensive damage. Telephone landlines were lost for an indeterminant period in several of the larger centres affected by the earthquake. The majority of systems to transmit cellular signals were designed to operate on battery reserve power, but within a few hours most batteries ran out. Underground infrastructure experienced extensive damage including burst water pipes, sewers and broken gas pipes, and this damage is taking a long time to restore. There was heavy damage to waste water systems, and there were some discharges of sewage into rivers.

An important lesson from Chile involves addressing the risk of damage to nonstructural components and systems. Most of the hospitals in Chile suffered minimal structural damage yet the Chilean Ministry of Health estimates that it will take three or four years and US$2.8 billion to repair hospitals across the country.[31] Most hospitals reported damage to suspended ceilings, cracking of the plaster over brick walls and partition damage. Some hospitals were evacuated due to unsanitary conditions resulting from this non-structural damage. Four hospitals became uninhabitable, twelve lost more than 75 percent of operations, 62 percent needed repairs, and 18 percent of the beds in public hospitals continued to be out of service one month after the earthquake. The majority of hospitals had back up systems to help them cope with the temporary loss of power and water, but most did not have similar back-up when their communications systems failed.

"Although Section 8 of the Chilean seismic code includes provisions for nonstructural components, these are usually not enforced… for most buildings it is not clear who is responsible for the design, installation, and inspection of seismic anchoring and bracing of nonstructural components."[32]

Financing the recovery

Standard & Poor's estimates that between US$8- and US$12 billion in private insurance funds will be paid to rebuild Chile.[33] Most commercial and industrial operations had insurance coverage that included earthquake damage. One quarter of homes had insurance coverage, including 90 percent of those with mortgages and 10 percent of those without.[34] "Insurance is not available for adobe homes, which represented two-thirds of the residential losses."[35] Guy Carpenter cautions that "much uncertainty remains about the final insured loss for the Chile earthquake… (as) historical events suggest earthquake losses take longer to develop when compared to wind losses… in part due to business interruption losses mounting over a longer period of time."[36] The Chilean insurance association said that 90 percent of the insurance claims will be recovered from international reinsurance. The Government of Chile has launched a US$2.5 billion housing reconstruction program called "A united Chile constructs better".[37]

Lesson 1: It is inevitable that a major earthquake will strike Canada

More than 4,000 earthquakes are recorded in Canada each year. Most are small and can only be felt by sensitive monitoring equipment, however, some are large. A major earthquake will strike some day in Canada. While almost 40 percent of Canadians live and work in zones of high or moderate risk of loss from an earthquake, many appear unaware of the hazard. An essential first step required for individuals, businesses and governments to reduce the risk of loss from an earthquake is to understand their vulnerability. In particular, this report focuses on two regions where more than 75 percent of the country's seismic vulnerability is concentrated:[38]

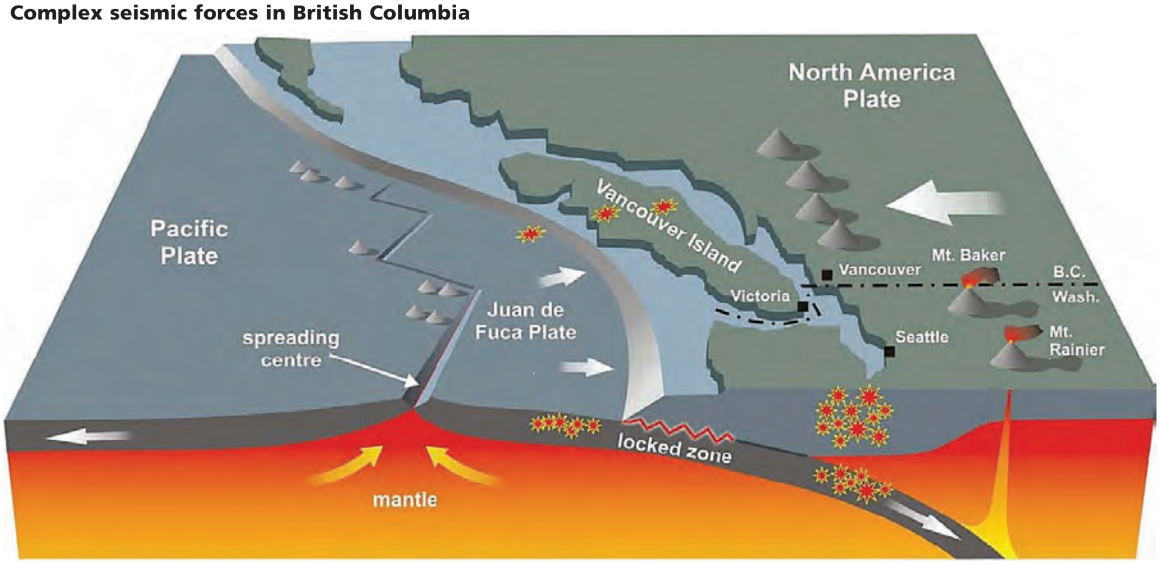
- **There is at least a 30 percent chance** that an earthquake strong enough to cause significant damage will strike southwestern British Columbia in the next fifty years.[39] This is a rapidly growing region that includes Vancouver and Victoria.
- **There is a 5 to 15 percent chance** that a damaging earthquake will strike in southern Quebec or eastern Ontario in the next fifty years. This region includes Montreal, Ottawa and Quebec City.

40% of Canadians live and work in zones of high or moderate risk of loss from an earthquake, many appear unaware of the hazard.

Earthquake hazard in British Columbia

The Pacific coast is the most complex and active seismic zone in Canada, as there are more than 2,000 earthquakes each year. Two hazards of concern in this report are the chance of a megathrust subduction earthquake, or a strong crustal event near an urban centre.

Complex seismic forces in British Columbia



Source: Geological Survey of Canada, Natural Resources Canada

The Cascadia subduction zone is located west of Vancouver Island where the North American and Juan de Fuca plates meet. It has resulted in some of the strongest earthquakes in the world. For example, the sudden movement in January 1700 of the North American plate over the Juan de Fuca plate resulted in an event estimated to be a magnitude 9.0 earthquake.[40]

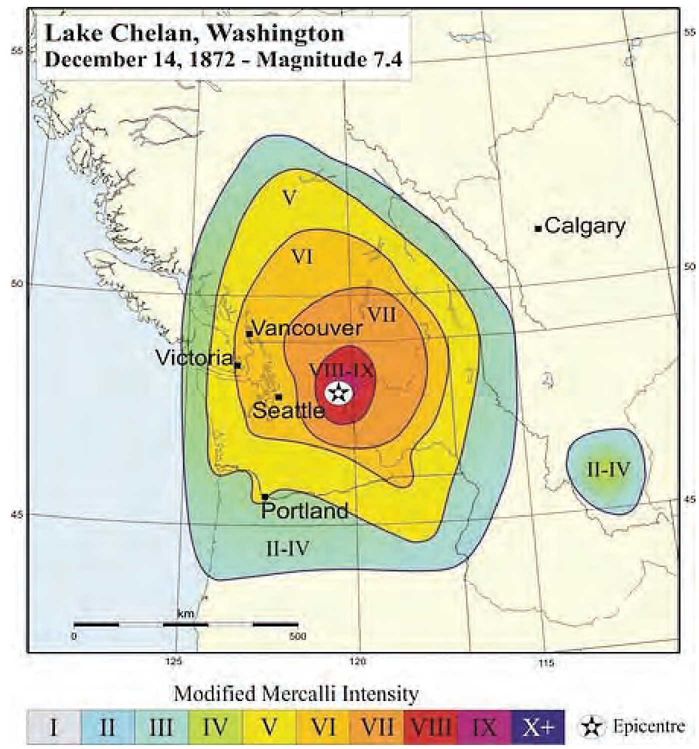
Geologic evidence suggests that magnitude 8.0 or greater subduction earthquakes have occurred six times over the past 3,000 years. The time between events has been 250 to 800 years, with an average of 500 years.[41] The last subduction event was 310 years ago. Seismologists predict a 10 to 15 percent chance of a Cascadia subduction event over the next 50 years, although some recent studies warn that the likelihood may be even greater.[42]

