The 11th Canadian Conference on Earthquake Engineering
Canadian Association for Earthquake Engineering

SEISMIC RISK IN BRITISH COLUMBIA – A MULTIDISCIPLINARY CONVERSATION

Maiclaire K. BOLTON
Senior Product Manager, Global Earthquake Products, CoreLogic, Inc., USA
mbolton@corelogic.com

Tuna ONUR
Seismic Hazard and Risk Consultant, Onur Seemann Consulting, Canada
onur.osc@gmail.com

Rob JOHNS
Emergency Coordinator, Victoria Emergency Management Agency, Canada
rjohns@victoria.ca

Andrew CASTALDI
Senior Vice President, Swiss Reinsurance America Corp, USA
Andrew_Castaldi@swissre.com

Dennis CHUA
Assistant Vice President, Catastrophe Management - Aon Benfield Analytics, Aon Benfield Canada ULC, Canada
dennis.chua@aonbenfield.com

Mazdak MOINI
Vice President Commercial Lines and Reinsurance, Aviva Canada, Canada
mazdak_moini@avivacanada.com

Trevor ALLEN
Seismologist, Natural Resources Canada, Canada
Trevor.Allen@NRCan-RNCan.gc.ca

ABSTRACT: Earthquakes, while rare, pose the greatest natural catastrophe risk in Canada, especially in southwestern British Columbia (BC) where the combination of exposure and hazard is greatest. This risk spans many facets from life safety to property damage to business continuity. Assessing seismic risk is a multi-disciplinary challenge. Various organizations and industries, although independent, all share a common goal of understanding the risk to be able to appropriately prepare. From hazard assessment, to building code regulations, to disaster planning, and the financial impact with the insurance industry – multiple stakeholders are all in this together.

Each stakeholder has a distinct responsibility to prepare for a major earthquake. This session brings together multiple representatives from the disciplines of seismology, engineering, emergency management and earthquake insurance to discuss how seismic risk in southwestern BC is relevant to them. While each stakeholder has an individual focus and distinct challenges, there is great benefit in working together in developing comprehensive and pragmatic solutions.

1. Introduction

Assessing seismic risk is a multi-disciplinary challenge involving geology, active tectonics, seismology, geotechnical and structural engineering, and social and economic sciences. Various public and private organizations and industries share a common goal of better understanding the seismic risk to be able to appropriately prepare. Local governments and the insurance industry are in the front lines of dealing with the aftermath of an earthquake.

Depending on the scale of the disaster, local governments are supported by the provincial and federal governments. In BC, the provincial government provides coordination, support and resources in response to disasters through Emergency Management British Columbia (EMBC). If the event is beyond the capacity of the Province, the provincial government is able to request assistance from the Federal government. All requests for federal assistance are coordinated through Public Safety Canada. While there are provincial and federal government disaster financial assistance programs in place to help those impacted by an uninsurable disaster, it must be noted that earthquakes are an insurable hazard and homeowners are encouraged to insure themselves (EMBC, 2008).

The insurance industry is made up of primary insurers, reinsurance brokers, and reinsurers. Individual property owners buy catastrophe (e.g. earthquake) insurance from primary insurers (usually through insurance brokers who provide an easier shopping-around experience for the property owners). Primary insurers in turn need to purchase reinsurance, usually through reinsurance brokers, for the loss that is in excess of their capacity to pay out. Hence reinsurers are in effect insurers of primary insurers. In Canada, insurance companies continue to increase their capacity limits annually to meet corporate governance and regulatory requirements. As such, over 70% of reinsurance purchased in Canada is based on the earthquake peril.

This paper summarizes the Special Session on seismic risk that brings together some of the key disciplines involved in assessing seismic risk (seismology and engineering), and key stakeholders with front-line responsibility for preparedness and response to earthquakes (local governments and insurance industry). In a panel style, the Special Session will focus on three important points to form the basis of discussion among all participants:

(1) What is your perception of seismic risk in southwestern BC?
(2) How is assessing seismic risk relevant to your organization?
(3) What is your organization doing about seismic risk in southwestern BC?

We hope to start a conversation among these various disciplines in this Special Session, with the long term goal of continuation and expansion of these conversations in assessing, preparing for and responding to seismic risk to a broader collection of stakeholders. While social vulnerability is also of great concern, this paper is mainly focused on risk to physical property.

2. Earthquakes in Canada

Although earthquakes most frequently occur near plate boundaries on the Pacific Coast of Canada, many earthquakes are also recorded away from plate boundaries, such as the reactivated ancient rift along the St Lawrence River Valley (Figure 1). The Canadian Shield (or the craton) is the least seismically active region of Canada. However, when earthquakes do happen here, they are felt over a larger area compared to earthquakes in the western Canada due to the efficiency of the craton in propagating the seismic waves.

