CITY OF VANCOUVER

COUNCIL REPORT

Report Date:	November 1, 2024
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Meeting Date:	November 12, 2024

Submit comments to Council

TO: Vancouver City Council

FROM: General Manager of Planning, Urban Design and Sustainability

SUBJECT: Seismic Risk and Risk Reduction in Existing Privately Owned Buildings

Recommendations

A. THAT Council receive this report on seismic risk and risk reduction in existing privately owned buildings for information.

B. THAT Council direct staff to engage stakeholder groups on seismic risk and potential seismic risk reduction actions and return to Council in 2025 with a private buildings seismic risk reduction strategy.

Purpose and Executive Summary

Vancouver is located in Canada’s most earthquake-prone region, placing it at daily risk of a highly damaging earthquake. While it is not possible to predict the exact timing or magnitude of the earthquake we will ultimately experience, Natural Resources Canada estimates there to be a one-in-five chance of a very strong earthquake in the next fifty years. Both federal and City risk assessments, including the City’s updated Hazard, Risk, and Vulnerability Analysis, have identified earthquakes as a top risk to both public safety and the economy.

Following direction from the City’s Resilient Vancouver Strategy, the purpose of this report is to provide findings from a recently completed seismic risk assessment and to seek direction to engage stakeholders on possible risk reduction actions identified by staff. This report details the modelled risk of casualties, disruption, displacement, and financial losses resulting from building damage and failure following a highly damaging, magnitude (M) 7.2 Georgia Strait planning scenario earthquake. Staff have identified several potential risk reduction actions following a two-year interdepartmental process supported by leading seismic engineers and are seeking to engage stakeholders on those actions to develop a buildings seismic risk reduction strategy in 2025.

Modelling shows that a large earthquake could result in nearly 6,100 heavily damaged buildings, leading to over 1,350 severe injuries and fatalities, the disruption and displacement of over one-third of residents and workers for more than three months, and over $17B in direct financial losses. Even a less intense earthquake, like the one used in the 2019 VanSlam earthquake exercise, could leave as many as 25,000 residents and workers disrupted or displaced for more than three months and cause as many as 200 severe injuries and fatalities.

Additionally, analysis of Census data from the city's highest-risk tracts indicates that these tracts are, on average, comprised of nearly 75% renters, of which over 30% are low-income, over 10% are seniors, nearly 40% identify as visible minorities, and nearly 10% are Indigenous Peoples. These groups may face additional challenges in preparing their households and upgrading their buildings, exposing them to potentially greater risk than other residents. While the City has policies in place to protect renters from displacement, as staff continue to develop actions and a strategy to reduce risk and increase public safety, mitigating potential displacement as well as disproportionate impacts to both residents facing additional barriers and neighbourhood small businesses must be a key consideration.

Council Authority/Previous Decisions

In 2019, Council adopted the Resilient Vancouver Strategy with the objective of protecting lives, decreasing displacement, and accelerating recovery following earthquakes. This strategy directs staff to complete a seismic risk assessment and to identify risk reduction actions for existing privately owned buildings and engage stakeholders on those actions.

In 2022, Council adopted the Vancouver Plan, directing staff to reduce seismic risk by promoting reinvestment and renewal of existing rental housing stock without displacement. Council further directed staff to pursue seismic risk reduction through careful and equitable redevelopment through its adoption of the Broadway Plan.

In 2024, Council approved an updated Hazard, Risk, and Vulnerability Analysis (HRVA), outlining the primary hazards that pose a risk to Vancouver. The HRVA identifies earthquakes as one of the most significant risks, with the highest potential consequences amongst the thirteen hazards evaluated. Local authorities are required to complete HRVAs under the Emergency and Disaster Management Act.

City Manager's Comments

The City Manager concurs with the foregoing recommendations.

Context and Background

Following decades of emerging knowledge about earthquakes in Southwestern British Columbia and City action to prepare for a large earthquake, City staff were deployed to support the response and recovery efforts following the 2010-2011 earthquakes in Christchurch, New Zealand. This sequence of several powerful earthquakes occurred along a previously unknown, or "blind," fault, leading to hundreds of casualties, over NZ$40 billion in total economic losses, and two-plus years of cordoning off (long term government closure) portions of the city's central business district. This led to a decade-long rebuilding process, some of which is still ongoing. This deployment shaped the City's 2013 Earthquake Preparedness Strategy, sharpening the City's focus on risk reduction in existing private buildings as a key element of preparedness.

To date, the City has worked to reduce risk through strengthening critical infrastructure, upgrading and replacing at-risk City-owned buildings, developing plans and emergency response exercises for an earthquake, and installing the Dedicated Fire Protection System (i.e., emergency water). A significant outstanding gap in the City's seismic preparedness efforts is the city's stock of highly vulnerable and aging existing private buildings.

In 2019, Council adopted the Resilient Vancouver Strategy, directing staff to advance the city's overall resilience, in part through the reduction of seismic risk in existing private buildings. To achieve this, the City partnered with the Natural Resources Canada and the Department of Civil Engineering at the University of British Columbia to complete the comprehensive seismic risk assessment presented in this report. To support risk reduction action development, staff formed an interdepartmental seismic working group in 2022 and a consultant team of local and international seismic experts was engaged to evaluate the costs, occupant impacts, and feasibility of building upgrades.

Modelling results underscore that Vancouver's seismic risk is heavily driven by the vulnerability of its existing private owned buildings. This assessment further shows that a set of five building types drive nearly 80% of citywide risk, in terms of severe injuries and fatalities and long-term resident and worker disruption and displacement lasting longer than three months. Critically, these buildings also contain nearly all the city's stock of existing purpose-built rental units and neighbourhood-serving small businesses. Very few of these at-risk buildings have been replaced or upgraded to withstand the level of earthquakes we now understand are possible in our region.

Staff have identified several tools that can meaningfully reduce the city's risk in existing private buildings. These include Part 11 of the Building By-law, which currently requires seismic upgrades on many buildings at the time of major renovation, the City's land use authority to incent the redevelopment of older, high-risk buildings, and our capacity to develop programs and policies aligned with specific needs and challenges of the city's buildings and their occupants face. Building retrofits and rezoning-induced building replacement will be challenging because of the risk of residential and small business displacement and the potential high costs. Given these challenges, provincial and federal partnerships will be required to support levels of action that more fully reduce seismic risk.

Cities along the West Coast, including San Francisco and Los Angeles, have significantly reduced their risk using decades-long risk reduction strategies that build awareness and capacity while reducing risk. Similar action, using a long-term strategy that builds on current policies and programs, would enable the City to begin reducing risk while balancing the impacts of action and securing the support needed from senior government. Overall, the sooner Vancouver begins to take action to reduce risk, even if initially modest, the less challenging it will be to protect residents and ensure recovery in the long term.

Discussion

This discussion provides background on seismic risk modelling, a summary of the citywide implications of a major earthquake, a description of the building types and neighbourhoods that drive risk, and details of the next steps staff can take to reduce these risks.

<u>Seismic Risk Modelling Background</u>

Seismic risk assessment utilizes specialized risk modeling software that incorporates a generalized building inventory, a selected earthquake scenario, and detailed information on building performance to determine the seismic risk for a set of buildings. For this assessment, a detailed building inventory developed by staff in 2018 was used as well as a M7.2 Georgia Strait planning scenario earthquake with forces near those currently required in the design of new buildings. Risk modeling produces estimates of the number and severity of damaged buildings, direct financial losses, and the extent of severe injuries, fatalities, and displaced occupants. Estimates of casualties and disrupted and displaced people account for both nighttime (residents) and daytime building occupants, as many buildings are additionally populated during the day by workers, customers, and others.

While modelling results provide a clear understanding of the building types and locations within the city that contribute most to citywide risk, guiding risk reduction action development, they are based on generalised information about building types and not individual building-scale engineering assessments. Additionally, this modelling considers Vancouver alone, and it does not consider additional risk from aftershocks, liquefaction, fire following earthquake, infrastructure failures, supply disruptions, nor emergency management and recovery limitations. Appendix A of this report provides more details on this modelling process and the risk assessment results.

Citywide Seismic Risk

Citywide seismic risk modelling results are presented below in Table 1. These results provide a high-level picture of seismic risk in Vancouver using a M7.2 Georgia Strait planning scenario earthquake, from which risk-driving building types and highest-risk neighbourhoods have been identified in the sections that follow.

Table 1: Citywide Seismic Risk Modelling Results, M7.2 Georgia Strait Earthquake

Completely and Extensively Damaged Buildings	Severe Injuries and Fatalities		Building Occupants Disrupted or Displaced for More than 90 Days		Direct Financial Losses
	Daytime	Nighttime	Daytime	Nighttime	
6,080	1,370	620	365,340	230,520	$17B

For this risk assessment, the following risk-driving building types and neighbourhoods were identified primarily considering four of the risk metrics above: daytime and nighttime (residential) severe injuries and fatalities (casualties) as well as daytime and nighttime occupants disrupted or displaced for more than three months (long-term). These are discussed further in the following two sections.

Risk-Driving Building Types

The building types shown in Table 2 below drive nearly 80% of citywide seismic risk while accounting for around 10% of buildings in Vancouver. These building types also contain the majority of the city’s total housing units, including 80% of the city’s purpose-built rental units, as well as all downtown offices and neighbourhood-serving small businesses. Identifying these risk-driving building types is a critical first step, dividing the challenge of seismic risk into more manageable pieces, and allowing for more targeted and thoughtful action planning.

Within these five types, not all the buildings are equally at risk. We know from modelling and engineering expertise that buildings built prior to early modern seismic design requirements (1990) and, even more critically, buildings built prior to the introduction of seismic design requirements (1973) are at the highest risk of heavy damage resulting in casualties and long-term occupant disruption and displacement. This finding is concerning as existing older purpose-built rental buildings provide relatively affordable housing options in the private market due to their age and longer tenancies. A recent Canada Mortgage and Housing Corporation survey recently found that average rents in Vancouver for units built pre-1960 are approximately

35% less than rents for units built from 2015 onwards.

Table 2: Risk-Driving Building Types, based on M7.2 Georgia Strait Planning Scenario Earthquake

Building Type	Risk Assessment Findings
Concrete mid- and high-rise multiunit residential buildings (MURBs)	• Concentrated in the West End and Downtown, containing many strata and 30% of purpose-built rental units. Nearly 50% were constructed prior to 1990. • Highest contributor to risk of residential casualties, driving nearly 40% (230) of modelled total. • Drive nearly 40% (85,200) of modelled long-term residential disruption and displacement. • Some buildings, particularly those built prior to 1990, are at risk for partial or complete collapse, and many older and some newer buildings are expected to be badly damaged, requiring replacement.
Unreinforced masonry (URM) MURBs	• Older brick residential buildings, concentrated in the Downtown Eastside and Gastown. Many single room occupancy (SRO) buildings are URM MURBs. • Drive nearly 30% (180) of modelled residential casualties. • Drive 10% (23,800) of modelled long-term residential disruption and displacement. • Very prone to partial or complete collapse, with additional severe impacts to sidewalk occupants and streets from falling debris.
Wood-framed MURBs	• Older wood apartment buildings, concentrated in the West End, Kitsilano, Fairview, and Mount Pleasant, containing 40% of the city's purpose-built rental units. 50% were constructed prior to 1973. • Highest contributor to risk of residential disruption and displacement, driving 45% (103,900) of modelled residential disruption and displacement. • Drive 20% (125) of modelled residential casualties. • Many buildings are expected to be uninhabitable or not repairable following an earthquake.
URM, wood, and low-rise concrete commercial buildings	• Contain nearly all small businesses, located along neighbourhood commercial corridors and arterials, and throughout Downtown. Over 70% were constructed prior to 1973. • Drive nearly 30% (380) of modelled daytime casualties. • Drive nearly 25% (85,900) modelled daytime long-term disruption and displacement. • One in three buildings are modelled to be heavily damaged, with additional severe impacts from falling debris to sidewalk occupants and emergency response.
Concrete mid- and high-rise commercial buildings	• Concentrated in Downtown and along Broadway, containing many of the city and province's major employers. Over 70% were constructed prior to 1990. • Drive 8% (110) of modelled daytime casualties. • Drive 8% (28,400) of modelled daytime long-term disruption and displacement. • Some buildings of this type, particularly those built prior to 1990, are at risk for partial or complete collapse, and many older and some newer buildings are expected to be badly damaged, requiring replacement.

Highest Risk Neighbourhoods

A limited number of neighbourhoods in Vancouver contribute the bulk of citywide seismic risk. Figure 1 illustrates the distribution of risk throughout the city, showing the relative risk amongst Census tracts as the average contribution of each tract to daytime and nighttime casualties and long-term disruption and displacement. The highest concentration of risk amongst all neighbourhoods is found in the West End, the Downtown Eastside (including Chinatown, Strathcona), Downtown, Kitsilano, Fairview, and Mount Pleasant. These six highest-risk neighbourhoods collectively contribute 65% of citywide seismic risk while containing the city and region's two largest employment districts and over two-thirds of the city's purpose-built market rental units in the city's densest residential neighbourhoods.

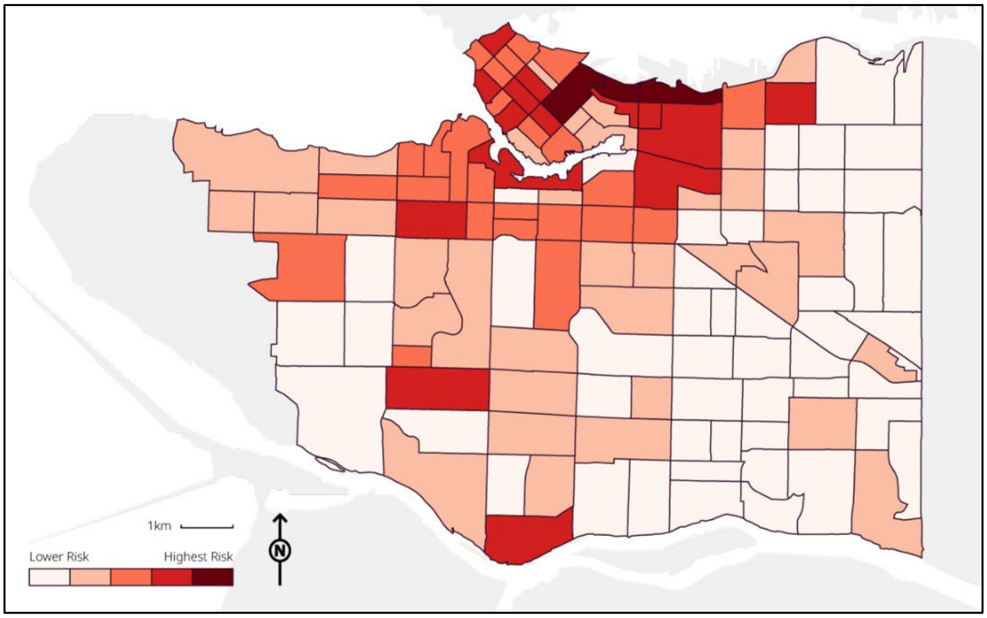

Figure 1: Relative Seismic Risk by Census Tract, M7.2 Georgia Strait Earthquake

Analysis of Census data from moderate- to highest-risk tracts within these neighbourhoods indicates that, on average, nearly 70% of the population are renters. Among these renters, nearly 20% are low-income, over 10% are seniors, 30% identify as visible minorities, and 4% are Indigenous Peoples. Given the additional housing affordability challenges and barriers these residents may face, many residents who face the most barriers to recovery from an earthquake currently live in the most at-risk buildings in the highest risk areas.

From past earthquakes elsewhere, we know that cordoning off areas of the city is often required. Cordoning is where areas with high concentrations of damage are closed to access by the government for weeks, months, or even years at a time. Cordoned areas are unsafe for any movement within, with damaged buildings impacting the safety of undamaged buildings. Areas like the West End, containing many older mid- and high-rise concrete multiunit residential buildings, and the Downtown Eastside, containing many unreinforced masonry (URM) MURBs, are particularly at risk for cordoning. Cordoning preserves life safety during earthquake response, but extend the duration and difficulty of recovery, increasing long-term social and economic impacts.

Commercial high streets and arterials throughout the city, containing many older URM, wood, and low-rise concrete commercial buildings, are also at high risk. As a result, these streets, particularly those within the Downtown Eastside and Downtown, have an additional risk of on-street injuries and fatalities from falling building debris. Along many arterials, such as Hastings Street, Kingsway, and others, on-street debris is likely to cause emergency response and transportation blockages as well. These blockages both increase the impacts of earthquake damage and, like cordoning, extend the duration and difficulty of recovery increasing long-term social and economic impacts.

A careful approach that considers the intersectional challenges faced by the existing residents within at-risk buildings will be needed to develop a risk reduction strategy. This approach balances reducing future earthquake risk with the need to mitigate near-term risks of displacement, the potential loss of existing more affordable rental housing, and disproportionate impacts on residents facing additional barriers and neighbourhood small businesses.

Next Steps

Reducing seismic risk in existing private buildings is achievable, but reducing risk while balancing displacement and affordability impacts will be challenging. Nevertheless, careful and strategic action that complements ongoing development and building safety improvements undertaken each year can significantly reduce risk over time. Cities along the West Coast, such as San Francisco and Los Angeles, have significantly reduced risk using long-term 25–30-year strategies while others, like Seattle, have begun reducing risk using at-risk building inventories. These approaches can balance the need for near and long-term seismic risk reduction with the impacts of that action by using measured steps taken gradually. Staff propose to engage key stakeholders on the seismic risks faced in private buildings and to seek their input on a set of near-to-midterm recommended actions the City can take to begin reducing risk. This feedback will be used to inform the development of a buildings seismic risk reduction strategy. Staff will then return to Council in 2025 with this proposed strategy.

Potential Risk Reduction Actions

Staff have identified several potential actions the City can take to begin reducing risk. Currently, the City reduces risk each year through VBBL Part 11 mandated upgrades of buildings required at the time of major renovations. Further, City-adopted community plans and policies enable the redevelopment of some at-risk buildings each year. These existing actions can be enhanced and improved to reduce additional risk. When taken alongside more additional, targeted actions, the City can begin to meaningfully reduce risk.

More targeted actions include the creation of an at-risk building inventory through seismic building evaluation, the development of nonmarket housing retrofit pilots, and community and owner education programs supportive of preparedness and voluntary upgrade action. Also, action can be taken to reduce additional risks beyond those modelled above (e.g., fire following earthquake). These early actions promote awareness and build capacity while actively reducing risk and positioning the City well to pursue additional senior government funding and tools in support of further, more challenging risk reduction action.

Stakeholder Engagement

Staff intend to engage key stakeholder groups representing owners, operators, and occupants (e.g., renters, employers) of risk-driving building types through small meetings and workshops taking place in 2025. This engagement will provide crucial insights on the impacts, opportunities, and potential challenges of seismic risk reduction actions to inform the development of a risk reduction strategy.

This engagement will include groups such as the Aboriginal Housing Management Association, the Tenants Resource and Advisory Committee (TRAC), and the Downtown Eastside SRO Collaborative, as well as Landlord-BC, the Building Owners and Managers Association of BC, and Condominium Homeowners Association of BC (CHOA-BC), and others. Engagement will also include key governmental stakeholders and partners to foster their understanding of the challenges and opportunities of risk reduction while building their ownership of this shared challenge. These stakeholders include BC Housing, Engineers and Geoscientists of BC (EGBC), the Structural Engineers Association of British Columbia, the BC Building and Safety Standards Branch, and the BC Ministry of Emergency Management and Climate Readiness (EMCR).

Conclusion

The risk of fatalities, long term displacement, and both direct and long-term economic losses threaten the safety and lives of Vancouver residents and businesses, impacting the city's ability to effectively and quickly recover from an earthquake. Additionally, many of those most impacted will also be those least able to prepare and reduce risk. This is one of the most significant risks to public safety Vancouver faces, but it is a risk that, following detailed risk assessment and ongoing analysis, we understand very well. The recommended next steps include stakeholder engagement to inform the development of a seismic risk reduction strategy for private buildings that will be brought for Council direction in 2025.

Financial Implications

There are no financial implications associated with this report's recommendations.

Legal Implications

There are no legal implications associated with this report's recommendations.

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Council date November 12, 2024

APPENDIX A

Seismic Risk in Vancouver, Canada's Existing Buildings

A Seismic Risk Assessment of Existing Privately Owned Buildings

Prepared by

Micah Hilt, City of Vancouver
Dr. Tiegan E. Hobbs, Natural Resources Canada

CITY OF VANCOUVER

This report provides a detailed seismic risk assessment of the approximately 90,000 existing privately-owned buildings within the municipal boundaries of the City of Vancouver, British Columbia, Canada.

Report Objective

This risk assessment supports the City of Vancouver's (the City) ***Seismic Risk Reduction in Existing, Privately Owned Buildings*** program, a multi-year staff effort to identify, evaluate, and engage stakeholders on seismic risk reduction actions for at-risk, existing, privately buildings. This work is connected to the City's 2019 Resilient Vancouver Strategy, which calls for the completion of a seismic risk assessment, as a first step to engage stakeholders regarding seismic risk reduction. This first step is foundational to the City's resilience objective of improving building performance to protect lives, decrease displacement, and accelerate recovery following an earthquake[i]. Additionally, this study expands upon the City's 2024 Hazard, Risk, and Vulnerability Analysis (HRVA).[ii] This report also directly supports the British Columbia Emergency and Disaster Management Act directive to create comprehensive emergency management plans that respond to HRVA risks and to include mitigation, preparedness, and recovery plans and actions.[iii] More broadly, this quantitative assessment is a critical first step toward implementation of a core goal of the United Nations Sendai Framework for Disaster Risk Reduction 2015-2030: to understand and reduce community disaster risk[iv].