Cascadia subduction events can have large regional impacts that extend from western British Columbia to northern California. More than 12 million people live in the region and would be vulnerable to widespread violent shaking, tsunami, landslides and fire-following earthquake.

Large crustal earthquakes are also a hazard in southwestern British Columbia. The eastern part of the Juan de Fuca plate is located under the North American plate, 70 km under the city of Vancouver and 45 km below Victoria. Earthquakes can result in strong local seismic events if they originate on this interface, within the Juan de Fuca plate, or within the North American plate. On average, there are more than 40 crustal earthquakes in British Columbia each decade that are magnitude 5.0 or greater (potentially strong enough to damage buildings).

A magnitude 7.4 earthquake occurred in 1872, near the surface and 170 km southeast of Vancouver. A similar intraplate event located closer to a major centre has the potential to cause extensive damage due to violent shaking, landslides, fire, inundation and economic disruption as a result of damage to public infrastructure.

Intensity of crustal earthquake near Vancouver



Source: Geological Survey of Canada, Natural Resources Canada

While southwestern British Columbia and the northwestern region of the United States are vulnerable to strong, shallow earthquakes, resulting losses from these earthquakes will be felt over a relatively small area compared to the extent of damage expected during a subduction event. Over the past 140 years, 11 strong crustal earthquakes of magnitude 7.0 or greater were widely felt in British Columbia.

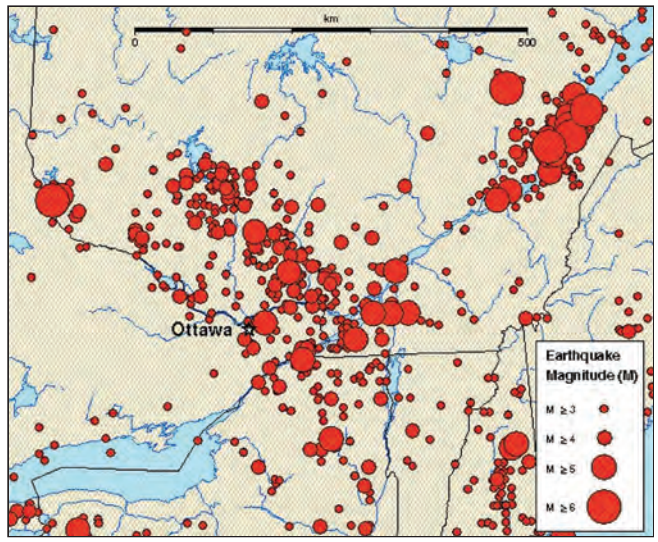
Earthquakes in Quebec and Ontario

On average, two to three earthquakes greater than magnitude 5.0 are experienced each decade in southeastern Canada, with the potential to cause damage. It is inevitable that eastern Canada will experience a magnitude 7.0 earthquake (like Haiti) a thousand times more powerful than the magnitude 5.0 event near Ottawa that surprised many people in June 2010.

The Charlevoix seismic zone, 100 km east of Quebec City, is very active. Over the past 350 years there have been five earthquakes in the zone that were magnitude 6.0 or greater. This is the region in eastern Canada with the greatest chance of a large earthquake.

The western Quebec seismic zone includes Montreal and Ottawa, two of Canada's largest cities. Over the past 380 years there have been five earthquakes that were magnitude 5.0 or greater in the zone, including the event in June 2010. There is a moderate risk of a large earthquake striking the Montreal/Ottawa region over the next 50 years, but the risk is lower, in terms of frequency and severity, than that for Vancouver or Victoria.

Earthquakes in Quebec and Ontario since 1700



Source: Geological Survey of Canada, Natural Resources Canada

Earthquake hazards elsewhere in Canada

Most other large urban centres in Canada are located in regions of low earthquake hazard, including Toronto, Calgary, Edmonton and Winnipeg. There is some chance of seismic damage to vulnerable buildings, but the likelihood is low.

There are several regions in Canada with smaller communities where there is a moderate or high risk of a major earthquake. For example, Canada's most deadly earthquake struck in 1929, a 7.2 magnitude event near the Grand Banks, when 28 people lost their lives due to the resulting tsunami in Newfoundland.[43] Large earthquakes strike regularly in northern Canada. There have been 12 earthquakes over the past 120 years that were magnitude 6.0 or greater in the region that includes the Yukon and the western Northwest Territories

Lesson 2: We can prevent earthquakes from becoming disasters

A disaster occurs when a vulnerable community is overwhelmed by a natural hazard. In most cases it is possible to help prevent severe hazards from becoming disasters.[44] Building codes, resilient infrastructure and emergency preparedness are examples of actions that reduce society's vulnerability to natural perils. Securing the will to invest in preparedness and resilience is often established through an understanding of the potential adverse impact that can be avoided, permitting an assessment of the potential benefits and costs that reduce the risk of damage from earthquakes.

The potential impact of a large earthquake

Justification for investments in seismic risk reduction and their prioritization should be based on an assessment of the potential consequences of an earthquake. This analysis can be done for a specific building or at a broader, societal level.

In 2003, a study was published by the New York City Consortium for Earthquake Loss Mitigation estimating that a magnitude 6.0 earthquake in New York could result in almost US$40 billion in damage and temporary shelter would be required for almost 200,000 people.[45] In 2008, a study was released by the U.S. Geological Service estimating that a 7.8 magnitude earthquake near Los Angeles would cause 1800 deaths and more than US$200 billion of economic losses.[46] And there have been a number of studies warning that Tokyo is overdue for a large earthquake that could result in more than US$1 trillion in damage. Most of these studies involved seismic experts from the government, academia and the private sector working together. Unfortunately, no comparable, multi-stakeholder study has been conducted in Canada.

The Munich Reinsurance Company of Canada commissioned a study that was published in 1992 to assess the impact of a 6.5 magnitude earthquake located near Vancouver.[47] The study estimated that there would be more than 200 fatalities, 7000 injuries, and economic losses of between C$14- and C$32 billion. Insured claims were predicted to be between C$7- and C$13 billion. Rapid economic and population growth in the Vancouver region over the past twenty years, and the recent study warning that an major earthquake in Los Angeles could result in more than US$200 billion in losses, implies that a current loss estimate for the Vancouver region would be much higher.

