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A selection of earthquake scenarios for government planning purposes in 2021

T.E. Hobbs

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Introduction

This document describes three earthquake scenarios developed for government planning purposes in 2021. They were requested from Natural Resources Canada, which holds federal subject matter expertise on seismic hazard and risk, by Emergency Management British Columbia and the Government Operations Centre in Ottawa, and are presented in an Open File report to allow for appropriate review and documentation. While the events were developed for particular government agencies, the scenarios are relevant for other applications and hence their documentation may be useful to other emergency management, planning, and preparedness organizations, and to the broader public.

This file presents a description of the impacts due to the following scenario earthquakes: a moment magnitude (M_w) 7.0 event in the Strait of Georgia near Vancouver, BC; a M_w 7.3 event on the Leech River Fault near Victoria, BC; and a M_w 7.5 event in Gatineau, QC, near the nation's capital. The seismic hazard and risk assessment is performed in the same manner as the National Seismic Risk Assessment [Hobbs et al., work in progress, 2022]; Journeay et al. (A), work in progress, 2022], which leverages the current best understanding of: seismic sources and ground motions [Kolaj et al., 2020], site conditions [Wald & Allen, 2007], exposed assets [Journeay et al. (B), work in progress, 2022], and fragility curves [Hobbs et al., work in progress, 2022]. In this document, sources will be cited as appropriate to support the scientific description of the events, but the text will generally be aimed at a non-technical audience.

All three earthquake scenarios occur on shallow faults in the Earth's crust, rather than at depth in, for instance, the Cascadia Subduction Zone. Shallow earthquakes can be particularly devastating as the shaking source is closer to the built environment, despite having smaller maximum magnitudes than their subduction zone counterparts. In Canada, we have relatively few mapped shallow faults that are documented as being potentially capable of experiencing large earthquakes. While there is growing evidence that these faults likely exist [Kelsey 2012; Rimando 2021], in this work we aim to use the locations of previous earthquakes or documented active faults to ensure these scenarios are well-grounded in seismological observations and consistent with the most recent sixth generation Canadian Seismic Hazard Model (CanSHM6) [Kolaj et al., 2020] that informs the seismic provisions in the National Building Code of Canada.

Disclaimer: It should be noted that estimates herein include only the impacts of earthquake shaking as it affects buildings and their inhabitants. Secondary hazards, such as aftershocks, tsunami, landslides, liquefaction, and fire following are not considered. Non-building impacts such as damage to vehicles, infrastructure, or business disruption costs are not considered either. Therefore, the estimates herein are likely to represent a minimum estimate on impacts.

Vancouver Scenario: M_w 7.0 Crustal Earthquake in the Strait of Georgia

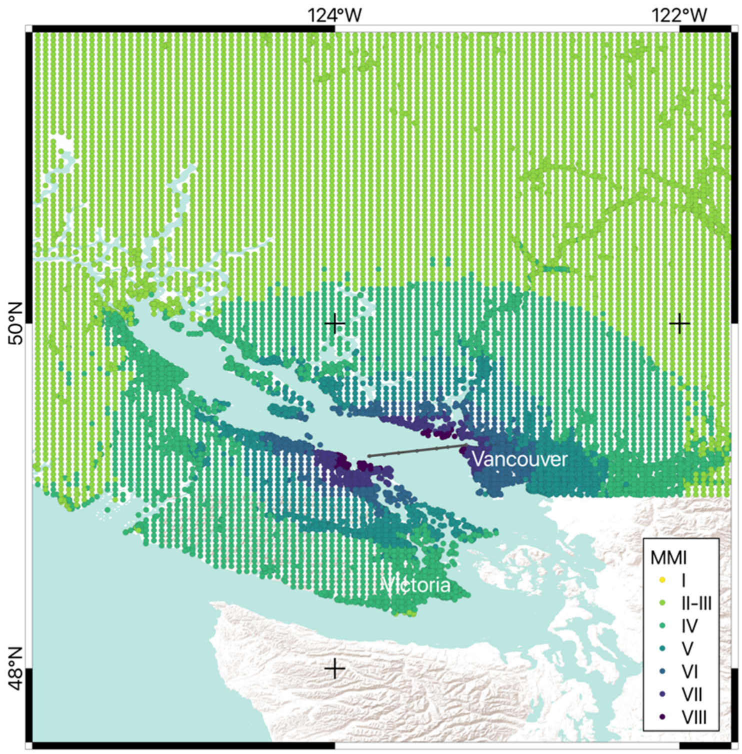

Figure 1. Shaking from the Mw 7.0 Vancouver scenario earthquake, in terms of Modified Mercalli Index. Fault line is shown in grey.