Risk Assessment Details

This risk assessment reflects an ongoing partnership between the Geological Survey of Canada within Natural Resources Canada the Department of Civil Engineering at the University of British Columbia, and the City. Following a brief description of seismic risk reduction planning at the City and the technical details of this assessment's seismic risk modelling, this report examines seismic risk in Vancouver's existing buildings in terms of both risk-driving building types (Section 5) and the at-risk neighbourhoods (Section 6) in which they are located. Finally, building on the analysis within this risk assessment, this report concludes (Section 7) by considering the potential for seismic risk reduction and seismic resilience in Vancouver.

This report additionally incorporates early findings from an ongoing study with Ausenco Engineering Canada ULC, bringing together 19 local and international earthquake engineering experts to assess the specific vulnerabilities of six key building types in Vancouver. The Ausenco Supporting Analysis for Seismic Risk Reduction Planning study (the Ausenco Study) assesses and illustrates the potential for upgrades in these building types and includes estimates for the costs of upgrades as well as the associated occupant impacts.[v] This study is expected to be finalized in 2025.

Limitations

Citywide risk modelling findings within this report describe risk from all existing buildings, including Vancouver School Board facilities and City owned and operated buildings. However, the policy effort driving this risk assessment is focused on reducing the risk contributed by existing privately owned buildings alone, at points narrowing this assessment's consideration by prioritising private building contributions to Vancouver's seismic risk.

Additionally, this assessment focuses on building damage from ground shaking from three earthquake planning scenarios, to understand the impacts to building occupants, Vancouver's neighbourhoods, and the city. As such, it does not include assessments of the impacts of infrastructure failure, delayed emergency response and recovery, business interruption, surge pricing, aftershocks, liquefaction, landslide, tsunami, or fire following earthquake. Those considerations will add additional levels of risk to the results of this assessment.

Territorial Acknowledgement

We acknowledge with respect and gratitude that this report was produced on the traditional, unceded territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish) and səlilwətaɬ (Tsleil-Waututh) Nations. The land known as the City of Vancouver today has been stewarded by these Peoples since time immemorial, and their unique relations, Title, and rights in these territories remain intact. We additionally acknowledge that these Nations have oral and written traditions describing our region's seismic hazard dating back hundreds of years prior to the inclusion of seismic forces in our building codes and planning.

Executive Summary

Vancouver is located in Canada's most earthquake-prone region, placing it at daily risk from a highly damaging earthquake. While it is not possible to predict the exact timing or magnitude of the earthquake Vancouver will ultimately experience, Natural Resources Canada (NRCan) estimates there to be a one-in-five chance of a very strong earthquake in the next fifty years.[vi] Following direction from the City of Vancouver's (the City) Resilient Vancouver Strategy, staff are working to develop potential actions to reduce the risks faced from heavy earthquake damage to Vancouver's existing, privately owned buildings. In support of that work, the City partnered with NRCan and the University of British Columbia to develop a comprehensive seismic risk assessment. This assessment, documented in this report, provides clear direction on which privately owned building types are most at risk and where they are found throughout Vancouver.

Modelling shows that a highly damaging, magnitude (M) 7.2 Georgia Strait planning scenario earthquake could result in nearly 6,100 heavily damaged buildings, as many as 1,350 severe injuries and fatalities, the disruption and displacement of over one-third of residents and workers for more than three months, and over $17B in direct financial losses. Even a less intense earthquake, like the one used in the City's 2019 VanSlam earthquake exercise, could leave as many as 25,000 residents and workers disrupted and displaced for more than three months and cause as many as 200 severe injuries and fatalities. This assessment further shows that a set of five building types, described in Table E-1, drive nearly 80% of citywide risk, in terms of both daytime and nighttime (residential) severe injuries and fatalities (casualties) and daytime and nighttime disruption and displacement lasting longer than three months (long-term).

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Table E-1: Risk-Driving Building Types, based on M7.2 Georgia Strait Planning Scenario Earthquake

Building Type	Risk Assessment Findings
Concrete mid- and high-rise multiunit residential buildings (MURBs)	• Concentrated in the West End and Downtown, containing many strata and 30% of purpose-built rental units. Nearly 50% were constructed prior to 1990. • Highest contributor to risk of residential casualties, driving nearly 40% (230) of modelled total. • Drive nearly 40% (85,200) of modelled long-term residential disruption and displacement. • Some buildings, particularly those built prior to 1990, are at risk for partial or complete collapse, and many older and some newer buildings are expected to be badly damaged, requiring replacement.
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URM, wood, and low-rise concrete commercial buildings	• Contain nearly all small businesses, located along neighbourhood commercial corridors and arterials, and throughout Downtown. Over 70% were constructed prior to 1973. • Drive nearly 30% (380) of modelled daytime casualties. • Drive nearly 25% (85,900) modelled daytime long-term disruption and displacement. • One in three buildings are modelled to be heavily damaged, with additional severe impacts from falling debris to sidewalk occupants and emergency response.
Concrete mid- and high-rise commercial buildings	• Concentrated in Downtown and along Broadway, containing many of the city and province's major employers. Over 70% were constructed prior to 1990. • Drive 8% (110) of modelled daytime casualties. • Drive 8% (28,400) of modelled daytime long-term disruption and displacement. • Some buildings of this type, particularly those built prior to 1990, are at risk for partial or complete collapse, and many older and some newer buildings are expected to be badly damaged, requiring replacement.

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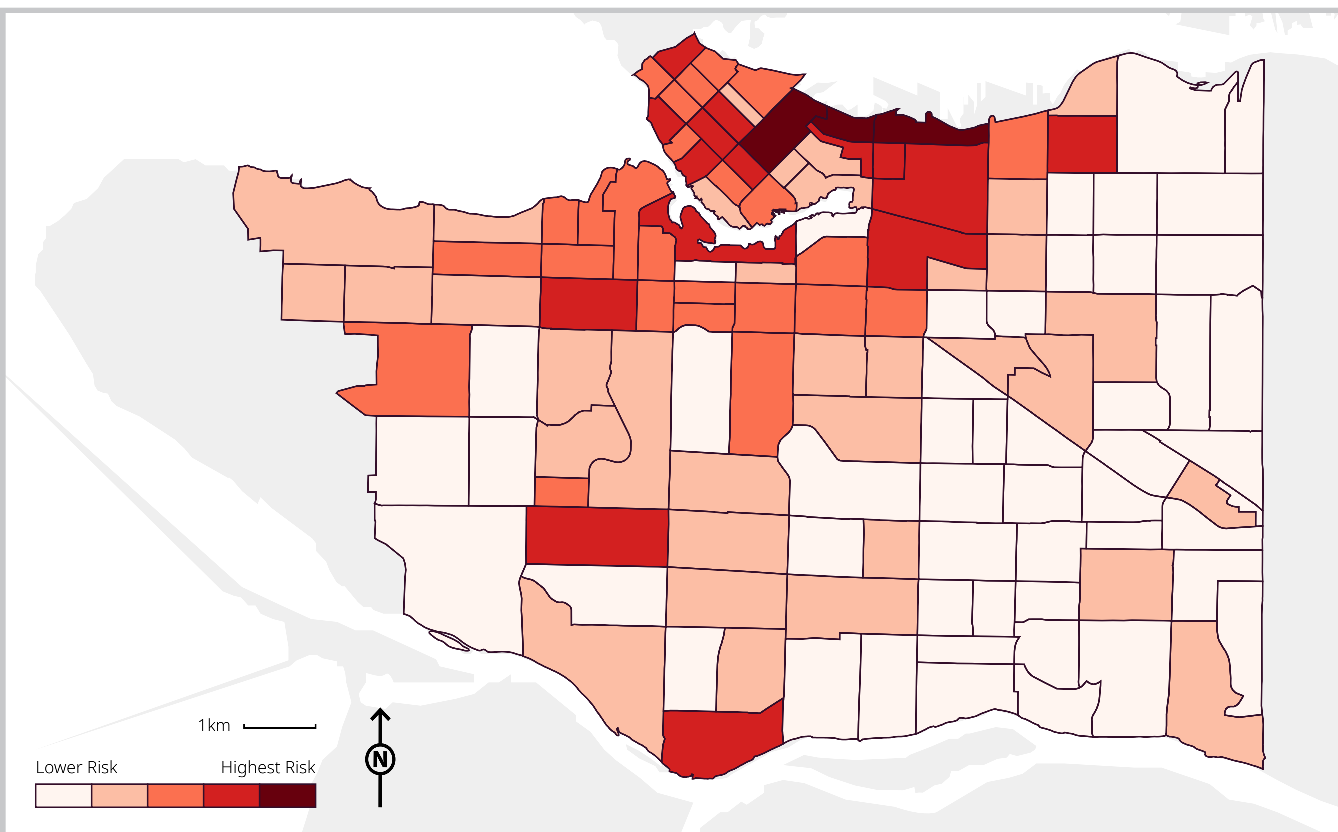
Critically, these risk-driving building types contain the majority of the city's total housing units, including 80% of purpose-built rental units, as well as downtown offices and neighbourhood-serving small businesses. Within these five types, not all buildings are equally at risk. We know from modelling and engineering expertise that buildings built prior to early modern seismic design requirements (1990) and, even more critically, buildings built prior to the introduction of seismic design requirements (1973) are at the highest risk of heavy damage resulting in casualties and long-term occupant disruption and displacement. This finding is concerning as existing older purpose-built rental buildings provide relatively affordable housing options in the private market due to their age and longer tenancies. A recent Canada Mortgage and Housing Corporation survey recently found that average rents in Vancouver for units built pre-1960 are approximately 35% less than rents for units built from 2015 onwards.

A limited number of neighbourhoods in Vancouver contribute the bulk of citywide seismic risk. Figure E-1 below illustrates the distribution of risk throughout the city, showing the relative risk amongst Census tracts as the average contribution of each tract to daytime and nighttime casualties and long-term disruption and displacement. The highest concentration of risk is found in the West End, the Downtown Eastside (including Chinatown, Strathcona), Downtown, Kitsilano, Fairview, and Mount Pleasant. These six highest-risk neighbourhoods collectively contribute an average of 65% of citywide seismic risk while containing the city and region's two largest employment districts and over two-thirds of purpose-built market rental units in the city's densest residential neighbourhoods.

Figure E-1: Relative Seismic Risk, M7.2 Georgia Strait Earthquake, by Census Tract



Relative seismic risk mapping is based on the outputs of the OpenQuake earthquake modelling engine and does not include the contribution of infrastructure failure, delayed emergency response and recovery, aftershocks, fire following earthquake, tsunami, landslides, or liquefaction (See section 3.1.6).

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Analysis of Census data from moderate- to highest-risk tracts within these neighbourhoods indicates that, on average, nearly 70% of the population are renters. Among these renters, nearly 20% are low-income, over 10% are seniors, 30% identify as visible minorities, and 4% are Indigenous Peoples. These groups may face additional challenges and structural barriers in preparing their households and recovering from an earthquake, exposing them to potentially greater risk than other residents.

From past earthquakes elsewhere, we know that cordoning off areas of the city is often required. Cordoning is where areas with high concentrations of damage are closed to access by the government for weeks, months, or even years at a time. In cordoned areas are unsafe for any movement, with damaged buildings impacting the safety of undamaged buildings. Areas like the West End, containing many older mid- and high-rise concrete multiunit residential buildings, and the Downtown Eastside, containing many unreinforced masonry (URM) MURBs, are particularly at risk for cordoning. Cordoning preserves life safety during earthquake response but extends the duration and difficulty of recovery, increasing long-term social and economic impacts.

Commercial high streets and arterials throughout the city, containing many unreinforced masonry, wood, and low-rise concrete commercial buildings, are also at high risk. These streets, as well as streets throughout the Downtown Eastside and Downtown, have an additional risk of on-street injuries and fatalities from falling building debris. Along many arterials, such as Hastings Street, Kingsway, and others, on-street debris is likely to cause emergency response and transportation blockages as well. These blockages both increase the impacts of earthquake damage and, like cordoning, extend the duration and difficulty of recovery, and increase long-term social and economic impacts.

Vancouver's Seismic Resilience – Reducing Risk

The analysis within this report presents a clear picture of the impacts of a large earthquake on Vancouver. The risk of fatalities, long term displacement, and both direct and long-term economic losses threaten Vancouver communities, residents, and businesses. A large earthquake is one of the most significant risks to public safety Vancouver faces, but it is a risk that is well understood following detailed risk assessment and analysis. This assessment, in addition to describing the consequences of a large earthquake, prioritises several areas of the city and several specific types of buildings, allowing careful work to reduce risk to begin. Seismic risk reduction action need not be taken all at once. It can start with small, strategic actions in a limited number of highest-risk buildings and in a limited set of at-risk areas of the city. Small actions that quickly build on existing City policies and programs have the added advantage of promoting awareness and positioning the City well to pursue additional provincial and federal government funding and tools in support of further, more challenging risk reduction action. The sooner Vancouver begins to take action to reduce risk, even if initially modest, the less challenging it will be to protect residents and ensure recovery in the long term.

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List of Figures and Tables

1. Background

This section provides background and context for this assessment as well as the City of Vancouver's (the City) effort to reduce risk in its stock of existing privately owned buildings.

It chronologically reviews both City policies and programs focused on earthquake preparedness and risk reduction and the evolving seismic design requirements and regulatory processes within the Vancouver Building Bylaw (VBBL).

The seismic design requirements within the VBBL during a building's year of construction, barring any upgrades to that building, dictate its performance during an earthquake. Each code cycle, the VBBL is updated to incorporate emerging knowledge about the region's seismic risk and state of the art seismic design practices. This update comes in the form of the adoption of the Building Code of British Columbia, which itself is an adoption of the National Building Code of Canada (NBCC) with some variation to meet local concerns. The VBBL, based on authority from the Vancouver Charter, also contains several Vancouver-specific alterations as well.

While rudimentary requirements for seismic design have been in the NBCC since 1941[vii], the adoption of the 1967 VBBL (1965 NBCC), with an updated version adopted in 1973 (1970 NBCC), represented the first

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introduction of standards that specifically addressed the ductile seismic design of buildings and the probabilistic determination of seismic hazard in Vancouver. In comparison to modern standards, the code's treatment of seismic design prior to 1973 was extremely limited. In this report, we will refer to 1973 as the 'introduction' point of seismic standards. 1990 marked another critical benchmark in seismic building design, where early modern techniques to advance the overall performance of buildings and stronger consideration of soil conditions were added to the VBBL[viii]. Within the report, these two years – 1973 and 1990 – are considered critical benchmarks within the design and development Vancouver's building stock.

The VBBL began requiring the seismic strengthening of existing buildings undergoing significant renovation within the 1973 VBBL (current day VBBL Part 11). Seismic upgrades, conducted alongside other required improvements, are currently to either 50% or 75% of current code design levels. Significant renovations were defined at the time by the permit cost levels. While these upgrades did, and continue to, improve several buildings each year, a 2000 administrative report to Vancouver's City Council[ix]noted that cost-triggered upgrades do not impact enough buildings especially in many higher-risk areas of the city to significantly reduce citywide risk. The report both called for a "seismic hazard abatement program for privately owned buildings" and provided results from Vancouver's first detailed seismic risk assessment of existing, privately owned buildings, the 1995 Delcan study[x]. This report examined the seismic vulnerability of 1150 existing, high-risk buildings, giving Vancouver a very early, high-level look into seismic risk. Following this report, the VBBL's existing building seismic upgrade requirements were adjusted (in 2007) to consider a project's scope of work, as opposed to cost, refining the City's approach to triggered upgrades.

In 2005, the British Columbia (B.C.) Ministry of Education announced a $1.5 billion effort to upgrade or replace seismically at-risk schools throughout the province, including 86 schools in Vancouver[xi]. The expected completion date for this initiative in Vancouver is 2030, and so far, 40 schools have already been upgraded or replaced.

Following the 2010-2011 Canterbury earthquake sequence in Christchurch, New Zealand, from a previously entirely unknown fault, that claimed the lives of over 180 people and caused severe destruction of the city's downtown,[xii] the City's Chief Building Official and other staff travelled to Christchurch to support and learn from that city's earthquake response and recovery efforts. After observing the disastrous impacts on Christchurch, Vancouver staff immediately began to develop the 2013 Earthquake Preparedness Strategy (EPS).[xiii] The EPS built on several previous City actions, including the establishment of Taskforce 1 Heavy Urban Search and Rescue within the Vancouver Fire & Rescue Services; the 2003 completion of the Dedicated Fire Protection System, a 10km secondary fire suppression system for the Downtown Core, as well as portions of Kitsilano and Fairview; and the establishment of an Emergency Operations Centre in 1998. The EPS directed staff to enhance the inputs to the City's early assessments of citywide seismic risk, to enhance government and community preparedness, and to establish a technical committee to advise the City on "high-risk building abatement options"[xiv].

Following the completion of the City's risk model, the City began the process of developing a comprehensive assessment of that risk, including the commissioning of the Ausenco Study and the establishment of an interdepartmental Staff Seismic Working Group. This working group supported the completion of this risk assessment and the development of several risk reduction actions.

Concurrently, in 2013 the City's Real Estate and Facilities Management group developed a seismic program within the group's facilities asset strategy to both identify City-owned buildings with high risk of severe damage and to prioritize the work required to mitigate that risk. This work, to date, includes the screening of approximately 170 City-owned buildings, including community centres, fire halls, police stations, and other civic facilities on a risk-based approach, as well as the 2015 demolition of the East Wing of City Hall, the 2017 retrofit of the West Annex of City Hall, and the upgrade and replacement of several fire halls.

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In 2017, staff began to develop the City's first resilient strategy, as part of City's participation in the Rockefeller Foundation's 100 Resilient Cities initiative. Part of that process was the development and hiring of the City's first dedicated seismic risk reduction planner position and the establishment of the "Seismic Mitigation for High-Risk Buildings" program. In 2019, the Resilient Vancouver Strategy was adopted by Council. The strategy included objectives, and actions to achieve those objectives, that would enhance the resilience of Vancouver to major shocks (e.g., earthquakes) and stresses (e.g., residential unaffordability)[xv] . The strategy also clarified earlier approaches to risk reduction planning for existing buildings, directing staff to complete a seismic risk assessment and engage stakeholders to identify risk reduction options for existing buildings (Action 3.1.C)[xvi] . The objective of this risk reduction was identified within the strategy as protecting lives, decreasing displacement, and accelerating community and citywide recovery following an earthquake (Objective 3.1).

As part of the strategy development process, staff convened a technical committee of earthquake engineers, academics, and key provincial and federal government partners called the Seismic Policy Advisory Committee. This committee and a multi-year partnership between the City, Natural Resources Canada (NRCan), and the University of British Columbia (UBC) Department of Civil Engineering supported the development of a building inventory (2018) and an initial citywide seismic risk model (within Resilient Vancouver) in 2019. Following the adoption of the strategy, the Seismic Mitigation for High-Risk Buildings program was moved into the Green and Resilient Buildings Branch of the Department of Planning, Urban Design and Sustainability, ensuring interdepartmental and comprehensive cooperative planning for existing buildings.

In 2020, NRCan introduced several key updates to many of the technical inputs to the City's risk model. These included updates to earthquake scenarios, risk assessment methods and tools, and updates to the Canada-specific implementation of the Global Earthquake model's OpenQuake risk modelling platform[xvii]. These updates, as well as refinements to the City's building inventory, led to several key refinements in the City's risk model, reflected in this risk assessment. In 2022, Council adopted the Broadway Plan[xviii], a 30-year comprehensive area plan for the neighbourhoods surrounding the 5.7 km extension of the Millennium Skytrain Line along Broadway, and the Vancouver Plan[xix], a 30-year, citywide land use plan. Both plans contain seismic risk reduction actions, expanding the mandate to reduce risk. This includes the Vancouver Plan's direction for "equitably planning for risk reduction, including building replacement and upgrades in existing buildings" and the Broadway Plan's call to "enable careful and equitable redevelopment – with comprehensive tenant protections – of the area's aging building stock to reduce seismic risk from building damage". The Broadway Plan additionally directed staff to "undertake further seismic risk reduction work for existing buildings and new buildings in the area."[xx]

Following the completion of the City's risk model in late 2022, the City began the process of developing a comprehensive assessment of that risk, including the commissioning of the Ausenco Study and the establishment of an interdepartmental Staff Seismic Working Group. This working group supported the completion of this risk assessment and continues to support the development of risk reduction actions.

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2. Vancouver's Earthquake Hazard

It is impossible to predict when the next major earthquake will occur, as one could occur near Vancouver at any moment.

To understand the seismic risk Vancouver faces from its existing buildings, three types of earthquakes were chosen to represent the range of damaging and plausible earthquakes across the three tectonic environments near Vancouver:

1. Megathrust earthquakes of the Cascadia Subduction Zone (CSZ) where the Juan de Fuca tectonic plate subducts beneath the North American plate,
2. Deep "intraslab" earthquakes within the Juan de Fuca tectonic plate as it is being pulled into the Earth's mantle, and
3. Shallow crustal events in the North American tectonic plate that result from compression between North America and the Juan de Fuca plate.

The Juan de Fuca tectonic plate crushes against and slides beneath the North American plate along the CSZ, which runs from Vancouver Island to northern California. Although the CSZ has been quiet of late, from paleoseismology, the study of ancient earthquakes, we know that the CSZ has a rupture along the entire fault zone, a magnitude of about 9.0, roughly every 434 years[xxi]. The last full rupture was on January 27, in the year 1700[xxii]. While it is tempting to infer that the next one will occur in about 100 years, we know that major events like this can happen with as little as 100 years between events or as much as 1100 years[xxiii]. The megathrust earthquake scenario used within this risk assessment is a M9.0 event running the full length of the CSZ, similar to the January 1700 earthquake. The strong shaking will likely last for over two minutes and a tsunami will probably be generated off the west coast of Vancouver Island, with wave heights of less than one metre expected near Vancouver[xxiv].