Peter Nemetz and Kelvin Dushnisky, who led the 1992 study for Munich Re, published a paper in 1994 estimating that the damage to buildings and infrastructure in the lower mainland of British Columbia from a megathrust Cascadia subduction earthquake would be from C$51- to C$97 billion.[48] This study did not provide an estimate of expected insurance claims, but did warn that "such losses would greatly exceed the financial reserves of the insurance industry. Moreover, these values exclude indirect economic losses (e.g. loss of business) which… can be the same order of magnitude as direct losses."

In 1995 the Insurance Bureau of Canada commissioned Risk Management Solutions (RMS) to estimate the potential damage to homes and commercial buildings in Quebec from a major earthquake in eastern Canada.[49] Many scenarios were assessed. The worst-case scenario was a magnitude 7.5 earthquake in western Quebec that resulted in C$7 billion in damage to homes and commercial buildings, and C$6 billion in insurance claims, including C$5 billion in fire claims.

The Institute for Catastrophic Loss Reduction commissioned a study in 2001 by Charles Scawthorn and EQE International that provided an estimate of the fire damage in Vancouver that would follow a major earthquake.[50] A Cascadia subduction earthquake would trigger an estimated C$5 billion in fire damage, while four simulated earthquakes near Vancouver resulted in fire damage of C$1- to C$9 billion.

Priorities for seismic risk reduction in Canada

These studies of the potential damage from a major urban earthquake and the experience in Haiti and Chile identify three priorities for investment in seismic risk reduction.

- **20 to 60 percent of the expected damage** from an urban earthquake will likely involve shake damage to buildings and their contents. Building codes reduce the risk of damage to new buildings, but it is possible to significantly mitigate expected losses to older buildings by retrofitting existing homes or structures. In particular, retrofits or replacement can be used to lower the risk of injury or damage in schools, hospitals and other buildings where large numbers of people may be exposed.
- **The destruction of homes and buildings** from fire has the potential to exceed the damage from severe shaking in large urban earthquakes. Earthquake mitigation programs should ensure that fire halls are earthquake-proof, the expected number of ignitions is reduced, and a variety of water sources are identified to suppress fires.
- **20 to 50 percent of the economic losses** following an earthquake will involve interruption of business activity due to failure of critical infrastructure. Businesses may be unable to function after a major urban earthquake due to disruption from loss of electricity, gas, water, and transportation systems. Investments to enhance the resilience of essential public infrastructure will reduce the expected losses.

The **destruction** of homes and buildings **from fire** has the potential to **exceed the damage from severe shaking**.

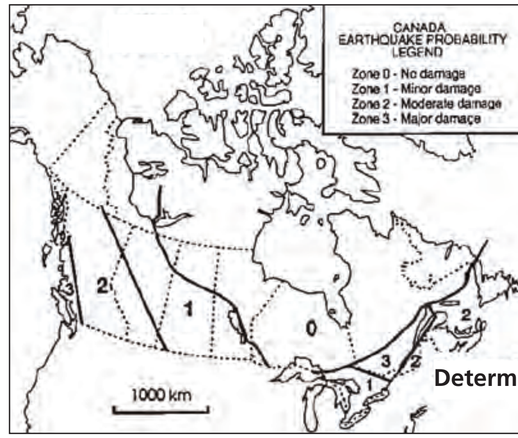
High consequence, low probability hazards are challenging for society to manage. Often the decision to invest in risk reduction follows a tragic event, seeking to ensure greater resilience should the peril return. But it is possible to learn from the experience elsewhere to motivate action before a hazard strikes. The experience in Haiti and Chile largely affirms the findings of impact studies showing that investment to retrofit homes and buildings will help prevent future injuries and economic damage. The research also shows that there is considerable scope to enhance the seismic resilience of essential public infrastructure.

Lesson 3: Building codes and retrofits protect lives and property

Most of the earthquake fatalities in Haiti and Chile occurred in collapsed buildings. These buildings were not designed to withstand major earthquakes. The application of building codes and standards that capture emerging knowledge about seismic safety is vital in preventing earthquake damage and fatalities.

Homes and most buildings constructed in Canada since the early 1970s have been required to meet the seismic safety requirements in the building code. These buildings have not been tested by a large earthquake, but there is confidence that most will perform well and sustain only modest, repairable damage. Experience in Chile and elsewhere warns that the greatest vulnerability for Canadians during an earthquake may be in older buildings. There is considerable scope to retrofit or replace vulnerable buildings to enhance their resilience to earthquakes.

Building code hazard map 1953



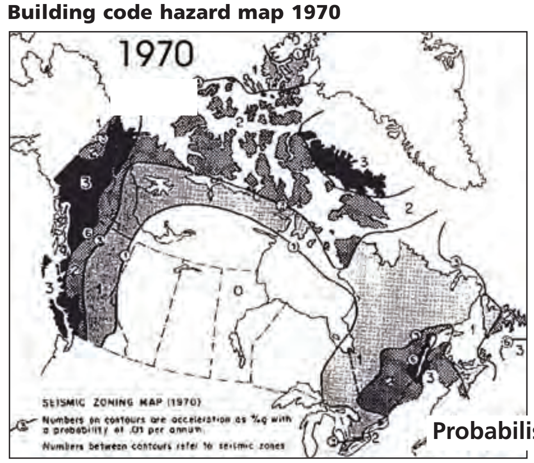
Deterministic

Source: Geological Survey of Canada, Natural Resources Canada.

Building codes in Canada

A patchwork of different construction standards was in place across Canada until the middle of the 20th century.[51] In 1941 the federal government published Canada's first national building code. The provincial and territorial governments have the legislative responsibility to regulate construction, and over the next twenty years the national code was adopted by the provincial and territorial governments with few modifications. The Government of Canada issues a revised code every five years or so and the provincial and territorial governments largely adopt the revised national building code following one or two years of consultation.

Building code hazard map 1970



Probabilistic

PGA at 0.01 p.a.

Source: Geological Survey of Canada, Natural Resources Canada.

The building code references hundreds of other construction documents. They include design, installation and testing documents from organizations that include the Canadian Standards Association, Underwriters Laboratories Canada and the National Fire Protection Association. These standards become legal obligations in Canada when referenced in the building code.[52]

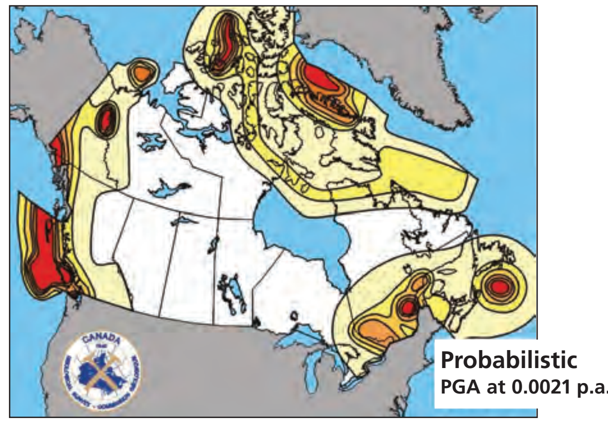
Provincial and territorial governments assign responsibility to municipal officials to issue building permits, inspect the design and construction of new or altered buildings, and otherwise ensure compliance with the provincial building code and town by-laws.