Description of the Earthquake

The geometry for this event is based on a smaller (local magnitude 4.6) event that occurred in the Strait of Georgia in 1997 along what is believed to be an active fault [Cassidy, Rogers & Waldhauser, 2000]. The magnitude is consistent with the current understanding of the average maximum magnitude for this type of earthquake in this region, which is M_w 7.5 according to CanSHM6. An event with magnitude equal to or greater than 7.0 in this broad region should occur, statistically, about every 1500 years. It was selected as a scenario event to produce impacts aligned with the design specifications of a plausible event with high damage in the Vancouver area.

This event, centered at 49.24°N and 123.63°W (Fig. 1), would likely produce peak earthquake shaking of 10-60% of gravitational acceleration (freefall) in Vancouver, consistent with a Modified Mercalli Intensity [Wood & Neumann, 1931; Caprio et al., 2015] of V-VIII in the Lower Mainland and Nanaimo. Such intensities are associated with moderate-to-severe perceived shaking. Shaking would be strongest in Downtown Vancouver, West Vancouver, Nanaimo, Gibsons, and on Gabriola and Bowen Islands, and will be amplified in areas with thick soil deposits like the Georgia Basin.

Damage to Buildings

This event would render over 10,000 buildings permanently uninhabitable, with another 6,100 buildings being only conditionally habitable. Of the most affected municipalities, roughly 3% of Vancouver's buildings would need to be replaced, with the same fraction in Richmond and 6% in Nanaimo. The complete damage is most pronounced in wood (26%), concrete (22%) and steel (19%) construction types (Fig. 2), especially in older buildings that predate rigorous seismic codes. Wood is a predominant building material in this region, so despite having the highest proportion of completely damaged buildings, wood actually performs quite well seismically.

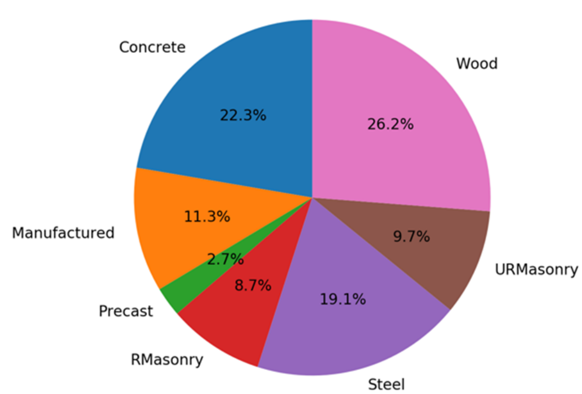

Figure 2. Building types as they contribute to the total number of uninhabitable buildings.

Debris is likely to litter the streets and obstruct response operations, as this scenario generates 13 million tonnes of mixed debris. Although it is not modelled, damage is expected to roadways – particularly on the saturated soils of the Fraser River Delta. Emergency vehicles, if they are not damaged or trapped in damaged garages, may need the ability to navigate disrupted roadways or clear debris from their routes.

Human Impacts

This event occurs during daytime hours (9am-5pm), when most people are at school or work. Sadly, modelling suggests this event would claim about 2,000 lives, with another 1,000 being critically injured (Fig. 3). Total hospital demand for critical and noncritical cases would be about 7,500 people, and 21,000 would require non-hospital injury care. The major hospitals in the affected area are Vancouver General Hospital, St. Paul's Hospital, Lion's Gate Hospital, University of British Columbia Hospital, and Nanaimo Regional General Hospital.

