TOWARDS QUANTIFYING THE EFFECT OF LONG DURATION GROUND MOTIONS ON REGIONAL SEISMIC RISK ASSESSMENT IN SOUTHWEST BRITISH COLUMBIA.

Ann Abraham [(1)], Carlos E. Ventura [(2)], Armin Bebamzadeh [(3)]

[(1)] *PhD Student, Department of Civil Engineering, UBC, ann1991@mail.ubc.ca*
[(2)] *Professor, Department of Civil Engineering, UBC, ventura@civil.ubc.ca*
[(3)] *Research Associate, Department of Civil Engineering, UBC, armin@civil.ubc.ca*

Abstract

Fragility curves generated based on site-specific seismic hazard are essential for accurate seismic risk assessment. The seismicity in southwest British Columbia (BC) comprises of subduction events occurring at the interface of the Juan de Fuca plate and the North American plate, inslab events occurring deep in the subducting Juan de Fuca plate and shallow crustal events in the North American plate. While the rare large magnitude (M>9.0) subduction events are characterized by long duration of shaking and rich low frequency content, frequent smaller magnitude inslab and crustal earthquakes (5.5<M<7.5) have a rich high frequency content and a short duration. These earthquakes present a major risk to the densely populated southwest BC, which has a compact but aging building stock. So, in southwest BC, the effect of these earthquake types must be accounted for during regional seismic risk assessment, for accurate damage estimation.

OpenQuake, developed by the Global Earthquake Model (GEM), offers a platform for risk assessment at different regional levels, adapting to new needs of disaster risk reduction, combining probabilistic seismic hazard analysis and fragility and vulnerability functions to assess seismic risk of a region. The recent Canadian National Risk model is developed in OpenQuake, with damage and loss assessment being carried out using fragility curves that are developed with FEMA p695 ground motion records -which are shallow crustal short duration ground motions- and developed for building typologies adopted from HAZUS. However, their use in southwest BC needs to be validated, as BC structures have lower strength capacities and since long duration earthquakes instigate structural collapse at lower intensity of ground motion shaking than short duration ground motions, thus increasing structural damage potential. In this paper, the results from quantifying and comparing the damage estimated in the City of Vancouver (which is taken as a study region) for two possible earthquake scenarios using the current and newly developed fragility curves are recorded. This comparison helps decide which fragility curves to use towards further regional seismic risk assessments, and to help quantify the effect of long duration ground motions on regional risk assessment. Results of this study, done for the most prevalent building typologies in southwest BC, estimated per building, on a complete database of buildings in the City of Vancouver, British Columbia is presented. It identifies misgivings of the current fragility models used to conduct seismic damage assessment in BC and the city's high-risk buildings to develop seismic policies, divert disaster funds and for proper emergency management.

Keywords: Seismic Risk Assessment; Fragility Curves; OpenQuake; Southwest BC; Long Duration Earthquakes.

1. Introduction

Seismic risk assessment and management is essential to develop realistic risk profiles, design emergency preparedness plans, determine suitable retrofit schemes and to legislate public policy in a region, as natural disasters seemingly cause larger risk across the globe due to rapidly increasing population, building stock and infrastructure. In southwest Canada, where there is a large likelihood of a magnitude (M~9.0) subduction earthquakes in the Cascadia subduction zone, the necessity of proper seismic risk assessment is indisputable. Southwest British Columbia (BC)'s building stock is largely composed of light frame wood structures and low-rise concrete and masonry constructions that predate building codes accounting for seismic design. This building stock profile in conjunction with an increasing population density dictates the need to properly assess the probability of expected damages and losses due to the seismic hazard expected at a site.

This paper compares the damage predicted for the most prevalent building typologies in the city of Vancouver, by the newly developed fragility curves that account for BC specific construction practices for crustal and subduction ground motions, to fragility curves currently used for the national regional risk assessment based off HAZUS, developed by Global Earthquake Model (GEM), Pavia. Scenario damage assessments are done for two potential damaging scenarios: a magnitude 9.0 rupture at the interface of the Juan de Fuca and North American plates (CSZ9.0) and a magnitude 7.3 rupture of a fault located in the strait of Georgia (GSM7.3), using appropriate fragility curves.

The city of Vancouver was chosen as a study region for this paper, as it is located near the Cascadia subduction earthquake zone where both rare large magnitude subduction events and frequent smaller crustal events occur. The city, with an area of 114.97 km^2, is the most populous city in BC with the highest population density in Canada and with a building stock dominated by wood construction and buildings built before 1972. For this study, a building inventory of about 92,000 buildings, put together by the Earthquake Engineering Research Facility (EERF) at the University of British Columbia (UBC) is considered. The combination of a high population density, high building density and an aging building stock makes the city of Vancouver an excellent example for proper seismic damage assessment studies under potential earthquakes.

2. Sources contributing to seismic hazard and scenarios considered

The seismic hazard at the site of interest (study region) has to be evaluated and contributing events of interest, identified for proper seismic risk assessment. Data acquired from the Geological Survey of Canada (GSC) 2015 seismic hazard model was implemented in EZ-Frisk, and the deaggregation plots for Vancouver at 0.5s and 1.0s at 2% in 50-year hazard is shown in Fig. 1.

