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An earthquake scenario catalogue for Canada: a guide to using scenario hazard and risk results

T.E. Hobbs[1,2], J.M. Journeay[1], and D. Rotheram[1]

[1]Geological Survey of Canada, 1500-605 Robson Street, Vancouver, British Columbia
[2]Department of Earth, Ocean, and Atmospheric Sciences, University of British Columbia, 2020-2207 Main Mall, Vancouver, British Columbia

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Abstract

As part of the national Canadian Seismic Risk Model, a collection of earthquake hazard and risk scenarios has been created and will be documented in a series of Open Files and other publications. This first document will help a user in interpreting and understanding raw scenario outputs, without any technical, pre-requisite skills. A future document will help orient a technical user seeking to run their own earthquake scenarios, by introducing the input files and a strategy for running the OpenQuake (OQ) Engine for Canadian earthquake scenarios. Other documents will help nontechnical users interact with the model and understand how it can be used for disaster risk reduction in Canada.

Following the first release of scenarios, tentatively scheduled for June 2021, all files will be accessed through the OpenDRR GitHub project page as they become available: <https://github.com/OpenDRR/earthquake-scenarios>.

The raw scenario outputs, formatted as comma-separated value (csv) files, contain information about economic losses, building damage, casualties, and other disruptive impacts. All of the impacts are referenced to a unique asset ID, which can be tied to census geographic divisions or latitude/longitude coordinates for plotting. This paper documents all outputs of these models with sufficient detail for a user to begin exploring the results.

1. Introduction

The National Earthquake Risk Profile for Canada will include probabilistic and deterministic risk assessments, made uniformly across the country. The deterministic portion is comprised of a catalogue of scenario earthquakes, created with a consistent methodology for representative earthquake source zones across Canada and presented for the first time herein.

Earthquake scenarios can provide insights into what and who will be impacted by a particular fault rupture. They can illuminate startling susceptibilities and gaps in our preparedness, or highlight our community successes in mitigating risk and strengthening our resilience. Most importantly, scenarios create a narrative that people can place themselves within. It helps us digest abstract or difficult ideas by imagining how earthquake events interact with our own reality. In fact, Lok et al. (2019) found that Vancouverites are more likely to take risk-reducing actions if presented with imagery of earthquake damage than with statistics alone. Thus, the use of narrative and imagery alongside these scenarios is likely to be an efficient tool for communicating risk to special interest groups and the public.

Unfortunately, scenario models are typically created for a single event or a limited region of interest, with different input variables and approaches. Without open access to scenario results calculated using large, uniform datasets, municipalities, provinces, or other stake-holders must pay large sums for such analyses, without the ability to compare between studies or regions. For these reasons, the Geological Survey of Canada (GSC) has created a catalogue of earthquake scenarios, presented in this document. Scenarios are freely available online. The datasets and functions used in the modelling are national and uniformly implemented, so risks may be compared between regions and ruptures. For most users, a full technical understanding of the OQ engine, including these input parameters, is not needed. Accordingly, this section is aimed at a user who wishes only to know how to extract relevant content from an earthquake scenario in the catalogue. Following this introduction (Section 1), Section 2 describes the files that are generated for each scenario, Section 3 outlines the types of information that are contained within those files, and Section 4 makes some basic recommendations for extracting pertinent information. Subsequent publications will detail the National Seismic Risk Model as well as describe the procedure for selection of scenarios for the catalogue.

It is important to note that these scenarios are not predictions. They represent a selection of plausible events which may bear a resemblance to events to come in the future, or which may have occurred in the pre-instrumental past. All of the fault rupture scenarios are based on our best scientific understanding of the tectonic landscape of Canada, historical seismicity, prehistoric earthquakes, and the quickly-advancing field of active fault study. The empirically-determined equations which relate ruptures to ground shaking and shaking to damage are based on the 2020 Canadian Seismic Hazard Model (CanadaSHM6, Kolaj et al., 2019, 2020) and standard Global Earthquake Model (GEM) implementation (Rao and Silva, 2017) of FEMA Methodology for Estimating Potential Losses from Disasters (HAZUS) fragility functions (FEMA, 2012a). The exposure model, a National Human Settlement Layer (Journeay et al., 2021), uses remote sensing of land use types to assign a representative suite of buildings based on density, census data, and up-to-date costing metrics, all of which is overlain on a national model for soil conditions that uses both global and local datasets (Wald and Allen, 2007; Allen and Wald, 2009; Journeay et al., 2021). In other words, while the model parameter space is large, all elements of this work are held to as high of a standard of scientific rigour as is available at this time between the fields of science, engineering, and computing. Still, the earth system is complex and Canada has only 2 recorded Moment Magnitude (M_w) ≥ 7 earthquakes. Much is left to be learned, but the hope is that these scenarios can be used by planners, emergency managers, policy makers, financial analysts, academics, engineers, and even the public to keep our communities safe as we learn.

2. Understanding the Files in the Scenario Folder

Each run of the OQ engine for a single scenario produces 7 files (Table 1), with information about the average shaking (‘Hazard’), damage to buildings (‘Damage’), economic losses from that building damage (‘Loss’), and subsequent impacts to people, businesses, and urban areas (‘Consequence’). These results are produced for baseline conditions, with our current building stock, and for retrofitted conditions, where we consider if every building were raised to a moderate level of seismic code (Figure 1), with exceptions for (a) buildings which are already at or above moderate code, (b) buildings that would likely be brought up to high code as they have a post-disaster function, and (c) buildings with unreinforced masonry structural elements which can only be retrofitted to a low-code level. For example, a building constructed in the highest seismic hazard zone (SSC-5) in 1985 would be a Moderate-Code building under baseline (‘b0’), and unaffected under the retrofit (‘r1’) scenario unless it is a hospital or emergency operations centre, or made with unreinforced masonry structural elements. A concrete shear wall apartment building in the same zone, that was constructed in 1970, would be pre-code in baseline and brought to moderate-code in retrofit. This pre-computed retrofit scenario provides an opportunity for users, likely planners and policy makers, to consider the impact of retrofitting subsets of buildings within the building stock. For example, a policy analyst might choose to select only those buildings that represent an imminent threat to life safety, or to select a portfolio of buildings that meet broader objectives of functional recovery. By using the retrofit values for each of these portfolios, they can assess the strengths and weaknesses of different retrofit strategies without having to re-run the scenario models for each instance.

The titles indicate the type of data contained, as well as information about the run and parameters:

s_FileType_RuptureType_Identifier_RetroFitLevel_Run#_ExposureType.csv

For example:

s_dmgbyasset_IDM6p8_Sidney_r1_61_b.csv

where ‘s’ indicates a scenario run; ‘dmgbyasset’ means the output data is building damage, listed per asset; ‘IDM6p8’ has two parts: the tectonic region (Table 2), which is in this case ‘Intraslab Deep’ or

ID, and the magnitude, which in this case is an M_w 6.8 or M6p8; 'Sidney' is the name of the scenario, often chosen to reflect a nearby city, fault, or historical earthquake; 'r1' is the retrofit level; '61' is the OQ engine calculation number on whichever machine was used to perform the run; and 'b' indicates that the exposure file used in this run was aggregated at the building level rather than the site ('s') level. The latter is more detailed, where each individual building is an asset, as opposed to building level exposure where multiple buildings are described in a single asset.