Compliance is seen as good in Canada, and is not a systemic problem. The professionalism of engineers in Canada adds to public confidence that new structures comply with the building code.

Seismic elements in Canada’s building codes

The 1953 Code introduced Canada’s first seismic hazard map. This was a qualitative map and did not quantify the relative risk of a damaging earthquake. Vancouver, Montreal, Ottawa, Victoria and Quebec City were located in the zone of highest hazard. The 1953 Code also introduced modifications for the construction of large buildings based on lessons learned from the 1940 Imperial Valley earthquake near Los Angeles, with a focus on the number of stories in the building. In 1965 reforms were introduced where hospitals, schools and other buildings with large assemblies of people were to be designed to a standard 30 percent greater than other structures because of their relative importance. A provision of 50 percent was added for buildings located on compressed soils.

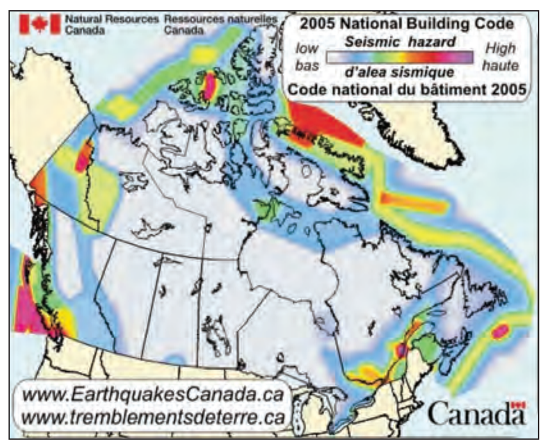
Building code hazard map 1985



Source: Geological Survey of Canada, Natural Resources Canada.

The 1970 Code developed Canada’s first probabilistic seismic zoning map using a probability of exceedance of one percent (a 100-year return period event). Vancouver, Victoria and Quebec City were located in the zone identified as subject to the greatest seismic hazard, while Montreal and Ottawa were in zones of high hazard. Homes and other structures built in Canada since the early 1970s were designed to provide protection from seismic events.

Building code hazard map 2005



Source: Geological Survey of Canada, Natural Resources Canada.

Important reforms were introduced in 1985 including new seismic zoning maps based on a probability of exceedance of 10 percent in 50 years (a return period of 475 years). Changes in the code in 1990 included lessons learned from the 1985 earthquakes in Mexico City, including a special provision for structures located on soft-grained soils with depths greater than 15 metres.

Perhaps the most significant changes of seismic design requirements in the National Building Code of Canada took place in 2005, based on a probability of exceedance of 2 percent in 50 years (a 2475-year return period). The Code set out that schools and communities centres must be designed for 130 percent of the regular design strength, while hospitals and emergency response facilities must be designed for 150 percent.

Lesson 4: Our public infrastructure is vulnerable to seismic damage

Much of Canada's public infrastructure was constructed between the 1950s and the 1970s. Most systems were likely built prior to the development of modern seismic design and their performance is rapidly deteriorating due to age and underinvestment in maintenance. Many systems essential to support Canada's economy and quality of life appear vulnerable to a major shock, like a large earthquake.

Canada's public infrastructure is vulnerable

Professor Saeed Mirza estimates that it will cost C$350 to C$400 billion to repair Canada's ageing public infrastructure, and that over the next 50 years the cost of deferred maintenance could grow to exceed five trillion dollars.[53] Dr. Mirza argues that persistent underspending to maintain local, provincial and federal systems leaves "Canada's infrastructure in a very dire state", and this assessment does not consider the additional challenge that would be evident if a large earthquake strikes.

The Federation of Canadian Municipalities warns that the choice to defer required maintenance has increased "the cost of fixing it… from $12 billion in 1985 to… $123 billion in 2007… The upward trend of the municipal infrastructure deficit over the past two decades points to a looming crisis for our cities and communities".[54]

Over the past two years, the Government of Canada began to address these challenges through its Building Canada and Economic Action Plan initiatives.[55] Unfortunately the deferred maintenance problem has been growing for decades and it will require many years to address.

Investments in public infrastructure during the 1950s, 1960s and early 1970s kept pace with growth in the economy and inflation. However, since the mid-1970s, spending to maintain facilities has been 0 to 2 percent of the initial cost of construction, and well below the target of 2 to 4 percent. There has been some investment in new systems in response to growth in the population, and some additional spending was required to repair failing systems. However, infrastructure spending fell well below the pace required to maintain the level of service that was established in the early 1970s.

A 2003 report found that almost 60 percent of Canada's infrastructure was put in place before 1960.[56] Accordingly, it is likely that the majority of Canada's public infrastructure included no modern seismic engineering knowledge during the design and construction. This vulnerability is likely to be higher in older communities like Montreal, and lower in communities with greater recent growth like Vancouver.

Canada has used up 80 percent of the total service life of its public infrastructure.[57] The federal, provincial and municipal governments consistently spend less than what is needed to maintain these systems. Ideally the initial design of public infrastructure should establish funding to guide the construction, maintenance and ultimate replacement of the new system. Actual practices, however, fail to adopt a sustainable, lifecycle approach. Indeed, current laws in Canada do not hold the engineer or contractor responsible after a five-year period. Over time, poor maintenance reduces the performance of critical systems and increases their vulnerability to shocks.

The experience in Haiti and Chile shows that public infrastructure can be severely compromised by a major earthquake. Some systems, like power and communications, appear resilient and should largely be restored in a few days. Others, like transportation and water systems, will likely have critical elements that are unavailable for an extended period of time following an earthquake and, in turn, impose health risks, prolonged businesses closures and severe economic disruption. One of the greatest opportunities for Canada to reduce the adverse impact of a major earthquake would be through increased investments to restore the health of its public infrastructure. The risk of tragic events, like the 2006 collapse of the de la Concorde Overpass in Laval, Quebec, can be reduced through remedial actions based on appropriate engineering audit to ensure the integrity of older systems.[58]

Risk to power and communications

Immediately following a major earthquake many businesses and individuals will experience a loss of power and communications. These systems have been disrupted in the past by wind and winter storms and were largely restored over several days, although some critical elements took several weeks. This experience suggests that these systems may be resilient to severe damage. Canadian utility operators will likely secure support from elsewhere in the country or from the United States following a large crustal earthquake in British Columbia, southern Quebec or eastern Ontario. But a Cascadia suduction megaquake may destroy systems over a large area, including most of Oregon and Washington, so fewer external resources would be available to support the recovery.[59]

The earthquake in Haiti and the 1998 Great Ice Storm in Quebec demonstrate that damage to core systems, like hydro towers, prolongs the time required for restoring power and communications. A unique vulnerability is found in central Vancouver. "Wood pole mounted transformers abound in the CSB (central business district), in many cases only inches from commercial buildings. In past earthquakes, pole mounted transformers arced and exploded… (and) it is expected that many ignitions would result."[60] Vancouver appears to be the only major city in North America that has not relocated its electric transmission underground in the city core.