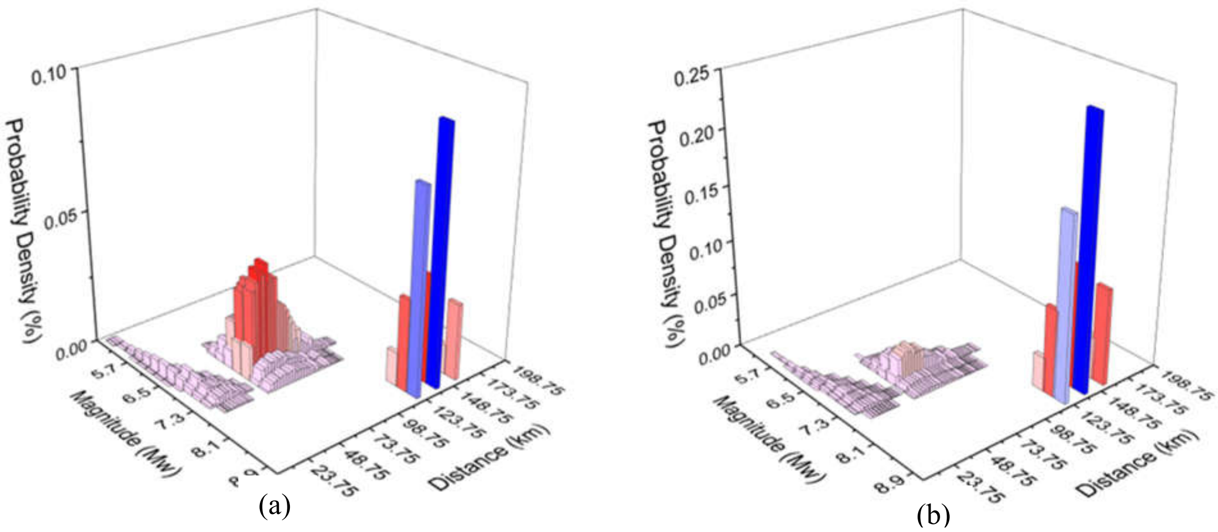


Fig. 1- Deaggregation plots for Vancouver [1]: (a) Vancouver Total Deaggregation for Sa(0.5sec) = 0.751g
(b) Vancouver Total Deaggregation for Sa(1.0sec) = 0.425g

From these deaggregation results, three types of earthquake sources are seen to dominate the seismic hazard at Vancouver: Crustal events at smaller magnitudes of 5.5 to 7.5 occurring near the surface at a depth less than 30km in the upper crust of the continental plate and at distances less than 80km, Sub-crustal events at magnitudes of 6 to 7.5 occurring at a depth of 30-60km, within the subducting Juan de Fuca tectonic plate and at distances of 30-150km and possible large magnitude subduction earthquakes occurring at the interface of the Juan de Fuca and North American Plate at depths of 0-50km, at the plate boundary and distances from about 50-250km depending on the site location [1]. Based off these deaggregation results, two scenarios that the City of Vancouver run as part of their exercises are chosen to highlight the difference in damage estimated when using the newly developed fragility curves.

2.1 Crustal Scenario Earthquake: Georgia Strait Shallow Crustal Earthquake M 7.3 (GSM7.3)

Strike-slip and thrust faulting mechanisms that occur within the oceanic Juan de Fuca plate and the continental North America plate create shallow crustal earthquakes, which are frequently recorded. Though most recorded events are small, larger magnitude events are also possible like the magnitude 8.1 Haida Gwaii (formerly Queen Charlotte Islands) earthquake of 1949 and the magnitude 7.3 Vancouver Island Earthquake of 1946. For the shallow crustal earthquake scenario, a rupture of the Georgia Strait, with its hypocenter around 30 km west of Vancouver, off the coast, at a depth of 5-10 km is modelled using a simple fault geometry [2]. This rupture length of about 40 km on the Strait of Georgia could produce a seismic event of magnitude 7.3 or higher [3]. An equally weighted combination of Boore et al (2014) [4], Abrahamson et al (2014)[5], Campbell and Bozorgnia (2014)[6] and Chiou and Youngs (2014)[7] Ground Motion Prediction Equations (GMPEs) were used to predict intensity of ground shaking due to the assumed rupture and is consequently used to determine damage states of buildings on respective sites.

2.2 Subduction Scenario Earthquake: Cascadia Rupture M 9.0 (CSZ9.0)

The Cascadia subduction events occur at the interface between subducting Juan de Fuca Plate and North America Plate and can cause large magnitude earthquakes, inducing intensive and destructive levels of ground shaking in nearby British Columbia (BC). The last known subduction earthquake in the Cascadia Subduction Zone is the magnitude 9.0 Cascadia Megathrust Earthquake of 1700. The Cascadia Subduction Zone (CSZ9.0) is fully ruptured over a rupture area 1020 km long and 125 km wide, extending between Northern California, till northern Vancouver Island to get a magnitude 9.0 earthquake scenario. An equally weighted combination of Abrahamson et al (2015)[8], Atkinson and Boore (2003)[9], Ghofrani and Atkinson (2014)[10] and Zhao et al. (2006)[11] subduction interface GMPEs are used to predict shaking levels produced by the assumed rupture and are consequently used to determine damage states of buildings on respective sites.

3 Soil Conditions in the city of Vancouver

Soil conditions at the site of interest can amplify (in case of soft soils) or deamplify (in the case of stiff soils and rock) the intensity of ground shaking at the site, and significantly influence the seismic response of the structure. The National Building Code of Canada (NBCC) classifies the soils into different site classes (A to F in decreasing order of shear wave velocity) from recorded shear wave velocity (Vs30) of the soil at the site. Based on the site class, NBCC amplifies the seismic demand on structures at the site of interest. The NEHRP Vs30 site classification for the city of Vancouver, put together in 2016 is mapped below and this soil site classification information is used by GMPEs of corresponding scenarios to calculate the intensity of ground shaking for different events in OpenQuake.