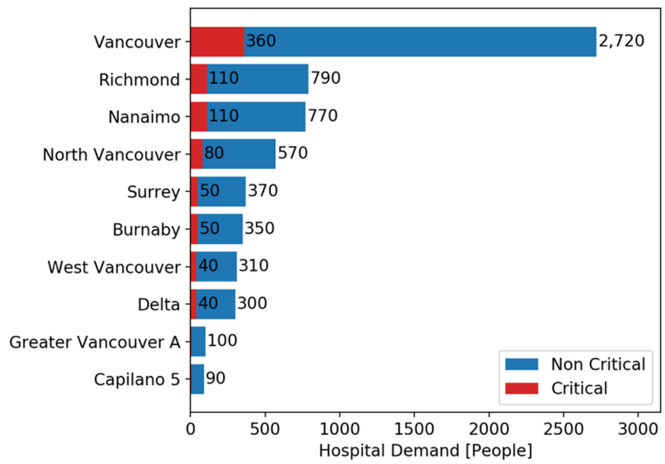

Figure 3. Hospital requirements for top 10 most impacted municipalities, in terms of critical and non-critical injuries, rounded to nearest 10. Critical injuries under 40 are not displayed.

It is estimated that up to 1.7 million people would have damage to their residences of some kind, of which we estimate that over 70,000 households would be displaced. Many of these people would stay with personal contacts or camp in their yards, but some proportion would likely seek shelter in mass care facilities.

Financial Losses

This earthquake has an estimated economic impact of around $30 billion CAD, accounting only for damage to buildings due to the mainshock shaking (see disclaimer). With a 2019 provincial gross domestic product (GDP) of $309 billion CAD [Statistics Canada], the loss from this earthquake represents about 10% of the provincial GDP.

Victoria Scenario: M_w 7.3 Crustal Earthquake on the Leech River Fault

Description of the Earthquake
This earthquake scenario is based on the CanSHM6 seismic source model, which characterized the geometry of the Leech River Fault [Halchuk et al., 2019]. They ascribe a magnitude of 7.3 to an event that occurs along the entire length of the fault, which would rupture through Victoria along its roughly east-west fault length (Fig. 4). According to recent paleoseismic studies of this fault, it has hosted an earthquake on average every 3500 years since the last ice age [Morell et al., 2018].

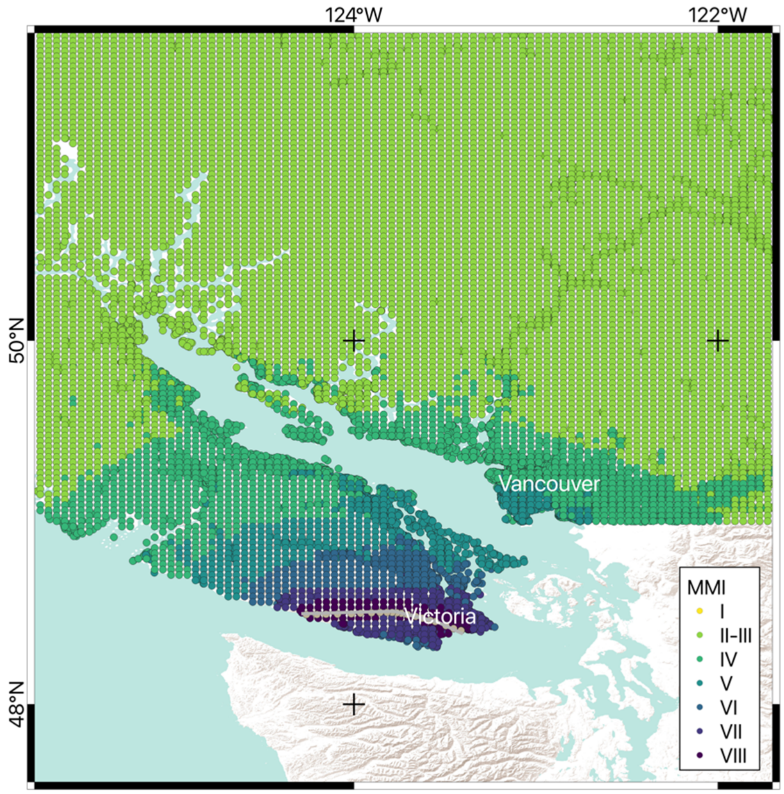

Figure 4. Shaking from the Mw 7.3 Victoria scenario earthquake, in terms of Modified Mercalli Intensity. Fault line is shown in grey.