The Hazard, Damage, Consequence, and Risk files contain an entry for every asset, corresponding to a collection of buildings with identical taxonomy in the same Settled Area. These Settled Areas are identified by a unique identifier, (the SAUID), and roughly analogous to the census Dissemination Area Unique Identifier (DAUID). The taxonomy refers to a string containing the occupancy, building typology, and code level. Occupancy can be any of the 28 typologies listed in the HAZUS Technical Manual Table 3.2 (FEMA, 2012b) and recreated in Table 3. There are 36 building typologies in HAZUS (Table 3.1 in FEMA, 2012b), recreated in Table 4. For example, a collection of 6 newly constructed, single family, wood frame homes in the same settled area in Victoria, BC, would be listed as a single asset with taxonomy RES1-W1-HC. These taxonomies are very useful for extracting information about the performance of certain categories of buildings, as we will see in Section 4. Each asset is made unique by adding a numeric value in front of the taxonomy.

The Hazard file, 'shakemap', contains information about the grid on which the hazard results were calculated. Often this is a uniform grid over the region of interest, augmented to include the asset locations, and described by latitude and longitude. The hazard intensity values at those grid sites are given for several intensity measurement types, including peak ground accelerations (PGA) and spectral acceleration (SA) for several periods.

To select the files of interest from this folder, you will need to know the name of a particular earthquake or you can browse through the list to find a suitable event. Markdown files (extension '.md') are created for each scenario, showing a high-level snapshot of the earthquake including the epicentre, likelihood, economic loss, irreparable damage, human impacts, and associated files. Note that the likelihood is expressed as a recurrence rate for any earthquake of magnitude equal to or greater than the scenario magnitude within the scenario source region (Kolaj et al., 2020), except for events on the Cascadia megathrust or the Leech River – Devil's Mountain Faults. These markdown files can be viewed directly in GitHub, and an example is shown in Figure 2. In future there will be web-based resources to spatially investigate the catalogue, and the results, making it easier than ever to gain intuition about how earthquakes affect people and the built environment for your region of interest or for a particular style of event.

3. Understanding Indicators

To start viewing the results of an earthquake scenario, it is important to consider the information being sought. There is a lot of data produced from a single scenario, which can be aggregated or filtered by, for example, census geographic divisions, building typology, occupancy class, or code level. Some questions are best answered with maps, others with charts, and some with a single number. For example, the Hazard could be represented as a map of PGA at each location on the grid or you could express simply the highest PGA value recorded anywhere for that earthquake. The available indicators — all the results that one can interrogate — are described in Tables 5 and 6. Outputs can subsequently be mapped into the Sendai Indicator Framework (see UNISDR, 2015; Aitsi-Selmi et al., 2015; Wahlström, 2015). This is an ongoing work and will be updated with the release of the National Seismic Risk Model. From these tables, one can select an indicator or several indicators of interest. For example, if one is interested in life safety one would care about the casualties of severity levels 3 and 4. Where a health system emergency manager might want to aggregate those serious injuries (level 3) to the neighbourhood level to determine hospital demand surge, a retrofit policy analyst might want to disaggregate the deaths (level 4) by building taxonomy to determine which types of structures are most likely to take lives. Additional information is provided for each asset to help with this filtering, aggregating, and disaggregating process, listed in Table 7.

4. Extracting Information from Scenarios

This section will outline a few illustrative examples of common analysis techniques, with the intention of showing some of the possibilities. It is left to the user to modify these examples for their own purposes. Because they are in csv format, the results can be easily read into many programs such as GIS mapping software, Microsoft Excel, Tableau, or Python. The method chosen should be based on the intended outputs and the familiarity of the user. For example, if a user who wishes to generate a pie chart of buildings in a complete damage state, they could do this quite simply in Python, Excel or Tableau if they have the proficiency with these tools. On the other hand, a map of the concrete and steel debris, however, would be very fast and easy to make in GIS for an analyst with this skillset.

For all examples herein we will use a M_w 9.0 Cascadia Subduction earthquake scenario, based on the CanSHM6 seismic source model (Kolaj et al., 2020). As we can see from Figure 2, this event has a maximum peak ground acceleration (ground shaking) of 38% of freefall, occurs about once every 433 years, does $38 billion dollars in damage, claims over 3,400 lives if it occurs in the daytime, and renders over 18,000 buildings uninhabitable. These values represent the average outcome of the models for this scenario.

4.1 Mapping Hazard in QGIS

To map hazard results in GIS or Tableau, one must import the relevant 'shakemap' file by adding a delimited text layer. The 'X Field' should be set to longitude, and 'Y Field' should be latitude. One can then plot any of the intensity (Table 5) measures by latitude and longitude. For example, create a map of PGA by creating a graduated colour scheme for the gmv_PGA column. Recall that it is in units of g (9.81 m/s^2). An example produced using QGIS software is shown in Figure 3, with a standard basemap.

4.2 Mapping Damage, Loss, and Consequences in Tableau

Assets are linked to Settled Areas, Census Geographic Divisions, and Lat/Lon pairs. Therefore, results can be plotted as points by their latitude and longitudes, or mapped onto SAUID or Census geometries. The geometry for Settled Areas can be downloaded from <https://github.com/OpenDRR/boundaries> as polygons in a geopackage format, and geometry for census divisions can be downloaded from Statistics Canada at <https://www12.statcan. gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-2016-eng.cfm>. It is worth noting that Consequence files have only the 'asset ref' (equivalent to 'asset id' in Damage and Loss files), instead of the full set of exposure elements (Table 7). Therefore, one must perform an attribute join, in GIS, or data connection, in Tableau, between the 'asset ref' column in the Consequence file and the 'asset id' column in the Damage and/or Loss files.