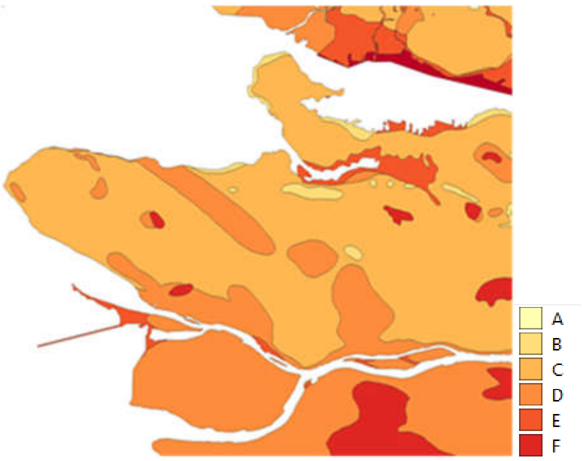
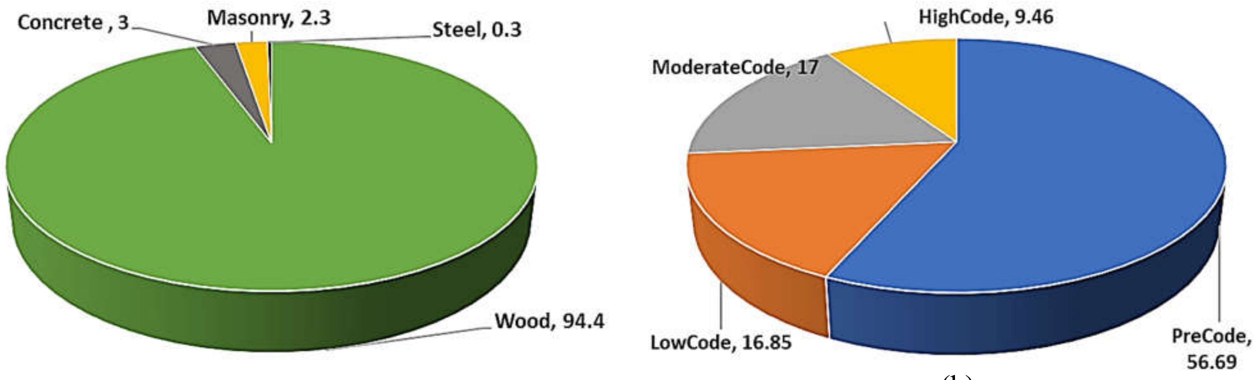


Fig. 3- NEHRP site classification for the City of Vancouver [1]

4. Overview of city of Vancouver building stock

From the most recent building survey conducted by the University of British Columbia (UBC) for the city of Vancouver, wood is seen to be the predominant construction material with approximately 94.4% of the buildings surveyed in city being wood construction. Approximately 92000 buildings were surveyed and classified based on construction material, building height, year of construction (used as a proxy for design level referring to building code evolution and hazard estimation), occupancy, number of stories, etc., preliminarily based off the HAZUS [12] building typology classification.



(a) (b)

Fig. 4 - City of Vancouver building stock [%] classified based on: (a) code design levels (b) construction material

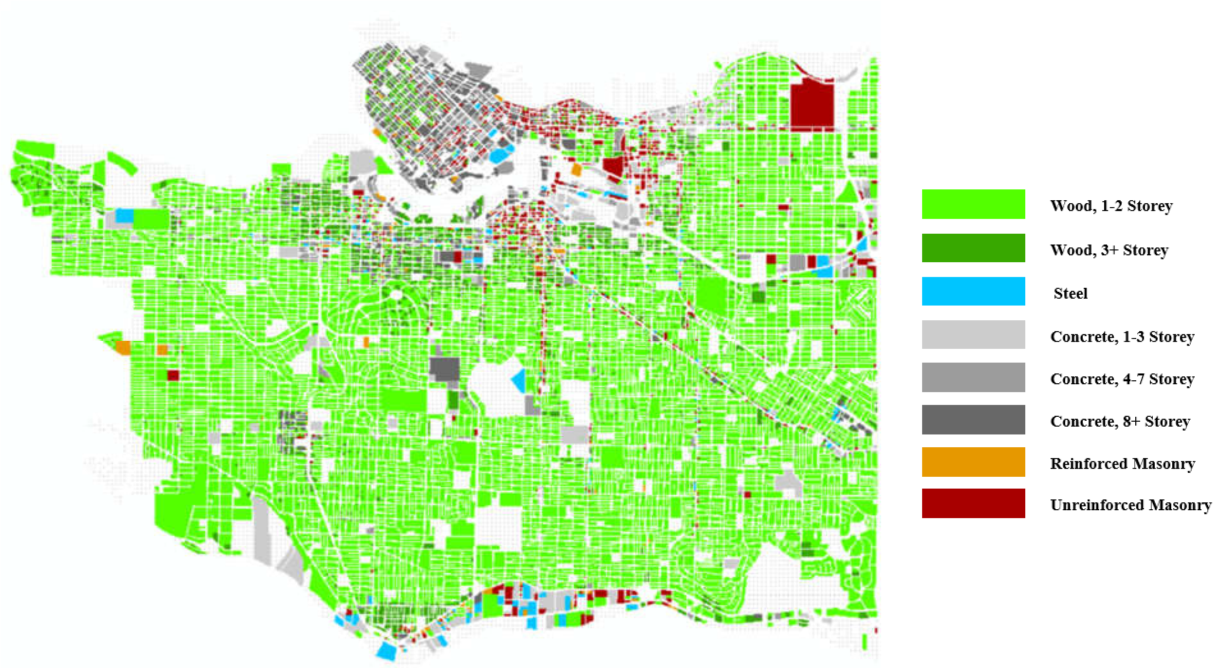


Fig. 5- Distribution of City of Vancouver building stock based on the UBC Building survey.