The possibility of a major earthquake cannot be ruled out for any location in Canada, including seismically quiet regions away from plate boundaries. Global stable continental analogues such as Australia (e.g. Clark *et al.*, 2014), China (Liu and Wang, 2012) and the United States (e.g. Petersen *et al.*, 2014) demonstrate the potential for rare large earthquakes (M > 7.0) in regions with sparse contemporary seismicity. Some examples of damaging earthquakes in eastern Canada include the 1663 M7 Charlevoix earthquake which caused damage in Quebec City and Montreal, the 1732 M5.8 Montreal earthquake which damaged approximately 300 buildings in Montreal, the 1925 M6.2 Charlevoix earthquake which caused damage to port facilities in Quebec City and the 1988 M5.9 Saguenay earthquake which caused damage in Quebec City and Montreal-East.

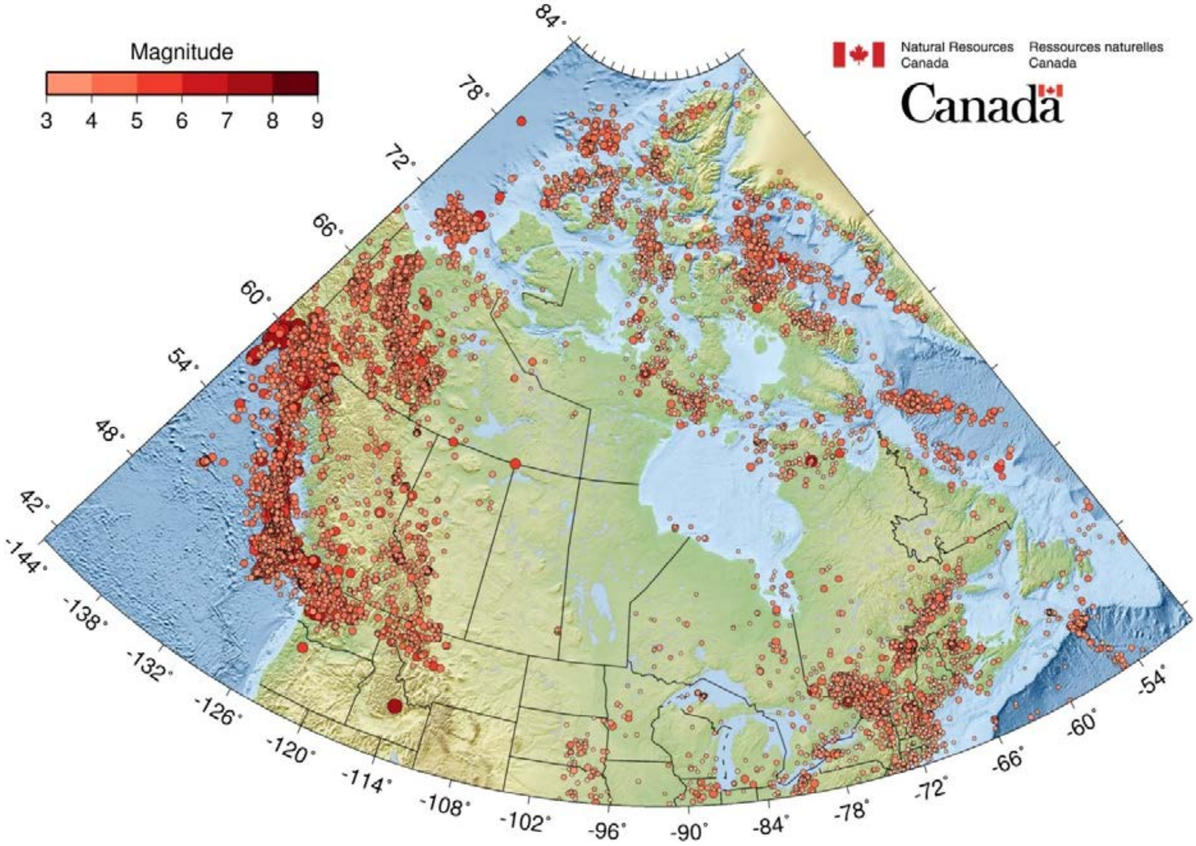


Figure 1 – Map of earthquakes of M_W 3.0 and larger in or near Canada from 1627 through August 2014. Epicentres are based on the catalogue of Halchuk *et al.* (2015), which is augmented from the online Earthquakes Canada database (NRCan, 2014) for post-2010 events.

The contribution to earthquake hazard in western Canada is dominated by two major fault zones: the Queen Charlotte Fault system and the Cascadia subduction zone. Two major urban centres are located near the Cascadia subduction zone: Vancouver and Victoria, making southwestern BC the highest seismic risk area in the country.