To create a Tableau map of hospital demand, aggregated by standard Census administrative boundaries (DAUID: Dissemination Area; CSDUID: Census Subdivision; CDUID: Census Division, etc), for a M_w 9.0 Cascadia earthquake scenario under baseline conditions:

1. Import Dissemination Area (DA) boundaries, downloaded from Statistics Canada, as a spatial file
2. Under 'Connections', add the damage file from the scenario (s_dmgbyasset _SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv) as a text file

3. Connect the files by the ‘DAUID’ tag from the DA boundaries and STR([dauid]) from the dmgbyasset file — the ‘STR’ is a calculation that can be typed by selecting ‘Create Join Calculation...’ from the dropdown
4. Under ‘Connections’ add the consequence file (s_consequences_SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv) as a text file
5. Connect the ‘asset id’ tag from the dmgbyasset file with the ‘asset ref’ tag from the consequence file
6. Click ‘Update Now’ from the lower data pane and ensure that results have uploaded with the correct formatting – Ensure that decimal numbers were uploaded as floats rather than integers or text.
7. Open a new sheet, ‘Sheet 1’
8. Double click on ‘Geometry’ under ‘Measures’, beneath your DA boundary file
9. In ‘Dimensions’, drag ‘ADAUID’ to ‘Detail’ in the ‘Marks’ toolbar
10. In ‘Measures’, right click on ‘casualties day severity 3’ and select ‘Create’ > ‘Calculated Field...’
11. Rename the calculation from ‘Calculation1’ to something like ‘Hospital Demand’ and in the calculation box below set it to sum the severity 3 and severity 2 injuries: [casualties day severity 3]+[casualties day severity 2]
12. Drag ‘Hospital Demand’ from ‘Measures’ to ‘Color’ in the ‘Marks’ toolbar
13. Zoom into a region of interest, say Vancouver, and move your mouse over different regions to highlight one Aggregate Dissemination Area (neighbourhood) at a time — the tooltip will show you the hospital demand for that region

One can adjust the colour scheme used to plot the data (double click on the colorbar in the right corner), change the aggregation level (drag another exposure element to the ‘Detail’ in ‘Marks’), or apply filters (drag filter element into the ‘Filters’ toolbar). For example, a filter can be used to see how different occupancy types (building uses) contribute to the hospital demand:

1. Under ‘Dimensions’, drag ‘OccClass’ from your dmgbyasset file to the ‘Filters’ toolbar
2. Select the building types to retain, for instance all Commercial (COM) occupancies

You’ll notice that the map looks quite similar, indicating that commercial occupancy buildings generally tend to be built from materials that perform poorly in earthquakes in this area (Figure 4).

4.3 Plotting Charts in Python

For quickly aggregating by different exposure elements, Python is a powerful tool. For example, it takes only a few lines of code to load a large data file and create a pie chart to show the contribution to total event losses from each construction material (Figure 5). The example herein uses Python version 3.6.8, pandas version 1.1.4, matplotlib version 2.1.2, and numpy version 1.16.5. Note that if copy-pasting code from below, it may be necessary to change apostrophes to plain text.

```
# Import Libraries
import pandas as pd
import matplotlib.pyplot as plt

# Read the data and group by an exposure element (construction type)
grouper = 'GenType'
df = pd.read_csv('s_lossesbyasset_SIM9p0_CascadiaInterfaceBestFault_b0_319_b.csv')
```

```
data = df.groupby(grouper)['totalLoss'].sum().reset_index()

# Print the total loss from this event
data['totalLoss'].sum()

# Plot a pie chart of losses by construction type
labels = data[grouper]
sizes = data['totalLoss']
fig1, ax1 = plt.subplots()
ax1.pie(sizes, labels=labels, startangle=90, autopct='%1.1f%%')
ax1.axis('equal')
plt.show()
```

Note that pieces of this or similar code can be used to quickly find totals for any of the files, such as total fatalities. For this Cascadia nighttime scenario there were 792 predicted fatalities. Note that this is much lower than the fatalities for the same scenario in the daytime, as we will see below.

```
# Import Libraries
import pandas as pd

# Read the data and sum over an indicator of interest
df = pd.read_csv('s_consequences_SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv')
df['casualties_night_severity_4'].sum()
```

One can also create more complicated graphs, like the following example featuring the so-called ‘three D’s’: deaths, dollars, and damage (Figure 6). Here, a bar chart is used to summarize the total losses, daytime fatalities, and buildings in a complete damage state for the baseline and retrofitted conditions. Losses were divided by $1,000,000 so the results would fit on the same chart, and a table was provided below to list the exact numbers. The script, below, can be saved and run directly from the terminal after editing the filenames to reflect the local directory structure.

```
# Import libraries
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

# Import data
loss1 = pd.read_csv(‘s_lossesbyasset_SIM9p0_CascadiaInterfaceBestFault_b0_319_b.csv’)
loss2 = pd.read_csv(‘s_lossesbyasset_SIM9p0_CascadiaInterfaceBestFault_r2_320_b.csv’)
cons1 = pd.read_csv(‘s_consequences_SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv’)
cons2 = pd.read_csv(‘s_consequences_SIM9p0_CascadiaInterfaceBestFault_r2_318_b.csv’)
damg1 = pd.read_csv(‘s_dmgbyasset_SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv’)
damg2 = pd.read_csv(‘s_dmgbyasset_SIM9p0_CascadiaInterfaceBestFault_r2_318_b.csv’)

# Extract values
loss1val = loss1[‘totalLoss’].sum()
loss2val = loss2[‘totalLoss’].sum()
cons1val = cons1[‘casualties_day_severity_4’].sum()
cons2val = cons2[‘casualties_day_severity_4’].sum()
damg1val = damg1[‘structural~complete’].sum()
damg2val = damg2[‘structural~complete’].sum()

# Create data array
value_increment = 1000000 #divisor for red tags and deaths
data = [[loss1val/value_increment, cons1val, damg1val],[loss2val/value_increment, cons2val,
damg2val]]

# Define data name, range, and decimal formatting
```

```
columns = ('Dollars [$Mil]', 'Deaths', 'Damage')
rows = ('Baseline','Retrofit')
values = np.arange(0, 40000, 1000) # Use this to set the range of results

# Get some pastel shades for the colors
colors = plt.cm.BuPu(np.linspace(0.6, 0.4, len(rows)))
n_rows = len(data)

# Initialize plot
index = np.arange(len(columns)) + 0.3
bar_width = 0.4
fig, ax = plt.subplots()
cell_text = np.rint(data)

# Plot bars
for row in range(n_rows):
   ax.bar(index, data[row], bar_width, color=colors[row])

# Add a table at the bottom of the axes
the_table = ax.table(cellText=cell_text, rowLabels=rows,
   rowColours=colors,
   colLabels=columns,
   loc='bottom')

# Adjust plotting layout
ax.get_yaxis().set_major_formatter(plt.FuncFormatter(lambda x, loc:"{:,}".format(int(x))))
plt.subplots_adjust(left=0.2, bottom=0.2)
the_table.set_fontsize(10)
plt.xticks([])
plt.title('Summary of Retrofit Impacts')
plt.show()
```

5. Conclusion

With this information, a user should be able to find the scenario of interest, load the results, and begin to explore the data. A list of the file types is provided in Table 1, and the available indicators in those files are described in Tables 5 and 6. These form the basis for extracting the relevant variables (like deaths, mass of debris, economic losses), and plotting them (Section 4). In the near future, these results will be made available through a web-based platform that will guide a user through the process of selecting and visualizing relevant data. While it is important to make the datasets referenced herein available for community use as soon as possible, the web platform will represent a significant improvement for the average, non-technical user of these results.