Earthquakes in the subducting Juan de Fuca tectonic plate can cause damage, as in the 2001 M6.8 Nisqually earthquake near Seattle[xxv], and are the most likely source of seismic hazard for Vancouver[xxvi]. These events are generally at depths of 45-70 km beneath the Strait of Georgia and Puget Sound[xxvii]. The deep (intraslab) earthquake

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we simulate for this risk assessment is a M7.0 event at a depth of 52-72 km beneath Galiano Island, similar to the scenario used in 2019 VanSlam earthquake exercise.

The final type of earthquakes to consider are shallow events occurring in the crust of the North American tectonic plate, like the 1946 M7.3 Vancouver Island Earthquake[xxviii] or the 1872 M7.0 Entiat earthquake in northern Washington State[xxix]. These events have the potential to be locally more devastating than a CSZ event if they occur near a major city like Vancouver. Several shallow crustal faults have recently been discovered on Vancouver Island, including two within the Capital Regional District; the Leech River Fault[xxx] and the XEOLXELEK-Elk Lake Fault[xxxi]. The shallow crustal earthquake we simulate for this risk assessment is a M7.2 event in the Strait of Georgia on the fault line of a 1997 M 4.6 earthquake[xxxii] . The scenario is meant to represent a very large event, without reaching the maximum expected magnitude for crustal earthquakes around Vancouver, which is believed to be M7.4-7.7.[xxxiii]

While the following earthquake planning scenarios, mapped below in Figure 2-1, are not the only earthquakes that can occur, they meaningfully guide planning policy work aimed at reducing risk from the breadth of potential earthquakes Vancouver may experience:

> *A M7.2 Georgia Strait scenario*
> *A M9.0 Cascadia Megathrust scenario*
> *A M7.0 Intraslab scenario*

Figure 2-1: Fault Line Upper Edges for Three Planning Scenario Earthquakes

While we cannot calculate the exact probability of each earthquake occurring, we can calculate the shaking expected at City Hall for each scenario and then compare it to the probability of experiencing that amount of shaking according to the NBCC 2020. Figure 2-2 below shows the probability of experiencing the levels of shaking expected from each planning scenario earthquake, expressed as the probability of exceeding increasing values of spectral acceleration (shaking) over any 50-year period. The Spectral Acceleration at 0.3 seconds (SA 0.3) is a ground motion intensity measure that best describes the potential damage to low-rise buildings, which are the majority of buildings in Vancouver's building stock.

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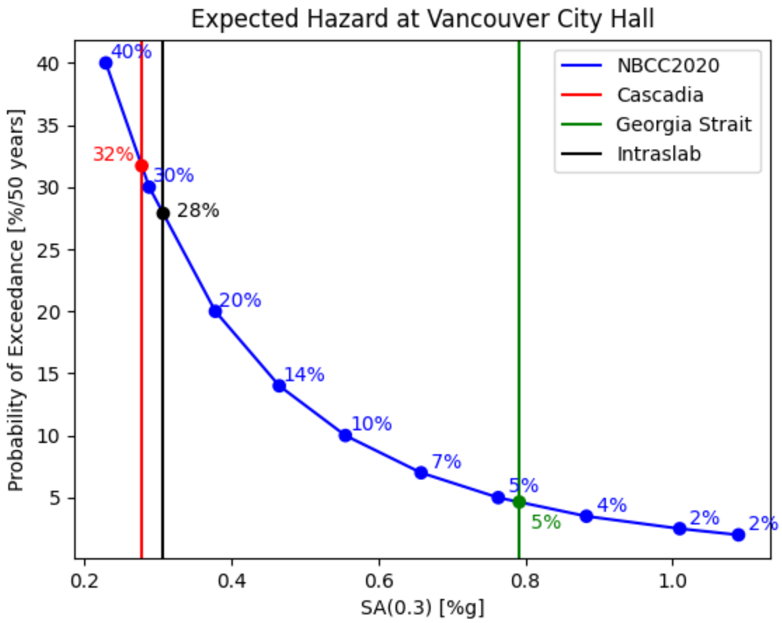
Figure 2-2: Probability of the Three Planning Scenario Earthquakes



This shows us that the shaking expected from the M9.0 Cascadia megathrust and M7.0 Intraslab scenarios would each have about a one-third probability of being exceeded in a 50-year period, according to the NBCC 2020. In other words, there is about a 30% chance of ground shaking like the M9.0 Cascadia megathrust scenario or the M7.0 Intraslab scenario in any 50-year period in Vancouver. The shaking from the M7.2 Georgia Strait scenario has a 5% probability of being exceeded at City Hall in a 50-year period, making it a much rarer earthquake.

2.1 Selection of a Primary and Supporting Earthquake Planning Scenarios

This risk assessment primarily considers the contribution of risk from a modelled M7.2 Georgia Strait planning scenario earthquake. This scenario, with a level of shaking at City Hall that is similar to that considered for the design of new buildings within the NBCC 2020 (2% probability of exceedance in 50 years for non-critical structures)[xxxiv], describes a plausible earthquake with impacts severe enough to make it useful for:

1. government planning that accounts for gaps in knowledge about local seismicity and ground conditions where there are expected increases in the seismic hazard; and
2. credibly and meaningfully capacity-testing urban systems (e.g., housing, commercial, etc.) to a degree that considers the long practical lifespans of buildings and the multi-decadal nature of municipal urban planning (e.g., Vancouver Plan, etc.).

The M9.0 Cascadia Megathrust and M7.0 Intraslab scenarios are used as supporting earthquake planning scenarios within this assessment, providing critical data to calibrate planning as it progresses and are supplied as supplementary information to contextualise the results of the M7.2 Georgia Strait scenario.

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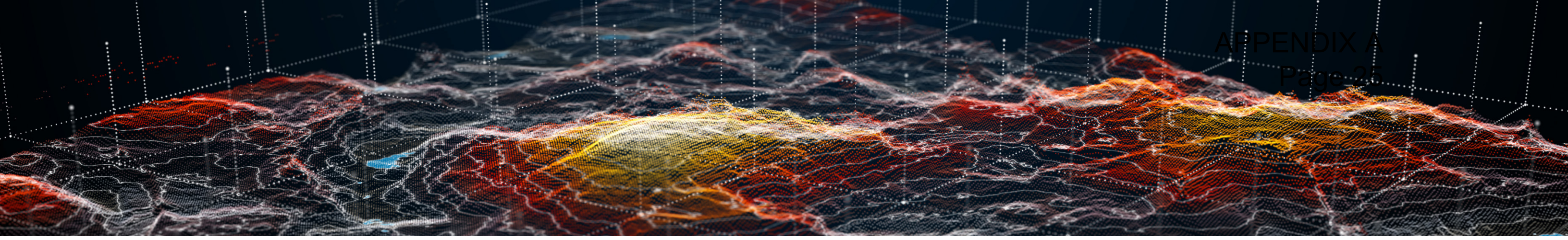

3. Methods

This section outlines the data and methods used for this seismic risk assessment and the seismic risk model supporting it.

To assess Vancouver's earthquake risk from its 90,000 existing buildings, seismic risk modelling was used to capture high level findings within cohorts of buildings and neighbourhoods.

Seismic Risk Modelling

The seismic risk modelling within this report was developed through a multiyear partnership between NRCan, the Department of Civil Engineering at UBC, and the City. This modelling follows NRCan's general method for seismic risk modelling across Canada, implementing the Global Earthquake Model Foundation's OpenQuake Engine software[xxxv]. Overall, seismic risk modelling is a common tool used by nations, regions, municipalities, and organisations to both prepare for and reduce the risk from earthquakes.

> *More specifically, **Seismic risk modelling** is the process of using specialised software to combine a **seismic hazard scenario**, the shaking expected from an earthquake; a **building inventory**, a generalised model of the city's building stock; and building **vulnerability** data, describing the likelihood of damage or loss occurring in the exposed buildings, to provide a quantitative account of the city's seismic risk in the form of risk metric outputs at the city, building type, and neighbourhood scale.*

It's important to note that this modelling is different from engineering analysis of seismic risk at the individual site or building scale, and only a detailed individual building-scale assessment can properly identify the risk of a building.

Risk Assessment

This report, a comprehensive seismic risk assessment, considers the risk Vancouver faces from its existing buildings, describing the impacts of an earthquake on the city, its neighbourhoods, and its residents, workers, and visitors. This assessment provides a clear and detailed picture of risk sufficient to support seismic risk reduction planning as well as City preparedness and resilience efforts focused on buildings.

The following sections will describe the elements, outputs, and limitations of seismic risk modelling. Additionally, there are sections that describe the methods used to determine and analyse the building types and neighbourhoods that drive much of the city's risk.

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3.1 Elements of Seismic Risk Modelling

The following subsections describes each element of the seismic risk model used within this risk assessment.

3.1.1 Seismic Hazard Scenario

Seismic 'hazard' within the context of seismic risk modelling is the shaking intensity expected from a specified earthquake scenario (i.e., a deterministic hazard) or from all possible sources over a time period of interest (i.e., probabilistic hazard). The seismic hazard information used in this study is based on the 6th Generation Canadian Seismic Hazard Model, which underlies the seismic provisions in the NBCC[xxxvi]. This includes ground motion prediction equations, which relate an earthquake rupture at its source to shaking at a site of interest. Additionally, this study also uses ground condition information from the United States Geological Survey[xxxvii, xxxviii] to predict local ground shaking response more accurately. This risk assessment and the risk modelling supporting it leverage a primary earthquake planning scenario, the M7.2 Georgia Strait scenario, and two supporting earthquake scenarios, namely the M9.0 Cascadia Megathrust and M7.0 Intraslab scenarios. These scenarios are reviewed in detail in Section 2 above.

3.1.2 The Study Area & Neighbourhoods

The study area, shown in Figure 3-1 below, shows the legal boundaries of the City's jurisdiction, including the VBBL, excluding the UBC Endowment Lands and Vancouver Campus, Port of Vancouver structures, and the Musqueam Indian Band Reserve. In the future, the City hopes to work with host Nations as well as UBC and the federal and provincial governments to expand on this risk assessment.

Figure 3-1: Risk Assessment Neighbourhoods

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Figure 3-1 above shows Vancouver's neighbourhoods considered within this study. Largely the bounds of each neighbourhood are reflective of the City's 22 "local area" neighbourhoods [xxxix] , however some modifications were made in response to the Downtown Eastside Plan[xl] and the False Creek Flats Plan[xli]. Specifically, these modifications reduce the extent of Downtown by pulling the Gastown-Victory Square areas of Downtown into sub-areas of the Downtown Eastside Plan Area. Additionally, the City's Strathcona local area has been altered as well, subdividing it and including the Downtown Eastside-Oppenheimer District, Chinatown, and its industrial and residential areas as subareas of the Downtown Eastside Plan Area. And finally, the southern (industrial) sections of Strathcona have been included in the False Creek Flats, following that neighbourhood's plan, and the Citygate and Thornton Park areas have been included in Downtown for this assessment. Additionally, localised assessments of risk and sociodemographic analysis, both throughout the city and within neighbourhoods, are performed within the city's 127 Census tracts, defined by Statistics Canada as "small, relatively stable geographic areas that usually have a population of fewer than 7,500 persons."[xlii]

3.1.3 Vancouver's Building Inventory

Seismic risk modelling requires an understanding of who and what are in harm's way. This understanding takes the shape of a building inventory capturing all the City's 90,000 existing buildings. In 2018, a comprehensive building inventory was completed by the City through a partnership between the City, UBC Civil Engineering, and NRCan.[xliii] The inventory was built by updating a 2009 UBC inventory of select neighbourhoods and types of buildings in Vancouver and included B.C. Assessor data on building construction age. For this data collection, UBC engineering students performed windshield surveys using Google Street View to update this previous archive, with a final dataset describing 90,014 buildings records. Some updates, following narrowly scoped quality control efforts, were performed between 2018 and 2022 with the final version of the building inventory completed in 2022. This dataset is considered accurate as a point-in-time description of Vancouver's buildings as of late 2018.

For each building surveyed, information was recorded about the construction type—its primary construction material and seismic force resisting system—as well as its primary occupancy, building area, and storey count. Construction type, considering the building's height, as well as primary occupancy were recorded based on the United States Federal Emergency Management Agency's Hazus Program (Hazus),[xliv] classification system, updated to account for B.C.-specific wood construction practices[xlv]. This approach reduces the complexity of each building's construction type and occupancy into a set of generalised types for the purposes of risk modelling[xlvi]. For each building record additional information was gathered or developed by NRCan, including the building's design level, replacement value, and number of building occupants.

For modelling, the buildings construction year is used to determine its **design level**. Design levels, accounting for the robustness of the seismic provisions within the building code in place at the time of the building's construction, are broken into four categories within Canada: 'Pre-code' refers to buildings constructed prior to any rigorous seismic provisions within the code (built before 1973[xlvii]), 'high code' refers to modern buildings (built after 2004), while 'low code' buildings (built between 1973 and 1989) and 'moderate' code (built between 1990 and 2004) refers to those built in between. In Vancouver and other locations adjustments were made in design level year assignments based on construction practices, code adoption cycles, and expert judgement.

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Replacement values for each building record are based on commercial costing information and average sizes for each building type, including values for the structural and non-structural components of each building and its contents[xlviii]. Values are in 2019 CAD.[xlix]

The **number of building occupants** at three points during the day of each building is estimated using the 2016 Canadian Census of Population, providing an estimate[l] of:

- Daytime building occupants, including workers, customers, occupants in residential buildings, and all other occupants within buildings between 9am and 5pm
- Nighttime building occupants, most of which are residents but any occupants in buildings between 7pm and 7am
- Transit building occupants, including all occupants of buildings between the hours of 7am to 9am and 5pm to 7pm

3.1.3.1 Final Building Inventory

Table 3-1 below, ordered by building count, describes Vancouver's 90,000 buildings in terms of a set of 10 building types organised using the building-scale structural type and occupancy classifications described above. These types are grouped according to the seismic structural characteristics as well as common use groupings used within City policies and plans. Additionally, estimated nighttime population counts are included for each type. Non-residential building types can contain nighttime occupants, such as overnight workers, residents within government-operated facilities, and other similar circumstances. Details on each building type as well as the B.C.-modified Hazus classification equivalents are provided below the table.

Table 3-1: Vancouver's Building Inventory

Building Type	Building Type Count	Building Type Nighttime Population
A Detached Homes	79,062 (87.8%)	292,116
B Wood Multiunit Residential Buildings	3,866 (4.3%)	160,887
C Unreinforced Masonry, Wood, and Low-Rise Concrete Commercial Buildings	2,722 (3.0%)	2,455
D Concrete Mid- and High-Rise Multiunit Residential Buildings	1,104 (1.2%)	124,916
E Industrial Use Buildings	1,097 (1.2%)	0
F Unreinforced Masonry Multiunit Residential Buildings	581 (0.6%)	24,671
G Institutional Use Buildings	570 (0.6%)	4,368
H Other Buildings	455 (0.5%)	8,116
I Concrete Low-Rise Multiunit Residential Buildings	280 (0.3%)	12,627
J Concrete Mid- and High-Rise Commercial Buildings	277 (0.3%)	1,348
Total	**90,014**	**631,504**

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A **Detached homes** (W1 and W4 buildings with RES1, RES2, RES3A occupancy codes) are light frame wood buildings with 1-2 storeys, with the addition of buildings with cripple walls (a short wall connecting the top of the foundation to the base of the first storey) conditions[li]. Detached home lots in Vancouver can contain as many as three units of housing, including a laneway house, and can be rental and/or owner occupancy. Some are duplex form houses, containing as many as four units of rental and/or owner occupancy housing.

B **Wood Multiunit Residential Buildings** (W2 buildings with RES3B-F, RES4, RES5, and RES6 occupancy codes) are light frame wood buildings with more than 2 storeys and are commonly (though not exclusively) associated with older, purpose-built rental housing in Vancouver. While some of these buildings have tuck-under parking, which makes them especially vulnerable to damage from seismic shaking, this vulnerability is not presently accounted for in this risk model.

C **Unreinforced Masonry, Wood, and Low-Rise Concrete Commercial Buildings** (C[1-3]L, PC[1-2]L, URM[L-M], W3 buildings with COM occupancy codes) is an expansive building type, containing low- and mid-rise unreinforced masonry commercial buildings as well as both low-rise concrete and wood commercial buildings. This type captures the diversity of buildings along commercial high street and arterial corridors as well as all commercial buildings other than mid and high-rise concrete commercial buildings located in Downtown.

D **Concrete Mid- and High-Rise Multiunit Residential Buildings** (C[1-3] [M,H] buildings with RES3B-F, RES4, RES5, and RES6 occupancy codes) are concrete residential buildings with 4 or more storeys, containing either rental or owner housing. Some have commercial uses at the ground floor.

E **Industrial Buildings** (IND occupancy codes) often containing production, distribution, and repair uses (i.e., PDR) and are located in large concentrations in East Vancouver near the Port of Vancouver, in the Mount Pleasant Industrial Area, and near the base of the Granville/Burrard Slopes (Broadway Plan). Over half of all industrial buildings are unreinforced masonry buildings.

F **Unreinforced Masonry Multiunit Residential Buildings** (URM buildings with RES3B-F, RES4, RES5, and RES6 occupancy codes) are older brick buildings containing rental or owner housing. This typology includes buildings of all heights. These buildings generally have little to no seismic load resisting capacity. Most are historic structures, and very few have been retrofitted.

G **Institutional Use Buildings** (GOV, REL, and EDU occupancy codes) contain all educational, government, and religious buildings located throughout the city. As mentioned in this report, there are retrofit efforts for B.C. Schools and many government buildings in Vancouver. These retrofits are not reflected in the modelling within this assessment.

H **Other Buildings** (all remaining buildings) describes buildings not otherwise captured above, including steel and reinforced masonry buildings. They contribute to overall citywide risk at a rate much lower than the other building types due to the low numbers of buildings.

I **Concrete-Low-Rise Multiunit Residential Buildings** (C[1-3]L buildings with RES3B-F, RES4, RES5, and RES6 occupancy codes) are less common but are a significant element of Vancouver's housing.

J **Concrete Mid- and High-Rise Commercial Buildings** (C[1-3][M,H], PC2M buildings with COM occupancy codes) are few in number, though contain a large portion of the city's downtown office uses. These are concentrated in the downtown central business district and along the Broadway corridor.

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3.1.4 Vulnerability

Risk modelling implements functions describing both the fragility and vulnerability of each Hazus building type, which combines structural type, occupancy, and design level. These functions quantify the expected performance of each type when exposed to varying levels of ground shaking at a period that is relevant to that structure. Fragility and vulnerability functions were developed by the Global Earthquake Model Foundation for use in Canada[lii,liii]. While the current functions are largely based on Hazus[liv], future work will include functions specifically for B.C. wood and concrete construction practices. These are under development through a partnership between UBC and NRCan[lv].

3.1.5 Seismic Risk Modelling Outputs

Seismic risk modelling within this assessment was performed using the Global Earthquake Model Foundation's OpenQuake (OQ) Engine[lvi] software, leveraging a partnership between NRCan and the Global Earthquake Model Foundation. The OQ Engine has calculators for probabilistic and scenario-based hazard and risk assessment, used to model the expected shaking, damage to buildings, and financial losses from earthquakes. Additionally, heuristics implemented in Hazus were used to calculate several consequence metrics based on the damage and loss outputs of the OQ Engine.[lvii]

3.1.5.1 Risk Modelling Outputs – Four Focus Metrics

While many outputs are available from seismic risk modelling, this study primarily focuses on four building damage consequence metrics, listed below in Table 3-2. For clarity, these metrics will be identified throughout this assessment as the **four focus metrics**. They were selected by the City's ongoing Staff Seismic Working Group process to best align with the City's seismic resilience goals as outlined Objective 3.1 of the 2019 Resilient Vancouver Strategy: "Protect lives, decrease displacement and accelerate recovery following earthquakes"[lviii]. These metrics are available at the citywide, neighbourhood, and Census tract scales, and can be disaggregated by building type, design level, and occupancy. The identification of drivers of risk and at-risk neighbourhoods will be in terms of these four focus metrics.

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Table 3-2: Four Focus Risk Metrics

Risk Metric	Unit of Measure	Explanation
1 Nighttime Severe Injuries and Fatalities	People	Count of building occupants who are critically hospitalised, killed, or entrapped by building damage. Specifically, it is equivalent to level 3 and 4 casualties in Hazus: critical hospitalizations and fatalities/entrapments. These two metrics are alternatively referred to as casualties.
2 Daytime Severe Injuries and Fatalities		
3 Nighttime Building Occupants Disrupted and Displaced for More than 90 Days	People	Count of building occupants whose use of the building is diminished to some extent for more than 90 days. We refer herein to disruption and displacement rather than displacement alone because we are calculating the number of residents in housing that is expected to take longer than 90 days to repair[30]. This generally refers to buildings that are extensively and completely damaged, whose inhabitants will tend to be displaced, though it may include some larger buildings with lesser damage. These two metrics are alternatively referred to long-term disruption and displacement.
4 Daytime Building Occupants Disrupted and Displaced for More than 90 Days		

Following Staff Seismic Working Group guidance and the City's resilience priorities, building damage findings were found to not appropriately prioritise building types. Similarly, direct financial losses findings are similar enough to building damage results, and therefore do not significantly alter the determination of drivers of risk sufficient to substantially alter the policy prospects of a building type or location. Counts of completely and extensively damaged buildings and direct financial loss amounts (Below in Table 3-3) are used to support the assessment of long-term disruption and displacement and casualties, but are not part of the four focus metrics. The Ausenco Study will provide a detailed cost-to-risk benefit assessment of seismic upgrades.