Risk to transportation systems

Long commute times in Vancouver, Montreal and Ottawa are testament to transportation systems under considerable stress.[61] A large earthquake would severely disrupt these systems, possibly for weeks or months. Newer systems will likely perform better, as recent knowledge about seismic engineering was available when the systems were designed. In particular, most of Canada's airports in zones of high and moderate seismic risk have been substantially modernized in recent years. However, there are many older systems, particularly bridges or port facilities, where the vulnerability to seismic damage needs to be assessed and addressed.

The transportation infrastructure is complex, and includes seaports, airports, roads, bridges, trains and subways. Many different governments and public agencies are responsible for parts of the systems. Knowledge about earthquake hazard risk and seismic engineering varies considerably among local decision makers. Most operators of these systems appear to have identified other concerns as higher priority, including the replacement of ageing equipment and growing service demand.

The earthquake in Chile brought forth new information about how liquefaction can damage structures – a risk that is present in a number of locations in Canada.[62] Detailed new information on soils was released in 2009 for Ottawa, and research under way in Vancouver, Montreal and Victoria will enhance the design of infrastructure with respect to liquefaction risks; however current structures may be vulnerable. Chile experienced damage in port facilities and failure in the ramps connecting bridges with the main roadway. Canadian engineers and construction companies have demonstrated their skill in applying emerging seismic design knowledge in new construction, however, vulnerabilities in existing systems are more difficult to address.

Risk to water and other underground infrastructure

Perhaps the most neglected aspects of Canada's public infrastructure are underground systems, including water and sewers. The alarming increase over the past two or three decades in sewer back-up damage claims paid by insurance companies warns that these systems are presently in severe difficulty.[63] When a major earthquake strikes there is likely to be widespread failure and limited capacity for repair. City officials warn that it will take many months to inspect these systems after a major earthquake and even longer to repair.[64]

There may be severe constraints on the capacity to extinguish fires that break out following an earthquake due to failures in the water supply. To mitigate this risk Vancouver has invested in a special earthquake-resistant water supply that firefighters could use in the central business district. Also some communities in British Columbia have invested in boats that can pump water for firefighters from the ocean. Nevertheless, many communities remain at considerable risk of destruction from fire following an earthquake due to the absence of water.

A risk over the medium term is that a major city may not be able to continue to operate without running water and sewage treatment. If these systems cannot be repaired quickly then the community may need to consider large-scale evacuations and expect prolonged business closures. A subduction earthquake, for example, could affect millions of people in southwestern British Columbia, leading to an unprecedented challenge with respect to relocation and shelter.

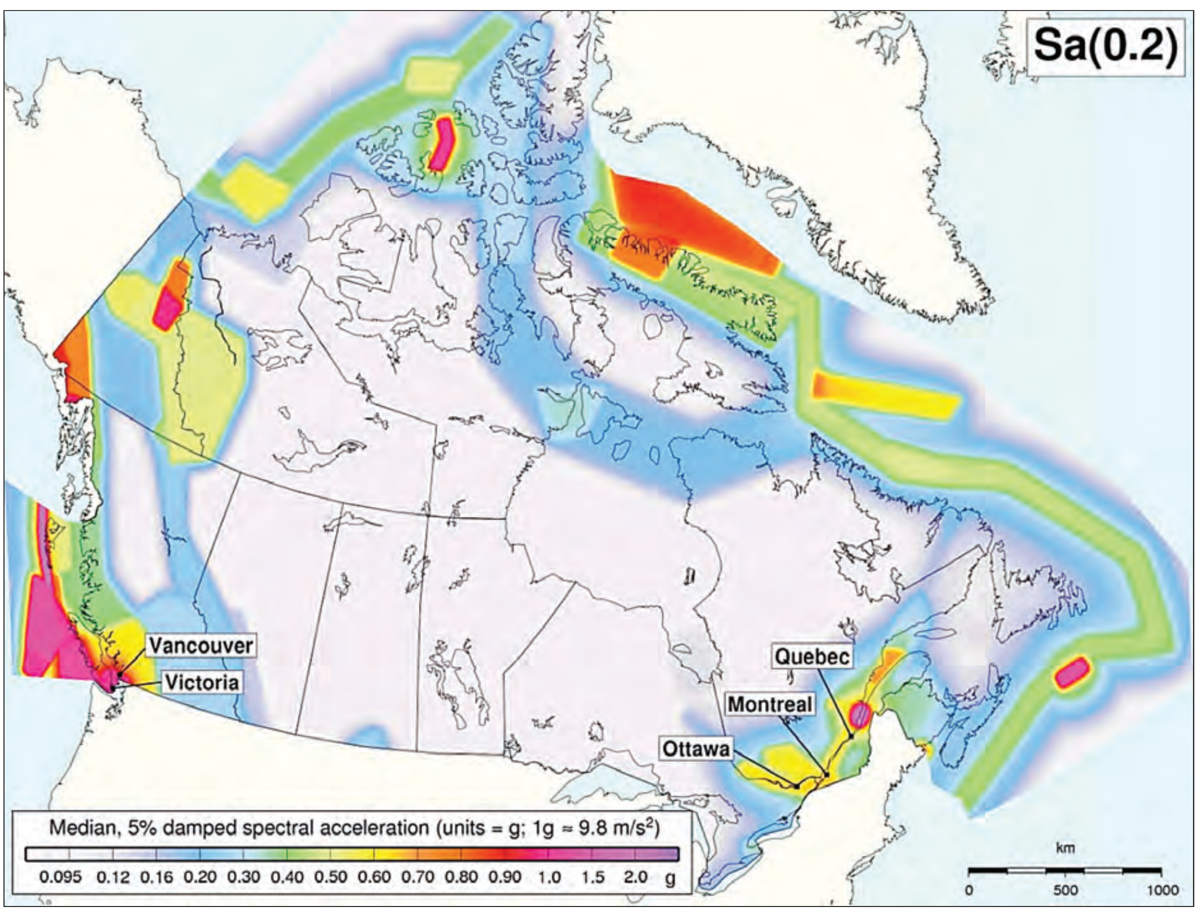
Longer-term risks will become evident as businesses and systems that are temporarily dislocated by the earthquake ultimately choose to relocate permanently. For example, the number of people living in New Orleans and the number of jobs in the area is half the level before Hurricane Katrina struck five years ago, with little prospect for a full recovery for many years or perhaps decades.

Risk to schools and hospitals

For the past 40 years the National Building Code of Canada has required schools and hospitals to be designed and built to achieve a higher standard of safety. Research is under way to identify the seismic safety needs of individual schools and hospitals, with a particular focus on vulnerable buildings. These structures reflect the seismic engineering knowledge available at the time, but older buildings will not include modern safety design and construction features unless retrofits have been completed.

Some funds have been directed to retrofit schools, hospitals and other critical buildings, particularly in British Columbia and Quebec; nevertheless considerable vulnerability remains. The knowledge exists about how to strengthen the resilience of schools and hospitals to major earthquakes, and this must be combined with the political will to make the necessary investments. In September 2010, the Government of Quebec decided to replace the hospital in Baie-St.-Paul and renovate a hospital in Malbaie because they do not offer sufficient protection from the risk of earthquakes in the Charlevoix region.[65] The Government of British Columbia launched an ambitious C$1.5 billion school seismic retrofit program in 2008.[66] These are welcome initial examples of the actions that can be taken to strengthen the resilience of public infrastructure and public buildings to the risk of damage from earthquakes.

