The Canadian Society for Civil Engineering, Vancouver Section

THE RESPONSE SPECTRUM

A Technical Seminar on the Development and Application of the Response Spectrum Method for Seismic Design of Structures

Seismic Hazard Analysis to obtain Uniform Hazard Response Spectrum (NBCC 2005)

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1-2 June 2007 Vancouver, BC

Outline

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- Overview of probabilistic hazard analysis
- The Uniform Hazard Spectrum
- Input parameters for national seismic hazard maps
- Hazard maps in 2005 NBCC

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Probabilistic seismic hazard analysis: Object

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- Determine the level of ground shaking expected at a site - with an acceptable probability of being exceeded! Thus the concept of risk comes into play
- Contrasts with a 'deterministic' analysis, which aims to find the maximum ground motions that could occur – such a deterministic analysis is not generally feasible in Canada
- If ground motions are specified, structures can be designed to withstand the earthquake-induced loads

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Types of probabilistic seismic hazard analysis

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- Seismic hazard zoning maps, as in the National Building Code of Canada (and the United States codes)
- Site-specific hazard analysis for critical structures such as dams, nuclear power plants, etc.
- Types differ in level of detail and reliability objectives
- Today's presentation focuses on seismic hazard maps in Canada (NBCC 2005)

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Seismic hazard zoning map: (GSC, 1999; NBCC 2005)

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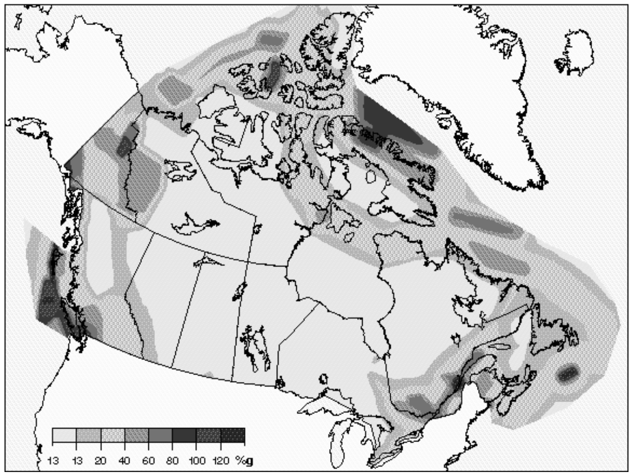
PSA 0.2 second 2%/50 year hazard values



- •Mapped ground-motion parameters:
- •Response spectra at 4 selected periods
- •Peak ground acceleration
- •Peak ground velocity

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Typical probability levels for earthquake design ground motions

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- 1/2500 per annum (= 2% in 50 years) for modern building codes including NBCC, 2005
- 1/10,000 p.a. (=1% in 100 years) for dams and many other critical structures
- 1/100,000 to 1/1,000,000 p.a. for nuclear power plants

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Seismic Hazard Methodology

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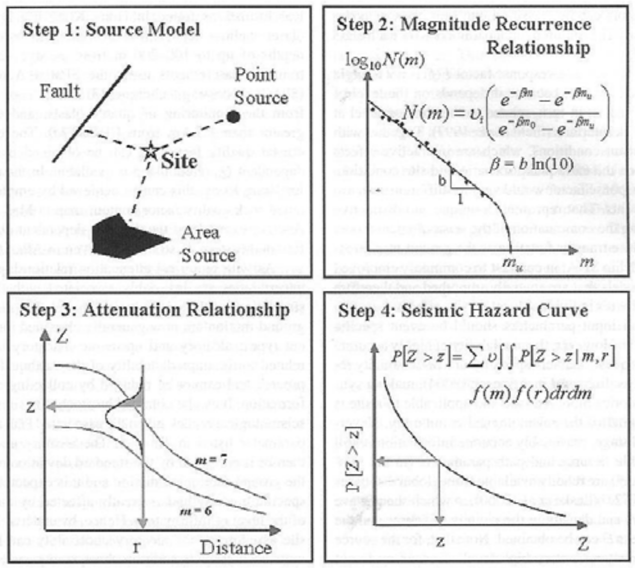

Figure 1. Steps involved in the conventional Cornell-McGuire probabilistic seismic hazard assessment (PSHA) (after Reiter, 1990).