Of these, 97.4% (~89400 buildings) were mostly wood and concrete. Single family wood houses (W1) make 89.5 % (~82,200 buildings) of the total building stock, with half of them having sub-floors or cripple walls and the rest are multi-storey wood structures of 3-4 stories (W2). The second common construction material is concrete (3% ~ 2700 buildings), followed by masonry construction -reinforced and unreinforced (2.3%) and steel (0.3%). Most mid-rise and high-rise construction is made of concrete and steel and dominates the building stock in downtown Vancouver. Most of the masonry buildings are unreinforced and are older buildings in downtown Vancouver. More than half of the city's building stock (~57 %) were built before 1972, when National Building Code of Canada (NBCC) stated the need for seismic design of structures. 1.26% (~1157 buildings) are concrete shear wall (C2) constructions before 1972, which could be brittle compared to those designed to newer building codes, making them more susceptible to damage at the same intensity of ground shaking. 53.5% of the City's building stock are made of single-family wood houses built before 1972 (W1-PC). Design levels are assigned to the structures based on year of construction as: High Code (HC) -2005 and Newer, Moderate code (MC)- between 1990-2004, Low code (LC) between 1973-1989 and Pre-Code (PC)-built before 1972.

Because the major typologies in the City of Vancouver (~97.2%) are single family wood housing (W1), multi-storey commercial and industrial wood (W2), concrete shear walls low-rise (C2L), concrete shear walls mid-rise (C2M) and concrete shear walls high-rise (C2H), this study will focus on these typologies. On examining these typology definitions in HAZUS, it was noted that they did not completely reflect the building construction in British Columbia. So, the concrete building models were updated to reflect the code-based strength and drift levels expected over the evolution of the Canadian concrete code. As for the wood, two classifications of the wood construction (W1 and W2) was deemed insufficient to reflect BC wood buildings and two new building typologies were introduced as explained in Table 1.

Table 1 – Summary of old and new Wood building taxonomies for BC construction practices

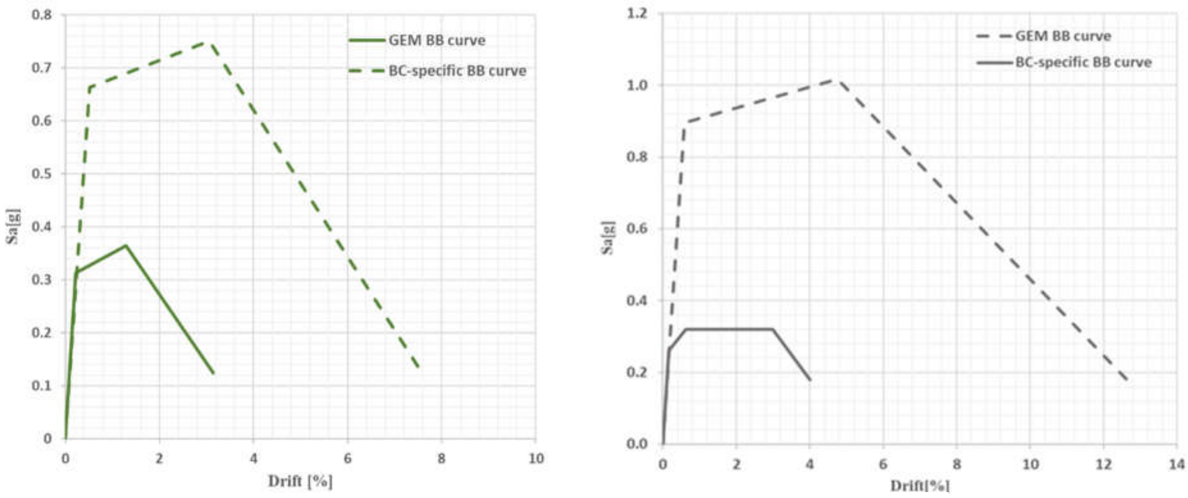
HAZUS building taxonomy	BC building taxonomy with details
W1: Wood, Light Frame (< 5,000 sq. ft.), 1 - 2 stories	**W1:** Wood, Low Rise Residential, 1 - 2 stories (45.8 % of total building stock)
	W4: Wood, Low Rise Residential with cripple wall or subfloor, 1 - 2 stories (43.7 % of total building stock)
W2: Wood, Commercial and Industrial (> 5,000 sq. ft.), All stories	**W2:** Wood, Residential, 3 - 6 stories (1.9 % of total building stock)
	W3: Wood, Commercial and Industrial, 1 – 4 stories (2.9 % of total building stock)

5. Comparison of updated fragility curves

Structural fragility functions define the probability of a structure attaining or exceeding a structural damage limit state for a given estimate of level of ground shaking - quantified by the spectral acceleration at the effective period of the structure. They account for variability and uncertainty associated with structural properties that leads to variability in structural response, damage states and ground shaking.

5.1 Developing BC construction specific capacity curves

The backbone curves used by GEM Pavia are developed from HAZUS initially, following the Ryu et al methodology for converting HAZUS capacity curves for use in non-linear time history analysis [13]. These backbone curves are subjected to FEMA p695 crustal ground motions under rigorous Incremental Dynamic Analysis (IDA) [14] to develop the fragility curves [15] currently used in the Canadian National Risk Model. But these fragility curves tend to underestimate structural damages in British Columbia (BC), because they were developed using building models with structural capacities based on building codes in California, USA where seismicity is high, as shown in Fig. 6(a) and Fig.6(b) for W1-PC and C2L-HC respectively. So, it is necessary to develop new fragility curves for these predominant building typologies (W and C2) in BC, based on updated capacity curves that reflect the building capacity for buildings constructed in BC over the years. In almost all cases for wood and concrete shear wall typologies, the building strength has been significantly reduced by more than half. For single family wood houses with sub-floors or cripple walls, the building height was taken as 1m to account for the cripple wall height, with the assumption that all damage sustained by the building will be concentrated at the level of the cripple wall.