This earthquake scenario creates shaking with peak acceleration up to about 63% of freefall and Modified Mercalli Intensities [Wood & Neumann, 1931; Caprio et al., 2015] of VI-VIII in the Victoria area (Fig. 4). These intensities are consistent with strong to severe perceived shaking in Victoria, Esquimalt, Langford, View Royal, Colwood, and Saanich. Shaking will likely be especially strong in regions with thick soil, including James Bay.

Damage to Buildings
This type of earthquake would make almost 7,000 buildings uninhabitable (red-tagged) and 4,200 buildings conditionally inhabitable (yellow-tagged). In context, 5% of Capital Regional District buildings would have to be replaced, including 8% in Victoria and 4% in Saanich. About 50% of the completely damaged buildings are made of wood and concrete, partially reflecting the most prevalent building construction materials in the Capital: 88% wood (Fig. 5). The remainder of the existing building stock of the Capital is about 3% unreinforced masonry, 3% reinforced masonry, and 2% each of concrete, steel, and manufactured. Concrete and steel, therefore, are particularly over-represented in terms of complete damage and are thus considers poor seismic performers.

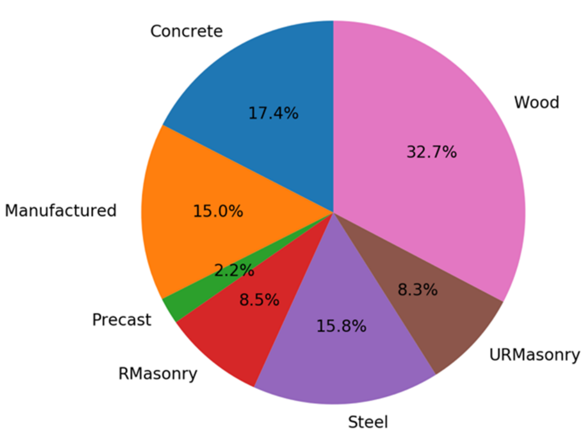

Figure 5. Building types as they contribute to the total number of uninhabitable buildings.

Human Impacts

There would be around 1 million people impacted by this event, with around 43,000 households being displaced from their homes. According to our model, over 10,000 people would require first aid, 3,200 would need to be treated in hospital for non-critical injuries, 500 would be in critical condition, and almost 1,000 would be fatally injured (Fig. 6). The most impacted municipalities are Saanich, Victoria, Langford, Esquimalt, Oak Bay and Colwood, as well as mainland communities of Vancouver, Richmond, and Surrey. This is likely to present a significant challenge for Victoria-area hospitals: Victoria General and Royal Jubilee.

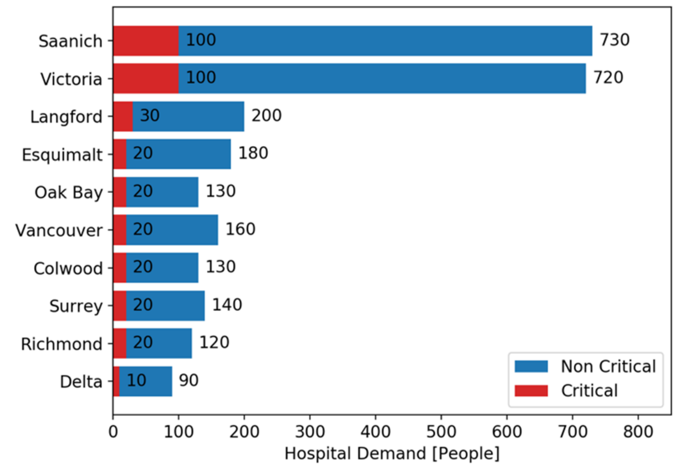

Figure 6. Hospital requirements for top 10 most impacted municipalities, in terms of critical and non-critical injuries, rounded to nearest 10.

Financial Losses

This event has a modelled economic loss of roughly $20 billion, representing about 6% of BC's GDP [Statistics Canada]. The residential component of this is about $11.5 billion. With a country-leading residential insurance penetration rate of 70% and deductibles of 8% in Victoria area [AIR 2013], this equates to residential insurance claims totalling approximately $7.4 billion with the remainder (over $4.1 billion) being paid by homeowners.