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Basic steps of seismic hazard analysis

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1. **Identify the potential sources of future earthquakes (seismic source zones)**
2. **Calculate the recurrence relationship that defines how frequently, on average, earthquakes of different magnitude occur within each source.**
3. **Define ground-motion prediction equations giving amplitude as a function of magnitude, distance**
4. **Calculate hazard by integration.**

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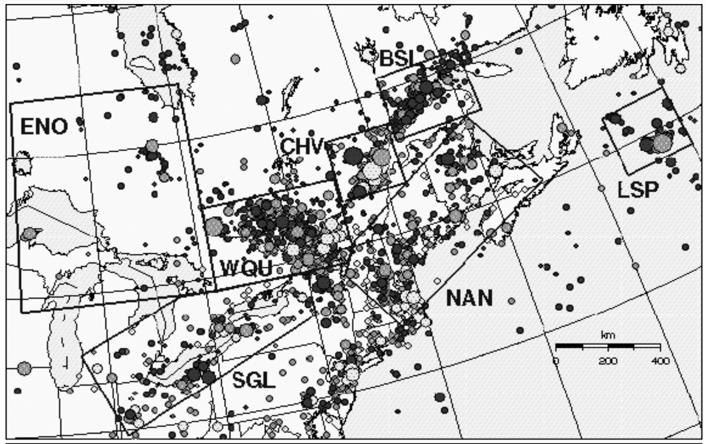
1. Zonation may be based on seismicity patterns… 9

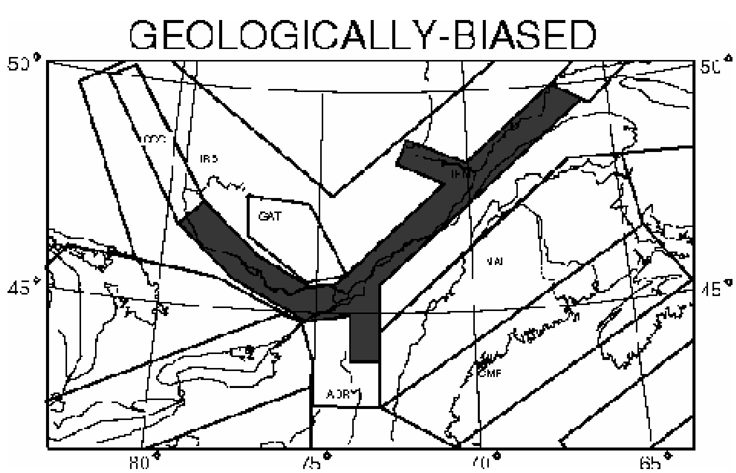


Historical Seismicity/Séismicité Historique

Yellow/Jaune - <1900 Uncertainty +/- 50km | Orange/Orange - 1900 - 1964 +/- 25km | Red/Rouge - 1965-1999 +/- 10km Incertitude

2.5 ≤ M < 3.0 · M ≥ 3.0 · M ≥ 4.0 · M ≥ 5.0 · M ≥ 6.0

… or zoning may be based on geologic concepts (GSC, 1999) 10



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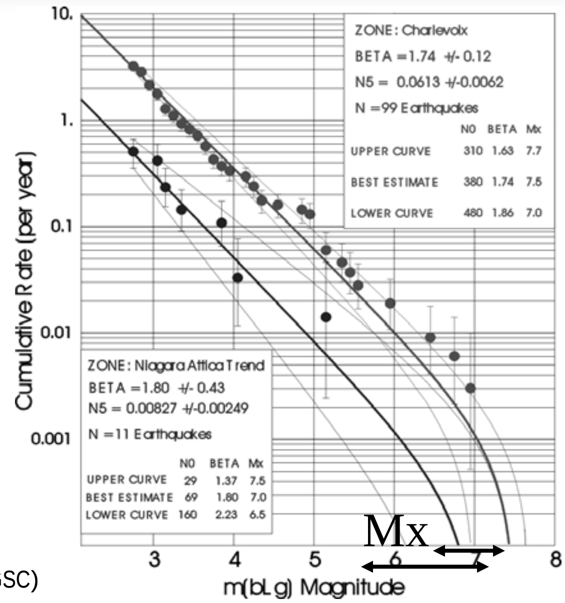
2. Define magnitude recurrence relations, giving rates of occurrence.