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Glossary

Consequence: An estimation of the tangible impacts from a scenario earthquake beyond damage to buildings and financial losses. For example, the number of displaced persons or the volume of debris generated.

Damage: The damage state of a building, or collection of buildings, following an earthquake.

Hazard: A measure of the expected ground shaking or the probability of a certain level of ground shaking for an earthquake or an earthquake source region/fault.

Loss: The financial losses, and possible the human fatalities, caused by a scenario earthquake or, probabilistically, from a collection of earthquakes within a source region.

Risk: The probability of damage and loss of exposed assets, from an earthquake, or from an earthquake source region. Note that OQ defines a 'risk' calculation as one which estimates Loss.

Acronyms

GEM	Global Earthquake Model
GIS	Geographic Information System
GMPE	Ground Motion Prediction Equation
GSC	Geological Survey of Canada
HAZUS	The United States Federal Emergency Management Agency's methodology for estimating potential losses from disasters
M_w	Moment Magnitude
NBCC	National Building Code of Canada
OQ	OpenQuake
PGA	Peak Ground Acceleration
SA	Spectral Acceleration

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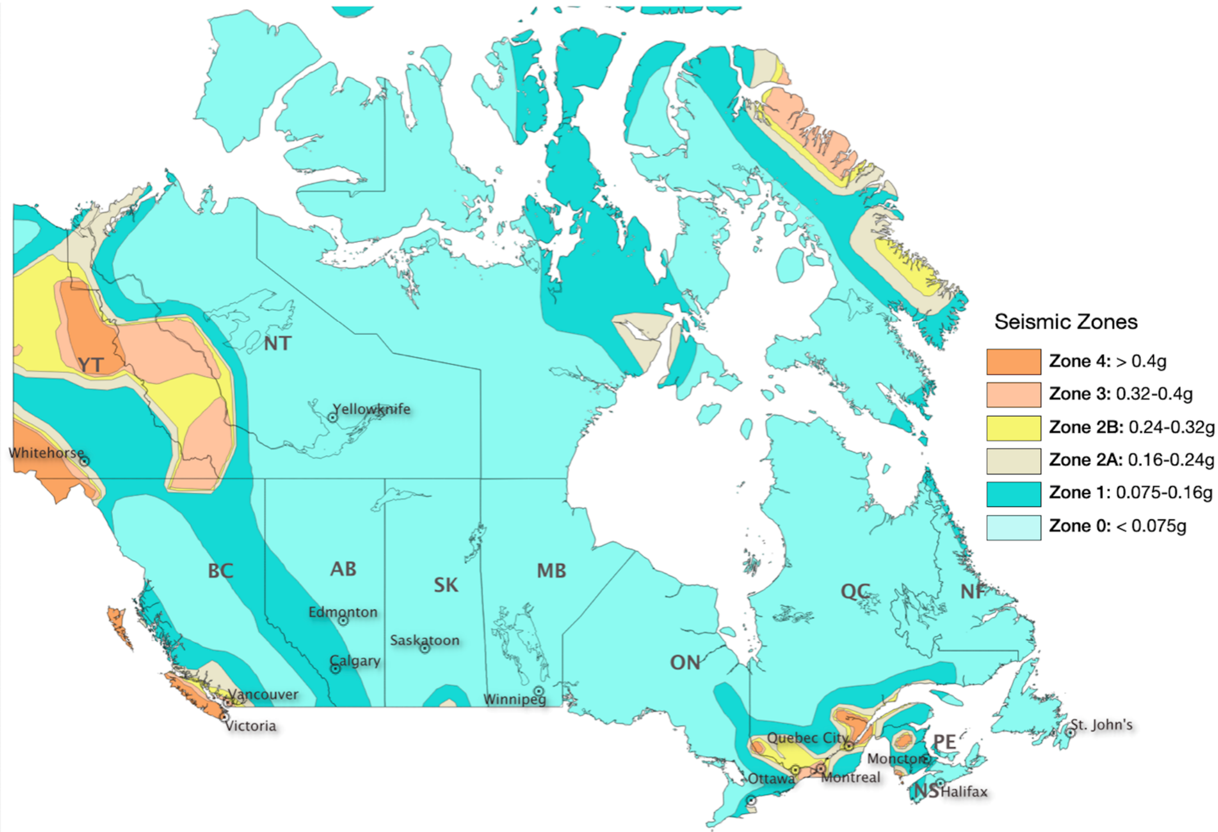
Figures



Proposed Seismic Design Levels for Existing Buildings in Canada

NBC Site Seismic Category (SSC)	PGA (2%/50yr)	Sa0.2 (2%/50yr)	Sa1.0 (2%/50yr)	2005-present	1990-2004	1973-1989	Pre-1972
SSC-5	>0.4	>=1.15	>=0.50	High-Code	High-Code	Moderate-Code	Pre-Code[1]
SSC-4	0.32-0.4	0.75-1.15	0.30-0.50	High-Code	Moderate-Code	Moderate-Code	Pre-Code[1]
SSC-3	0.24-0.32	0.35-0.75	0.15-0.30	Moderate-Code	Moderate-Code	Low-Code	Pre-Code[2]
SSC-2	0.16-0.24	0.20-0.35	0.10-0.15	Moderate-Code	Low-Code	Pre-Code[2]	Pre-Code[2]
SSC-1	0.075-0.16	0.10-0.20	0.05-0.10	Low-Code	Low-Code	Pre-Code[2]	Pre-Code[2]
SSC-0	0.05-0.075	<= 0.10	<=0.05	Low-Code	Pre-Code[2]	Pre-Code[2]	Pre-Code[2]

1. Assume Moderate-Code design for residential wood-frame buildings (W1).
2. Assume Low-Code design for residential wood-frame buildings (W1).

Figure 1. Designation of seismic code level in the National Human Settlement Layer, based on the seismic hazard and date of construction. The former is based on the National Building Code (NBC) of Canada's Seismic Site Categories, and reflects the level of seismic design that would have been mandatory during the era of construction. For more information, please consult Journeay et al., 2021.