Ottawa Scenario: M_w 7.5 Crustal Earthquake near Val-des-Bois

Description of the Earthquake

This event is modelled after the 2010 M_w 5.0 Val-des-bois, Quebec earthquake north of Ottawa, Ontario at 45.904ºN, 75.497ºW with a depth of 21 km [Ma & Motazedian, 2012]. At the time it occurred, it was the strongest shaking ever recorded in the Capital of Canada, with Modified Mercalli Intensities of up to VII [Atkinson & Assatourians, 2010]. For the scenario presented here, the magnitude was increased to M_w 7.5, shy of the maximum magnitude of 7.95 for this region, according to CanSHM6 [Kolaj et al., 2020]. Using that same seismic source model, an event with magnitude equal to or greater than M_w 7.5 would be forecast in the broad Gatineau Region only once every 4,000 years and significantly less frequently so close to Ottawa. Therefore, this event should be considered a very low probability earthquake, somewhat akin to a 'worst case scenario'.

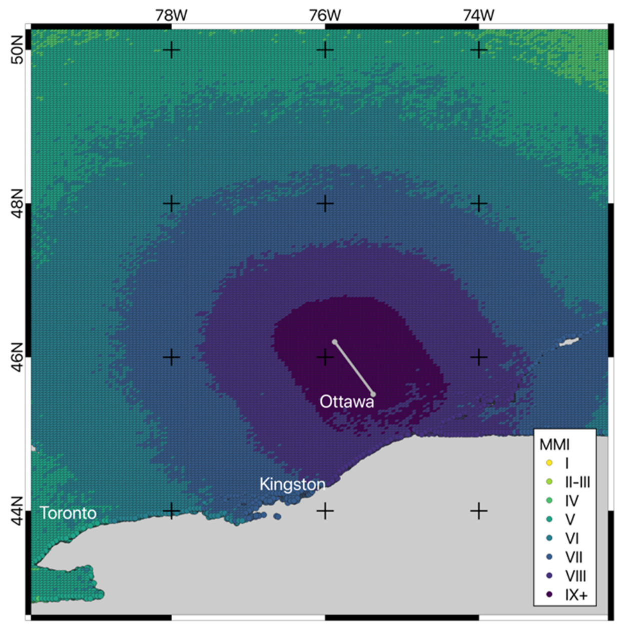

Figure 7. Shaking from the Mw 7.5 Val-des-bois scenario earthquake, in terms of Modified Mercalli Index. Fault line is shown in grey.

Shaking from this event is likely to be strongest nearer the epicentre and in locations with relatively thick soil deposits, such as in Downtown Ottawa [Lamontagne, 2010]. It would be felt across much of Ontario, Quebec, the Maritimes, and the Northeast United States (Fig. 7). In Toronto, shaking would be light (MMI IV) whereas in Ottawa, Gatineau, and Montreal it would have an MMI [Wood & Neumann, 1931; Caprio et al., 2015] of X or more, equating to violent and extreme shaking. The maximum PGA for this event is about 300% of freefall near the source, and varies between about 20-100% of freefall in Ottawa. This is very strong, in fact it is likely an over-prediction by the ground motion models, as has been seen for other strong earthquakes in other regions [ex: Takai et al., 2016].

Damage to Buildings

From reports of previous earthquakes in this region [Lamontagne, 2010], we know that the greatest damage will likely be to older buildings and those with unreinforced masonry (brick) elements. Approximately 35,000 buildings would be damaged beyond repair (red-tagged) in Ontario and Quebec. A further 20,000 buildings would be extensively damaged, allowing for conditional habitability in the immediate aftermath. In Ottawa, Gatineau, and Montreal, the percentages of buildings which would be red-tagged are around 6%, 5%, and 2%, respectively. The majority of completely damaged buildings are made of wood, unreinforced masonry, and steel (Fig. 8); and 75% were constructed prior to the advent of seismic design codes in the early 1970's.