The oceanic Juan de Fuca Plate is subducting beneath the continental North America Plate off the west coast of Vancouver Island down to northern California, forming the Cascadia subduction zone. This tectonic environment generates three distinct types of earthquakes:

1) **Deep earthquakes within the subducting Juan de Fuca Plate.** These are sometimes referred to as subcrustal, inslab, intraslab, or Wadati-Benioff earthquakes. They occur at about 50-60km depth under Georgia Strait and Puget Sound and typically cause less damage than shallower earthquakes. However they are felt over a larger area, occur frequently, and hence are a significant contributor to short-period ground shaking hazard in this region. Examples of these earthquakes include the 1949 and 1965 Puget Sound Earthquakes and the 2001 Nisqually Earthquake, all between M_W 6.5 and M_W 7.0.

2) **Shallow crustal earthquakes in the overriding North America Plate.** Large shallow crustal earthquakes are rare in southwestern BC. When they occur near urban areas, they have the potential to cause significant damage in the epicentral region though the shaking intensity often decreases rapidly with distance. An example is the 1946 M7.3 Central Vancouver Island Earthquake.

3) **Giant megathrust earthquakes at the interface of the two plates.** Subduction interface earthquakes happen on average every 500-530 years in the Cascadia subduction zone (though they have happened as close together as 300 years and as far apart as 1,000 years), and the most recent such earthquake was in 1700 (Goldfinger *et al.*, 2012). The estimated magnitude of the 1700 earthquake was M_W 9.0 and it

caused a major ocean-wide tsunami (e.g. Atwater *et al.*, 2005). These earthquakes, though offshore and hence relatively distant to major urban centres, cause long-duration strong shaking over a large area, typically lasting several minutes (compared to less than a minute of strong shaking during other two types of earthquakes). They are the largest contributor to the long-period ground shaking hazard in southwestern BC.

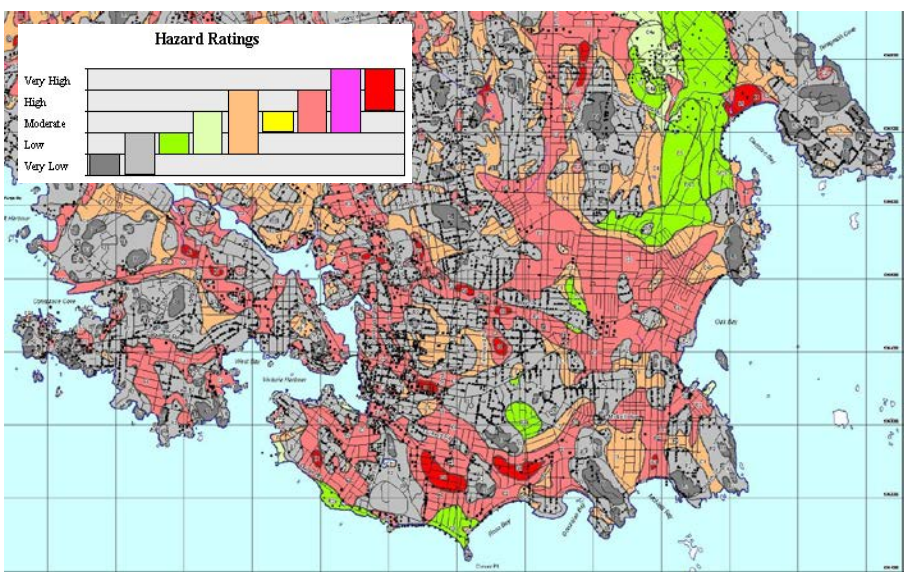
All these seismic sources can be analysed in a probabilistic framework called the Probabilistic Seismic Hazard Analysis (PSHA) to provide a quantitative measure of the ground shaking hazard at a location of interest. Geological of Survey of Canada (GSC) carries out this kind of analysis to provide ground shaking levels that form the basis of earthquake design as outlined in the National Building Code (NBC) of Canada (e.g. Adams *et al.*, 2015).Quantifying seismic hazard alone is not enough, however, to understand earthquake risk. In a given urban area, two given locations may have vastly different seismic risk even if the ground shaking hazard is relatively similar. The two largest contributors to this risk differential are: 1) the local ground conditions at the site (soft soil, firm soil, rock, etc.) and 2) the characteristics of the structure (concrete high-rise, single-family wood house, bridge, etc.) that determine its capacity to withstand strong ground shaking.

2.1. Amplification of Ground Shaking

Three main characteristics of ground shaking are altered as the seismic waves that propagate through the Earth's crust approach the surface depending on the stiffness and the density of the near-surface sediments; amplitude of the shaking, the frequency/period content of the shaking, and the duration of the shaking. In general, locations on deeper softer sediments shake stronger, longer, and at a lower frequency (longer period) compared to locations on stiff rock.