Table 3-3: Supporting Risk Metrics

Risk Metric	Unit of Measure	Explanation
Direct Financial Losses	Canadian dollars (CAD)	Direct financial losses only, in 2019 Canadian dollars, for building and contents replacement. Does not take into account surge pricing, business interruption, or alternative living expenses.
Completely and Extensively Damaged Buildings	Buildings	Count of buildings damaged beyond immediate use without repair. Many will require demolition (i.e., completely damaged) and some will collapse. This corresponds to "red-" and "yellow-tagged" buildings. This metric is alternatively referred to as heavily damaged buildings.

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3.1.5.2 Use of Daytime and Nighttime Risk Metric Values

As seen above in Table 3-2, seismic risk modelling outputs provide values for each focus risk metric as both daytime and nighttime values. Daytime casualty and long-term disruption and displacement are considered within this risk assessment alongside nighttime values to provide a full picture of earthquake impacts on the city, a neighbourhood, and building types. Nighttime values will also be expressed as "residential" or "residents," to underscore the connection between a building type or neighbourhood's nighttime population and the disruption and displacement of residents resulting from earthquake damage.

3.1.6 Seismic Risk Modelling Limitations

The risk modelling supporting this risk assessment considers the impacts from mainshock ground shaking alone. As such, it does not consider secondary hazards, explored in more detail below, like aftershocks, fire following earthquake, tsunami, landslides, or liquefaction. Additionally, this model does not include any linear infrastructure, such as roadways, pipes, or transmission lines, and it does not account for delayed or disrupted emergency response and recovery, including disruptions of business or government operations, surge pricing, or losses to other sectors from damage in a linked sector. These unmodeled and additional sources of indirect loss are estimated to equate to 12-32% of the total direct losses[lix]. Seismic risk modelling, though containing building-level data, considers buildings as generalised types. This risk assessment should not be considered as an individual assessment of any building.

3.1.6.1 Liquefaction & Basin Effect

Liquefaction is a process by which earthquake shaking causes soil to behave temporarily like a liquid. Liquefaction is a possibility wherever there are saturated soils, such as those found in the Fraser River lowlands[lx]. While liquefaction is a relatively low risk to life safety, it can be a major problem for roadways and buildings. For example, in the New Zealand Canterbury Earthquake Sequence of 2010-2011, approximately 35% of the roadways near Christchurch had to be replaced due to liquefaction[lxi] and entire neighbourhoods had to be rebuilt or moved.[lxii]

Similarly, this study does not consider the effect of amplification of earthquake shaking by sedimentary basins, like the Georgia Basin that underlies much of Metro Vancouver[lxiii]. The impact of the basin is known to alter hazard appreciably, particularly in tall buildings, but work remains to determine how to implement this for the Canadian Seismic Hazard Model that underpins the seismic provisions in the NBCC.[lxiv]

3.1.6.2 Fire Following Earthquake

Fire following earthquake has long been identified as a major source of risk, since the 1906 Great San Francisco Earthquake in which 80% of the 28,000 buildings destroyed were from fire rather than shaking[lxv]. In a 2020 study by the Institute for Catastrophic Loss Reduction[lxvi] on fire following earthquake in the Lower Mainland, it was estimated that a deep M6.8 intraslab earthquake, similar to but slightly smaller than the M7.0 Intraslab scenario considered for this risk assessment, would cause an average of $7.4 billion CAD in losses, whereas a shallow M7.3 crustal earthquake in the Strait of Georgia would cost $10.7 billion on average. The modelled Cascadia M9.0 earthquake caused $170 million in damage. The actual cost of fire following a major earthquake in B. C. will depend largely on factors like timing, weather, and fire department response.

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3.1.6.3 Intention of Seismic Risk Modelling

Overall, the results within this report, including all numerical figures and maps, should be considered as indicative not predictive, best suited for the purpose of developing policies, programs, and citywide plans alone. For any understanding of individual building's potential performance in an earthquake, a design professional should be consulted to perform a building-specific analysis.

3.2 Methods of Seismic Risk Assessment

Seismic risk modelling serves as the core of this seismic risk assessment, providing findings across building types and neighbourhoods of the city. Specifically, seismic risk models allow for risk to be broken into specific, smaller, and categorised pieces that can be prioritised within preparedness and risk reduction planning. This assessment identifies several **risk-driving building types** and **at-risk neighbourhoods** within the city. Collectively these building types and neighbourhoods are responsible for most of the city's seismic risk, providing a clear picture of priorities for risk reduction planning. The following subsections describe the methods used to determine risk-driving building types and at-risk neighbourhoods, as well as the analysis methods used to assess them.

3.2.1 Risk Driving Building Types – Identification and Assessment

The process of identifying the highest contributing, or risk-driving, types amongst the city's ten building types (Table 3-1) begins with a comparative assessment of each type's contribution to each of the four focus risk metrics (Table 3-2). From this qualitative identification process building types are then prioritised and sorted, in terms of their contribution to risk and any other local context driving buildings policy work (e.g., regulatory authority, resilience objectives, etc.), and analysed. The following subsections describe each step of this process.

3.2.1.1 Quantitative Identification of Risk-Driving Building Types

Risk modelling outputs for each building type allow for the comparative assessment of each building type in terms of citywide contribution to each of the four focus risk metrics identified in Section 3.1.5.1. This allows building types to be prioritised amongst one another, surfacing building types that drive significant portions of the city's risk, or "risk-driving building types." In terms of risk reduction action, action focused on these prioritised building types will achieve high risk reduction returns. To determine a final set of risk-driving building types, types that contribute to the leading 90% of a metric's citywide value are identified for each focus metric. Amongst these, risk-driving building types are those that contribute to the leading 90% of more than one focus metric's citywide value.[lxvii]

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3.2.1.2 Prioritising Risk-Driving Building Types – Considering Local Context

Quantitatively determining a city's risk driving building types is a critical first step, but the final prioritised list must consider a city's (local) regulatory and policy context[lxviii]. Within this assessment, building types that are outside the regulatory authority of the City, already part of a governmental assessment and upgrade-replacement program, or outside the scope of the programmatic effort will not be prioritised within this assessment. Specifically, institutional use buildings, including schools and governmental buildings, will not be prioritised within Sections 5 and 6 of this assessment, as those buildings either already have a dedicated assessment and upgrade-replacement program (i.e., B.C. Schools, City of Vancouver buildings) and are not existing privately-owned buildings (i.e., the focus of this policy effort). Additionally, plans and policies addressing existing buildings (e.g., land use planning, rental building policies, etc.) must be considered, in terms of prioritising types, how types are assessed, or how types are addressed through risk reduction action. In this assessment, emphasis has been given to rental buildings and their occupants as well as existing community plans within highest-risk neighbourhoods.

3.2.1.3 Analysis of Risk Driving Building Types

Following the prioritisation of building types into a set of risk-driving building types (in Section 5.1), each risk-driving type is assessed in terms of their location, occupancy patterns, risk contribution, and common vulnerabilities and upgrade methods. Information within Section 5.2 is supported by risk modelling outputs, City plans and polices, and the Ausenco Study.

3.2.2 At-Risk Neighbourhoods – Determination and Assessment

In addition to identifying risk driving building types, this assessment identifies key areas of risk, both in terms of City-defined neighbourhoods (defined in Section 3.1.2) and in terms of Census tracts. Risk analysed in terms of highly recognisable City-defined neighbourhoods enhances the understanding of risk while aligning risk assessment, and indeed risk reduction planning, to the City's community plans and policies. Tract-level analysis (i.e., within neighbourhoods) allows for both a much more highly localised understanding of risk and the ability to identify areas beyond high-risk neighbourhoods containing concentrations of citywide risk contribution (See Section 3.2.2.1). Additionally, the use of Census tract-level assessment allows for the connection to sociodemographic factors within Census data, allowing the City to understand the implications of seismic risk to residents within City-defined neighbourhoods better (See Section 3.2.2.3).

3.2.2.1 Determining Highest-Risk Neighbourhoods and At-Risk Areas

To identify a set of high-risk neighbourhoods, each neighbourhood's contribution to each of the four focus metrics is considered as a percentage of each metric's citywide value. Similarly to the determination of risk-driving building types, those neighbourhoods that contribute to the leading 65% of more than one metric's citywide value are considered a highest-risk neighbourhood. A different threshold value (65% instead of 90%) was applied for neighbourhoods, as they are more numerous than building types, with risks being distributed more across spatial areas than specific types.

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3.2.2.2 Census Tract Relative Seismic Risk

To identify areas of concentrated citywide risk contribution, a calculation of relative seismic risk at the Census tract level is used. For each tract, a relative seismic risk value is calculated by averaging each tract's contribution across each of the four focus risk metrics. Each tract is then assigned a rank of lower, moderate-lower, moderate, high, or highest based on this value. To assign these ranks, groupings of values were determined using Jenks Natural Breaks. Once ranked, citywide seismic risk contribution within neighbourhoods (i.e., at the tract level) can be understood. Additionally, Census sociodemographic data is available at this scale, allowing for connections between concentrated areas of risk within neighbourhoods, risk-driving building types, and the residents of area buildings to be made.

3.2.2.3 Analysis of Highest-Risk Neighbourhoods and At-Risk Areas

Within this assessment, the city's highest-risk neighbourhoods are assessed in terms of patterns of risk, building type composition, and links between existing City plans and neighbourhood-scale building risk. In addition to this, summary findings from sociodemographic analysis are provided for each moderate- to highest-risk tract (See Section 3.2.2.1) within each of the highest-risk neighbourhoods (i.e., Section 6). Specifically, for these tracts, Census data that indicates a potentially increased household or personal impact from earthquake-induced residential disruption-displacement was collected. Building on the vast body of research into the connections between sociodemographic factors and post-earthquake outcomes within communities[lxix], the following factors (in Table 3-4) were determined through engagement with City housing policy emergency management planners. They are intended to indicate groups where additional challenges and structural barriers to preparing their household and upgrading buildings may be faced. These challenges and barriers potentially expose them to greater risk than other residents.

It is essential to note that this sociodemographic assessment is a starting point, providing preliminary and high-level information about the connections between sociodemographic data, communities in Vancouver, and localised seismic risk. More study and further engagement, including the determination of additional or different metrics, is needed.

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Table 3-4: Sociodemographic Factors, Seismic Risk Assessment

Theme	Factor	Source-Year
Income	Household median income, owners (CAD)	Census 2021
Income	Household median income, renters (CAD)	Census 2021
Income	Population that are low income (%; LIM-AT: low-income measure, after tax)	Census 2021
Age	Population aged 65 or over (%)	Census 2021
Age	Households containing one or more person aged 0-5 years (%)	Census 2021
Identity	Population that are a visible minority (%)	Census 2021
Identity	Population that identifies as Indigenous (%)	Census 2021
Health	Households with at least one member that has an activity limitation all the time (%)	Census 2021
Renter	Population that are renters (%)	Census 2021
Renter – Income	Renter population that are low-income (%; LIM-AT)	Census 2021
Renter – Age	Renter population age 65 or older (%)	Census 2021
Renter – Age	Renter households containing one or more person aged 0-5 years (%)	Census 2021
Renter – Identity	Renter population that are a visible minority (%)	Census 2021
Renter – Identity	Renter population that identifies as Indigenous (%)	Census 2021
Renter – Health	Renter households with at least one member that has an activity limitation all the time (%)	Census 2021
Renter – Identity	Renter population that are a visible minority (%)	Census 2021
Renter – Health	Renter households with at least one member that has an activity limitation all the time (%)	Census 2021

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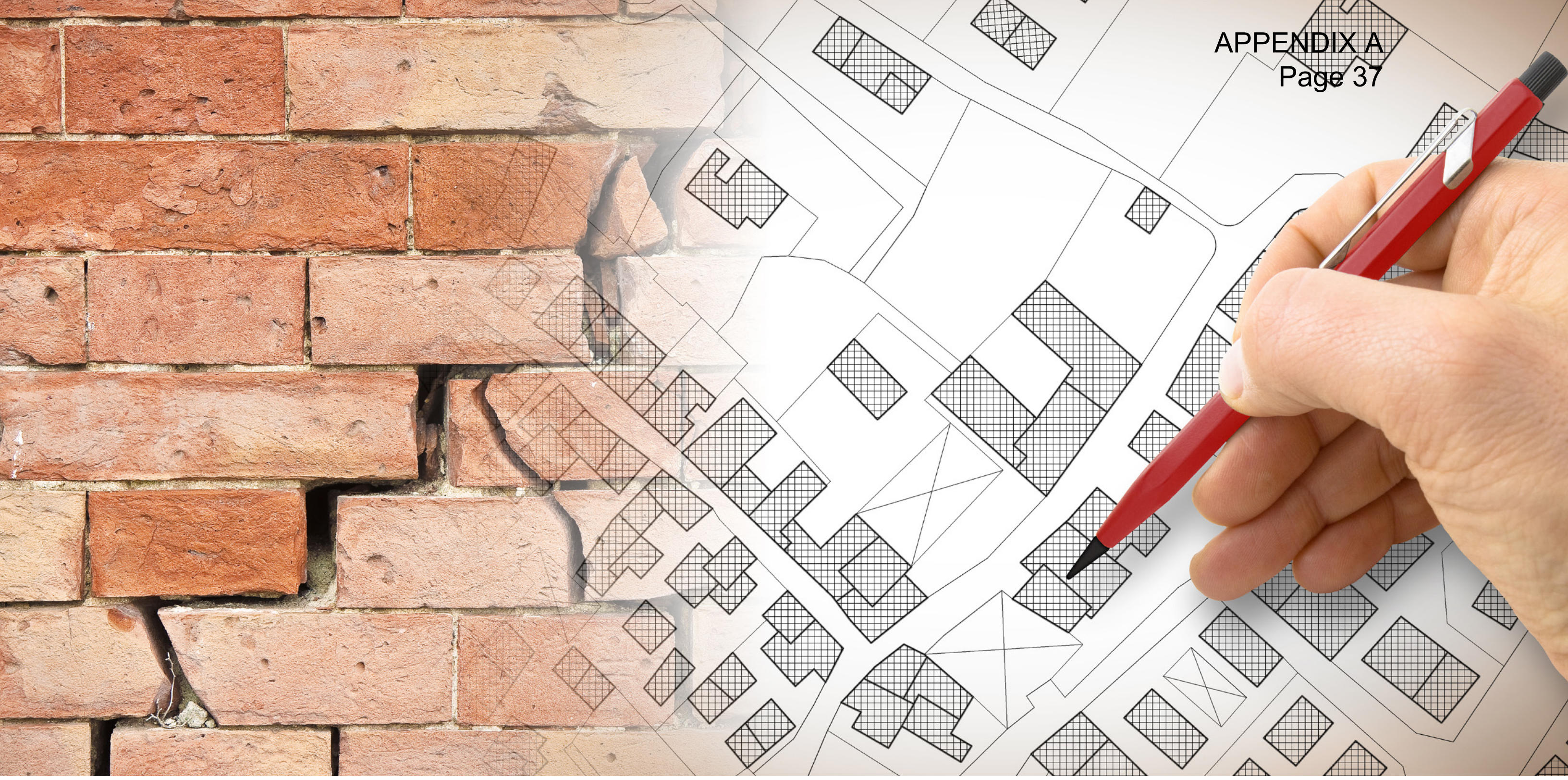

4. Citywide Results from Seismic Risk Modelling

Citywide seismic risk modelling results are presented below in Table 4-1, providing a high-level picture of the impacts of a M7.2 Georgia Strait planning scenario earthquake on existing buildings and their occupants.

Table 4-1: Citywide Risk Modelling Results, M7.2 Georgia Strait Earthquake

Completely and Extensively Damaged Buildings	Severe Injuries and Fatalities		Building Occupants Disrupted or Displaced for More than 90 Days		Direct Financial Losses
	Daytime	Nighttime	Daytime	Nighttime	
6,080	1,370	620	365,340	231,520	$17B

This table presents risk modelling outputs rounded to the nearest ten or, in the case of financial losses, to the nearest billion. Seismic risk modelling results are based on the outputs of the OpenQuake earthquake modelling engine and does not include the contribution of infrastructure failure, delayed emergency response and recovery, aftershocks, fire following earthquake, tsunami, landslides, or liquefaction (See section 3.1.6).

Figure 4-1 below illustrates the distribution of risk throughout the city, showing the relative risk amongst Census tracts by averaging each tract's contribution to citywide daytime and nighttime severe injuries, fatalities, and disruption and displacement lasting more than three months.

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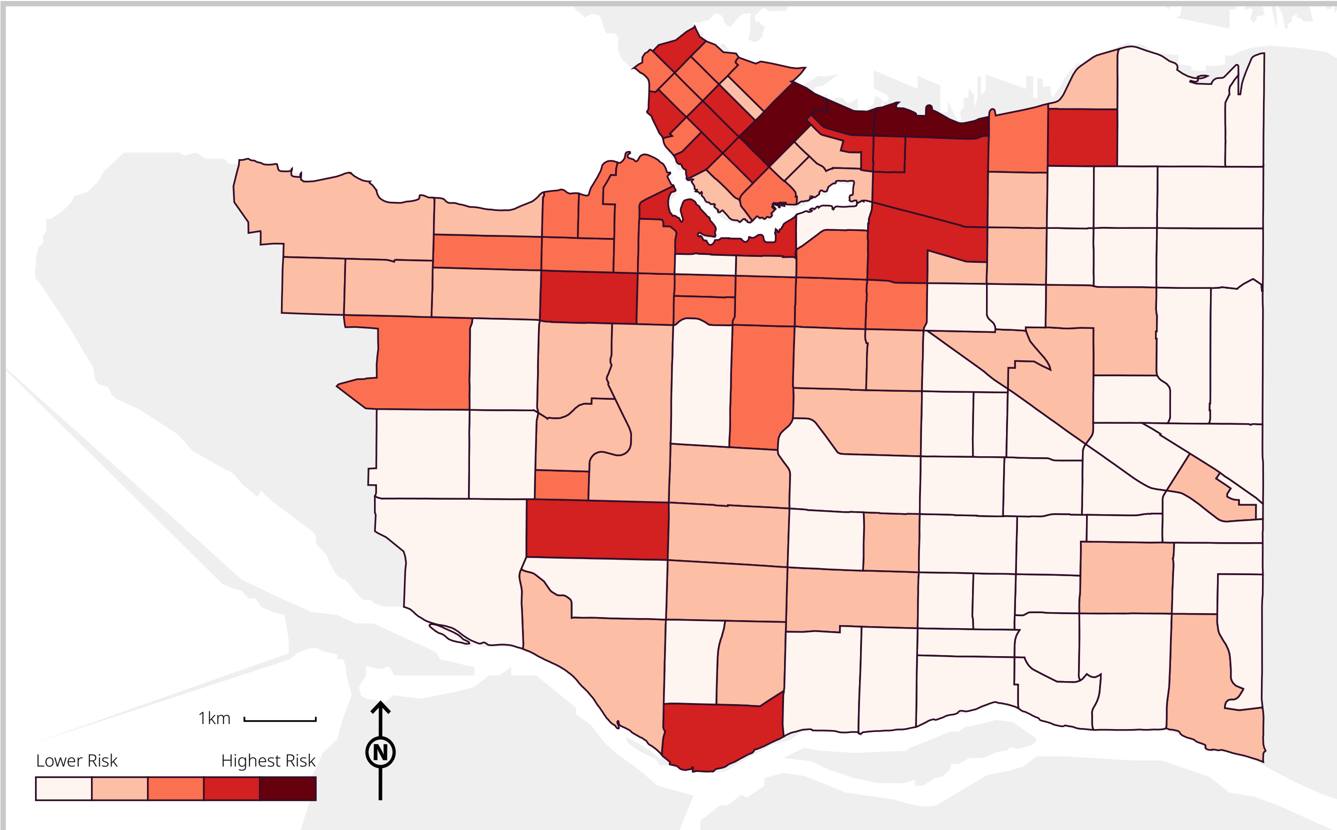
Figure 4-1: Relative Seismic Risk, M7.2 Georgia Strait Earthquake, by Census Tract



Relative seismic risk mapping is based on the outputs of the OpenQuake earthquake modelling engine and does not include the contribution of infrastructure failure, delayed emergency response and recovery, aftershocks, fire following earthquake, tsunami, landslides, or liquefaction (See section 3.1.6).

While the risk modelling results seen in both Figure 4-1 and Table 4-1 are not intended as predictions of the exact outcomes of an expected earthquake, they provide critical insights into patterns of risk. These insights are an essential first step in risk reduction planning. Citywide results also provide and understanding of the extent of damage, as well as casualties, disrupted and displaced population, and direct financial losses. For example, the number of severe injuries and fatalities from the M7.2 Georgia Strait event would constitute the largest instantaneous demand on hospital resources ever seen in Vancouver, significantly surpassing the impact of the catastrophic 2021 Heat Dome[lxx]. In Sections 5 and 6 of this assessment the building types driving this risk and areas of concentrated risk are identified and examined in detail.

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4.1 Citywide Risk Modelling – Supporting Earthquake Planning Scenarios

Table 4-2 below shows the seismic risk modelling results of the two supporting earthquake planning scenarios used within this assessment, the M9.0 Cascadia Megathrust and M7.0 Intraslab scenarios.

Table 4-2: Citywide Risk Modelling Results, Supporting Earthquake Planning Scenarios

Supporting Earthquake Planning Scenarios	Completely and Extensively Damaged Buildings	Severe Injuries and Fatalities		Building Occupants Disrupted or Displaced for More than 90 Days		Direct Financial Losses
		Daytime	Nighttime	Daytime	Nighttime	
M9.0 Cascadia Megathrust	1,440	400	170	140,000	115,850	$3.8B
M7.0 Intraslab	720	190	70	25,420	15,230	$3.1B

This table presents risk modelling outputs rounded to the nearest ten or, in the case of financial losses, to the nearest billion. Seismic risk modelling results are based on the outputs of the OpenQuake earthquake modelling engine and does not include the contribution of infrastructure failure, delayed emergency response and recovery, aftershocks, fire following earthquake, tsunami, landslides, or liquefaction (See section 3.1.6).