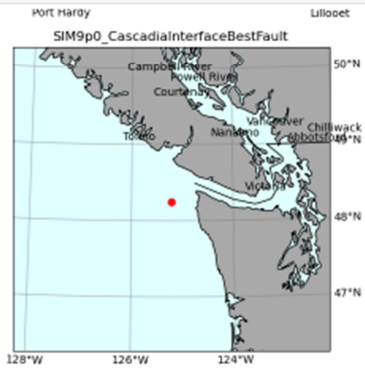
Name	SIM9p0_CascadiaInterfaceBestFault
magnitude	9.0
latitude	48.250 degrees
longitude	-125.217 degrees
maximum_peak_ground_acceleration	0.372 g
recurrence rate	433 years*
	*For Cascadia, Leech River, and Devil's Mountain Faults these are characteristic earthquakes, else they are recurrence interval for an event of equal or greater magnitude in the scenario source region.
cost	$38,402,326,693
redtag	18,375 buildings
displaced	577,039 people
deaths	3,417 people
critical_injuries_and_entrapments	1,709 people
all_hospitalizations	12,610 people
epicentre_map	
shakemap_file	./s_shakemap_SIM9p0_CascadiaInterfaceBestFault_11.csv
damage_baseline_file	./s_dmgbyasset_SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv
damage_retrofitted_file	./s_dmgbyasset_SIM9p0_CascadiaInterfaceBestFault_r1_318_b.csv
consequence_baseline_file	./s_consequences_SIM9p0_CascadiaInterfaceBestFault_b0_317_b.csv
consequence_retrofitted_file	./s_consequences_SIM9p0_CascadiaInterfaceBestFault_r1_318_b.csv
loss_baseline_file	./s_lossesbyasset_SIM9p0_CascadiaInterfaceBestFault_b0_319_b.csv
loss_retrofitted_file	./s_lossesbyasset_SIM9p0_CascadiaInterfaceBestFault_r1_320_b.csv
site_model_file	../../../openquake-inputs/earthquake/sites/regions/site-vgrid_BC.csv
rupture_model_file	../ruptures/rupture_SIM9p0_CascadiaInterfaceBestFault.xml
rupture_mesh_spacing	4
gsim_logic_tree_file	../../../CanadaSHM6/OpenQuake_model_files/gmms/LogicTree/ OQ_classes_NGASa0p3weights_interface.xml
truncation_level_risk	3.0
maximum_distance	1000
number_of_ground_motion_fields_risk	200
exposure_file	../../../openquake-inputs/exposure/general-building-stock/oqBldgExp_BC.xml
taxonomy_mapping_baseline	../../../openquake-inputs/earthquake/vulnerability/CanSRM1_TaxMap_b0.csv
structural_fragility_file	../../../openquake-inputs/earthquake/vulnerability/structural_fragility_CAN.xml
structural_vulnerability_file	../../../openquake-inputs/earthquake/vulnerability/vulnerability_structural_CAN.xml
nonstructural_vulnerability_file	../../../openquake-inputs/earthquake/vulnerability/vulnerability_nonstructural_CAN.xml
contents_vulnerability_file	../../../openquake-inputs/earthquake/vulnerability/vulnerability_contents_CAN.xml

Figure 2. Sample markdown file, viewed on GitHub, providing a high level overview of each scenario.

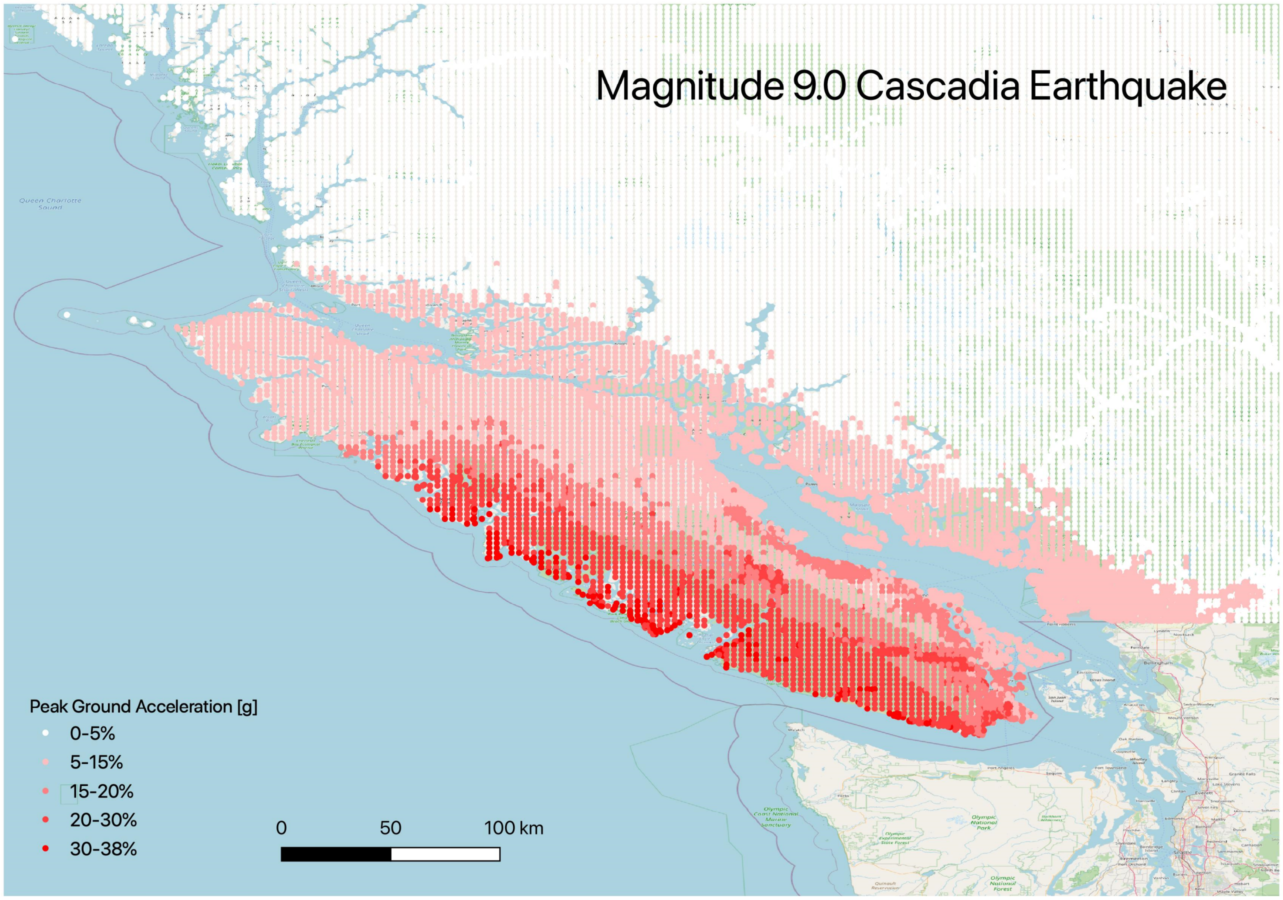


Figure 3. Expected Peak Ground Accelerations (PGA) from an example version of a Mw 9.0 Cascadia earthquake scenario, using the ground motion prediction equations of the trial 6th Generation Canadian National Seismic Hazard Map (Kolaj et al., 2020).