Deep sediment basins such as Fraser River Delta pose a significant ground shaking amplification potential (Harris *et al.,* 1998). Since deep sedimentary basins amplify low frequency (long period) shaking, tall buildings and other long-period structures such as bridges are particularly susceptible to damage in these areas. In Richmond, BC for example, there are over 100 high-rises (buildings that are 10 storeys or taller), built on the Fraser River Delta sediments.

Amplification potential can be presented in terms of microzonation maps such as those prepared for Victoria by the BC Geological Survey (Figure 2). These maps highlight soft sediment areas where damage is likely to be more severe (coloured red in Figure 2) compared to rock or stiff sediment areas (coloured grey in Figure 2) given the same earthquake.



http://www.em.gov.bc.ca/Mining/Geolsurv/Surficial/hazards/amplification.htm

Figure 2 – Amplification Potential Map for Greater Victoria Area (Monahan *et al.,* 2000)

2.2. Seismic Vulnerability of Buildings

Seismic vulnerability of buildings is dependent on many factors including but not limited to building material (concrete, steel, masonry, wood, etc.), the lateral load-bearing system (moment frame, braced frame, shear wall, etc.), age of the building and its state of repair, seismic provisions that the building was designed to, construction quality, height of the building, and presence of stiffness irregularities.

In general, unreinforced masonry buildings pose the greatest seismic risk as they exhibit brittle failure during earthquake shaking. In western Canada, majority of buildings in core downtown of Victoria and many buildings in older neighbourhoods of Vancouver are of this type (Figure 3). In eastern Canada, unreinforced masonry is prevalent in many major cities including Montreal, Quebec City and Ottawa.

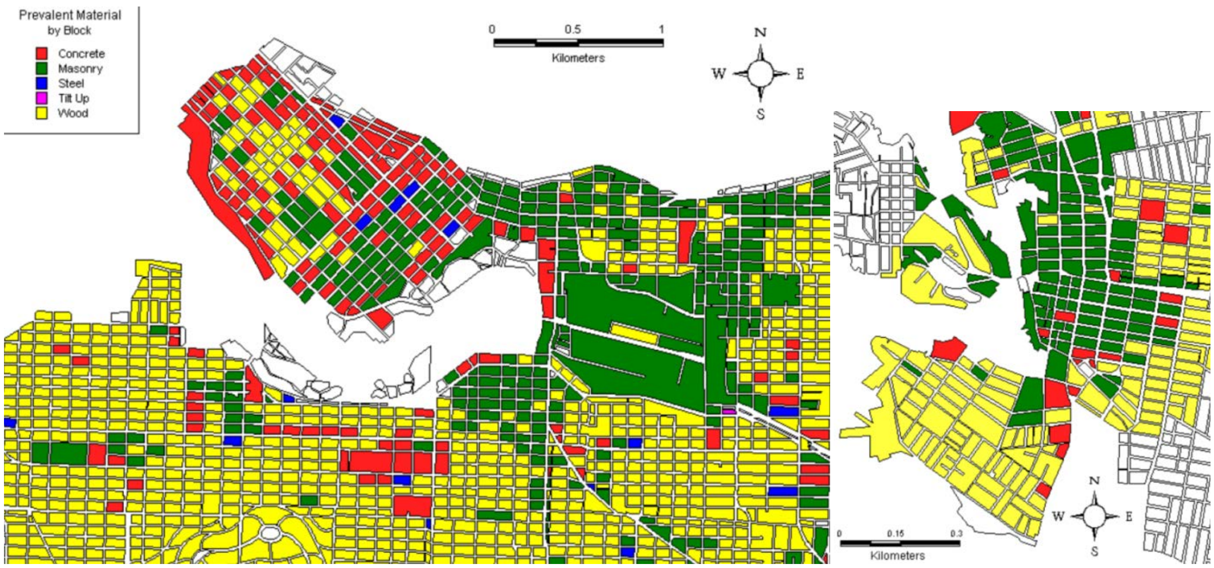


Figure 3 – Distribution of prevalent building material types by city block in Vancouver and Victoria (Onur *et al*, 2005)

Though most concrete buildings perform adequately when designed and detailed properly, a considerable proportion of the older concrete buildings, known generally as non-ductile concrete frame buildings, have performed poorly during recent earthquakes in California and elsewhere, significantly contributing to loss of life (Anagnos, *et al*, 2008).

Light wood frame buildings generally perform well during earthquakes, unless they exhibit stiffness irregularities such as large garage openings or tuck-under parking on the ground floor. These irregularities, commonly referred to as soft-storey, caused a considerable number of wood building collapses in earthquakes in California. Another common cause of major damage to older wood buildings is the lack of bolts that tie the wood superstructure to the concrete foundations.