These results show that the expected number of damaged buildings is likely to be in the hundreds and disrupted and displaced residents is likely to be in the tens of thousands, even when considering a more moderate event like the M7.0 Intraslab scenario. Additionally, while the financial losses for that event and the M9.0 Cascadia scenario are similar, the number of disrupted occupants is an order of magnitude higher for the latter.

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5. At-Risk Buildings

Seismic risk is distributed unevenly amongst building types.

Using the building types identified within Section 3.1.3.1, this section identifies the specific building types that drive citywide seismic risk, in terms of the four focus metrics of daytime and nighttime severe injuries and fatalities and daytime and nighttime building occupant disruption and displacement lasting more than three months (See Section 3.1.5.1). The risk within these building types is driven largely by construction year (i.e., code vintage) as well as characteristics of the type's material and seismic design. Risk modelling results described within this section consider the impacts of the M7.2 Georgia Strait earthquake used as the main planning scenario for this assessment. For each risk driving building type, high-level findings from the Ausenco Study will be provided.

5.1 Identifying Drivers of Risk

Figure 5-1 below provides a high-level breakdown of the city's inventory of buildings and citywide seismic risk by building type. The latter two figures illustrate the contribution of each building type to each of the four focus risk metrics, in terms of a combined "life safety risk" value, describing both daytime and nighttime severe injuries and fatalities, and a combined "disruption risk" value, describing both daytime and nighttime building occupant disruption and displacement lasting longer than three months.

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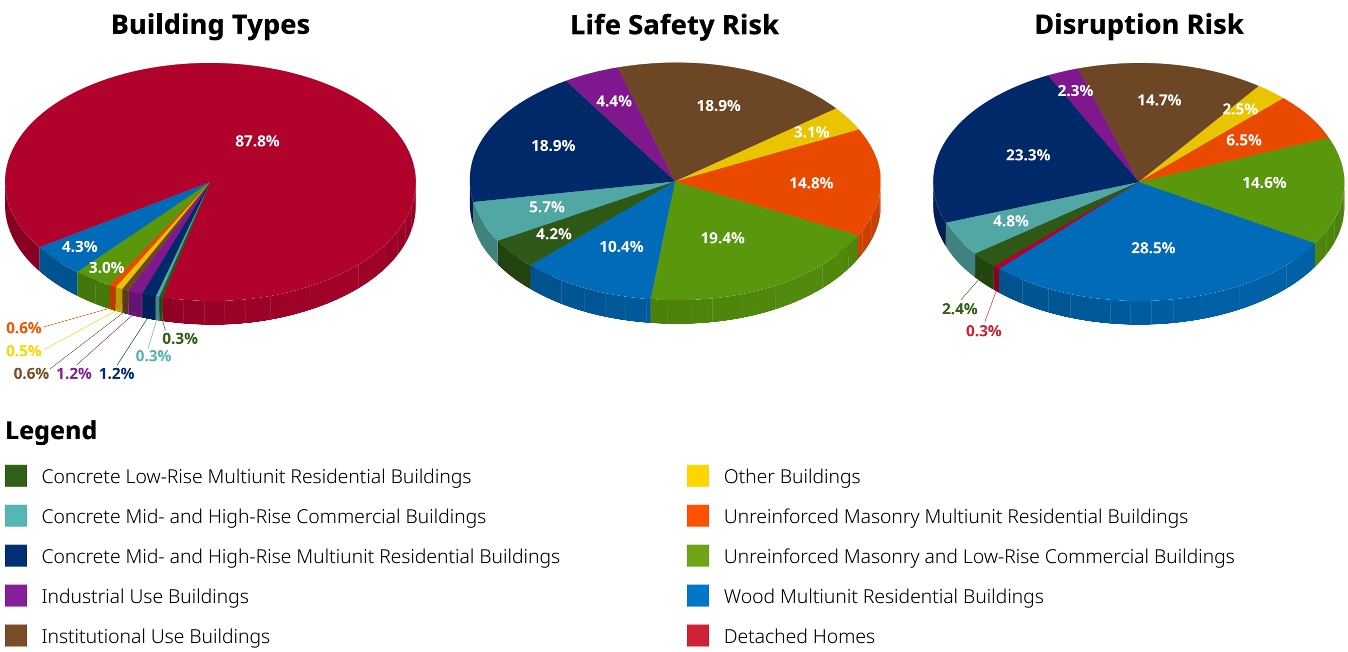
Figure 5-1: Building Inventory and Citywide Risk, by Building Type



Considered together, several themes and patterns within both the city's building stock and citywide risk emerge. Specifically, a limited number of building types contribute a large share of the city's casualties and long-term disruption and displacement. Unreinforced masonry (URM) and low-rise commercial buildings, concrete mid- and high-rise multiunit residential buildings (MURBs), wood MURBs, institutional buildings, and URM residential buildings are all significant contributors. Additionally, by comparing the risk contribution in the right-most figures to the inventory composition in the left-most figure, it is clear that a very small portion of Vancouver's buildings drive the majority of seismic risk. Considering these risk themes more closely, Table 5-1 below, ordered by contribution to citywide nighttime severe injuries and fatalities, shows the specific contribution of each building type to each of the four focus risk metrics. This allows for a type-to-type comparison, enabling prioritisation of types into a set of risk-driving building types to focus both risk assessment and risk reduction action development.

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Table 5-1: Citywide Seismic Risk Contribution, Building Types, M7.2 Georgia Strait Planning Scenario Earthquake

Building Types	Building Count (Percent of Citywide)	Percent of Citywide Total			
		Severe Injuries and Fatalities		Occupants Disrupted and Displaced for More than 90 Days	
		Nighttime	Daytime	Nighttime	Daytime
Concrete Mid- and High-Rise Multiunit Residential Buildings	1,104 (1.2%)	37.5%	10.5%	37.0%	14.7%
Unreinforced Masonry Multiunit Residential Buildings	581 (0.6%)	29.3%	8.3%	10.3%	4.1%
Wood Multiunit Residential Buildings	3,866 (4.3%)	20.7%	5.9%	44.9%	18.2%
Concrete Low-Rise Multiunit Residential Buildings	280 (0.3%)	8.3%	2.4%	3.7%	1.5%
Institutional Use Buildings	570 (0.6%)	2.0%	26.5%	1.2%	23.2%
Other Buildings	455 (0.5%)	1.2%	4.0%	1.5%	3.1%
Unreinforced Masonry, Wood, and Low-Rise Concrete Commercial Buildings	2,722 (3.0%)	0.8%	27.8%	0.6%	23.5%
Concrete Mid- and High-Rise Commercial Buildings	277 (0.3%)	0.3%	8.2%	0.2%	7.8%
Detached Homes	79,062 (87.8%)	0.0%	0.0%	0.5%	0.2%
Industrial Use Buildings	1,097 (1.2%)	0.0%	6.4%	0.0%	3.7%

The highlighted cells in Table 5-1 above indicate the leading contributors (i.e., leading 90% of each metric's citywide value; See Section 3.2.1) to each of the four focus metrics. Three building types contribute to the leading 90% of all focus metrics: concrete mid- and high-rise MURBs, URM MURBs, and wood MURBs. Following those, three additional types drive citywide risk across two focus risk metrics, specifically institutional use buildings, URM, wood, and low-rise concrete commercial buildings, and concrete mid- and high-rise commercial buildings. Finally, industrial buildings and concrete low-rise residential buildings each drive one metric, while detached homes and buildings of other types do not drive citywide risk within any of the four focus risk metrics. The following building types contribute to the leading 90% of more than one focus risk metric, and are considered risk-driving building types within this assessment:

- Concrete Mid- and High-rise Multiunit Residential Buildings
- Unreinforced Masonry Multiunit Residential Buildings
- Wood Multiunit Residential Buildings
- Institutional Use Buildings
- Unreinforced Masonry, Wood, and Low-Rise Concrete Commercial Buildings
- Concrete Mid- and High-Rise Commercial Buildings

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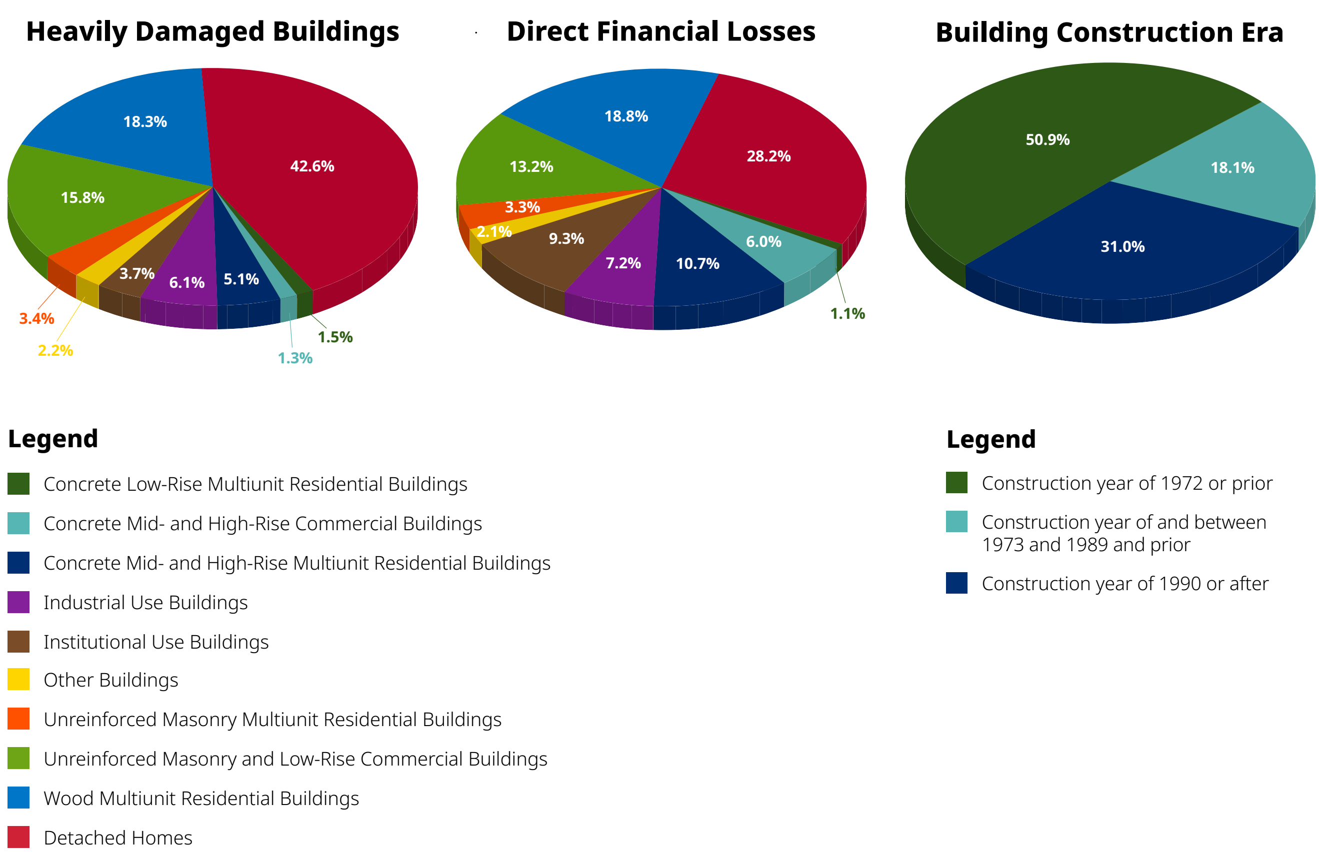
5.1.1 Prioritising Risk-Driving Building Types

The final list of risk-driving building types used throughout this section were prioritised to reflect the regulatory and policy context of the City (See Section 3.2.1.2). The scope of the program driving this risk assessment is focused on existing, privately owned buildings. As such, institutional use buildings are not assessed alongside other risk-driving building types within this assessment. Additionally, Province of B.C. has an ongoing Seismic Mitigation Program for all public schools, as does the City, within its Real Estate and Facility Management group, for its buildings Significant contributions by institutional use buildings to the risk with neighbourhoods or Census tract risks are mentioned in Section 6.

5.1.2 Analysing Risk-Driving Building Types

The following considerations guide the assessment of risk-driving building types. Specifically, the supporting risk metrics of extensively and completely damaged buildings, direct financial losses, and building type code vintage guide both the analysis of risk-driving building type casualty and long-term disruption and displacement estimates and the interpretation of which buildings within a type are most likely to generate seismic risk. Figure 5-2 below visualises, from left to right, the building type contributions to citywide extensively and completely damaged buildings and direct financial losses and the construction year breakdown of the building inventory.

Figure 5-2: Building Inventory Construction Year and Building Type Contribution to Extensively and Completely Damaged Buildings and Direct Financial Losses



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While Table 5-1 described the highly negligible role detached homes play in driving citywide casualties and long-term disruption and displacement, we see, in left-most figure within Figure 5-2 above, that detached homes are significant contributors to citywide extensively and completely damaged buildings. This risk dynamic is caused by the relatively low population in most detached home and the lower life-safety risk of heavy damage. This finding is significant, though, to post-earthquake building assessment planning and highlights the importance of owner education programs.

Figure 5-2 (left figure) underscores the risk driven by wood MURBs and URM, wood, and low-rise concrete commercial buildings. These two types drive nearly 20% of citywide expensively and completely damaged buildings. Additionally, it shows that one-third of extensively and completely damaged buildings are MURBs (including wood MURBs). The middle figure in Figure 5-2 visualises the contributions of each building type to citywide direct financial losses. It shows that detached homes, linked to contributing a high percentage of citywide heavily damaged buildings, drive nearly one-third of losses. It also shows that wood MURBs, concrete mid- and high-rise concrete MURBs, and URM, wood, and low-rise concrete commercial buildings drive between 10% and 20% each.

Finally, rather than presenting risk results, Figure 5-2 (right-most figure) visualises the city's existing buildings in terms of three key code vintages: buildings constructed prior to 1973, before the introduction of seismic design provisions for buildings; buildings constructed after 1990, when early modern seismic standards were introduced into building design; and those buildings constructed between those two dates (See Section 2). We see above that the majority of buildings in Vancouver were constructed prior to 1990, with nearly half built prior to 1973. To aide in the interpretation of risk modelling results, the proportion of buildings built prior to these two dates will be noted below.

5.2 Risk-Driving Building Types

The following subsection reviews the general characteristics and risk profile of each risk-driving building type. At a high level, modelling shows that nearly 80% of citywide risk, in terms of the average contribution to each of the four risk metrics across all five risk-driving building types, is driven by types accounting for less than 10% of Vancouver's 90,000 buildings. The following subsections describe the risk contribution from each risk-driving building type, as well as presents information about the location, construction vintage, occupancy patterns, and vulnerability of each type.

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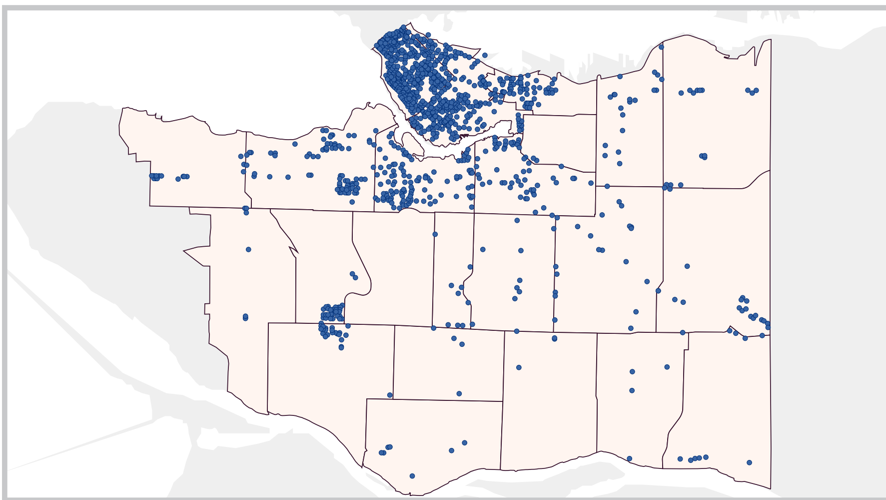
5.2.1 Concrete Mid- and High-Rise Multiunit Residential Buildings

Concrete mid- and high-rise residential buildings are concrete residential apartment or strata buildings with four or more storeys. They are heavily concentrated in the West End, with 32% of buildings of this type found in the West End, as well as in Downtown (21%), Fairview (10%), Kitsilano (7%), and in Mount Pleasant (5%). They account for 1% of total buildings and house 20% (124,900 people) of the city's modelled residential population. This type contains many more-affordable housing units as well as many strata units. When compared to other MURBs they are on average newer (average year of construction 1986) buildings, though nearly half were built prior to 1990 and almost a third prior to 1973.

Figure 5-3: Map of Concrete Mid- and High-Rise Residential Buildings



Residential mid- and high-rise concrete buildings are modelled to be the highest risk building type in terms of their contribution nighttime casualties, driving 37% (230) of the citywide total. With nearly 28% of buildings of this type modelled to be extensively or completely damaged, it is expected that 70% of estimated population will be disrupted and displaced for longer than three months. Additionally, they drive nearly 37% (85,200) of residential long-term disruption and displacement as a result, and drive over 11% of citywide direct financial losses.

The Ausenco Study assessed the vulnerabilities of the over 650 pre-1990 mid- and high-rise concrete residential and commercial buildings. Typical vulnerabilities include an inadequate number of interior walls and the lack of strength in walls due to design standards in force within older building codes. These vulnerabilities can lead to localised or complete building collapse. Some residential buildings may be able to be upgraded using exterior upgrades, without displacing occupants, while many upgrades will require interior upgrades that will require partial or total displacement of occupants during upgrade.[lxxi]

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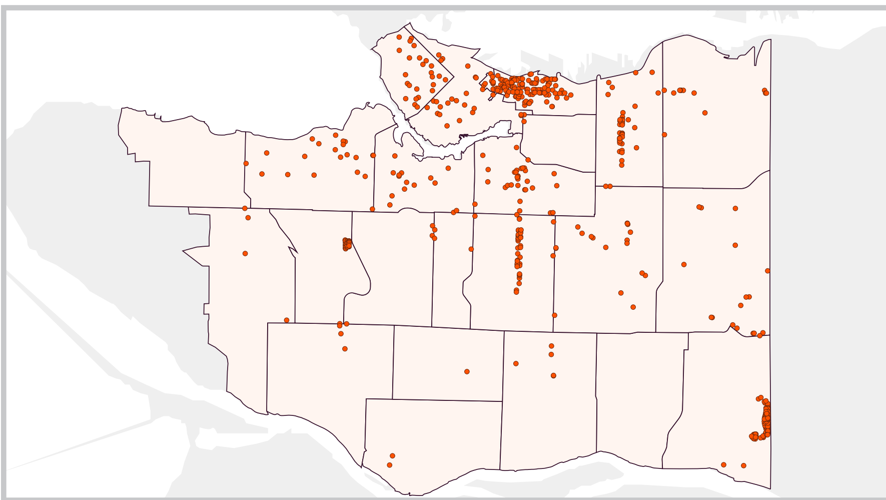
5.2.2 Unreinforced Masonry Multiunit Residential Buildings

URM MURBs, or older brick apartment buildings, are constructed prior to modern seismic standards and are known poor-performers, seismically.[lxxii] After past earthquakes in other cities, they caused high loss of life, occupant disruption and displacement, and building collapses.[lxxiii] These buildings account for less than one percent of Vancouver's buildings, housing nearly 4% (24,700) of the modelled residential population. They are highly concentrated in Gastown, the Downtown Eastside, and Chinatown, with others located throughout the city. Many of the city's Single Room Occupancy (SRO) buildings are URM residential buildings. While some URM buildings that have been repurposed from non-residential use to residential use are retrofitted, most residential URMs in Vancouver were not converted and are therefore not retrofitted, remaining at high risk.

Figure 5-4: Map of Unreinforced Masonry Multiunit Residential Buildings



Modelling shows that URM residential buildings drive 29% (180) of nighttime casualties and around 10% (23,800) of the city's long-term residential disruption and displacement. 35% of URM MURBs are expected to be extensively and completely damaged, leading to over 97% of residents in these buildings disrupted and displaced for more than three months. Given the extensive damage in these buildings and their location largely in densely populated areas of the city, these buildings are also expected to cause additional on-street injuries and deaths[lxxiv],[lxxv] as well as long-term neighbourhood closures[lxxvi].

The Ausenco Study emphasises that URM buildings have low strength and are brittle in resisting earthquake movement, which can cause the heavy mass of these historic buildings to experience very significant, even collapse-inducing, damage. Many of these buildings have parapets and gable end walls that are very prone to collapse onto exterior areas immediately adjacent to the building. Additionally, URM buildings are challenging, disruptive, costly, and sometimes impractical to upgrade to near current code levels, especially if the building has a heritage rating. Most URM upgrades are associated with a complete change of use of the building or with additions to the structure, such as adding a tower, etc.[lxxvii]

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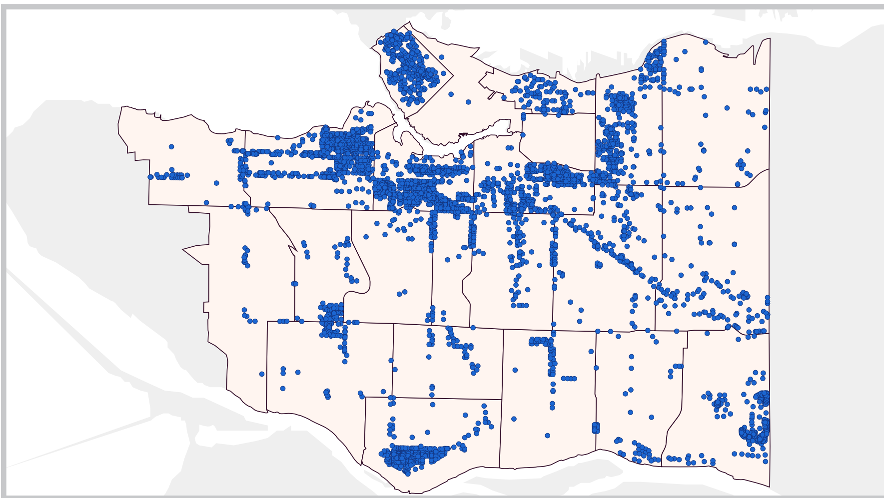
5.2.3 Wood Multiunit Residential Buildings

Wood MURBs, typically seen as wood-framed walk-up apartment buildings, account for over 4% (3,860) of all, housing around 25% (160,900) of the city's modelled residential population. Additionally, they represent 87% of buildings protected under the Rental Housing Stock Official Development Plan, whose intent is to prevent against the loss of rental housing units. Citywide, 30% of these buildings are found collectively in Fairview and Kitsilano, 9% in Mount Pleasant and over 7% in the West End, with an additional 16% collectively located in Grandview-Woodland and Marpole. 81% of wood MURBs were built prior to 1990 and 50% prior to 1973, making their average construction year 1969.