Eg. this shows rates and their uncertainties for 2 eastern Cdn. Source zones



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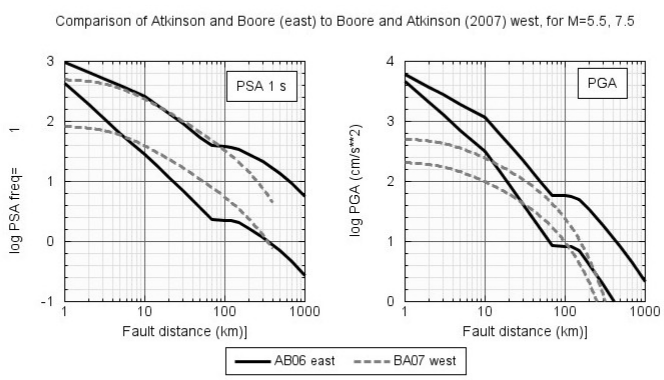
3. Define ground-motion prediction equations that describe shaking amplitude as fn(M, dist), for each ground motion parameter (typically response spectra)



Ground-motion relations for response spectra at 1 sec and PGA for ENA and California.
For NEHRP B/C boundary site conditions.

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Note on eastern vs. western ground motions and hazard 13

Ground motion characteristics are different in ENA than they are in the west. Eastern motions have higher frequency content, and attenuate more slowly with distance. These differences mean the nature of eastern and western hazard may be different. (and the time histories will have a different character)

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4. Hazard calculation 14

$$\lambda(X \geq x) = \sum_{i=1}^{I} \upsilon_i \iint f_i(m) f_i(R \mid m) P(X \geq x \mid m, R) dR dm$$

Calculation of the rate of exceedence of a specified amplitude (for any selected parameter) involves integrating the contributions to the hazard over all possible earthquake magnitudes and distances. (Thus our inputs involve source geometry, seismicity rates, and ground-motion prediction equations giving A=fn(M,dist).

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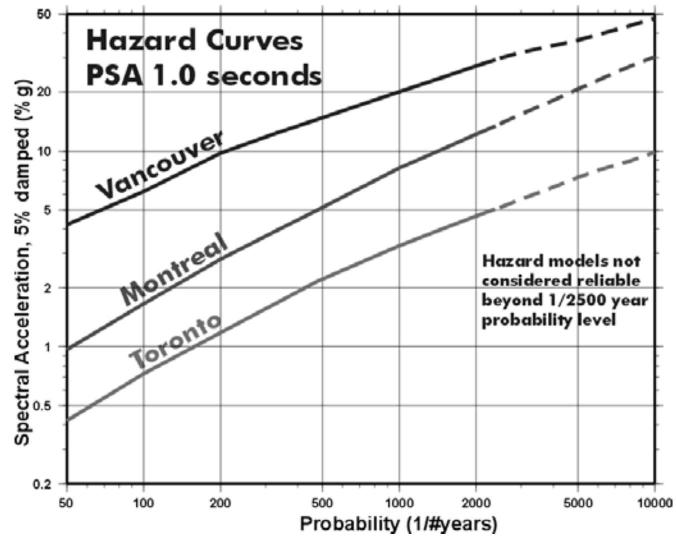
Result: expected ground motion as a function of probability of exceedence



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Measures of ground-motion intensity for engineering purposes

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- PGA, PGV
- Response spectra (elastic) – Uniform Hazard Spectrum
- Others (avg. spectra over freq., power spectra, Fourier amplitude spectra)
- Time series