The National Building Code (NBC) of Canada is a model code that becomes law when adopted by provinces. There is typically a one-to-two-year time lag between when the NBC is released and when it is adopted by the provinces. For example the 2010 NBC led to the 2012 BC Building Code. The NBC's seismic provisions (Part 4) aim to prevent building collapse against ground shaking levels that have a return period of 2,475 years. Although implicitly assumed to limit damage in lower return periods, the NBC does not require an explicit check on building performance at any other return periods.It should also be noted that the NBC's seismic provisions are not mandatory for wood-frame buildings that are three storeys or lower and that have a footprint area of less than 600 m^2. These buildings are constructed following the prescriptive requirements in NBC's section on Housing and Small Buildings (Part 9). Hence, when assessing seismic risk to single family wood houses and smaller wood apartment buildings in Canada, the lack of mandatory seismic engineering requirements should be taken into consideration.

Damage to buildings is only one part of seismic risk. Stakeholders requiring seismic risk information to prepare for the aftermath of a major earthquake need to consider other factors that add up to the total picture on seismic risk, such as damage to infrastructure, potential injuries and life loss, financial losses including business interruption, and impacts of secondary hazards such as fire following earthquakes, tsunami, and earthquake triggered landslides. The ability of the local governments to respond effectively, with support from provincial and federal governments, will enable the repair and rebuilding efforts to start as quickly as possible. Although repair and rebuilding will be undertaken by the insurance industry for insured buildings, it will, at a minimum, require access to damaged buildings and essential services and utilities to be up and running.

3. Local Governments and Earthquakes

Of all the levels of government, local governments are in the front lines of dealing with the aftermath of an earthquake (with support from the provincial and federal governments, depending on the size of the event). In this Special Session, we focus on City of Victoria in BC as an example. The Victoria Emergency Management Agency (VEMA) is the City of Victoria's resource for helping the community prepare for an emergency. VEMA is responsible for preparing the Corporation of the City of Victoria through emergency planning, training and exercises.

The City of Victoria is the Canadian urban area with the closest proximity to the Cascadia subduction zone, though it can also experience damaging deep intraslab and shallow crustal earthquakes. The city has a one in three combined probability of experiencing a damaging earthquake shaking over the next 50 years and as such has one of the highest probabilities of damaging levels of ground shaking in the country (Onur and Seemann, 2004). The risk associated with each type of earthquake varies, but generally it is known that buildings and infrastructure, particularly those that pre-date seismic codes are susceptible to damage from all three types of earthquakes that can occur in the region. Infrastructure and buildings in the city date from the late 1800s to the present day.

An increasing awareness of the seismic risk in this region has led to a willingness to gain a greater understanding of the risk associated with the seismic hazard. In 2012 the City created a new Official Community Plan. For the first time this document included a section on emergency management and recommended a series of emergency management related actions. Subsequently, in the new draft 2015-2018 corporate strategic plan, it has been recognized that there is a need to have a greater understanding of the seismic hazard and to explore ways of increasing the overall resiliency of the community to this eventuality. The City of Victoria has identified seismic risk assessment as one of its priorities over the next few years. This will include a seismic assessment of civic structures and a high level seismic risk assessment of buildings across the community. These assessments will be used to inform decisions related to retrofit policy, expenditures, and priorities for retrofit.

Earthquake science is being coupled with modern geotechnical and structural engineering as new buildings are designed and built to a higher seismic standard in the community. Community-wide soil risk mapping is combined with site specific geotechnical assessments before buildings are designed and constructed, leading to more resilient structures. Older buildings that see a change of use are to be retrofitted to at least 60% of the seismic loads prescribed for new buildings in the current building code. The combined effect of new construction, coupled with retrofits to older buildings is leading to the increased resilience of the community.

Aside from evaluating the risk, in recent years the City of Victoria has undertaken several projects to increase the overall resiliency of the community. These include replacement of an aging life-line bridge, retrofit of large diameter water pipes with more earthquake resilient options, investment in response capacity through equipment, training and exercises, and through grants to owners of heritage buildings who undertake seismic retrofit. Over the next few years the City will also upgrade or replace its main fire hall to a post-seismic standard.

4. Insurance Industry and Earthquakes

The main concept of insurance, or spreading risk, has been around as long as human existence and is as old as society itself. Facing large-scale adverse events, people quickly learned that by sharing risk they would have a much better chance to survive that risk. In 1666, the great fire of London destroyed approximately 14,000 buildings. As a response to the chaos and outrage that followed the burning of London, groups of underwriters who had dealt exclusively in marine insurance formed insurance companies that offered fire insurance. Consider a home worth $500,000. In the unlikely chance that home was totally destroyed by fire then very few home owners would have the financial resources to rebuild that home without potentially bankrupting themselves. However, if that homeowner enters into a contractual agreement to share each other's risk with 1,000 other home owners then each would be responsible for $500 of the loss, a number that is manageable by most. With this concept, the purpose of an insurer is to facilitate this risk transfer through the collection of premiums and in the payment of claims.