Figure 5-5: Map of Wood Multiunit Residential Buildings



Wood MURBs are responsible for 45% (103,500) of long-term residential disruption and displacement, being the highest driver of that metric amongst all building types. 64% of all residents in wood MURBs are expected to be disrupted and displaced for longer than 90 days. With nearly one-third of these buildings are modelled to be extensively or completely damaged, wood MURBs are modelled to drive 21% (130) of residential casualties. Additionally, wood MURBs are responsible for 19% of direct financial losses.

The Ausenco Study, focused on the city's nearly 3,200 wood MURBs built prior to 1990, shows that many of these buildings lack stiffness and strength in their walls, leading to excessive building damage. This is likely to cause the building to be uninhabitable or not repairable following an earthquake. Additionally, some of these buildings may be prone to partial or complete collapse, due to the lack of strength and stiffness of the floors and roof. A small portion of these buildings are very prone to local collapse due to soft-storey effects from tuck-under parking. Although not explicitly considered in the simplified building types modelling within this assessment, these vulnerabilities taken together account for the grouping's disproportionately high contribution to the potential of citywide residential disruption and displacement.[lxxviii]

When considering seismic risk impacts and Vancouver's ongoing housing crisis together, Wood MURBs are particularly at-risk. These buildings provide an essential source of affordable rental housing as, largely due to the age of the buildings, rents are significantly lower than in newer purpose-built rental housing. In Vancouver, the average rent for buildings built before 1960 is approximately 35% less than rent in buildings built in 2015 and after[lxxix]. Additionally, the 2018 Rental Reinvestment Study and 2018 Measures to Retain the Rental Housing Stock report[lxxx] both emphasised that many building components in wood MURBs are near or beyond their projected service lives[lxxxi]. In addition to seismic risk, many of these buildings potentially require significant capital upgrades in the next 10 to 30 years.[lxxxii]

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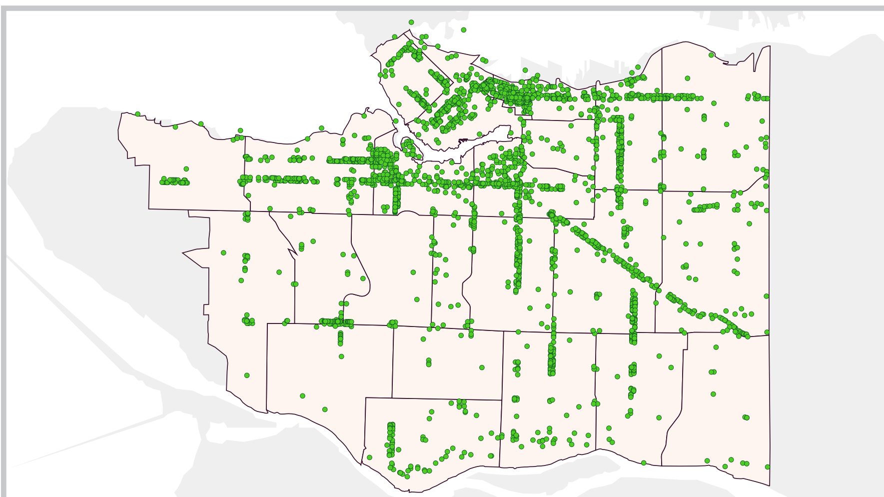
5.2.4 Unreinforced Masonry and Low-Rise Commercial Buildings

This study considered an aggregate of the city's stock of over 2,700 URM, wood, and low-rise commercial buildings, including all mid- and low-rise URM commercial buildings and all wood and low-rise concrete commercial buildings. They are typically found along arterials and neighbourhood commercial cores (e.g., Granville Street, Denman Street, Kingsway, Broadway, etc.), containing the city's small and neighbourhood-serving businesses. 29% of these buildings are found along commercial streets, including Broadway in Fairview, Mount Pleasant, and Kitsilano. Additionally, these buildings are concentrated within Downtown (7%) as well as Gastown, the Downtown Eastside, and Chinatown (collectively 12%). They contain 17% (124,400) of the city's daytime population. URM, wood, and low-rise concrete commercial buildings are an older stock of buildings, with an average construction year of 1955. 88% of buildings were built prior to 1990 and 72% were built prior to 1973.

Figure 5-6: Map of Unreinforced Masonry, Wood, and Low-Rise Concrete Commercial Buildings



Example damage along commercial corridors and arterials, as seen during the M6.9 1989 Loma Prieta earthquake in the downtown of Santa Cruz, California.

URM, wood, and low-rise concrete commercial buildings are a significant driver of citywide risk, contributing 24% (85,900) of daytime long-term building occupant disruption and displacement. 71% of all daytime building occupants in these buildings are expected to be disrupted and displaced for over 90 days. Additionally, these buildings drive 28% (380) of daytime casualties. With nearly 35% of this building type extensively or completely damaged, they drive 16% of citywide heavily damaged buildings and contribute 13% of citywide direct financial losses. Given the damage profile of URM buildings (Over 35% of this type are URM) described above (Section 5.2.2), heavy on-street damage is expected, causing on-street causalities, and severely impacting the flow of (local, citywide, and regional) transportation along arterials. This will have severe impacts on community, neighbourhood, and citywide recovery.

The Ausenco Study shows that this typology carries many of the same risks as the residential buildings already reviewed within this study, namely URM and wood MURBs. These buildings, though, additionally lack strength and stiffness in storefronts, which can precipitate failures in the buildings more readily. The nature of commercial use does potentially ease the logistical challenges of building upgrade, as commercial use does not often take place for as many hours of the day as residential use.[lxxxiii]

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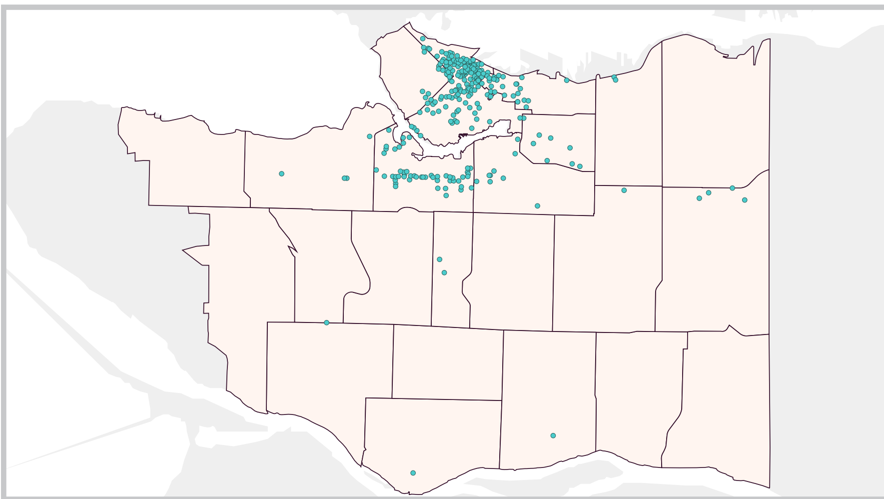
5.2.5 Concrete Mid- and High-Rise Commercial Buildings

Concrete mid- and high-rise commercial buildings are concrete commercial buildings having four or more storeys. These buildings account for less than one percent of the city's buildings, though contain nearly 8% (60,900) of the city's modelled daytime building occupants. These buildings take the form of office towers and mid-rise commercial buildings with various commercial occupancies. 53% of these buildings are located in Downtown, with an additional 10% located in Gastown, the Downtown Eastside, and Chinatown, and 18% located in Fairview. 71% of these buildings were constructed prior to 1990 and 42% prior to 1973.

Figure 5-7: Map of Concrete Mid- and High-Rise Commercial Buildings



Commercial mid- and high-rise concrete buildings contribute significantly to citywide risk, with 29% of buildings within the type extensively or completed damaged. These buildings contribute 8% of both daytime casualties (110) and long-term daytime building occupant disruption and displacement (28,400). Nearly half of all occupants are modelled to be disrupted and displaced for more than 90 days. Additionally, these buildings drive 6% of direct financial losses, though given their significant role in the local and regional economy, secondary economic losses will be significantly higher.

The Ausenco Study assessed the vulnerabilities of the over 650 pre-1990 mid- and high-rise concrete residential and commercial buildings. Typical vulnerabilities include an inadequate number of walls and lack of wall strength and ductility due to design standards enforced within older building codes. These vulnerabilities can lead to localised or complete building collapse. Commercial buildings may be able to be upgraded outside of normal work hours, or by upgrading portions of floors or groups of floors in a carefully staged and sequenced construction, to minimize displacement of tenants and building occupants.[lxxxiv]

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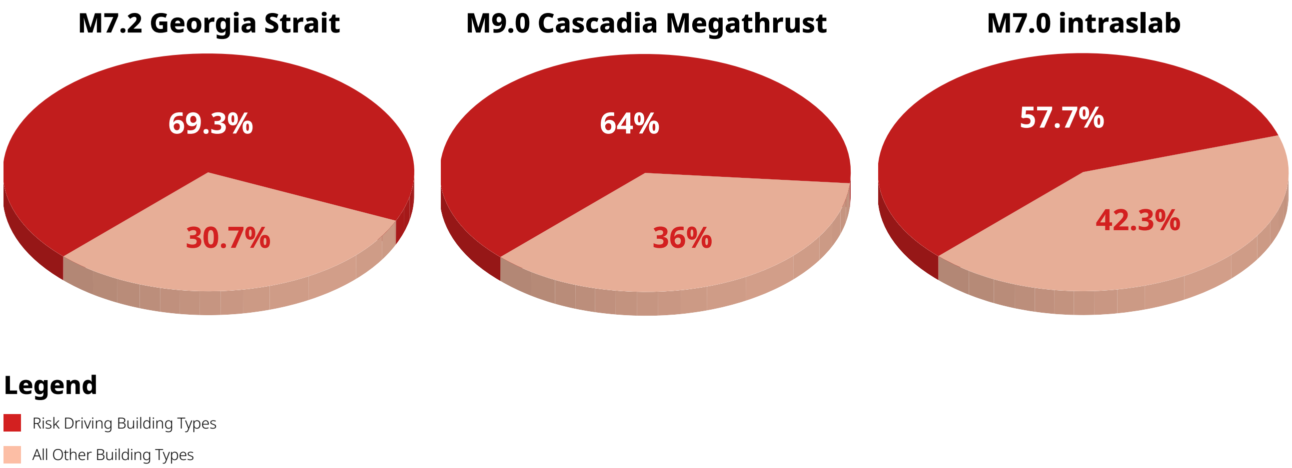
5.3 Risk-Driving Building Types and Supporting Earthquake Planning Scenarios

While this assessment's analysis of Vancouver's existing, privately owned buildings primarily considers the impacts from a M7.2 Georgia Strait planning scenario earthquake, this subsection will describe the primary differences in risk distribution amongst building types when examining the two supporting earthquake planning scenarios, the M7.0 Intraslab and M9.0 Cascadia Megathrust scenarios. To visualise a trend within these differences Figure 5-8 compares the casualty contribution, as a combination of daytime and nighttime severe injuries and fatalities, of risk-driving building types and all other building types.

Figure 5-8: Distribution of Casualties, All Building Types, Considering All Three Planning Scenario Earthquakes



While the distribution of seismic risk broadly shifts to a more diverse set of building types caused by an overall decrease in damage to wood MURBs, the majority of both causalities and disruption-displacement (See Figure 5-8 above) remains dominated by risk-driving building types in the supporting scenarios. One notable exception to this trend is the growing role of institutional-use buildings in contributing to daytime, long-term disruption and displacement within the supporting scenarios. Wood MURBs continue to drive at least a quarter of all residential disruption and displacement lasting more than 90 days, with high contributions from concrete mid- and high-rise MURBs and URM MURBs. The share of long-term residential disruption and displacement contributed by concrete low-rise and URM MURB's increases greatly in the M7.0 Intraslab scenario. Additionally, alongside concrete low-rise and URM MURBs, wood MURBs and concrete mid- and high-rise concrete MURBs drive around 95% of nighttime severe injuries and fatalities in the M7.0 Intraslab scenario. Overall, the role of risk-driving building types in driving the majority of seismic risk is consistent across the three planning scenarios, though the role of concrete low-rise and URM MURBs as well as institutional buildings show them to be an important focus when considering intraslab events from the southwest.

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6. At-Risk Neighbourhoods

Seismic risk is unevenly distributed throughout Vancouver.

At a high level, modelling shows that an average of 65% of citywide seismic risk is contributed by only six neighbourhoods. Using the neighbourhoods identified with Section 3.1.2, this section identifies the city's highest-risk neighbourhoods as well as additional areas of localised citywide risk contribution, in terms of the four focus metrics of daytime and nighttime severe injuries and fatalities and daytime and nighttime building occupant disruption and displacement lasting more than three months (See Section 3.1.5.1). Risk modelling results described within this section consider the impacts of the M7.2 Georgia Strait earthquake used as the main planning scenario for this assessment. The risk in these areas, either entire neighbourhoods or the many moderate- to high-risk Census tracts within neighbourhoods, is driven by high concentrations of at-risk building types. This section additionally provides summary findings of Census data sociodemographic analysis (Section 3.2.2.3) within each neighbourhood's moderate- to high-risk tracts, allowing the impacts of modelled building risk to be understood in terms of the building occupants impacted.

6.1 Identifying Highest-Risk Neighbourhoods and At-Risk Areas

Table 6-1 below, ordered by contribution to citywide residential severe injuries and fatalities, shows the citywide risk contributions across each of the four focus risk metrics for all Vancouver neighbourhoods. At a high level, this table shows that several neighbourhoods stand out in terms of their risk contribution, specifically Downtown, the Downtown Eastside, and the West End.

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Table 6-1: Citywide Seismic Risk Contribution, Vancouver Neighbourhoods, M7.2 Georgia Strait Planning Scenario Earthquake

Vancouver Neighbourhoods	Building Count (Percent of Citywide)	Percent of Citywide Total			
		Severe Injuries and Fatalities		Occupants Disrupted and Displaced for More than 90 Days	
		Nighttime	Daytime	Nighttime	Daytime
West End	920 (1.0%)	20.6%	8.6%	19.8%	10.1%
Downtown Eastside Plan Area	1,406 (1.6%)	19.5%	13.5%	10.1%	9.8%
Downtown	720 (0.8%)	10.2%	13.4%	10.8%	12.5%
Kitsilano	4,941 (5.5%)	9.4%	7.6%	11.3%	8.6%
Fairview	1,342 (7.3%)	7.3%	8.4%	10.6%	9.8%
Mount Pleasant	2,320 (3.6%)	4.9%	7.0%	6.7%	7.8%
Grandview-Woodland	3,821 (4.2%)	4.8%	5.7%	3.9%	4.32%
Arbutus Ridge	3,199 (3.6%)	3.3%	2.2%	2.8%	2.1%
Oakridge	2,497 (2.8%)	2.7%	1.3%	2.2%	1.4%
Marpole	3,867 (4.3%)	2.5%	2.6%	5.4%	4.34%
Kerrisdale	3,525 (3.9%)	2.0%	2.5%	2.1%	2.2%
West Point Grey	3,449 (3.8%)	1.7%	2.0%	1.8%	1.7%
Killarney	3,999 (4.4%)	1.5%	1.1%	1.5%	1.3%
Kensington-Cedar Cottage	9,227 (10.3%)	1.3%	3.7%	1.7%	4.5%
Riley Park	4,938 (5.5%)	1.1%	2.2%	1.3%	2.6%
Hastings- Sunrise	7,861 (8.7%)	1.1%	2.3%	1.2%	2.6%
South Cambie	1,444 (1.6%)	1.1%	1.8%	1.4%	1.6%
Sunset	6,885 (7.6%)	0.9%	2.7%	0.9%	2.9%
Dunbar- Southlands	6,175 (6.9%)	0.9%	3.2%	0.6%	1.7%
Victoria-Fraserview	5,943 (6.6%)	0.8%	2.3%	1.4%	2.6%
Shaughnessy	2,333 (2.6%)	0.8%	1.5%	1.0%	1.1%
Renfrew-Collingwood	8,888 (9.9%)	0.7%	2.2%	0.9%	2.8%
False Creek Flats	242 (0.3%)	0.7%	1.9%	0.5%	1.4%

The highlighted cells in Table 6-1 above indicate the leading contributors (i.e., leading two-thirds of each metric's citywide value; See Section 3.2.1) to each of the four focus metrics. Five neighbourhoods contribute to the leading two-thirds of all four focus metrics: The West End, The Downtown Eastside Plan Area, Downtown, Kitsilano, and Fairview. Following those, Mount Pleasant contributes heavily to citywide risk across three metrics. Finally, Kensington-Cedar Cottage contributes heavily to two metrics and both Marpole and Grandview-Woodland contribute heavily one risk metric. The remaining 15 neighbourhoods do not contribute to the leading two-thirds of seismic risk in any of the four focus risk metrics.

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Having contributed to the leading two-thirds of three out of the four focus risk metrics, the following neighbourhoods are considered highest-risk neighbourhoods and are examined in detail within Section 6.2:

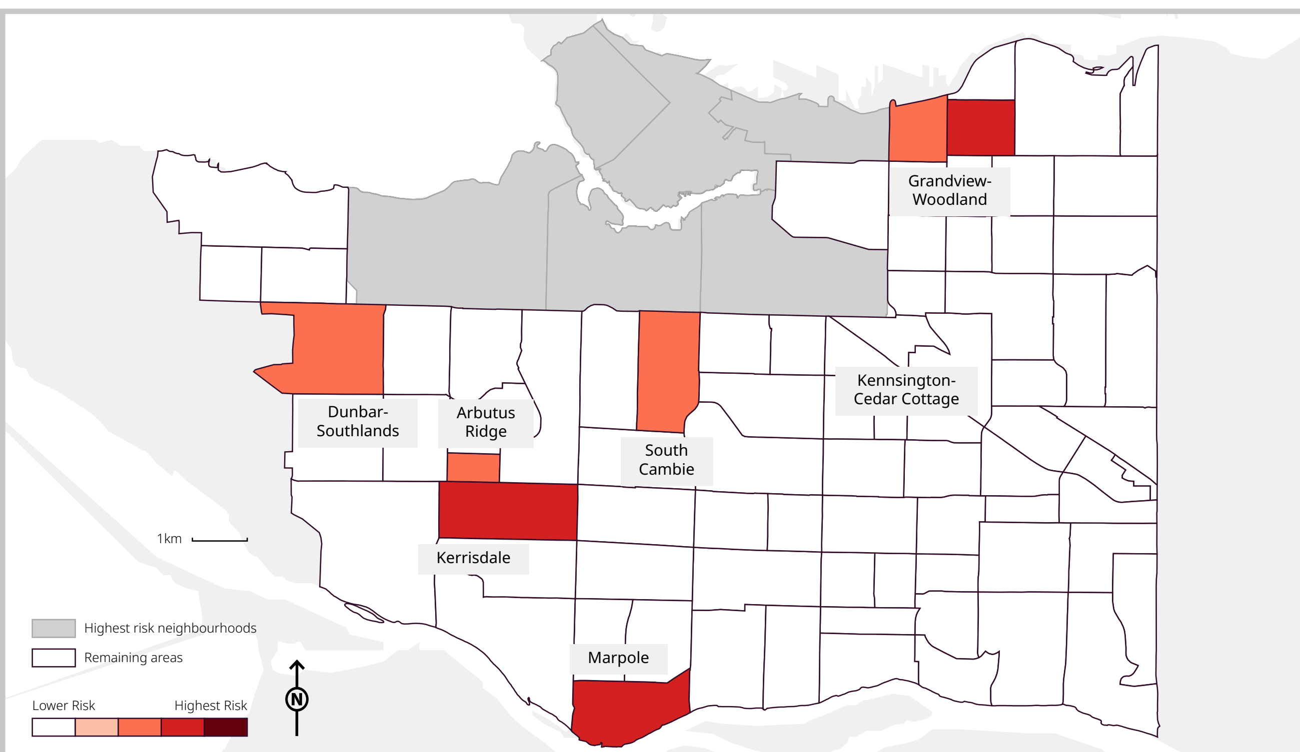
- The West End
- The Downtown Eastside Plan Area
- Downtown
- Kitsilano
- Fairview
- Mount Pleasant

Kensington-Cedar Cottage, which contains no moderate- to high-risk Census tracts, as well as Grandview-Woodland and Marpole, both of which contain moderate- to high-risk tracts, are significant to understanding the localised risk throughout the city and are examined as at-risk areas below in Section 6.3.

