Seismic Hazard Maps for the National Building Code of Canada – past, present and future

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Natural Resources Canada, Ottawa,
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Seismology Background

Movement on a fault plane causes vibrations...

The larger the area on which there is slip (rupture)...

the larger the magnitude of the earthquake
Relative fault areas

Haiti 2010 M7.0

Japan 2011 M9.1

~ 1000 times larger than M7.0

M6.2
Magnitude

**Magnitude**
- depends on the size of the reactivated fault surface;
- as magnitude increases, the strength of ground shaking, duration, and area impacted increases very quickly.

**Ground shaking**
Increases by 10 times for every magnitude unit

**Energy released**
Increases by 32 times for every magnitude unit

**Duration of shaking**
From a few seconds (M 4) to several minutes (M 9)
Major earthquakes are related to movements at Plate Boundaries
Global Seismicity over 20 years: concentrated at plate boundaries
Tectonic Context of Canada’s West Coast

Vancouver

source of the great earthquake of 1700 AD

Earthquake Source Areas:
- Magnitude 5 - 6
- Magnitude 6 - 7
- Magnitude 7 - 8
- Magnitude 8 - 9

OCEAN CRUST

PLATE MOTION

PARTIAL MELTING

MANTLE

CONCEPTUAL CRUST

J Cassidy, GSC

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Southeastern Canada Earthquakes since 1700

- Timiskaming 1935 M6.1
- Cornwall 1944 M5.8
- Attica 1929 M4.9
- Saguenay 1988 M5.9
- Charlevoix 1663 M~7
- Montreal 1732 M~6
Size described by magnitude (one magnitude per earthquake!)

Effects described by shaking intensity (Modified Mercalli scale: IV, VII)

Magnitude 5.9 Saguenay
1988 Nov 25 suppertime

Damage in Montreal 250 km away
Cornwall 1944  Mw 5.7

School Gymnasium
Most recent sizable earthquake

Val-des-Bois
Mw 5.0
June 2010

Earthquakes magnitude 2.0 and larger, 1980 - present
Val-des-Bois Earthquake

June 23rd shaking in Ottawa was
• strongest in Ottawa’s history
• once-in-150-year level of shaking
• only 1/5th as strong as current building code requires

Potentially felt by about 19 million people

Web reports from 59,000 people

Felt much farther to the southwest than to the northeast
Examples of Val-des-Bois earthquake effects

At less than 70 km
While in Toronto, 400 km away …..
How often do earthquakes happen?
Magnitude-recurrence statistics near Toronto

Western Lake Ontario (WLO)

80 earthquakes occur within the zone
26 earthquakes passed completeness
earthquakes larger than magnitude are complete
from the year
6.25 1960
5.25 1970
4.75 1920
3.75 1910
3.25 1992
2.75 1990

Approximate area of source zone: 25000 km²

Magnitude

Cumulative Rate (p/a)

About once in 3000 years

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Why do earthquakes happen here?

Earthquake Magnitude (M)

- $M \geq 2.5$
- $M \geq 3$
- $M \geq 4$
- $M \geq 5$
- $M \geq 6$
- $M \geq 7$

Failed Rift
Ancient Rifted margin
Hot Spot
We can’t stop earthquakes
We can’t forecast them in a useful way (yet!),
So we must mitigate their effects
Globally most deaths in earthquakes are from:

- Tsunamis 11%
- Earthquake-triggered landslides 8%
- Fire 4%
- Liquefaction; heart attacks ~1%

People killed in collapsing buildings 77%

2.6 million fatalities, 1900-2010
Source: Daniell 2011, Figure 10

We have done something about collapsing buildings, through Canada’s National Building Code
National Building Code

The minimum standard to protect the life and safety of building occupants and the general public as the building responds to strong ground shaking.

Expected shaking comes from seismic hazard maps.
Probabilistic seismic hazard

- Earthquake Catalog
  - Earthquake locations
  - Earthquake number - sizes - rates
  - Shaking vs distance relations
  - Seismic hazard
National Building Code

The minimum standard to protect the life and safety of building occupants and the general public as the building responds to strong ground shaking

Expected shaking comes from seismic hazard maps

1953
One map
Primarily a zoning map
Peak Acceleration for 4 zones
1970
One map
Peak Acceleration for 4 zones
Probabilistic at 1/100 years

1985
Two maps
Peak Acceleration & Velocity
7 zones
Rock and Firm Ground
Probabilistic 10% /50 years
= 1/475 years
2005
Four maps
Spectral Acceleration
(plus Peak Acceleration)
No zones
Firm Ground (Site Class C)
Probabilistic at 2%/50 years
= 1/2475 years

2010
Similar to 2005
(see next slide)
NBCC 2010

Issued at end of 2010

In process of being adopted by Provinces and Territories

Similar parameters to 2005

Chief seismic difference: model for eastern ground motion shaking changed from Quadratic to 8-parameter fit because this reduced unnecessary conservatism