In order to function well, the risk sharing community has to be large and in the case of natural catastrophes, where more than one location may be affected, the risk sharing community has to go beyond its own locality. This is why many insurers use reinsurers or capital market vehicles to further spread and diversify the risk. In general, smaller events are shared within the local community (local insurers) while the larger events are shared globally (global insurers and reinsurers).

Globally, the insurance industry continuously evolves to increase their understanding of earthquake and other catastrophe risk. Probabilistic and stochastic catastrophe risk models are commonly used to gain an understanding of the expected damage and loss for catastrophes like earthquakes. The industry strives to understand the models and manage the inevitable uncertainty associated with them. Accuracy and transparency are a top priority when establishing catastrophe limits (i.e. the level of insurance capacity purchased), especially in a Canada, where the regulatory environment, both federal and provincial, implement rigorous protocols and requirements to help minimize insolvency.

Canada is one of the top countries dedicated to a higher regulatory compliancy for earthquake risk. The goal of the Canadian regulatory environment is to help reduce the probability of “risk of ruin”. Since 1997, the Office of the Superintendent of Financial Institutions (OSFI) has regulated the minimum amount of reinsurance limit required for the peril of earthquake. In 2010, Canadian catastrophe treaties required $3 billion of additional limits (an increase of 23%) as a result of an updated catastrophe risk model in the market that addressed new engineering and earth science information. Table 1 presents the return period limit by which different capital environments are regulated. At a 430-year return period Canada’s limit is higher than many other markets.

Table 1 – Summary of Regulatory Limits for Various Capital Environments.

Capital Model	Return Period	Peril	Basis
Australia	250	Single Peril	Single Occurrence
Bermuda	100	All Perils	Aggregate
Canada	430	Earthquake BC or QC	Single Occurrence
Canada 2014*	430	Earthquake Canada Wide	Single Occurrence
Chile	None	N/A	N/A
Japan	70 250	Wind Earthquake	Single Occurrence
Lloyd’s	Realistic Disaster Scenarios (RDS) 200	All Risk Estimate	Single Occurrence
Solvency I	None	N/A	N/A
Solvency II	200	All Perils	Aggregate
U.K.	200	All Risk Estimate	Aggregate
U.S.	None	N/A	N/A
AM Best	100 250	Wind Earthquake	Single Occurrence
S&P	250	All Perils	Aggregate

**Canada’s regulatory environment continues to increase the return period limit by 10 years per year until it reaches the 500-year return period. In 2014 the limit reached 430 years (will be 440 years in 2015).*

In this Special Session, we have the following representatives from the insurance industry: primary insurer: Aviva, reinsurance broker: Aon Benfield, and reinsurer: Swiss Re.

4.1. Primary Insurer Perspective

From a primary insurer perspective, Aviva and the insurance industry are well aware of the catastrophic potential of seismic risk in both eastern and western Canada. Given applicable regulatory solvency requirements in Canada, which are conservative relative to comparable international jurisdictions, the insurance industry in Canada is well capitalized to cope with damaging earthquake events. However, earthquake insurance penetration (take up rate) is limited in BC and even more so in Quebec, despite the fact that both of these provinces have significant earthquake risk. Hence in the event of a major earthquake, insured losses will be a fraction of the total economic losses. Recent studies commissioned by the industry have confirmed that seismic risk in southwestern BC is truly a national issue given the net negative impact to macro-economic output and growth resulting from major catastrophic events. Earthquake risk and capability to recover is not limited to insurer balance sheets. This is why the industry is looking to take a lead in creating a national discourse on this issue.

The assessment of seismic risk is of vital importance to primary insurers. In many cases, earthquake is the single largest risk to solvency for a Canadian insurer. As a whole, the insurance industry in Canada spends hundreds of millions of dollars annually on catastrophe risk models and reinsurance to quantify and manage the exposure generated by the earthquake policies held by insureds.

Preparedness for a primary insurer can be thought of as falling into three categories: (a) prudent capitalization, (b) operational readiness for business continuity, and (c) maintenance of claims servicing capacity.

The insurance industry is increasingly paying attention to improvement of government and public awareness of the extent and impact of seismic risk in BC.

4.2. Reinsurance Broker Perspective

Aon Benfield Canada plays a pivotal role as Canada's largest natural catastrophe reinsurance broker placing around 65% of the approximately $22 billion (CAD) of the western Canada earthquake catastrophe limit in the international reinsurance market.