National Building Code of Canada Hazard Map 2010



Source: Geological Survey of Canada, Natural Resources Canada

Lesson 5: Effective preparedness will reduce the risk of loss

Canada's emergency management system has consistently performed well, with local and provincial officials successfully responding to dozens of events each year. However, the system has never been confronted by a disaster as severe as a large urban earthquake. Moreover, most first responders are concerned that the Government of Canada is not fully prepared to support the local and provincial response, or to ensure full continuity of services from the federal government

The Canadian system of emergency response

Provincial and territorial governments have primary responsibility for emergency management in Canada under the Constitution Act of 1867. This includes preparedness, response, recovery, mitigation and prevention. Provincial and territorial legislation has assigned this responsibility to local governments.[67] Communities identify local hazards, and set out a response plan. Provincial and territorial legislation gives the Mayor and Council authority to request support from their provincial or territorial government if they believe a hazard has overwhelmed the community's capacity to respond. Similarly, the federal Emergency Management Act sets out the process whereby the provinces and territories can request support from the Government of Canada through Public Safety Canada.

Almost all emergencies in Canada are successfully resolved by local actions, sometimes with support from neighboring communities or the provincial government. On a few occasions provincial governments have requested assistance from the federal government. For example, in September 2010 Canadian Forces soldiers and reservists were deployed to support the recovery in Newfoundland following Hurricane Igor, including the rebuilding of two bridges and an airlift of food and water.[68] But most emergencies in Canada are resolved exclusively using local and provincial resources.

The Canadian system of financial assistance

In 1970 the federal, provincial and territorial governments established the Disaster Financial Assistance Arrangements.[69] The Arrangements set out guidelines the Government of Canada uses to reimburse part of the expenses incurred by the provincial or territorial governments when response and recovery costs exceed their capacity. Expenses eligible for federal cost sharing include: evacuation operations; restoration of public infrastructure; and disaster relief to help repair or replace essential personal property of individuals, small businesses and farmsteads.

The program follows a sliding scale. The Government of Canada gives no funds to the provincial and territorial governments for small emergencies, but will reimburse up to 90 percent of the eligible expenses for a major disaster, like a large urban earthquake. The federal government has paid C$2 billion to the provinces since the Agreement was established, representing an average annual payment of C$50 million. A major urban earthquake will likely result in tens of billions of dollars of payments by the Government of Canada.[70] In particular, the federal government will be responsible for reimbursing the provincial government for most of the cost of repairing or replacing damaged schools, hospitals, bridges, roads, sewers, water systems and other public infrastructure – in addition to disaster relief for homeowners and small businesses.

Emergency communications and power

The experience in Haiti and Chile confirms that a major earthquake is likely to severely disrupt communications. These systems will likely be restored within a few days, but emergency response officials are planning for the possibility that these vital systems may not be available during the critical period immediately after an earthquake strikes. The 2008 report on emergency preparedness by the Senate Standing Committee on National Security and Defence was critical of the Government of Canada for failing to establish a national emergency public communications system, or a public warning system based on automated telephone dialing technology.[71]

There have been a number of incidents where millions of Canadians lost power, including the 2003 North American blackout and the 1998 Great Ice Storm. Power was restored within days for most Canadians, except in areas where the 1998 ice storm destroyed the power distribution infrastructure. The Government of Canada, through Public Safety Canada, has legislative responsibility to ensure that critical infrastructure is managed to anticipate risks like a major earthquake, but the 2008 Senate Committee Report warns, "why have Canadians had to wait for nearly a decade without the federal government formulating its long-awaited National Critical Infrastructure Protection Strategy?"[72]

The scope of the emergency will be unprecedented

A major challenge for the response will be the scope of the effort. A Cascadia subduction earthquake may affect more than 12 million people from Vancouver to northern California. A large intra-plate crustal earthquake in Vancouver, Montreal or Ottawa could result in more fatalities and property damage than any previous Canadian disaster. Fire, police, ambulance and other first responders will be severely challenged by the size of the event. Many hospitals, for example, have lengthy waiting times for treatment on a regular day, so they may be overwhelmed by a large earthquake.

Firefighters may also experience extraordinary demands.[73] Severe shaking may destroy the water supply needed to extinguish fires and debris may block roads, increasing the risk that fires build into conflagrations. The 2008 simulation of a 7.8 magnitude earthquake near Los Angeles resulted in 1600 ignitions, including more than 1200 that could not be controlled by one fire crew.[74] That simulation required six days to bring the fires under control, with 885 fatalities and $65- to $125 billion in property damage. The potential for extreme fire losses in Vancouver, Montreal or Ottawa is unknown, but it could involve thousands of homes.

Confidence in local preparedness but federal concerns

Confidence in the capacity and skills of emergency management officials is highest at the local level, and less strong for the federal government. The communities with a high or moderate risk of a large earthquake have well-established emergency response plans. These response plans have been tested with smaller, non-seismic events, and performed well. Moreover, all parties are aware that a large earthquake will overwhelm local response efforts so there is an expectation that this peril would immediately escalate into a request for provincial assistance.

The governments in British Columbia, Quebec and Ontario are aware that some day they will need to support the local response to a major earthquake and subsequent recovery. The Government of British Columbia has published its earthquake response plan.[75] In 2005, the Government also launched an ambitious $1.5 billion school seismic retrofit program.[76] The Government of Quebec is working to identify, and in a few instances retrofit or replace, hospitals and infrastructure at risk.

Moreover, over the past decade emergency management legislation in British Columbia, Quebec and Ontario was modified to embrace a modern, comprehensive approach to emergency management that seeks to move beyond the traditional focus on preparedness to respond after disaster strikes by championing risk reduction through investments in mitigation and prevention.

The Government of British Columbia launched an ambitious **$1.5 billion school seismic retrofit program**.

The Government of Quebec is working to **identify**, and to begin to **retrofit or replace**, hospitals and infrastructure at risk.

The 2008 Senate Committee survey of first responders found that only 15 percent of municipal emergency management officials believe that the federal government is prepared to respond to an emergency, while 90 percent are confident that their provincial government will support local efforts. The 2008 Report on Emergency Preparedness by the Senate Committee warns that "We have seen no evidence that implementation and testing has taken place. This means that Canadians have no assurance that essential government operations will function during emergencies." In December 2009, the Government of Canada published its long-awaited emergency response plan, nevertheless concern remains about its preparedness.[77]

In June 2010, following the 5.0 magnitude earthquake near Ottawa, the Geological Survey of Canada quickly identified the nature and extent of the event, affirming confidence that they are prepared to respond to future earthquakes. However, most of the evidence published by the Senate Committee, Auditor General and other stakeholders warns that Public Safety Canada and other federal agencies have not demonstrated that they are prepared for a major disaster. For example, the Senate Committee expressed concern that international military commitments and budget constraints means that "territorial response capacity under Canada Command barely seems to exist… first responders have no way of knowing what they can actually expect from the Canadian Forces in times of crisis."[78] The Auditor General warns that Public Safety Canada "has not exercised leadership necessary to coordinate emergency management activities, including critical infrastructure protection in Canada."[79] There is considerable scope for the Government of Canada to improve its preparedness.