(a) (b)

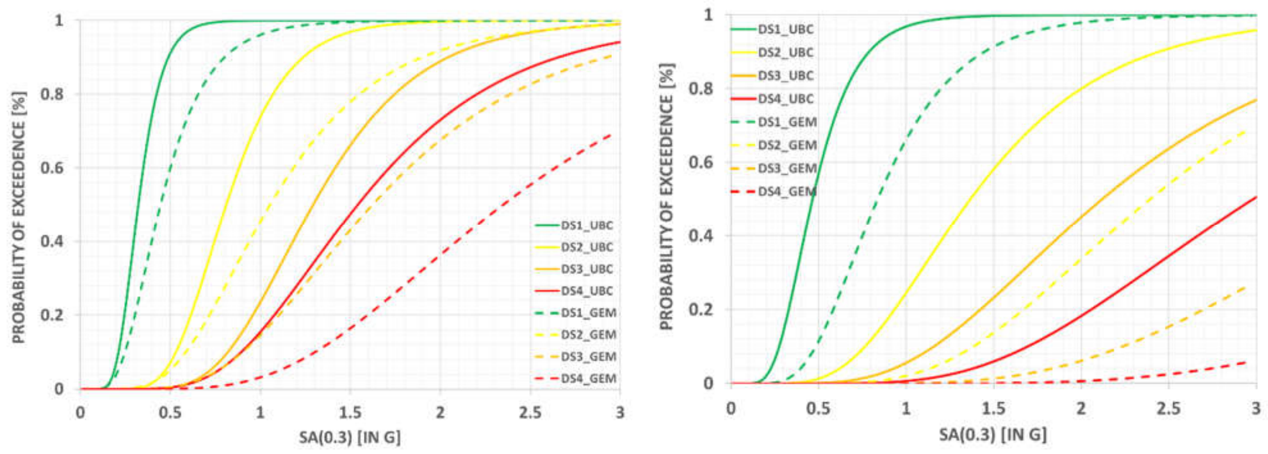
Fig. 6 - Comparison of backbone curves used by GEM (GEM BB curve) to BC construction specific Backbone curves (BC-specific BB curve): (a) W1-PC (b) C2L-HC

Four damage states are defined as Slight (DS1), Moderate (DS2), Extensive (DS3) and Complete (DS4), following HAZUS [12] definitions. The damage state criteria used to allocate buildings into a damage state are set to correlate 100% with the capacity curve [15]. In this paper, the damage limit states are assumed as factors of the ultimate displacement (Sd_u) and the yielding displacement point (Sd_y), with Complete damage (DS4) set as the displacement at maximum strength capacity. Slight damage limit (DS1) is considered as 0.75*Sd_y, where Sd_y is the yielding displacement point. Two equi-distant points between DS1 and DS4 on the capacity curves are chosen to represent the Moderate damage limit (DS2) and Extensive damage limit (DS3) states. This assumption is used while developing the fragility curves. Revised values for damage limit states will be presented and discussed once the first author completes her doctoral studies [16].

5.2 Comparison of crustal GEM fragility curves to new crustal fragility curves

This section compares the fragility curves developed by GEM using the FEMAp695 ground motions to the recently developed fragility curves developed for BC construction using crustal ground motions. The fragility curves were developed for W1, W2, W3 and W4 typologies and for C2L, C2M and C2H typologies, which were determined to be most prominent in the city. Because the trend of the change in fragility curves is similar throughout the typologies, an example case for pre-1972 single family wood construction (W1-PC) and post 2005 low-rise concrete shear-wall buildings (C2L-HC) are discussed in detail here. Fig. 7(a) and Fig. 7(b) compares the GEM crustal fragility curves (_GEM) to new crustal fragility curves (_UBC) for W1-PC and C2L-HC respectively.The GEM fragility curves (in dashed lines) seem to predict significantly lower damage than the fragility curves developed for BC specific construction practices, especially for the higher damage states of DS3 and DS4. The former predicts a lower probability of Extensive and Complete damage compared to the latter at higher intensity levels of shaking.

Fig. 8 compares the new crustal fragility curves for single family wood houses without cripple wall or sub-floor of pre-code construction (W1-PC) to the new fragility curves for single family wood houses with cripple wall or sub-floor of pre-code construction (W4-PC). A much higher damage is observed in W4 when compared to W1 at the height of the cripple wall. While the slight and moderate damage fragility curves are further away from each other, the Extensive and Complete damage states are very close, possibly since only a very slight increase in displacement could drive the cripple wall to a complete collapse due to the short-storey effect.



(a) (b)

Fig. 7 - Comparison of crustal GEM fragility curves (_GEM) to new crustal fragility curves (_UBC) (a) W1-PC and (b) C2L-HC

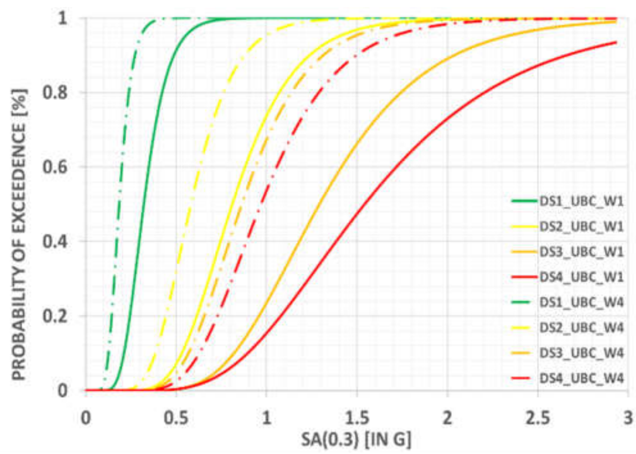
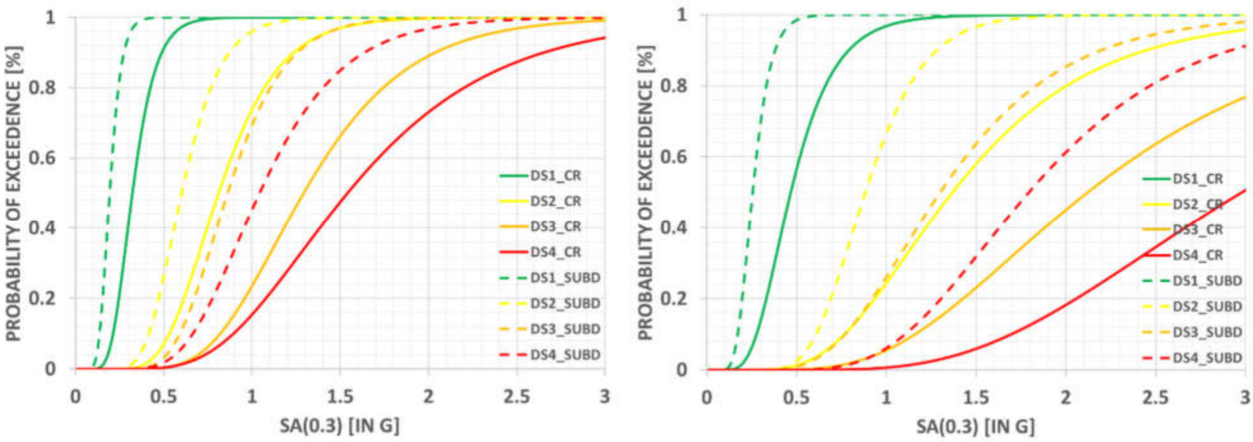