The earthquake peril is Canada's largest insured natural catastrophe exposure and, as such, Aon Benfield takes on the responsibility not only to understand this exposure in the context of insurance risk but also offer consultation and analytics available to help primary insurance companies manage these exposures according to each company's unique risk appetite. The cost for protection for both the primary insurance companies and the homeowner is increasing in Canada due to the steady increase in regulatory limits. As such, primary earthquake insurance deductibles have gone up in Canada along with earthquake rates to help manage the amount reinsurance required, translating to higher premiums and deductibles for homeowners. While reinsurance limits in Canada have steadily increased since 2010 because of the earthquake risk; the percentage of homeowners who purchase earthquake insurance cover in mainland BC has decreased. In 2014, approximately 45% of homeowners purchased earthquake insurance; a steady decline from the once 55-60% insurance take up rate.

Just as the reinsurance brokers' placement of US and European windstorm storm risk puts these insurance markets on the global reinsurance radar screen regarding accumulation control and volatility exposure, Aon Benfield Canada's role as a leading reinsurance broker placing Canadian earthquake risk has a similar effect on this international financing mechanism.

4.3. Reinsurer Perspective

From a reinsurance perspective, seismic risk in BC is one of low frequency and high severity with one of the greatest potential events coming from the Cascadia subduction zone. Historically, the largest magnitude event that has struck BC occurred along the Cascadia subduction zone in 1700 and was responsible for a sizeable tsunami hitting Japan. Through modern times (last 50 years) the region has been spared from damaging earthquakes, which lead to unintentional complacency in the society. The first National Building Code of Canada was issued in 1953 and since then 11 updates were made, the latest being the 2010 code. Nevertheless most of the inventory in the region was built prior to 1990s with many built to the pre-1985 code. A major Cascadia event will impact both Canada and the US with 20-40% of the loss coming from Canada. Much of the exposure in Vancouver is on softer soils with a high potential for liquefaction. The Insurance Bureau of Canada (IBC) estimates that the event could cost as much as $20 billion (http://assets.ibc.ca/Documents/Studies/IBC-EQ-Study-Full.pdf). This estimate ignores many of the risk modeling blind spots which may contribute or in the case of liquefaction drive much of the loss potential. Recent global events have shown that, especially given the extended period of time since the last major damaging earthquake in BC, regardless of the planning undertaken, there will likely be surprises.

Considering that most of the potential liabilities are with extreme events, Swiss Re as a reinsurer devotes significant resources into understanding and managing these risks, taking great care in assessing the risk and striving to remain aware of any changes in the understanding of hazard, including any secondary hazards like liquefaction, landslide, and tsunami. To remain solvent and continue to be able to financially support the primary insurers, reinsurers must manage their accumulations and potential liabilities across the globe. However, this is not a trivial task as many of the events are low frequency and high severity. Damaging earthquakes happen often enough on a global basis but infrequently at any local seismic area. The insurance industry is built on past statistics and large quantities of data used to predict the future. But in the case of a rare earthquake there is not enough accurate historical loss data to accurately predict the future. In instances like these, the industry uses risk models based on science, engineering, similar experience, and other data to simulate future potential events.

Catastrophe risk models have become very important to the industry and industry regulators. If the risk is mismanaged, then individual organizations, and indeed the industry as a whole could fail. Considering both the insured as well as the uninsured loss, the protection gap is huge and needs to be considered by homeowners, businesses and governments. The insurance industry surplus is close to $700 billion globally. A rough estimate is that the industry could lose 20% of that surplus and still have the capacity to remain strong. A BC earthquake of $20 billion would fall into the top ten largest insured natural catastrophe losses incurred between 1970 and 2014. Although an event of this size would have little impact on the global insurance and reinsurance community, a $20 billion loss would have a significant impact in terms of Canada's property written premiums.

5. Discussion and Conclusions

There is a common goal of better understanding the seismic risk across various organizations. As an insurable disaster, a major damaging earthquake will have the insurance industry playing a major role in bearing the burden of the financial impact through business interruption compensation as well as repair and/or rebuilding of physical property for businesses and individuals, however earthquakes are not just an insurance risk.

The scientific community plays a key role in providing the current scientific information in a manner that can be used by various stakeholders in order to support the policy and decision making for governments, businesses and members of the public. This allows increased awareness regarding current understanding of seismic hazards and the specific risks associated with them.

Governments, starting at the local level, have the responsibility to seek out relevant information that will help them better understand and prepare for the impacts of a major earthquake in their jurisdiction. They then have to act on the available information to make sure the coordination of the disaster response is carried out effectively so that various organizations and private citizens can return to their normal operations and lives as quickly as possible.

One of the greatest challenges with earthquake risk remains public education – from understanding the level of seismic hazard in their area, to the specific risk to themselves and their property, and to the distinct roles of the government and private earthquake insurance in recovering from a disaster, there are many facets of education that remain considerably in the dark and sometimes misunderstood. It is the responsibility of all the stakeholders in this session, the governments, the insurance industry, and the scientific community to make sure this education reaches down to the individual citizen level.