6.1.1 Additional At-Risk Areas

Identified through relative seismic risk mapping (See Section 3.2.2) there are seven moderate- to high-risk Census tracts located outside the six identified highest-risk neighbourhoods. These tracts, as seen highlighted in Figure 6-1 below, are found within the Grandview-Woodland, Marpole, Kerrisdale, South Cambie, Arbutus Ridge, and Dunbar-Southlands neighbourhoods. These tracts are considered at-risk areas and are examined in detail below in Section 6.3. Additionally, as seen in Table 6-1, there are neighbourhoods that significantly contribute to citywide risk, indicating the presence of many risk-driving buildings, yet do not contribute as highly across all metrics as other neighbourhoods.

Figure 6-1: Moderate-to High-Risk Census Tracts, Citywide Relative Seismic Risk Map, M7.2 Georgia Strait Earthquake



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There is one notable exception to the treatments of at-risk neighbourhoods and areas outlined thus far. False Creek Flats is a largely industrial area of Vancouver containing relatively few building occupants. The Census two tracts comprising the neighbourhood push beyond its city-designated bounds to include large amounts of buildings from Strathcona (Downtown Eastside Plan Area) to the north and Mount Pleasant to the south. As such, the relative risk contribution seen above (Figure 6-1) is much more highly reflective of the residential and non-residential building contribution from Strathcona and Mount Pleasant than buildings within the False Creek Flat's. The sociodemographic composition of these two Census tracts will be examined within Section 6.2.2 (Downtown Eastside) and 6.2.4 (Mount Pleasant).

6.1.2 Cordoning

Cordoning is a situation where entire neighbourhoods or large sections of the city experiencing high concentrations of building damage are closed by emergency responders to most or all access, meaning all buildings in the neighbourhood, damaged or undamaged, are inaccessible and uninhabitable for days, weeks, and sometimes months at a time. This measure is meant to preserve life safety of occupants, in the event of aftershocks or delayed collapse of heavily damaged structures. From past earthquakes, like the 2010-2011 Canterbury Earthquake Sequence,[lxxxv] we know this measure can last anywhere from months to years. The sections of Vancouver discussed below in Section 6.2, or portions thereof, may require such measures, as discussed below.

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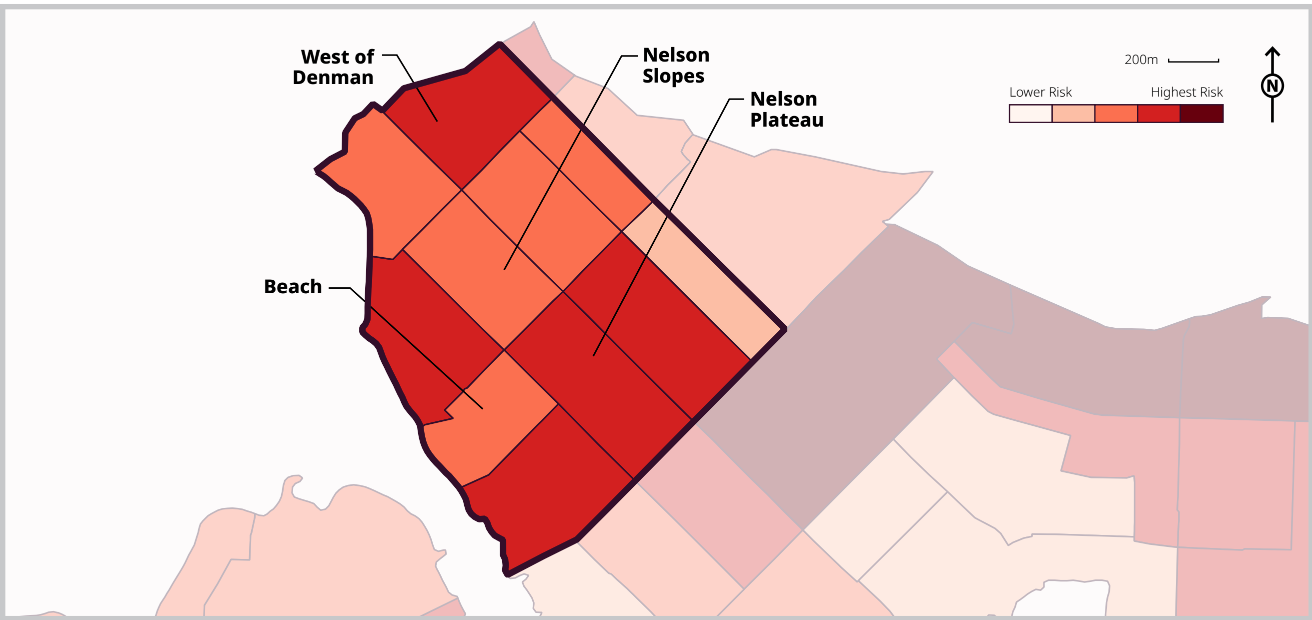
6.2 Highest-Risk Neighbourhoods

This section will discuss the city's highest risk neighbourhoods identified above in detail. These subsections will provide analysis of each neighbourhood's risk-driving building types and the sociodemographic characteristics of moderate- to high-risk Census tracts contained entirely or largely within each neighbourhood.

6.2.1 The West End

The West End is a dense downtown residential neighbourhood with a population of around 45,000 residents, located directly adjacent to Vancouver's Downtown central business district. The neighbourhood is characterised by the city's highest concentration of housing, primarily located in the Nelson Slopes-Plateau, West of Denman, and Beach subareas of the neighbourhood. Additionally, the neighbourhood contains three commercial cores located along Davie, Denman, and Robson Streets.

Figure 6-2: Seismic Risk in The West End, M7.2 Georgia Strait Planning Scenario Earthquake



The West End's building stock is dominated by over 350 concrete mid- and high-rise MURBs and over 275 wood-framed MURBs located within the three aforementioned residential subareas. Across all building types, the average construction year of buildings in the West End is nearly a decade older (1959) than the city as a whole (1967), reflecting the neighbourhood's history of rapid densification in the form of MURBs servicing the quickly growing Downtown worker population in the 1950s and 1960s.

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Modelling shows the West End is the highest risk neighbourhood in the city in terms of residents disrupted and displaced for more than 90 days and nighttime severe injuries and fatalities. Twenty percent of both citywide residents disrupted and displaced for more than 90 days (45,800) and citywide residential severe injuries and fatalities (nearly 130) are in the West End. Driving these findings, 36% of the neighbourhood's approximately 900 buildings are modelled to be extensively and completely damaged, leading to 95% of the neighbourhood's population modelled to be disrupted and displaced for more than 90 days. This modelled disruption and displacement figure does not consider cordoning. Additionally, early findings from the Ausenco Study have determined that there is a significant potential for partial or complete building collapses as well. Given this extent of damage, as well as the modelled consequences of this damage, it is possible that a high level of cordoning will be required in the West End.

275 concrete mid- and high-rise MURBs located in the Beach, West of Denman, and Nelson Slopes-Plateau subareas are significant drivers of both neighbourhood and citywide risk. These buildings contribute around 10% (25,200) of citywide long-term residential disruption and displacement and over half of the neighbourhood's long-term residential disruption and displacement. Additionally, they are also modelled to contribute over half of the neighbourhood's residential severe injuries and fatalities. Wood MURBs in these subareas, highly concentrated in Nelson Slopes-Plateau (51% of West End wood MURBs), are significant contributors to West End's risk as well, disrupting and displacing nearly 9,600 residents.

Sociodemographic analysis of the nine moderate- to high-risk Census tracts within the West End shows that the impacts of the seismic risk in the neighbourhood will significantly fall on those residents who also face the most barriers to recovery. Specifically, these tracts are, on average, comprised of 80% renters, of which nearly 20% are low income, nearly 15% are seniors, over 30% identify as visible minorities, and 3% are Indigenous Peoples. Additionally, 4% of renter households contain at least one child aged 5 and under and nearly 20% of renters reported experiencing consistent activity limitations in their daily life. The rate of renters is nearly 30% higher than the citywide rate and the medium income for renters is $10,000 lower than the citywide median.

In addition to the neighbourhood's seismic risk, it is critical to note that the 2013 West End Plan[lxxxvi] guides the West End's redevelopment and many of the buildings discussed above contain displacement-sensitive, affordable purpose-built rental units. The West End Plan includes a policy to "maintain the character of the four residential neighbourhoods while providing additional opportunities for new laneway infill rental housing."[lxxxvii] As a result, building redevelopment opportunities are lower within the higher-risk subareas of Nelson Slopes-Plateau, West of Denman, and Beach while greater along the Georgia and Burrard corridors where redevelopment to greater heights and densities is enabled.

6.2.2 The Neighbourhoods of the Downtown Eastside Plan Area

The Downtown Eastside Plan Area (henceforth, "the plan area" or "the area") contains the dense residential and commercial neighbourhoods located to the east of the Downtown Central Business District, extending along Hastings Street to include Gastown-Victory Square, Chinatown, and the Downtown Eastside itself (i.e, the Oppenheimer District, henceforth "the Downtown Eastside"), as well as Port of Vancouver-adjacent industrial areas and Strathcona.[lxxxviii]

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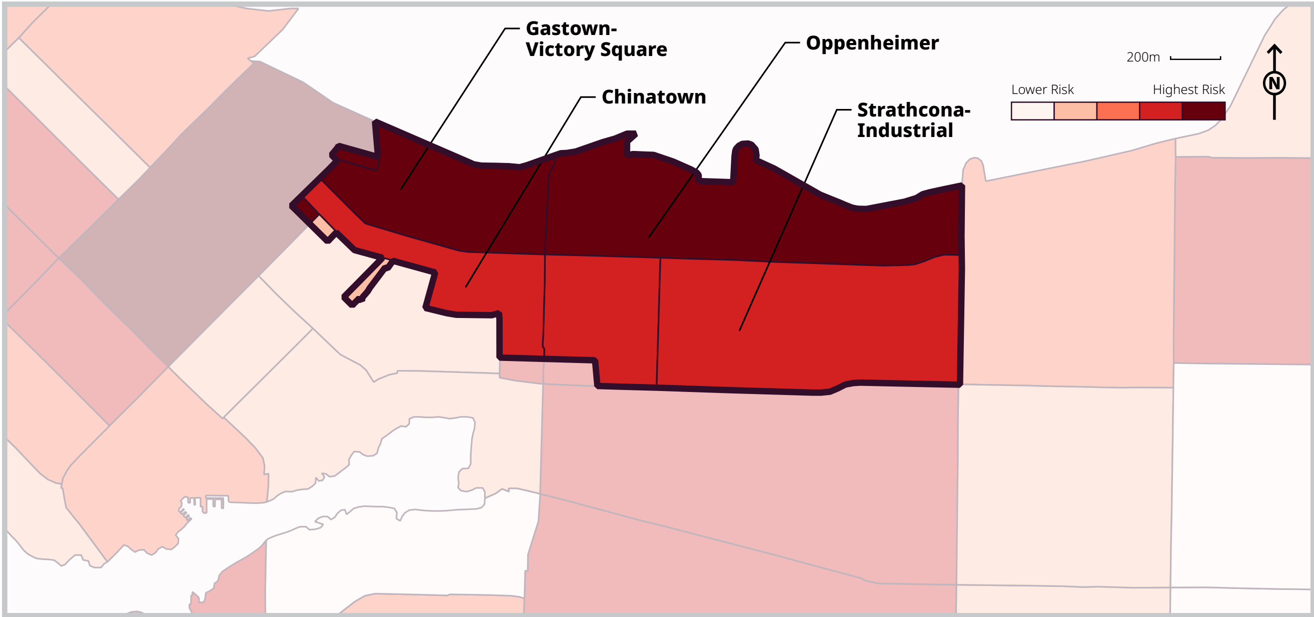
Figure 6-3: Seismic Risk in the Downtown Eastside, M7.2 Georgia Strait Planning Scenario Earthquake



Being an historic section of Vancouver, the area is characterised by both URM MURBs as well as URM, wood, and low-rise concrete commercial buildings, with two-thirds (around 400, average construction year of 1929) of Downtown Eastside, Chinatown, and Gastown-Victory Square buildings being URM buildings. Continuing further east along Hastings Street, there are many older industrial buildings (average construction year of 1960) located adjacent to the Port of Vancouver and many older detached homes (average construction year of 1934) in Strathcona, housing many Chinatown community members[lxxxix].

Plan area neighbourhoods drive 20% (120) of nighttime severe injuries and fatalities and 10% (23,200) of long-term residential disruption and displacement, making the Downtown Eastside Plan Area the second most at-risk area in the city. 22% (1,400) of plan area buildings are modelled to be extensively and completely damaged. Driven by the high concentration of URM buildings, the plan area also has the highest residential severe injury and fatality rate (i.e., percentage of residents) of all neighbourhoods considered in this assessment.

Amongst the area's neighbourhoods, the Downtown Eastside and Gastown-Victory Square drive the majority of these risks, contributing nearly 75% of the area's long-term residential disruption and displacement and 80% of the area's severe injuries and fatalities. These two neighbourhoods are also within two of the city's highest risk Census tracts, making them amongst the most risk-concentrated areas within the city overall. Many of the city's single room occupancy (i.e., SRO) units are within URM buildings concentrated within the Downtown Eastside. Additional nighttime severe injuries, fatalities, and long-term disruption and displacement is contributed from Strathcona, containing several wood and URM MURBs.

Plan area neighbourhoods also account for 14% (185) of citywide daytime casualties and 10% (35,700) of citywide long-term daytime disrupted and displaced occupants, largely driven by the area's approximately 150 industrial buildings and nearly 400 URM, wood, and low-rise concrete commercial buildings (average construction year of 1935). Gastown-Victory Square and the Downtown Eastside contribute over 75% of the neighbourhood's daytime casualty and long-term disruption and displacement contributions. In Chinatown, URM, wood, and low-rise concrete commercial buildings and URM MURBs (around 75% of Chinatown's 150 buildings), both containing many historic and neighbourhood-serving businesses, are significant contributors to neighbourhood risk.

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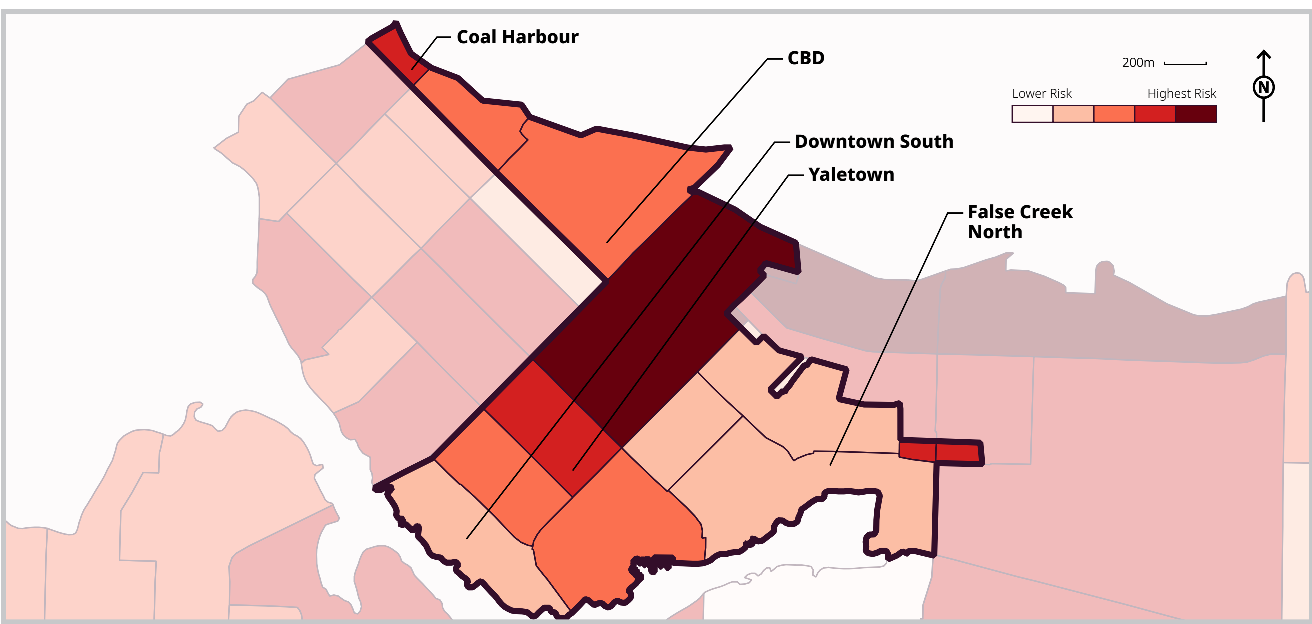
Sociodemographic analysis of the plan area's five moderate- to high-risk Census tracts shows the area is, on average, comprised of nearly 80% renters, and of those renters 35% are low-income, nearly 20% are seniors, 40% identify as visible minorities, and 12% are Indigenous Peoples. Additionally, 3% of renter households contain at least one child aged 5 or under and 31% of renters reported experiencing consistent activity limitations in their daily life. The rate of renters is nearly 30% higher than the citywide rate and the medium income for renters is around half the citywide median. Overall, this analysis shows that the impacts of the risks discussed above will significantly fall on those residents who also face the greatest barriers to recovery.

With one in five buildings in the area extensively or completely damaged, two-thirds of which are concentrated in the Downtown Eastside itself, Gastown-Victory Square, and Chinatown, there is a high potential for cordoning in these neighbourhoods. Also, given the extent of damage, the high population density in these areas, and the risks particular to URM buildings, there is an additional high potential for sidewalk and on-street injuries and fatalities. And finally, with Hastings and Main streets both serving as critical arteries throughout the city and region, severe on-street impacts will additionally disrupt the critical flow of transportation and emergency responders, delaying hindering response and delaying recovery.

6.2.3 Downtown

Downtown Vancouver includes, amongst others, the Central Business District (CBD), Granville Street, and Coal Harbour neighbourhoods of the Downtown peninsula, including Yaletown and the more recent development areas of Downtown South and False Creek North. It is bound to the west by Stanley Park and the West End and to the east by the Downtown Eastside Plan Area.

Figure 6-4: Seismic Risk in Downtown, M7.2 Georgia Strait Planning Scenario Earthquake



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Downtown is characterised by a diversity of building types, with a high concentration of concrete mid- and high-rise residential and commercial buildings as well as URM, wood, and low-rise concrete commercial buildings. Along Granville and in Yaletown, many low-rise commercial buildings are much older (average construction year around 1935), where the CBD is mixed with both older URM, wood, and low-rise concrete commercial buildings as well as both newer and much older commercial towers. Additionally, Coal Harbour and both Downtown South and False Creek North (excluding Granville and Yaletown) are areas where formerly industrial and commercial buildings have been replaced by large concrete mid- and high-rise MURBs built largely after 1990.

30% of Downtown's diverse stock of buildings (210) are modelled to be extensively or completely damaged, driving 10% (60) of citywide nighttime casualties and 13% (185) of daytime casualties. The neighbourhood drives over 10% of both citywide long-term nighttime (24,800) and daytime (45,600) building occupant disruption and displacement, respectively. This level of disruption amounts to 64% of resident disrupted and displaced for longer than 90 days. With high concentrations of damage from concrete mid- and high-rise concrete buildings as well as URM, wood, and low-rise concrete commercial buildings throughout Downtown, a high volume of debris falling into the streets from buildings is expected. This has a high potential of causing sidewalk and on-street injuries and fatalities, particularly in the CBD, along Granville, and in Yaletown. High levels of building debris can also disrupt the critical flow of both local and regional transportation, delaying emergency response and recovery. Overall, this level of risk in Downtown has the high potential of severely impacting the city and region's primary hub of social and economic activity.

Heavily driving that risk, the Census tract comprising most of the CBD alone accounts for around 7% of both citywide daytime causalities (95) and long-term building occupant disruption and displacement (22,700). Risk in Downtown is highly driven by the area's older (average construction year around 1965) concrete mid and high-rise commercial buildings, resulting in over 17,200 daytime building occupants to be disrupted and displaced for over three months. Another significant driver of risk, particularly for the CBD, Yaletown, and along Granville Street, are the neighbourhood's nearly 200 URM, wood, and low-rise concrete commercial buildings (average construction year around 1945). Additionally, while many of Downtown's over 200 concrete mid- and high-rise residential buildings were built more recently (average construction year around 1995), these densely populated buildings are responsible for nearly 19,500 (around 8% of citywide) neighbourhood residents disrupted and displaced for more than three months.

Sociodemographic analysis of the Downtown's six moderate- to high-risk Census tracts shows an average composition of 60% renters, of which nearly 20% are low-income, nearly 10% are seniors, over 45% identify as visible minorities, and 2% are Indigenous Peoples. Additionally, 6% of renter households contain at least one child aged 5 or under and 15% of renters reported experiencing consistent activity limitations in their daily life. The rate of renters is around 15% higher than the citywide rate and the medium income for renters is nearly $15,000 higher than the citywide median.