Fig. 8 - Comparison of new crustal fragility curves for pre-code single family wood houses without cripple walls (_UBC_W1) to new crustal fragility curves for pre-code single family wood houses with cripple walls (_UBC_W4)

5.3 Comparison of new crustal fragility curves to new subduction fragility curves

This section discusses the effect of ground motion duration on the fragility curves for the most prominent building typologies in Vancouver. Because the trend remains for all prominent typologies, an example is made of pre-1972 single family wood construction (W1-PC) and post 2005 low-rise concrete shear-wall buildings (C2L-HC).

Fig. 9(a) and Fig. 9(b) compares the new crustal fragility curves (_CR) to new subduction fragility curves (_SUBD) for W1-PC and C2L-HC respectively. The crustal fragility curves (solid lines) predicts lower damage than the fragility curves developed using subduction ground motions (dashed lines) for the same level of ground shaking, as the fragility curves shift to the left. This is because the duration of shaking impacts the energy dissipation capacity of the structure and increases structural damage. The probability of Extensive and Complete damage is on an average, doubled at higher intensity levels of subduction motion. The extensive and complete fragility curves for W1-PC are relatively close, unlike the C2L-HC due to the ductility introduced in the C2L-HC.



(a) (b)

Fig. 9 - Comparison of new crustal fragility curves (_CR) to new subduction fragility curves (_SUBD) (a) W1-PC and (b) C2L-HC

6. Overview of damage to building stock

This section demonstrates and reviews the damage results predicted for each of the earthquake scenarios when using the different fragility curves sets. The scenarios are developed and run in the OpenQuake engine.

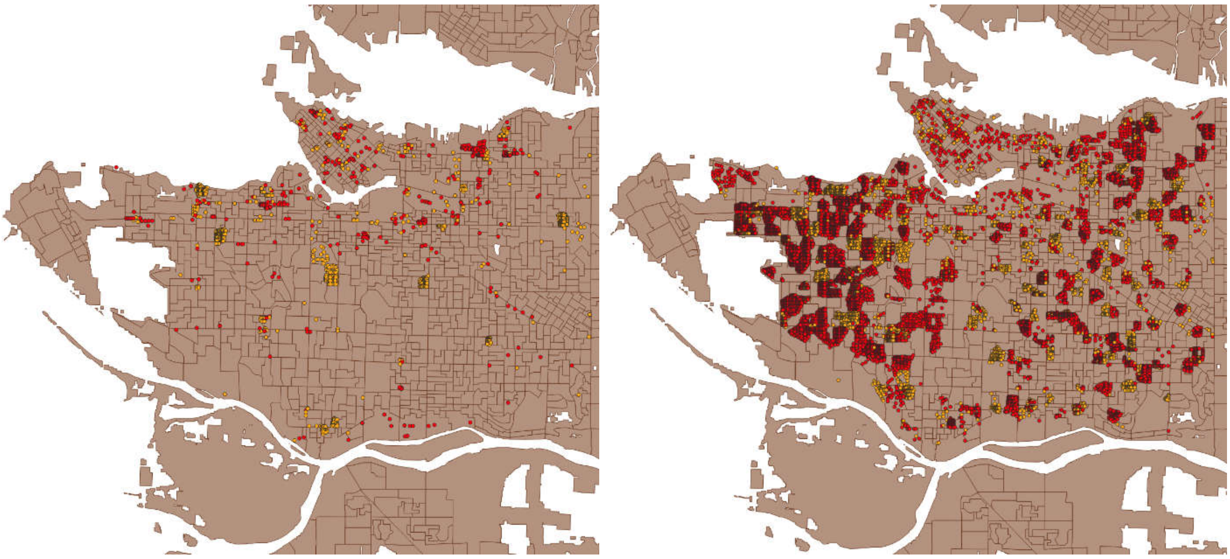
6.1 Crustal Scenario: Georgia Strait Shallow Crustal Earthquake M 7.3 (GSM7.3)

The Strait of Georgia fault rupture produces very destructive levels of ground shaking due to its proximity to the City of Vancouver and shallow depth. In the first analysis, the Magnitude 7.3 crustal scenario is run using fragility curves developed by GEM for Canada (GEM-Crustal). In the second analysis, the Magnitude 7.3 crustal scenario is run using the newly developed fragility curves for BC specific construction, developed using shallow crustal FEMA p695 ground motions. A summary of comparison of damage to building stock for the two analyses is tabulated in Table 2, where five damage states are considered: complete (red), extensive (orange), moderate (yellow), slight (green), and none (blue) and compares the percentage of damage to the building stock generated using each fragility curve. Fig. 10 (a) illustrates the result of the first analysis and Fig. 10 (b), of the second analysis. Only individual buildings in Extensive (orange) and Complete (red) damage state are marked for better clarity.