• Reduced hazard at short periods in low-hazard zones
• Increased hazard at long periods in low-hazard zones
• Reduced PGA (still used in geotechnical designs)
• Spectra tilted from the changes
Change in 2010
Blue = 2005
Red = 2010

Reduced PGA
Reduced Sa(0.2) in lower hazard regions
Increased Sa(2.0) in lower hazard regions
NRCan website for seismic hazard calculations

www.EarthquakesCanada.ca
2010 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836
Western Canada English (250) 363-6000 Facsimile (250) 363-6565

Requested by:
Site Coordinates: 45.4 North 75.7 West
User File Reference:

December 14, 2011

National Building Code ground motions:
2% probability of exceedance in 50 years (0.0000404 per annum)
Sa(0.2)  0.635
Sa(0.5)  0.308
Sa(1.0)  0.137
Sa(2.0)  0.046
PGA     0.324

Notes. Spectral and peak hazard values are determined for firm ground (NBCC 2010 soil class C - average shear wave velocity 360-750 m/s). Median (50th percentile) values are given in units of g. 5% damped spectral acceleration (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are tabulated. Only 2 significant figures are to be used. These values have been interpolated from a 10 km spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the calculated values.

Ground motions for other probabilities:
Probability of exceedance per annum 0.010  0.0021  0.001
Probability of exceedance in 50 years 40%  10%  5%
Sa(0.2)  0.089  0.249  0.386
Sa(0.5)  0.043  0.122  0.186
Sa(1.0)  0.017  0.056  0.087
Sa(2.0)  0.006  0.016  0.028
PGA     0.039  0.122  0.201

References
National Building Code of Canada 2010 NRCC no. 53301; sections 4.1.8, 9.20.1.2, 9.23.10.2, 9.31.6.2, and 6.2.1.3
Appendix C: Climatic Information for Building Design in Canada - table in Appendix C starting on page C-11 of Division B, volume 2
Commentary j: Design for Seismic Effects

Geological Survey of Canada Open File xxx
Fourth generation seismic hazard maps of Canada: Maps and grid values to be used with the 2010 National Building Code of Canada (in preparation)
See the websites www.EarthquakesCanada.ca and www.nationalcodes.ca for more information
Also disponible en français
**NBCC 2015:** 5th Generation Seismic Hazard Maps

Trial results: focus is on computing and understanding the hazard values for populated SE and SW Canada – main cities

**Main changes**
- Catalog
  - 18 years more earthquakes
  - Moment magnitude catalog
- Replacement of Robust approach
  - Replacement of H and R models
    - East
    - West
  - Probabilistic treatment of Cascadia
  - Integrated treatment of Floor source
- New Ground Motion relations
- New spectral values (shorter and longer periods)
- Adjusted reference ground condition
New earthquakes

Last model used earthquakes up to 1990/1991

Now will add earthquakes up to end of 2010

Adds lots of smaller earthquakes (GSC used to locate 1500 earthquakes a year, now locates 4500+ per yr)

Adds a number of significant earthquakes in the last decade (Denali, Nisqually, Queen Charlottes, Val-des-Bois…)

New data for inslab earthquakes

New data for moderate M5 earthquakes
**Improved catalog in Moment magnitude (Mw)**

For 2015:
- largest events have had Mw assigned by inspection of data and publications
- Events smaller than Mw~4.7 converted from catalog values

Sensitivity tests:
- **East:** centre of Gatineau zone
  - $\text{Sa}(0.2) = 0.26 \text{ g from mN catalog}$
  - $0.25 \text{ g from Mw catalog}$
- **West:** Prince Rupert
  - $\text{Sa}(0.2) = 0.37 \text{ g from mN catalog}$
  - $0.33 \text{ g from Mw catalog}$

Sensitivity test: Not much effect on onshore hazard
Eastern source zones: Replacement of Robust approach

The issue:
2005/2010 approach

Locations very different in H model, reflecting local earthquake activity

Locations rather similar in R model

<table>
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<tr>
<th>Sa(0.2) in cm/s/s</th>
<th>2005 H</th>
<th>2005 R</th>
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<td>2300</td>
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<td>Quebec City</td>
<td>520</td>
<td>590*</td>
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<td>640</td>
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<tr>
<td>Ottawa</td>
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</table>

* Low because IRM zone boundary badly placed

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2015 draft
Historical seismic source models

GSC 2011

Atkinson
Earthquake rate considered in IRM source zone:

Best estimate curve for IRM Source Zone

Best estimate curve for CIE

Work by Lan Lin, GSC Aug 2009
Parameters considered in IRM source zone:

Best estimate curve for IRM Source Zone

Best estimate curve for CIE

Work by Lan Lin, GSC Aug2009
Seismotectonic seismic source model from GSC

5 large zones as sources for Random Big Earthquakes (RBE)
Parameters considered in IRM source zone:

- Best estimate curve for IRM Source Zone

Mw ≥ 6.8

Composite seismic source model

Mw < 6.8

Work by Lan Lin, GSC Aug 2009

Best estimate curve for CIE

Best estimate curve for IRM Source Zone

Parameters

- Mx = 7.5
- BETA = 1.98 +/- 0.10
- B = 0.858 +/- 0.04
- N5 = 0.113 +/- 0.008
- N = 215 Earthquakes

Including all earthquakes to the end of 1990

- UPPER CURVE: Mx, BETA, B, N5, N
- BEST ESTIMATE: Mx, BETA, B, N5, N
- LOWER CURVE: Mx, BETA, B, N5, N
Historical seismic source models → Composite Model

We can use the “H” models directly, or composite with the RBE model

The transition magnitude used doesn’t matter very much
What rates for Random Big Earthquakes?