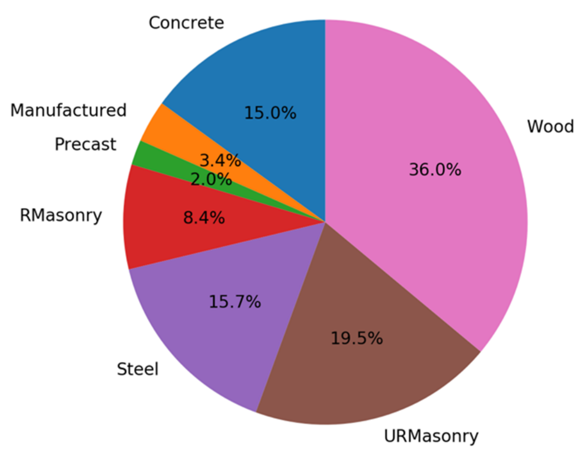

Figure 8. Building types as they contribute to the total number of uninhabitable buildings.

Debris is likely to present a significant challenge to response operations, especially in densely populated areas like downtown Ottawa and Gatineau. In total, modelling anticipates over 36 million tonnes of mixed concrete, steel, wood, and brick detritus to be generated across the impacted region.

Human Impacts

Due to the high population in the Toronto-Montreal Corridor, over 4 million people could be impacted by this event and around 6,000 fatalities could result if the earthquake happened during the daytime. In this scenario, a predicted 24,000 people would require hospital care: 21,000 in non-critical care and 3,000 in critical care. Most injuries would be sustained in Ottawa, Montreal, and Gatineau (Fig. 9). The greatest burden would be placed on trauma-capable hospitals in Ottawa and Montreal. Another 61,000 people would require first aid treatment that could be provided outside of a hospital context.

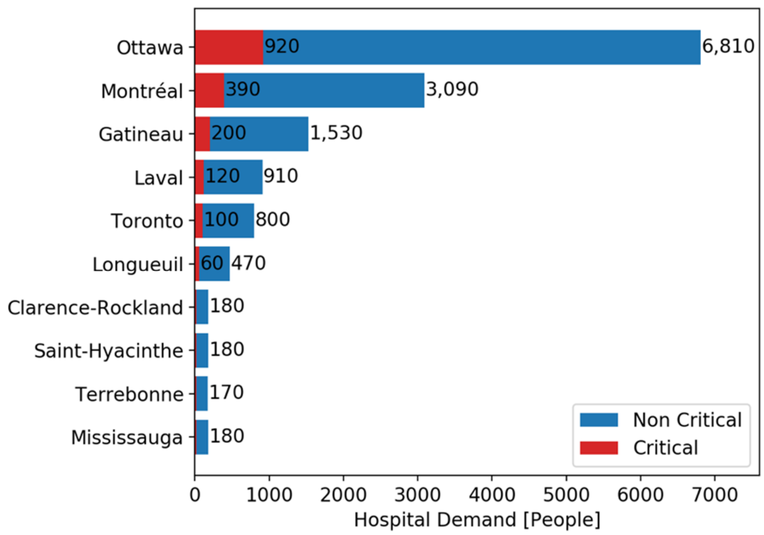

Figure 9. Hospital requirements for top 10 most impacted municipalities, in terms of critical and non critical injuries, rounded to nearest 10. Critical injuries under 40 are not displayed.

Our model indicates that around a quarter of a million households would be displaced from their homes, suggesting that damage to multi-unit buildings will be considerable in some of Canada's largest cities. Some of these people will require shelter in mass care facilities, although most will likely find alternative housing.

Financial Losses

The magnitude 7.5 earthquake is predicted to cause around $75 billion in losses due to building damage from the mainshock (see disclaimer). The high cost of this event is likely due to the very broad region over which shaking would be felt, the relatively poor seismic performance of historic unreinforced masonry buildings, and the proximity of this very large earthquake to major urban areas including Ottawa, Montreal, and Toronto.

Of this $75 billion loss, roughly $50 billion is to residential buildings. Assuming that residential insurance penetration is somewhere around 2-5% in Quebec [AIR 2013], then only $1-2.5 billion of this would be covered, from which homeowners would still pay 5% in deductibles. In British Columbia, insurance penetration varies from 40-70% [AIR 2013]. From this standpoint, a large earthquake in Eastern Canada would put proportionately far more demand on government assistance programs than the equivalent event in the West.

Acknowledgements

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