Table 2 - Comparison of damage to building stock [in %] for Magnitude = 7.3 Crustal Scenario

	None	**Slight**	**Moderate**	**Extensive**	**Complete**
GEM-Crustal	54.4	38.4	5.7	1.0	0.5
UBC-Crustal	11.7	46.5	21.8	5.0	15.0

From the GEM results in Fig. 10(a), complete and extensive damage is mostly localized to the pre-1990 concrete buildings in downtown Vancouver. Almost no complete and extensive damage is seen in the low-rise wood structures, with most wood buildings being in None or slight damage states. This is logically impossible, due to the large number of single-family wood buildings with and without cripple walls built before 1972 which make up a large portion of the City's building stock. The only complete and extensive damages to wood buildings were observed in the multi-storey residential and industrial buildings built before 1990, situated near downtown Vancouver. Fig.10(b) reveals a significant increase in Complete and Extensive damage in concrete structures built after 1990 (ie Moderate code and high code designs) and in single family wood houses. The significant increase in damage predicted for single family wood houses arises due to the introduction of new fragility curves for those with cripple walls and sub-floors (W4), which essentially pushes a building which was previously in an estimated damage state to a higher damage state. For example, a single-family wood house with cripple wall in soil class C was predicted to be in damage state DS2 (Moderate damage) when using the GEM fragility curve would be in DS3 (Extensive damage) when using the new fragility curve developed for W4. The buildings on softer soils were predicted to sustain higher levels of damage.



(a) (b)

Fig. 10 - Extensive and Complete Damage Distribution for the GSM7.3 Crustal Scenario using: (a) GEM fragility curves (b) BC specific fragility curves

6.2 Subduction Scenario: Cascadia Rupture M 9.0 (CSZ9.0)

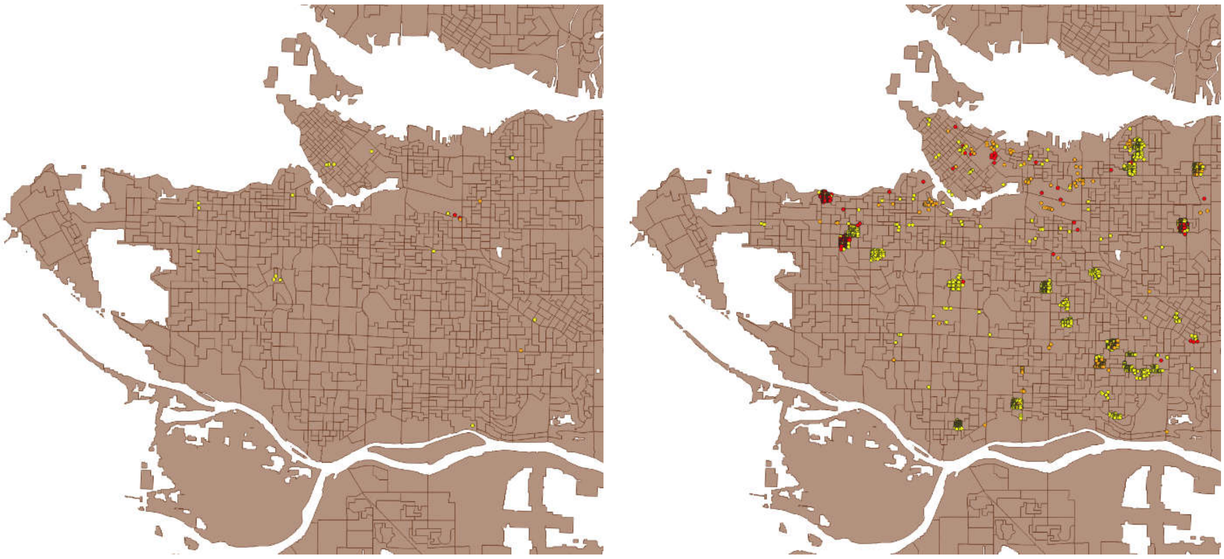
In the first analysis (GEM-Cr-Subduction), the M9.0 Cascadia subduction rupture scenario is run using the GEM crustal fragility curves (as is currently done for national regional risk assessment) and the damage expected is illustrated in Fig. 11(a). For clarity on buildings in higher damage states, only buildings in complete (red), extensive (orange) and moderate (yellow) are shown. Virtually all the buildings (~98.8% of the building stock) are predicted to be unaffected.

In the second analysis (UBC-Subduction), the M9.0 Cascadia subduction rupture scenario is re-run using newly developed fragility curves that account both for BC specific building capacities and for the effect long duration characteristic of ground motions produced by subduction events. The damage expected is illustrated in Fig. 11(b) and Fig. 12(b). About 670 buildings are seen to be in extensive or complete damage states, of which most are single family wood houses built before 1990, with cripple walls and concrete shear wall buildings built before 1972. It is also observed that these clusters of buildings in higher damage state are located in softer soils, where the ground shaking intensity is amplified, and the buildings jump up one or two damage levels. Most of the wood buildings are classified as in None or Slight damage, depending on soil conditions. However, the effect of duration of shaking is visible from the damage predicted, as higher duration of shaking pushes the structure to increased roof displacements and corresponding damage levels.

A third scenario analysis (UBC-Cr-Subduction) was run, to isolate the effect of long duration shaking on the energy dissipation capacity of the structures, by running the scenario with newly developed fragility curves that account for BC specific capacity curves, but for shallow crustal ground motions, and the damage expected is illustrated in Fig. 12(a). The results show that these fragility curves tend to lower the expected damage state of the structures by an average of one level, when compared to the damage results using subduction fragility curves (Fig. 12). A summary of comparison of damage to building stock for all three analyses is tabulated in Table 3.