Lesson 6: Canadians must understand recovery tools like insurance

Many individuals and most businesses in Canada buy insurance against the risk of loss from an earthquake. After a major urban earthquake strikes in Canada, insurers would pay billions of dollars in damage claims to support the recovery of individuals and businesses. Some other recovery mechanisms include disaster relief and charitable support. It is important that individuals, businesses and governments take the time to understand the role of insurance and the other essential tools designed to support recovery following a major earthquake.

Helping commercial and industrial property owners recover

Insurance is widely available in Canada. Coverage is available against most perils facing businesses. The majority of commercial and industrial firms in Canada (80 to 90 percent) choose to purchase all-hazard insurance coverage that includes earthquake damage.[80] Policies differ, so businesses must take the time to understand the specific risks that are covered. In particular, it is important to clarify the property damage and business interruption risks that are covered.

Disaster relief programs provided by governments and charitable agencies in Canada exclude commercial and industrial operations. This exclusion is expressly set out in the federal, provincial and territorial Disaster Financial Assistance Arrangements, and in provincial disaster relief programs.[81] The major role for governments in supporting the recovery of businesses will not be financial, but will focus on repairing and rebuilding essential public infrastructure.

Beyond insurance, loss prevention is the most important earthquake hazard management tool available to commercial and industrial operations. Seismic retrofits can significantly reduce the risk of property damage, business disruptions and the need for recovery following an earthquake. Moreover, investment in seismic safety can reduce the cost of buying insurance for residual risks.

The insurance industry will be the primary source of funds to support the recovery of commercial and industrial operations following a major earthquake.[82] Experience in Chile and elsewhere suggests that payment of business interruption claims will be one of the largest costs for insurance companies. The insurance industry should speak regularly with government officials responsible for emergency management to reinforce the industry's capacity to provide financial support for commercial and industrial operators following an earthquake.

Helping homeowners and small businesses recover

A comprehensive insurance policy will cover the risk of damage from fire, theft and a broad range of perils, unless they are specifically excluded. Insurance coverage for earthquake damage due to severe shaking is available, but must be specifically chosen by property owners because it is typically excluded from the basic policy.[83]

The Insurance Bureau of Canada estimates 60 to 65 percent of homeowners in southwestern British Columbia buy earthquake insurance.[84] Risk of large earthquakes in British Columbia is similar to or lower than that in California and Oregon, yet the Insurance Information Institute reports that 12 percent of homeowners in California buy coverage and the Oregon Department of Consumer and Business Services found that 20 percent of homeowners in Oregon buy earthquake insurance.

Earthquake coverage in Canada is subject to **deductibles** that are significantly **higher than those for fire, theft and other perils**, at 5 or 10 percent of the value of the home. High deductibles **reduce** the **cost** of earthquake insurance, but they may **not be well understood** by policyholders.

Nevertheless, many homeowners (35 to 40 percent) and most renters in British Columbia do not have insurance protection against damage from severe shaking. Moreover, the Insurance Bureau of Canada estimates that very few homeowners (less than 2 percent) elsewhere in Canada buy earthquake insurance, including those in Montreal, Ottawa and Quebec City. Data for small businesses are not available but likely to follow a similar pattern.

Earthquake coverage in Canada is subject to deductibles that are significantly higher than those for fire, theft and other perils, at 5 or 10 percent of the value of the home. High deductibles reduce the cost of earthquake insurance, but they may not be well understood by policyholders.

Almost all homeowners, tenants and small businesses in Canada with fire insurance also have coverage against losses from fires that may follow an earthquake. Fire damage is subject to low deductibles, as established in the basic policy. It is important that homeowners and small businesses take the time to understand their insurance coverage.

Disaster relief programs are provided in Canada by provincial and territorial governments and vary across the country. Relief programs are not the same as insurance and they do not seek to provide full recovery. To qualify for relief, homeowners and small businesses typically must provide a letter from their insurance company stating that coverage is not available.

Provincial governments, in turn, can recover up to 90 percent of their eligible disaster relief payments from the federal government under the Disaster Financial Assistance Arrangements.[85] Provincial payments to homeowners qualify for federal assistance under this arrangement if they involve replacing or repairing essential personal property, and if affordable insurance was not available.

Non-government organizations in Canada may also provide compassionate assistance to individuals and families unable to secure support through insurance or disaster relief.[86] In particular, the Canadian Red Cross, Salvation Army, Mennonite Disaster Service and St. John Ambulance may provide support to individuals and families for immediate, basic needs.

Poor understanding about insurance coverage has the potential to disrupt the recovery following a disaster. For example, homeowners and small businesses without coverage that experience seismic damage may challenge in the courts the efforts of brokers and other insurance representatives to inform them about the coverage options that were available. This was an issue in the United States following Hurricane Katrina.[87]

Insurance will be the largest source of funds to support the recovery for most homeowners and small businesses in British Columbia that experience earthquake shake or fire damage. Insurance is pre-funded disaster aid and therefore less subject to delays and goodwill. In Quebec and Ontario insurance will cover fire damage to homes and small businesses following a major earthquake, but property owners will likely apply for disaster relief if they experience damage from severe shaking. A significant part of any losses will be the responsibility of property owners given the large deductibles involved in insurance coverage. Insurance, provincial disaster management officials and non-government organizations should meet regularly to discuss coverage issues and to clarify roles and responsibilities for supporting the recovery following a major urban earthquake.

The capacity of insurers to pay claims

Every insurance company that provides coverage to property owners in British Columbia, southern Quebec or eastern Ontario is required to report to their solvency regulator each year with current information to show that they have simulated the expected claims that may arise from a major earthquake, and to demonstrate that they have the financial capacity to pay these claims without affecting their ongoing operations.[88] Accordingly, there is strong confidence that Canada's insurers have the capacity to provide billions of dollars to pay the damage claims following a large earthquake.

Insurance companies in Canada buy billions of dollars in catastrophic insurance coverage from reinsurance companies. Reinsurance is the primary source of funds that insurers will use to pay damage claims when an earthquake strikes. In recent years the international reinsurance industry has demonstrated its capacity to respond to major disasters around the globe. Some of these events, like Hurricane Katrina, involved insurance payments that were larger than what would be expected from a major earthquake in Canada. Canada's insurers also presently hold C$35 billion in capital, a total that is more than C$16 billion in excess of the minimum required by regulation.[89] Excess capital would be available to pay earthquake claims without affecting ongoing operations.

Nevertheless, there are areas where the solvency implications of a major earthquake in Canada would benefit from further research. For example, there is uncertainty about the risk of litigation by those who are uninsured and those who may argue that they were unaware of the large deductibles involved in earthquake coverage – a risk that may temporarily tie up several billion dollars of capital until disputes are resolved. Also, the models used to simulate possible earthquake damage claims predict few fire claims unless the earthquake is extremely large, so there is a risk that the fire following damage may surprise some insurers. In addition, it would be useful to assess the financial and operational capacity of insurers to cope with a megathrust Cascadia earthquake given the potential for extensive damage.

Lesson 7: Science and research provide the foundation for action

Science and research can provide a strong foundation for advancing seismic safety. Key sources of emerging seismic safety knowledge come from engineering research in laboratories and from field examination of earthquake damage. Academic publications, building codes and engineering standards are some of the mechanisms used to share this knowledge with design and construction professionals. This process of knowledge formation and transfer requires a sustained commitment and appropriate resources.