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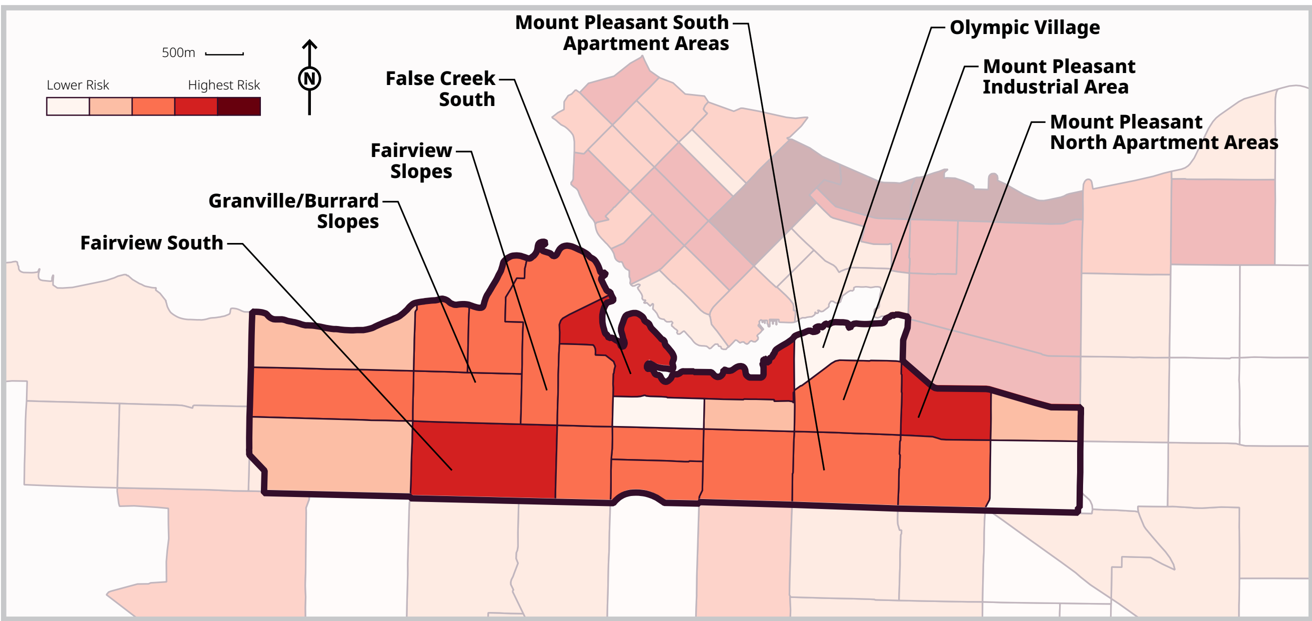
6.2.4 Kitsilano, Fairview, and Mount Pleasant

This subsection describes the seismic risk within the final three highest-risk neighbourhoods: Kitsilano, Fairview, and Mount Pleasant. Together, these three adjacent neighbourhoods located just south of Downtown function as dense concentrations of residents and commercial activity. They are also the focus of the 2022 Broadway Plan, a 30-year plan focused on the opportunities to integrate new housing, jobs, and amenities around the new Broadway Subway. This subsection will use the sub-neighbourhood names from that plan to assess risk in the neighbourhoods' 8,600 (around 10% citywide) buildings. Collectively, these neighbourhoods contribute an average of 25% of citywide daytime and nighttime casualties and daytime and nighttime long-term disruption and displacement.

Figure 6-5: Seismic Risk in Kitsilano, Fairview, and Mount Pleasant, M7.2 Georgia Strait Planning Scenario Earthquake



Sociodemographic analysis of 16 moderate- to high-risk Census tracts, across all three neighbourhoods, shows an average composition of 60% renters, of which an average of 14% are low income, 9% are seniors, 25% identify as visible minorities, and 3% are Indigenous Peoples. Additionally, 5% of renter households contain at least one child aged 5 or under and nearly 20% of renters reported experiencing consistent activity limitations in their daily life. The rate of renters is around 15% higher than the citywide rate and the medium income for renters is around $5,000 higher the citywide median. These 16 moderate- to high-risk tracts are home to over one-quarter of the city's market rental units, with the highest concentration (amongst these neighbourhoods) located in Fairview (over 7,000 units in its 1,300 buildings).

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6.2.4.1 Kitsilano

Kitsilano, located just to the west of Fairview, is much larger than both Fairview and Mount Pleasant, containing over 4,900 buildings. Over 3,900 of these buildings are detached homes located throughout large sections of the neighbourhood. Kitsilano's dense apartment districts are located east of Larch Street, north of Broadway, south of Broadway, and east of Vine Street. Additionally, Kitsilano contains a small area of concrete mid- and high-rise residential buildings near Arbutus Street and Broadway (i.e., Broadway-Arbutus South), the upcoming terminus of the Broadway subway line extension. Fourth Street and Broadway both contain many URM, wood, and low-rise concrete commercial buildings, with an additional number of wood MURBs in Kitsilano.

Kitsilano drives around 9% of both citywide residential casualties (60) and long-term residential disruption and displacement (26,100), with the neighbourhood's 725 MURBs driving nearly all of that risk. Specifically, the neighbourhood's 570 wood MURBs (average construction year of 1966) drive 71% of neighbourhood long-term disruption and displacement and 44% of neighbourhood nighttime severe injuries and fatalities, while nearly 80 concrete mid- and high-rise residential buildings (average construction year of 1992) drive an additional 21% and 39%, respectively, of neighbourhood risk. Additionally, Kitsilano's 230 URM, wood, and low-rise concrete commercial buildings drive around 30% each of the neighbourhood's daytime severe casualties and long-term disruption and displacement, while institutional-use buildings contribute 27% of daytime casualties and 15% of daytime long-term disruption and displacement.

6.2.4.2 Fairview

Fairview, located just east of Kitsilano and adjacent to Mount Pleasant to its east, is characterised by apartment districts mostly comprised of wood MURBs and several commercial districts. Unlike both Mount Pleasant and Kitsilano, Fairview contains very few detached homes. Fairview also contains Vancouver General Hospital and a section of Vancouver's City Hall complex (City Hall is itself located in Mount Pleasant, on the east side of Cambie Street).

Fairview's 1,300 buildings drive 7% (45) and around 11% (24,500) of citywide residential casualties and long-term residential disruption and displacement (respectively), with the largest contribution to this risk coming from the 570 wood MURBs (average construction year of 1967) primarily located in Fairview South and Fairview Slopes. These MURBs drive over 36% of the neighbourhood's nighttime severe injuries and fatalities and 60% of long-term residential disruption and displacement. Fairview's risk is also driven by over 100 concrete mid- and high-rise concrete residential buildings (average construction year of 1986), contributing 47% of neighbourhood nighttime severe injuries and fatalities and 34% of nighttime long-term disruption and displacement.

The over 300 URM, wood, and low-rise concrete commercial buildings located along both Broadway and Granville Street and within the Granville-Burrard Slopes at the base of the Granville Bridge drive 30% of neighbourhood long-term daytime building occupant disruption and displacement and 41% of daytime severe injuries and fatalities. Fairview also contains the city's highest concentration of concrete mid- and high-rise commercial buildings outside of Downtown. Additionally, the neighbourhood is home to both Granville Island, comprised of several older industrial and commercial buildings, and the residential neighbourhood of False Creek South, comprised of many pre-1990 wood and concrete mid-rise MURBs. These areas comprise the neighbourhood's highest-risk tract.

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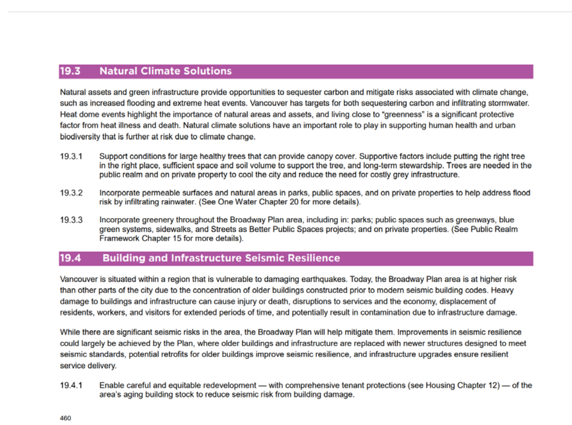
6.2.4.3 Mount Pleasant

Mount Pleasant is located to the southeast of Downtown, to the south of the city's railyard industrial areas located in the False Creek Flats and to the east of Fairview. It contains two dense apartment districts, of which the Mount Pleasant North Apartment Areas, located between Broadway and Great Northern Way, house around 25% of neighbourhood residents. The other, the Mount Pleasant South Apartment Areas, located on either side of Main Street to the south of Broadway, are home to around 20% of neighbourhood residents. In addition to the three arterial commercial cores of Broadway, Main Street, and Kingsway, there is also the Mount Pleasant Industrial Area. This light industrial area, which is quickly redeveloping, contains many older industrial buildings mixed in with new office buildings. Finally, the neighbourhood also contains Olympic Village to the northwest, a dense concentration of much newer (average construction year of 2001) concrete mid-rise residential buildings, and over 1,100 detached homes within the neighbourhood's south and east.

Mount Pleasant's 2,300 buildings drive 5% (30) of citywide nighttime casualties and 7% (15,400) of long-term residential disruption and displacement, with the neighbourhood's North and South Apartment Areas driving 54% and 70% (respectively) of that risk. Within these apartment districts and throughout the neighbourhood, over two-thirds of neighbourhood risk is driven from wood MURBs (average construction year of 1971). Additionally, 26% of neighbourhood daytime long-term disruption and displacement is driven by URM, wood, and low-rise concrete commercial buildings, many of which are located along Broadway, Main Street, and Kingsway, as well as industrial buildings, located largely within the Mount Pleasant Industrial Area.

6.2.4.4 The 2022 Broadway Plan

The Broadway Plan, covering many sections of Mount Pleasant, Fairview, and Kitsilano, sets out a land use vision for the areas surrounding the Broadway Subway, the 5.7-kilometre-long Millennium Line extension to Arbutus Street in Kitsilano. In addition to densification and sustainability concerns, the plan focuses on the high degree of seismic risk in the area and the role that replacement of older earthquake-prone structures has in reducing that risk.[xc] The plan also calls for additional neighbourhood scale risk reduction planning, indicating the importance of assessing and reducing the area's seismic risk in existing buildings, in addition to redevelopment.



19.3 Natural Climate Solutions

Natural assets and green infrastructure provide opportunities to sequester carbon and mitigate risks associated with climate change, such as increased flooding and extreme heat events. Vancouver has targets for both sequestering carbon and infiltrating stormwater. Heat dome events highlight the importance of natural areas and assets, and living close to "greenness" is a significant protective factor from heat illness and death. Natural climate solutions have an important role to play in supporting human health and urban biodiversity that is further at risk due to climate change.

19.3.1 Support conditions for large healthy trees that can provide canopy cover. Supportive factors include putting the right tree in the right place, sufficient space and soil volume to support the tree, and long-term stewardship. Trees are needed in the public realm and on private property to cool the city and reduce the need for costly grey infrastructure.

19.3.2 Incorporate permeable surfaces and natural areas in parks, public spaces, and on private properties to help address flood risk by infiltrating rainwater. (See One Water Chapter 20 for more details).

19.3.3 Incorporate greenery throughout the Broadway Plan area, including in: parks; public spaces such as greenways, blue green systems, sidewalks, and Streets as Better Public Spaces projects; and on private properties. (See Public Realm Framework Chapter 15 for more details).

19.4 Building and Infrastructure Seismic Resilience

Vancouver is situated within a region that is vulnerable to damaging earthquakes. Today, the Broadway Plan area is at higher risk than other parts of the city due to the concentration of older buildings constructed prior to modern seismic building codes. Heavy damage to buildings and infrastructure can cause injury or death, disruptions to services and the economy, displacement of residents, workers, and visitors for extended periods of time, and potentially result in contamination due to infrastructure damage.

While there are significant seismic risks in the area, the Broadway Plan will help mitigate them. Improvements in seismic resilience could largely be achieved by the Plan, where older buildings and infrastructure are replaced with newer structures designed to meet seismic standards, potential retrofits for older buildings improve seismic resilience, and infrastructure upgrades ensure resilient service delivery.

19.4.1 Enable careful and equitable redevelopment — with comprehensive tenant protections (see Housing Chapter 12) — of the area's aging building stock to reduce seismic risk from building damage.

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Significantly, the Broadway Plan includes several of the city's densest affordable rental housing areas. As seen above, the Broadway Plan's rental buildings are largely pre-1973 wood MURBs, putting them at high risk of damage extensive enough to render them uninhabitable. Heavily damaged wood MURBs, as noted within early returns from the Ausenco Study, will likely lead to demolition, causing long-term and even permanent displacement of residents.[xci] Within the plan, where redevelopment of existing rental housing was enabled, new enhanced tenant protections and affordability requirements in new buildings were key policy directions to mitigate negative impacts of redevelopment on existing renters and to avoid permanent displacement from their neighbourhoods.[xcii]

6.3 Additional At-Risk Areas

Outside of the six highest-risk neighbourhoods examined above, there are several at-risk areas of concentrated seismic risk throughout the city. These areas are found within seven moderate- to high-risk Census tracts (See Section 6.1.1) located throughout the city as well as three neighbourhoods: Grandview-Woodland, Marpole, and Kensington-Cedar Cottage. While these three neighbourhoods do not contribute a strongly to citywide risk as the highest-risk neighbourhoods above, they still warrant closer review. Sections of these neighbourhoods will be examined below as at-risk areas, followed by the seven moderate- to high-risk tracts located within the South Cambie, Kerrisdale, Arbutus Ridge, and Dunbar-Southlands neighbourhoods.

6.3.1 Grandview-Woodland

Grandview Woodland, bordering Strathcona, False Creek Flats to the west, and the Port of Vancouver to the north contains two moderate- to high-risk tracts. These tracts, spanning the entirety of the neighbourhood to the north of Venables and Adanac Streets, are characterised by a high concentration of industrial buildings as well as wood and concrete low-rise MURBs. While concrete low-rise MURBs do not contribute as significantly as other MURBs to citywide risk, they drive a significant portion of risk in these two tracts, contributing nearly 70% of residential severe injuries and fatalities and half of long-term residential disruption and displacement. Industrial and URM, wood, and low-rise concrete commercial buildings are significant contributors here as well, driving over 60% of daytime severe injuries and fatalities and nearly half of long-term daytime building occupant disruption and displacement.

6.3.2 Marpole

Marpole, the city's southernmost neighbourhood, bordering the Fraser River, contains one moderate- to high-risk Census tract. The neighbourhood is known for the area surrounding the Canada Line Skytrain station, but this tract, located between Granville and Cambie streets to the south of West 70th Avenue (to the river), is characterised by over 200 wood MURBs (over 60% of all tract buildings). Additionally, the tract contains an additional 50 industrial buildings mostly located to the south of Marine Drive. Wood MURBs drive most of the tract's risk, with industrial, institutional, and URM, wood, and low-rise concrete commercial buildings contributing lower portions of the neighbourhood's severe injuries, fatalities, and long-term building occupant disruption and displacement. Significantly, 85% of residents within these wood MURBs are renters – will above the citywide average.

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6.3.3 Kensington-Cedar Cottage

Kensington-Cedar Cottage is a largely detached-home residential neighbourhood in East Vancouver, bisected by Kingsway, a large regional arterial road lined by URM, wood, and low-rise concrete commercial buildings and MURBs. The detached home nature of Kennington leads many of the tracts within it to appear lower risk, while the neighbourhood's population of around 200 commercial buildings, 50 school and community buildings, and over 200 MURBs contribute significantly to citywide risk. Specifically, as seen in Table 6-1 above, Kensington contributes to nearly 5% (16,500) of citywide long-term disrupted and displaced building occupants and nearly 4% (50) of citywide daytime casualties.

6.3.4 South Cambie

South Cambie's single moderate- to high-risk Census tract is bounded by Oak and Cambie Streets, extending through the mostly detached homes (Over 90% of tract buildings) of the neighbourhood from West 16th to West 33rd Avenues. The tract includes a large hospital complex, containing the B.C. Women's Hospital & Health Centre and the B.C. Children's Hospital, as well several schools and several wood MURBs along Cambie and Oak Streets and West 16th Avenue. The risk in this tract is heavily driven by those wood MURBs, driving 60% of tract residential risk, as well as the many institutional use buildings located throughout the tract.

6.3.5 Arbutus Ridge and Kerrisdale

The largely detached home neighbourhoods of Arbutus Ridge and Kerrisdale contain two moderate- to high-risk tracts, with one in each neighbourhood centred at the intersection of West 41st Avenue and the Arbutus Greenway. Most residential risk across both tracts is driven by approximately 50 concrete mid- and high-rise MURBs and 100 wood MURBs that characterise the areas between Larch Street and the Arbutus Greenway (between West 37th and West 45th avenues). These dense residential areas surround the 41st Avenue commercial core, where risk is driven by over 50 URM, wood, and low-rise concrete commercial buildings.

6.3.6 Dunbar

Dunbar, as well as the neighbourhood's one moderate- to high-risk tract is characterised (98% of tract buildings) by detached homes, though a small count of MURBs and institutional use buildings are located within this tract. Neighbourhood daytime severe injuries, fatalities, and disruption and displacement is driven largely (Average of 75%) by institutional use buildings. While schools and government buildings are not the focus of the risk reduction planning driving this assessment, as they are subject to government assessment and evaluation programs, it is important to note the impact they have on localised and neighbourhood risk.

6.4 Localised Impacts of Other Planning Scenarios

While this assessment's analysis of Vancouver's existing, privately owned buildings primarily considers the impacts from a M7.2, Georgia Strait earthquake planning scenario, this subsection will describe the primary differences in distribution of risk amongst neighbourhoods when examining the two supporting earthquake planning scenarios: the M7.0 Intraslab and M9.0 Cascadia Megathrust scenarios. To visualise a trend within these differences Figure 6-6 compares the casualty contribution, as a combination of daytime and nighttime severe injuries and fatalities, of highest-risk neighbourhoods and all other Vancouver neighbourhoods.

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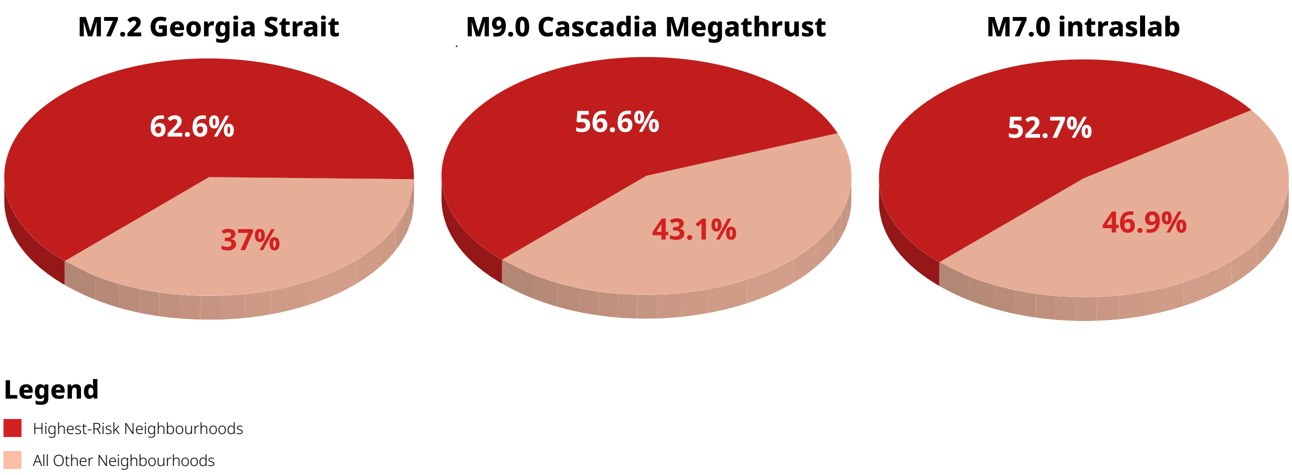
Figure 6-6: Distribution of Casualties, All Neighbourhoods, Considering All Three Planning Scenario Earthquakes



These graphs combine both daytime and nighttime severe injuries and fatalities to more simply visualise the relative share of casualties amongst all building types when considering three earthquake planning scenarios.

The changes in distribution of risk amongst neighbourhoods seen in Figure 6-6 above are driven by changes in the risk contribution from various building types (as seen in Section 5.3). Though there is a redistribution of risk, from highest-risk neighbourhoods to a more even distribution throughout the city, the six highest-risk neighbourhoods identified above continue to dominate risk contribution across all three planning scenario earthquakes. One notable exception is daytime long-term disruption and displacement, where the share of risk shifts from the highest-risk neighbourhoods to less dense neighbourhoods further from Downtown in the Intraslab scenario. Additionally, neighbourhoods with wood MURBs saw decreases in risk share (e.g., the West End) where neighbourhoods with high concentrations of URM buildings saw increasing shares of risk (e.g., the Downtown Eastside). Despite changes in risk distribution, the identified highest-risk neighbourhoods drive around 70% of residential causalities and near or above half of daytime casualties in the Intraslab scenario. Overall, while the two supporting scenarios show changes in the spatial distribution of risk the six highest-risk neighbourhoods continue contribute the majority of citywide seismic risk across all three planning scenarios.

7. Conclusion - Seismic Risk Reduction

The analysis within this report presents a clear picture of the impacts of a large earthquake on Vancouver.

The risk of fatalities, long term displacement, and both direct and long-term economic losses threaten Vancouver communities, residents, and businesses. The risks described in this assessment will also impact the city's ability to effectively and quickly respond to and recover from a large earthquake, only compounding the risk Vancouver faces. Several neighbourhoods, including the West End, Downtown, and the Downtown Eastside, will likely see cordoning lasting months - if not longer - and most of the city's more affordable housing stock and many small businesses will be permanently lost. Those most impacted will also be the least able to prepare and reduce risk. Overall, a large earthquake is one of the most significant risks to public safety Vancouver faces, but it is a risk that is well understood following detailed risk assessment and analysis.

This assessment, in addition to describing the consequences of a large earthquake, prioritises several areas of the city and several specific types of buildings, notably concrete mid- and high-rise multiunit residential buildings, URM and wood multiunit residential buildings, and URM, wood, and low-rise concrete commercial buildings. These findings enable the work of seismic risk reduction to being and to be undertaken more precisely and carefully. This is particularly important given existing challenges in maintaining a supply of affordable and safe housing in Vancouver.

Seismic risk reduction action need not be taken all at once. It can start with small, strategic actions in a limited number of highest-risk buildings and in a limited set of at-risk areas of the city. Small actions that quickly build on existing City policies and programs have the added advantage of promoting awareness and positioning the City well to pursue additional senior government funding and tools in support of further, more challenging risk reduction action. The sooner Vancouver begins to take action to reduce risk, even if initially modest, the less challenging it will be to protect residents and ensure recovery in the long term.

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