Hospital Demand from Commercial Buildings

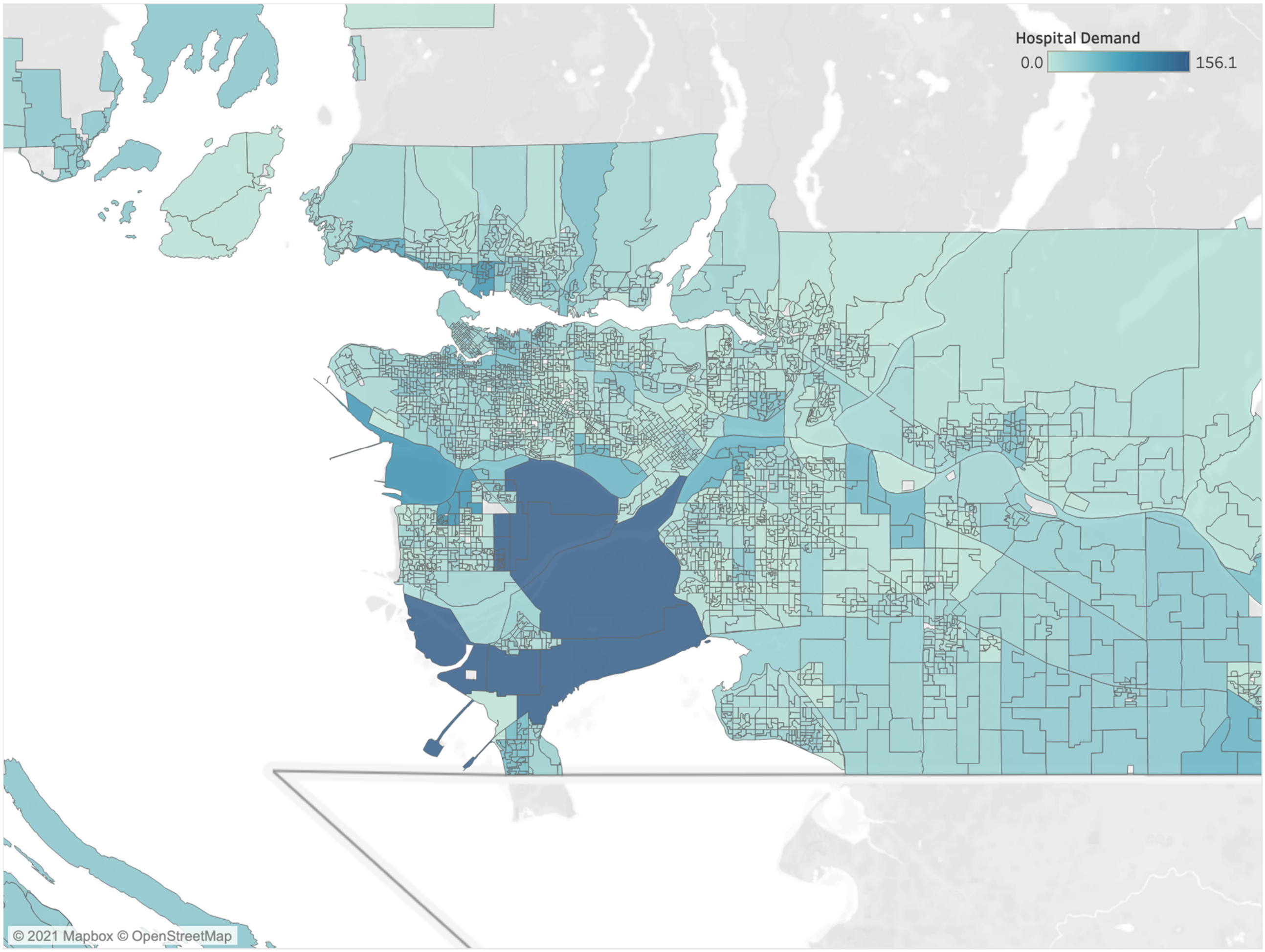


Figure 4. Hospital demand (sum of severity 2 and 3 casualties) for a daytime M_w 9.0 Cascadia earthquake scenario, aggregated by ADAUID and filtered to show only COM1-7 occupancy types.

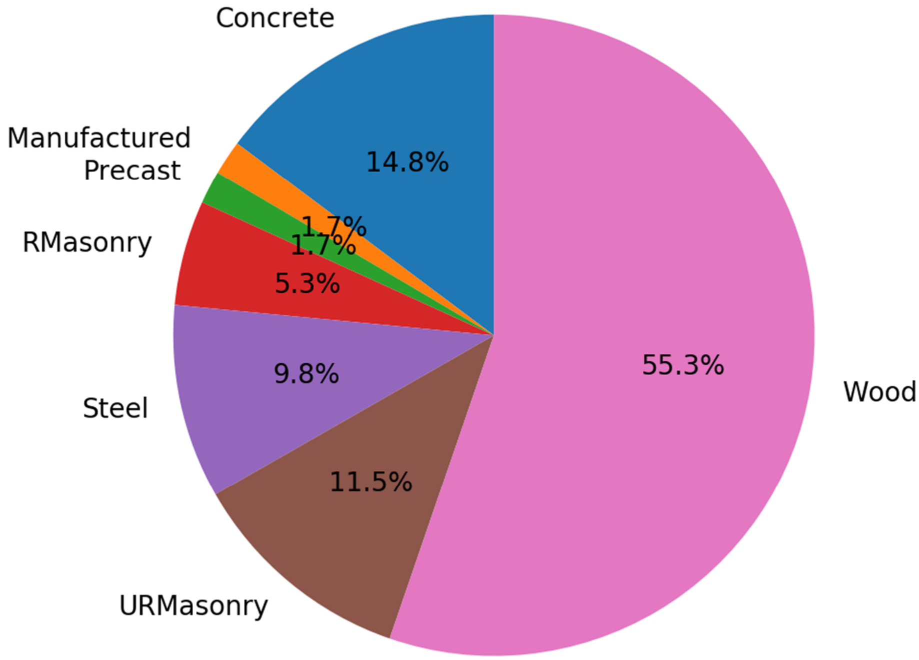
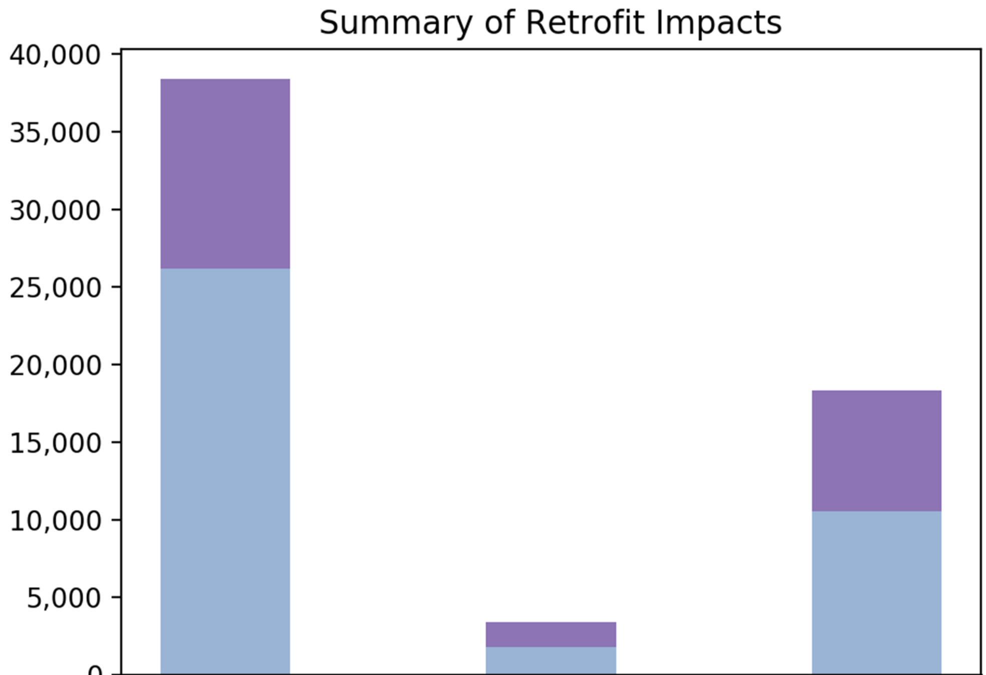


Figure 5. Pie chart showing contributions, from each construction material, toward the total scenario event loss of $38.4 billion.