The Canadian seismic research effort is directed primarily at the characterization of the earthquake hazard and identification of potential actions for risk reduction. There has been little research directed toward understanding the decision making process of individuals, businesses and governments.[91]

The International Council for Science program for integrated research on disaster risk sets out three objectives that are useful when assessing the state of earthquake research in Canada:[90]

1. characterization of hazards, vulnerability and risk
2. understanding decision-making in complex and changing risk contexts
3. reducing risk and curbing losses through knowledge-based actions.

In Canada, Governments provide leadership on issues of public safety, including earthquake hazards. Some costs will be borne by individuals and businesses, like the modest increase in the cost of building resilient structures, but public agencies are responsible for providing most of the funding for the development and dissemination of safety knowledge. This includes financial support for academic studies and research by government agencies on reducing the risk of damage from earthquakes and other hazards.

The federal government, and to a lesser extent the provincial governments, provide funds to support academic research on seismic safety. Some of the federal agencies involved include the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Foundation for Innovation, the Social Sciences and Humanities Research Council, and the Canadian Institutes for Health Research.

In 2008, NSERC provided funds to establish the Canadian Seismic Research Network as a new forum allowing leading academic researchers across Canada to support earthquake risk reduction in major urban centres.[92] The Network is coordinating 16 engineering and seismology research projects under the themes of hazard assessment, vulnerability assessment and mitigation. Nonetheless, earthquake research funds in Canada are much lower than those available to academic researchers in the United States and Japan.

Some federal and provincial government agencies in Canada are directly involved in earthquake hazard research. This includes programs by the Geological Survey of Canada to monitor earthquakes and identify future risks. These programs are managed to support public policy objectives including building code development and emergency management. Scientists with the Geological Survey of Canada are widely respected and recognized as leaders in the seismic safety community.

Research by Dr. Neil Swan found that the societal savings that result from seismic research within the Geological Survey of Canada were ten times greater than the cost of the program.[93] In particular, this research shows that the expected safety benefits from applying seismic improvements in the building code are greater than the extra construction costs. Dr. Swan concludes his paper with the observation that "the high cost effectiveness of past research may be seen as grounds for optimism about the value of future research."

Earthquake hazard researchers with the Geological Survey of Canada have done a good job of sharing their findings and ensuring their availability to speak with other stakeholders. Also some academic researchers have built links to decision makers in government and the private sector. There remains, however, considerable scope to improve this exchange. In particular decision makers need to demonstrate a greater commitment to communicating directly with earthquake hazard researchers.

The insurance industry has established on ongoing dialogue with earthquake researchers through the Institute for Catastrophic Loss Reduction and the Insurance Bureau of Canada. This reflects the role of insurance in managing seismic risks, through its financial support for recovery. The insurance industry has long provided leadership in fire prevention and road safety, but it is yet to champion earthquake risk reduction, although it has made initial steps in this direction through its support of seismic research.[94]

There is a strong relationship between researchers and those responsible for building codes. Researchers and earthquake experts participate in the process used to establish building codes in Canada, communicating with design and construction professionals about emerging findings.

There is a link in Canada between those responsible for emergency management and earthquake hazard experts. Simulation exercises, for example, provide an opportunity for emergency management professionals to work with seismologists to anticipate future events. There is scope to strengthen this exchange, particularly with respect to better understanding the potential complexity of the disaster that will result from a large urban earthquake. This exchange would benefit from an increased involvement of social scientists who can help anticipate the financial, health and behavioural challenges involved in the recovery from a major disaster.

There is a strong relationship between **researchers** and those **responsible for building codes**. **Researchers** and **earthquake experts** participate in the process used to establish building codes in Canada, communicating with **design** and **construction professionals** about emerging findings.

Seismic safety is a central element in the design of structures with long expected operating lives and where failure would bring significant consequences including tall buildings, nuclear power facilities, major pipelines and large concrete dams. For example, the Trans-Alaska Pipeline has been operating since 1977 and carries 1 million barrels a day of crude oil across a region vulnerable to large earthquakes.

In 2002, a 7.9 magnitude earthquake struck Denali National Park in Alaska, near the Canadian border, the largest earthquake from a continental strike slip fault in North America since the 1906 earthquake in San Francisco. The pipeline was designed to move laterally along beams and absorb the shock. An assessment of the event by Steve Sorensen and Keith Meyer concluded that: "The innovative above-ground crossing design was developed over 30 years ago when 'lifeline earthquake engineering' was in its infancy. The 2002 Denali Fault earthquake provided a full-scale test of this crossing concept, and the pipeline and support system performed as expected, without damage to the pipeline or leakage of oil."[95]

Conclusion

It is inevitable that a large earthquake will strike at some point in a major urban centre in Canada like Vancouver, Montreal, Ottawa, Victoria or Quebec City. Actions taken to prepare for this peril will reduce the fatalities, property damage and economic disruption when the hazard strikes. It is important to learn from the tragic earthquakes in Haiti and Chile, and to identify actions to enhance seismic safety in Canada. The greatest challenge in advancing public safety is to stimulate action from key stakeholders, including individuals, businesses and governments.

The greatest risk of earthquake fatalities and property damage in Canada appears to be in **older buildings** that did not include the safety knowledge present in modern structures.

Most fatalities in Haiti and many in Chile were in buildings that collapsed. Canada has a reputation for sound construction. Building codes and other standards in Canada have not been tested by a major earthquake, but appear to function well as a mechanism to systemically institutionalize emerging knowledge about seismic design and construction. The greatest risk of earthquake fatalities and property damage in Canada appears to be in older buildings that do not include the safety knowledge present in modern structures. This risk can be addressed through seismic retrofits or replacement of older structures. In particular, it is important to address safety in schools, hospitals and other essential buildings.

The disaster in Haiti was made worse by the absence of any preparedness and the resulting chaotic response. Canadian emergency response systems have proven their effectiveness to address small and moderate events, but they have not been tested by a major disaster. Confidence is high that local response efforts will be appropriate and provincial systems appear to be sound. The greatest uncertainty in the Canadian emergency response to a large earthquake is the capacity of the federal government to sustain federal services and support the provinces when requested. There is scope for the Government of Canada to improve its preparedness to respond to an emergency.

The recent earthquakes resulted in infrastructure failures that will delay the recovery in Chile by months and in Haiti by years. An important opportunity to take action today to reduce the adverse impact of a major earthquake in Canada would be to repair or replace ageing public infrastructure. Transportation and underground systems, like water, may be compromised for months if a large earthquake strikes Vancouver, Montreal or Ottawa. Many of these essential systems are vulnerable due to age and years of deferred maintenance – a weakness that is likely to be fully exposed when a large earthquake strikes, increasing the risk of evacuations, business closures and prolonged economic disruption.

The most important finding for individuals, businesses and public officials in Canada from the tragic earthquakes earlier this year in Haiti and Chile is that the knowledge exists to help prevent a future earthquake in Canada, even a very large earthquake, from becoming a disaster. Canadian businesses, homeowners and governments should take action now to invest in seismic safety to strengthen the resilience of their buildings and infrastructure, and improve preparedness.

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