Very little constraints from data, paleoseismic or otherwise

St. Lawrence rift source: expect one Mw≥6.8 per 300 years

Other “best” rates for Mw≥6.8 by judgement based on relative seismicity levels

Large uncertainty – taken as factor of 3 up and down

Can infer unreasonable maximum rates from history (used to additionally constrain upper limits in blue)
Effect of Composite model is more evident in low seismicity regions like Trois Rivieres

Montreal

Trois Rivieres

Change in hazard still being modelled, but….

- Montreal not the same as Ottawa
- Trois Rivières lower than Montreal and Quebec City
- Charlevoix still high, but less high than before

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Western sources
2011 model
Will remove areas of obvious **induced** events
Crustal and sub-crustal (mauve) sources
Probable replacement of 2010 deterministic Cascadia approach by 2015 probabilistic fault model

Cascadia scenario earthquake contours in green (heavier where this model dominates) superimposed on robust H and R model shaded contours

Just replacing “or” by “and” increases hazard ~40% along this line
2015 Cascadia model

Inboard edge of rupture
Rupture model for Cascadia and Explorer plates

Projected surface trace of fault (heavy solid line on map)

Rupture surface of fault (dotted lines on map)

Cascadia probabilistic model, developed for Penrose conference, ca. 2000 for use with FRISKGSC program
Rupture model for Cascadia and Explorer plates - detail

Locus is at 30 km depth
Comparison of Cascadia inboard loci (best estimates)

~15 km closer to Victoria
## Paleohistory of Great Cascadia Events – after Goldfinger et al 201X

### Table 9. Magnitude calculated from time interval, plate motion and rupture zone dimensions

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<th>northern margin following interval years</th>
<th>northern margin slip from following (m)</th>
<th>southern margin interval years</th>
<th>southern margin slip from (m)</th>
<th>northern &amp; southern slip</th>
<th>Segment name</th>
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<td>total slip</td>
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Intervals for complete rupture events

Dates for past events (10,000 year history)

J Adams 20120113
Cascadia Magnitude-recurrence for complete rupture events

10,000 year history (we have one sample of the 1/10,000 year event!) Assume that each rupture of interest to Canada is complete, end-to-end (i.e. all M~9, not some M9 + many M~8)

Use time interval * plate tectonic rate to get the slip per event \( \rightarrow \) magnitude

Protypical event happens every **550 years**, ruptures length of **1020 km** and width of **125 km**, has slip of **25 m** and has magnitude of **9.3**

Events range in magnitude from 8.5 - 9.1 or 8.9 - 9.5 depending on input assumptions

– but nearby seismic hazard is not very sensitive to exact magnitudes when earthquakes get this big
Magnitude-recurrence for complete rupture events using 2 sets of possible input parameters
**Trial run**

Probabilistic Cascadia motions

Sa(0.2) for 2%/50 years

2011 geometry

Youngs’ GMPE

Results indicative only

Locus is uncertain by ~20 km, and results in ~15% change in hazard
Mmax in non-extended-SCR is M7.25±0.1 and in extended-SCR is M7.65±0.1
Integrated Treatment of Floor source

Will add as a source to the eastern and western models

Will use two alternative models (probably 4\textsuperscript{th} Gen and Martens-Atkinson models, equally weighted)

Will allow Mmax to 7.2 + (Leonard & Clark, 2011)

Expect hazard to drop in centre of country, may increase it at margins, near other earthquake sources (e.g. Calgary, Sudbury)

May still need a floor value?
New Ground Motion Prediction Equations

Gail will talk about these

Evolution of spectral periods

In 1985 it was PGA and PGV

In 2005/2010 Sa at 0.2, 0.5, 1.0, 2.0 seconds

For 2015 may add 0.15, 5, 10 seconds

Not yet certain how these periods would be used in the Code
Adjusted reference ground condition

In 1985 it was **Rock or Firm Ground**
In 2005 **Fa and Fv** factors were introduced
  • reference condition = Site Class C
  • reduction factor of 20-50% for being on rock

For 2015 the reference ground condition is likely to be the boundary between site class B and site Class C (“B/C” = B/SlashC) for consistency with all recent Ground Motion relations

Probably no design level implications
  (though the Fa and Fv values will change)
Summary

Seismic hazard estimates are improving

More data leads to improvements and increased confidence in our estimates

2015 estimates will provide an improved basis for the distribution of engineering anti-seismic measures across Canada

www.EarthquakesCanada.ca

Thank You