	Dollars [$Mil]	Deaths	Damage
Baseline	38402.0	3417.0	18375.0
Retrofit	26192.0	1764.0	10562.0

Figure 6. Bar chart showing the total economic loss, in millions of dollars [CAD], the anticipated deaths from a daytime scenario, and the number of buildings in a 'complete' damage state for an M_w 9.0 Cascadia scenario. The results are shown for baseline and retrofitted conditions, to highlight the potential benefits of retrofitting aging buildings.

Tables

Name	Description
s_consequences_IDM6p8_Sidney_b0_#_e.csv s_consequences_IDM6p8_Sidney_r1_#_e.csv	Consequence results, by asset, for baseline and retrofit (r1) conditions, with calculation number # and exposure file type 'e'.
s_dmgbyasset_IDM6p8_Sidney_b0_#_e.csv s_dmgbyasset_IDM6p8_Sidney_r1_#_e.csv	Damage results, by asset, for baseline and retrofit (r1), with calculation number # and exposure file type 'e'.
s_lossesbyasset_IDM6p8_Sidney_b0_#_e.csv s_lossesbyasset_IDM6p8_Sidney_r1_#_e.csv	Loss results, by asset, for baseline and retrofit (r1) conditions, with calculation number # and exposure file type 'e'.
s_shakemap_IDM6p8_Sidney_#.csv	Hazard results, along a specified grid, with calculation number #.

Table 1. All output files produced by a full run of OQ. Exposure files can be either aggregated building-level (b) or site-level (s), with the place-holder 'e' being used here.

East	SC	Stable Crustal
West	AF	Active Fault
	IS	Intraslab Shallow (30 km)
	ID	Intraslab Deep (55 km)
	SI	Subduction Interface
Either	SM	ShakeMap imported from USGS

Table 2. All possible tectonic regimes used in Canada.

Label	Occupancy Class	Example Descriptions
Residential		
RES1	Single Family Dwelling	House
RES2	Mobile Home	Mobile Home
RES3	Multi Family Dwelling	Apartment/Condominium
	RES3A	Duplex
	RES3B	3-4 Units
	RES3C	5-9 Units
	RES3D	10-19 Units
	RES3E	20-49 Units
	RES3F	50+ Units
RES4	Temporary Lodging	Hotel, Motel, Inn
RES5	Institutional Dormitory	Group Housing, Jails
RES6	Nursing Home	
Commercial		
COM1	Retail Trade	Store, Marketplace
COM2	Wholesale Trade	Warehouse
COM3	Personal and Repair Services	Service Station, Shops
COM4	Professional/Technical Services	Offices
COM5	Banks	
COM6	Hospital	
COM7	Medical Office / Clinic	Urgent Care, Walk-in Clinic
COM8	Entertainment & Recreation	Restaurants/Bars
COM9	Theaters	Theaters
COM10	Parking	Garages
Industrial		
IND1	Heavy	Factory
IND2	Light	Factory
IND3	Food/Drugs/Chemicals	Factory
IND4	Metals/Minerals Processing	Factory
IND5	High Technology	Factory
IND6	Construction	Office
Agriculture		
AGR1	Agriculture	
Religion/Non/Profit		
REL1	Church/Non-Profit	Temple
Government		
GOV1	General Services	Office
GOV2	Emergency Response	Police/Fire Station/EOC
Education		
EDU1	Grade Schools	
EDU2	Colleges/Universities	Does not include group housing

Table 3. Occupancy classes used herein, based on Table 3.3 from HAZUS (FEMA, 2012b).

Label	Description	Height	Stories
W1 [W1]	Wood, Single Family (RES1, RES3A Occupancy)		1–3
W2 [W2]	Wood, Multi Family (RES3B, RES4, RES5, RES6)		All
W3 [W2]	Wood, Commercial & Industrial		All
W4 [W1]	Wood, Single Family with Cripple Wall or Subfloor		1–3
S1L	Steel Moment Frame	Low-Rise	1–3
S1M		Mid-Rise	4–7
S1H		High-Rise	8+
S2L	Steel Braced Frame	Low-Rise	1–3
S2M		Mid-Rise	4–7
S2H		High-Rise	8+
S3	Steel Light Frame		All
S4L	Steel Frame with Cast-in-Place Concrete Shear Walls	Low-Rise	1–3
S4M		Mid-Rise	4–7
S4H		High-Rise	8+
S5L*	Steel Frame with Unreinforced Masonry Infill Walls	Low-Rise	1–3
S5M*		Mid-Rise	4–7
S5H*		High-Rise	8+
C1L	Concrete Moment Frame	Low-Rise	1–3
C1M		Mid-Rise	4–7
C1H		High-Rise	8+
C2L	Concrete Shear Walls	Low-Rise	1–3
C2M		Mid-Rise	4–7
C2H		High-Rise	8+
C3L*	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise	1–3
C3M*		Mid-Rise	4–7
C3H*		High-Rise	8+
PC1	Precast Concrete Tilt-Up Walls		All
PC2L	Precast Concrete Frames with Concrete Shear Walls	Low-Rise	1–3
PC2M		Mid-Rise	4–7
PC2H		High-Rise	8+
RM1L	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	Low-Rise	1–3
RM1M		Mid-Rise	4+
RM2L	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms	Low-Rise	1–3
RM2M		Mid-Rise	4–7
RM2H		High-Rise	8+
URML*	Unreinforced Masonry Bearing Walls	Low-Rise	1–2
URMM*		Mid-Rise	3+
MH	Mobile Homes		All

Table 4. Building taxonomies used herein, based on Table 3.2 from HAZUS (FEMA, 2012b). Wood taxonomy has been updated in the Canadian exposure inventory to reflect nuance in construction practices. At this time, fragility and vulnerability functions for these wood buildings are not available, so they are mapped to common HAZUS typologies indicated in square brackets ([]). Note that entries marked with an asterisk (*) cannot be designed or retrofitted to higher than Low-Code (Table 1) due to the observed poor seismic response of these types of load bearing systems.