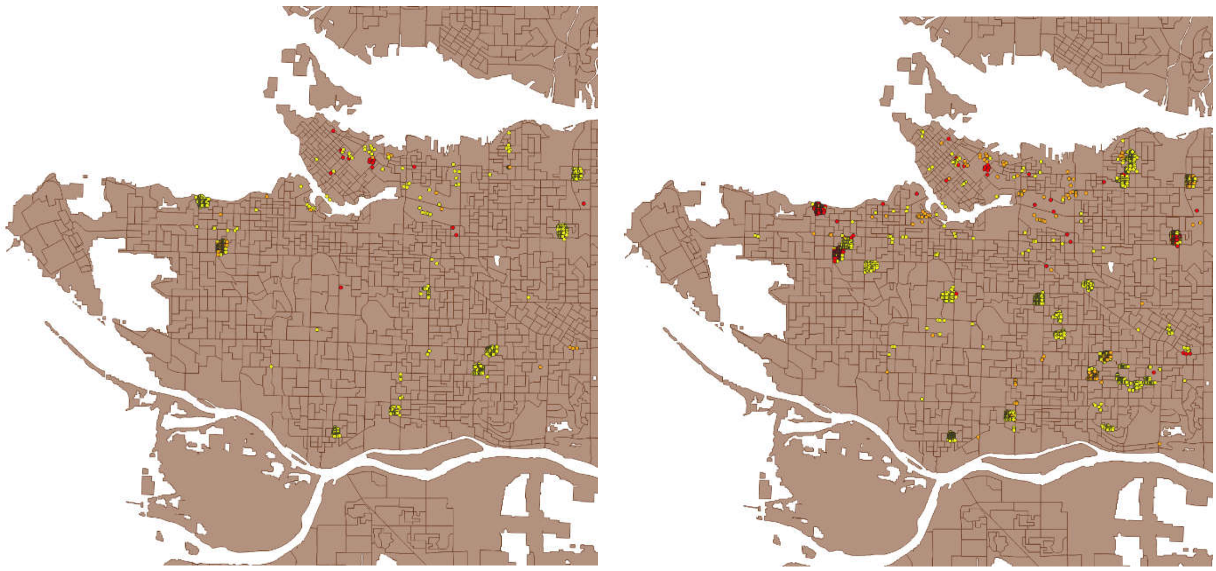
Table 3 - Comparison of damage to building stock [in %] for Magnitude = 9 Subduction Scenario

	None	Slight	Moderate	Extensive	Complete
GEM-Cr-Subduction	98.8	1.2	0.0	0.0	0.0
UBC-Subduction	62.6	35.1	1.5	0.4	0.4
UBC-Cr-Subduction	78.9	20.2	0.7	0.2	0.0



(a) (b)

Fig. 11 - Extensive and Complete damage distribution for the CSZ9.0 Subduction Scenario using: (a) GEM fragility curves (b) BC specific subduction fragility curves



(a) (b)

Fig. 12 - Extensive and Complete damage distribution for the CSZ9.0 Subduction Scenario using: (a) BC specific crustal fragility curves (b) BC specific subduction fragility curves

7. Conclusions

This paper analyses and quantifies the difference in damage predicted in two possible damaging earthquake scenarios for the City of Vancouver: a crustal scenario due to a rupture in the Strait of Georgia creating a magnitude 7.3 earthquake (GSM7.3) and a subduction scenario caused due to the rupture of the Cascadia subduction zone, creating a magnitude 9.0 earthquake (CSZ9.0), when using fragility curves developed by GEM Pavia using FEMA p695 crustal ground motions (that are currently used to develop the National Canadian Seismic Risk model) and new fragility curves developed using capacity curves developed for British Columbia (BC) construction practices for wood (W1, W2, W3, W4) and concrete shear wall (C2L, C2M, C2H) buildings over the years, using shallow crustal ground motions and subduction ground motions predicted in Vancouver.

When the crustal scenario was assessed using the GEM fragility curves, damage is significantly underestimated, especially for single family wood constructions and concrete shear wall buildings built after 1990. On using fragility curves updated for BC construction practices to run the crustal scenario, a large percentage of the building stock shows severe damage levels in the city of Vancouver, predominantly due to the greater damage predicted for concrete shear wall buildings built after 1990, single family residential wood buildings without cripple walls and the from the introduction of the increased damage predicted from single family residential wood buildings with cripple walls. Fragility curves for Extensive and Complete damage for single family wood building with cripple walls or sub-floors are very close to each other, which could because for such buildings, only a very small increase in displacement could drive the structure from an extensive to a complete collapse damage. This also makes the damage prediction of single-family wood houses of pre-code construction highly sensitive to the intensity of ground shaking

Pre-code single family wood houses and concrete shear wall structures that constitute a large portion of the Vancouver building stock should be carefully inspected for further retrofit schemes, as they are seen to be heavily damaged under both scenarios. The wood houses with cripple walls endures short-storey effects under strong shaking, making it extra vulnerable to damage. The concrete shear wall structures built before 1972 in downtown Vancouver also need to be carefully considered for retrofitting schemes, as they are mostly office buildings with high occupancy and shows non-ductile behavior. The rich long period spectral content and long duration excitation of the subduction ground motions introduces an increased seismic demand potential, and its effects are seen to have an influence on the fragility curves of all typologies, especially for high-rise concrete structures, as the SDOFs oscillate within the elastic region for a longer time, increasing the collapse potential due to subduction events as compared to crustal and sub-crustal events. Generally, buildings on stiffer soils are anticipated to perform better under all scenarios, while those on softer soils are predicted to experience higher damage, as is demonstrated in the subduction scenario analyses.

The main contribution of this study is the development of fragility curves tailored for BC construction practices for crustal and subduction earthquakes. These new fragility curves that are provided can now be used for future regional seismic risk assessments in southwest BC and western Canada for more refined seismic risk studies. Further study will be done to quantify and isolate effect of long duration ground motions on regional seismic risk assessment in BC using these new fragility curves.

8. Acknowledgments

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9. References

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