6. References

ADAMS, J., HALCHUK, S., ALLEN, T., and ROGERS, G. (2015). Canada's 5th Generation seismic hazard model for the 2015 National Building Code of Canada, *11th Canadian Conference on Earthquake Engineering*

ANAGNOS, T., M. C. COMERIO, C. GOULET, H. NA, J. STEELE, AND J. P. STEWART (2008) Los Angeles Inventory of Nonductile Concrete Buildings for Analysis of Seismic Collapse Risk Hazards. *Proceedings of the 14th World Conference on Earthquake Engineering*, Oct. 12-17, Beijing, China.

ATWATER, B. F., MUSUMI-ROKKAKU, S., SATAKE, K., TSUJI, Y., UEDA, K., and YAMAGUCHI, D. K. (2005). The orphan tsunami of 1700, *U. S. Geological Survey Professional Paper 1707*, 133 pp.

CLARK, D., MCPHERSON, A., and VAN DISSEN, R. (2012). Long-term behaviour of Australian stable continental region (SCR) faults, *Tectonophys.*, Vol. 566-567, pp. 1-30, doi: 10.1016/j.tecto.2012.07.004.

EMERGENCY MANAGEMENT BC (EMBC), PROVINCE OF BRITISH COLUMBIA. (2008). British Columbia Earthquake Response Plan (2008), http://www.embc.gov.bc.ca/em/hazard_plans/EQ_Plan.pdf

GOLDFINGER, C., NELSON, C. H., MOREY, A. E., JOHNSON, J. E., PATTON, J. R., KARABANOV, E., GUTIÉRREZ-PASTOR, J., ERIKSSON, A. T., GRÀCIA, E., DUNHILL, G., ENKIN, R. J., DALLIMORE, A., and VALLIER, T. (2012). Turbidite event history—Methods and implications for Holocene paleoseismicity of the Cascadia subduction zone *U.S. Geological Survey Professional Paper 1661–F*, 170 pp.

HALCHUK, S., ALLEN, T. I., ROGERS, G. C., and ADAMS, J. (2015). Seismic Hazard Earthquake Epicentre File (SHEEF2010) used in the Fifth Generation Seismic Hazard Maps of Canada, *Geological Survey of Canada Open File XXXX*pp.

HARRIS, J.B., HUNTER, J.A., LUTERNAUER, J.L., AND FINN, W.D.L. (1998). Site amplification modelling of the Fraser delta, British Columbia, **in** Geology and Natural Hazards of the Fraser River Delta, British Columbia, (Ed.) JJ. Clague, J.L. Luternauer, and D.C. Mosher. *Geological Survey of Canada Bulletin 525*, pp. 211-216.

LIU, M., and WANG, H. (2012). Roaming earthquakes in China highlight midcontinental hazards, *EOS*, Vol. 93, No. 45, pp. 453-454.

MONAHAN, P. A., LEVSON, V. M., HENDERSON, P., AND SY, A. (2000). Relative Amplification of Ground Motion Hazard Map of Greater Victoria, British Columbia Geological Survey, Ministry of Energy and Mines,Victoria, B.C., Geoscience Map 2000-3, Sheet 3B. http://www.empr.gov.bc.ca/Mining/Geoscience/NaturalHazards/VictoriaEarthquakeMaps/amplification/Pages/default.aspx.

NATURAL RESOURCES CANADA (NRCan). (2014). Earthquakes Canada, http://www.earthquakescanada.nrcan.gc.ca/index-eng.php.

ONUR, T., and SEEMANN, M. (2004). Probabilities of significant earthquake shaking in communities across British Columbia: Implications for emergency management, *13th World Conference on Earthquake Engineering*, Vancouver, B.C., Canada, Paper No. 1065.

ONUR, T., VENTURA, E.C., FINN, W.D. (2005) Regional seismic risk in British Columbia—damage and loss distribution in Victoria and Vancouver. Can J Civ Eng 32: pp. 361-371

PETERSEN, M. D., MOSCHETTI, M. P., POWERS, P. M., MUELLER, C. S., HALLER, K. M., FRANKEL, A. D., ZENG, Y., REZAEIAN, S., HARMSEN, S. C., BOYD, O. S., FIELD, N., CHEN, R., RUKSTALES, K. S., LUCO, N., WHEELER, R. L., WILLIAMS, R. A., and OLSEN, A. H. (2014). Documentation for the 2014 update of the United States National Seismic Hazard Maps, *U.S. Geological Survey Open-File Report 2014–1091*, 243 pp, http://dx.doi.org/10.333/ofr20141091.