Variable	Description
Hazard ('shakemap')	
gmv_PGA	Peak Ground Acceleration (PGA) in units of g [9.81 m/s^2]
gmv_SA(0.1)	Spectral acceleration at 0.1 seconds in units of g
gmv_SA(0.2)	Spectral acceleration at 0.2 seconds in units of g
gmv_SA(0.3)	Spectral acceleration at 0.3 seconds in units of g
gmv_SA(0.5)	Spectral acceleration at 0.5 seconds in units of g
gmv_SA(0.6)	Spectral acceleration at 0.6 seconds in units of g
gmv_SA(1.0)	Spectral acceleration at 1.0 second in units of g
gmv_SA(2.0)	Spectral acceleration at 2.0 seconds in units of g
Damage ('dmgbyasset')	
structural~no_damage	Number of buildings in that asset with no damage.
structural~slight	Number of buildings in that asset with slight damage: Small (<1/8 inch) cracks in masonry chimneys or veneers, or in plaster at corners of doors, windows and wall-ceiling intersections.
structural~moderate	Number of buildings in that asset with moderate damage: Large plaster or gypsum-board cracks at corners; small diagonal cracks across shear wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
structural~extensive	Number of buildings in that asset with extensive damage: Large diagonal cracks across shear wall panels or at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
structural~complete	Number of buildings in that asset with complete damage: Structure may have large permanent lateral displacement or be in imminent danger of collapse due to failure of cripple wall or the lateral load resisting system; some structures may fall off the foundation; large foundation cracks. Three percent of the total area of buildings with Complete damage are expected to collapse, on average.
Loss ('lossesbyasset')	
contents	Dollar value of the losses from contents of building in this asset.
nonstructural	Dollar value of the losses to nonstructural elements of buildings in this asset.
structural	Dollar value of the losses to structural elements of buildings in this asset.
totalLoss	Dollar value of the total losses from the asset buildings (structural + nonstructural + contents).
Consequences ('consequences')	
asset_ref	Equivalent to 'asset_id' in other files, used to join consequence outputs to other outputs.
collapse_ratio	Proportion of buildings in this asset which are likely to be collapsed.
mean_repair_time	The ideal time, in days, that it would take for clean up and construction to repair or replace buildings in this asset.
mean_recovery_time	The more realistic time, in days, that it would take for repair of buildings in this asset, taking into account delays due to inspection, financing, permitting, negotiating, etc.
mean_interruption_time	The time it would take for a building to resume functionality, based on its occupancy type, calculated as the recovery time multiplied by an interruption modifier.

Table 5. Indicators available from each of the scenario output files. Descriptions of Damage and Consequence are adapted and abridged from FEMA (2012a). An interested reader is referred to that resource for a thorough description, including Table 7.1 therein. From HAZUS: daytime is 9am–5pm, nighttime is 7pm–7am, and transit is the intervening hours of 7–9am and 5–7pm.

Variable	Description
casualties_day_severity_1	Injuries requiring basic medical aid, but without hospitalization (treat and release), for a daytime earthquake scenario.
casualties_day_severity_2	Injuries requiring medical attention and hospitalization, but not considered to be life-threatening, for a daytime earthquake scenario.
casualties_day_severity_3	Casualties that include entrapment and require expeditious rescue and medical treatment to avoid death, for a daytime earthquake scenario.
casualties_day_severity_4	Immediate deaths, for a daytime earthquake scenario.
casualties_night_severity_1	Injuries requiring basic medical aid, but without hospitalization (treat and release), for a nighttime earthquake scenario.
casualties_night_severity_2	Injuries requiring medical attention and hospitalization, but not considered to be life-threatening, for a nighttime earthquake scenario.
casualties_night_severity_3	Casualties that include entrapment and require expeditious rescue and medical treatment to avoid death, for a nighttime earthquake scenario.
casualties_night_severity_4	Immediate deaths, for a nighttime earthquake scenario.
casualties_transit_severity_1	Injuries requiring basic medical aid, but without hospitalization (treat and release), for an earthquake scenario during transit hours.
casualties_transit_severity_2	Injuries requiring medical attention and hospitalization, but not considered to be life-threatening, for an earthquake scenario during transit hours.
casualties_transit_severity_3	Casualties that include entrapment and require expeditious rescue and medical treatment to avoid death, for an earthquake scenario during transit hours.
casualties_transit_severity_4	Immediate deaths, for an earthquake scenario during transit hours.
sc_Displ3	Number of nighttime occupants (typically residences) with damage to their building after 3 days.
sc_Displ30	Number of nighttime occupants (typically residences) with damage to their building after 30 days.
sc_Displ90	Number of nighttime occupants (typically residences) with damage to their building after 90 days.
sc_Displ180	Number of nighttime occupants (typically residences) with damage to their building after 180 days.
sc_Displ360	Number of nighttime occupants (typically residences) with damage to their building after 3 days.
sc_BusDispl30	Number of daytime occupants (typically businesses) with damage to their building after 30 days.
sc_BusDispl90	Number of daytime occupants (typically businesses) with damage to their building after 90 days.
sc_BusDispl180	Number of daytime occupants (typically businesses) with damage to their building after 180 days.
sc_BusDispl360	Number of daytime occupants (typically businesses) with damage to their building after 360 days.
debris_brick_wood_tons	Mass of brick and wood debris produced by buildings in this asset, in tons. This lightweight debris can usually be moved without specialized equipment.
debris_concrete_steel_tons	Mass of concrete and steel debris produced by buildings in this asset, in tons. Concrete and steel debris will tend to require specialized equipment for moving.

Table 6. Continuation of Table 5.

Element	Description
BldEpoch	Construction year, binned as in Figure 1.
BldgType	Building typology, defined in Table 3.
EqDesLev	Seismic code level, defined in Figure 1.
GenOcc	Land use classification, detailed.
GenType	Building construction material.
LandUse	Land use classification, simple.
OccClass	Occupancy class, defined in Table 2.
SAC	Statistical area classification code identifier.
SSC_Zone	Seismic hazard zone, as defined in Figure 1.
SauidID	Settled area identifier.
adauid	Aggregate census dissemination area identifier.
cdname	Census division name.
cduid	Census division identifier.
csdname	Census subdivision name.
csduid	Census subdivision identifier.
dauid	Census dissemination area identifier.
ername	Census economic region name.
eruid	Census economic region identifier.
fsauid	The first 3 characters of the postal code.
prname	Province name.
pruid	Numeric province identifier per census.
sauid	Numeric Settled Area ID.
taxonomy	Taxonomy string composed of occupancy, taxonomy, and code level.
lon	Longitude
lat	Latitude

Table 7. Exposure elements provided for each asset, primarilybased on Statistics Canada definitions: <https://www150.statcan.gc.ca/n1/pub/92-160-g/2011002/tbl/tbl4.12-eng.htm>.