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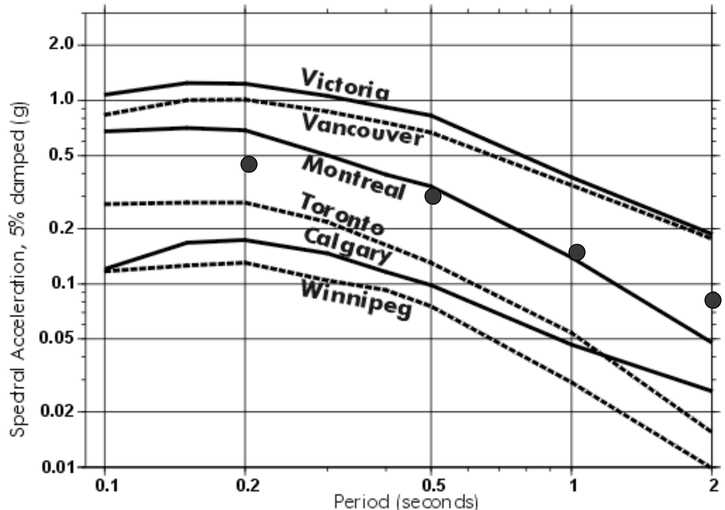
To obtain the Uniform Hazard Spectrum: expected response spectrum for specified probability, at each period, is obtained (from the hazard curves) and plotted vs. period



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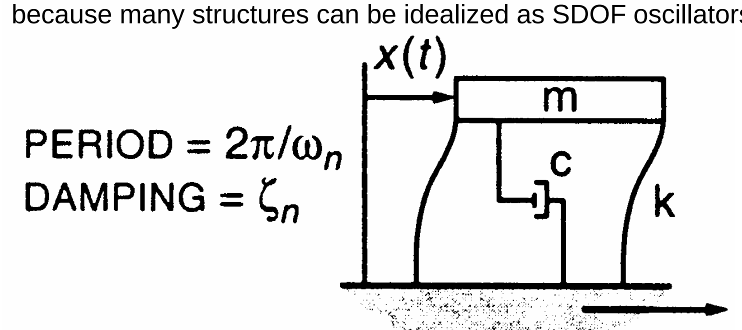
Why Uniform Hazard Spectra?

It provides a response spectrum for the target probability level

The response spectrum is handy for engineering applications because many structures can be idealized as SDOF oscillators



Consider a damped single-degree-of-freedom oscillator. The response spectrum gives the maximum displacement of the oscillator when subjected to the ground motion.

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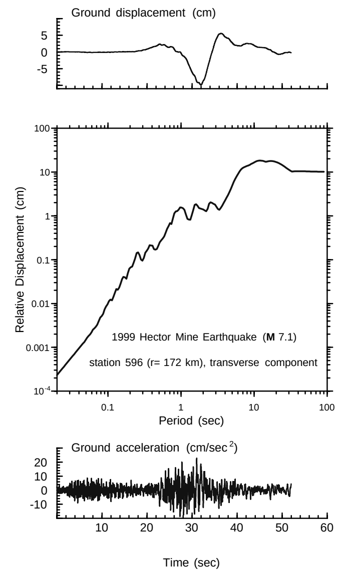
Response spectrum of Hector Mine earthquake record, showing oscillator displacement.



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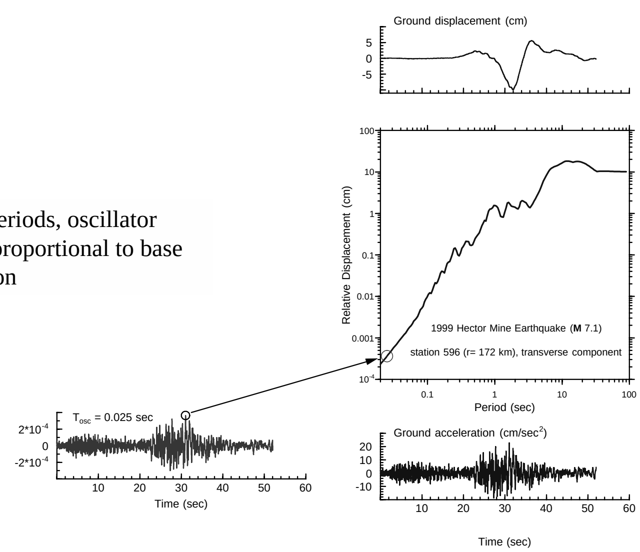
At short periods, oscillator response proportional to base acceleration



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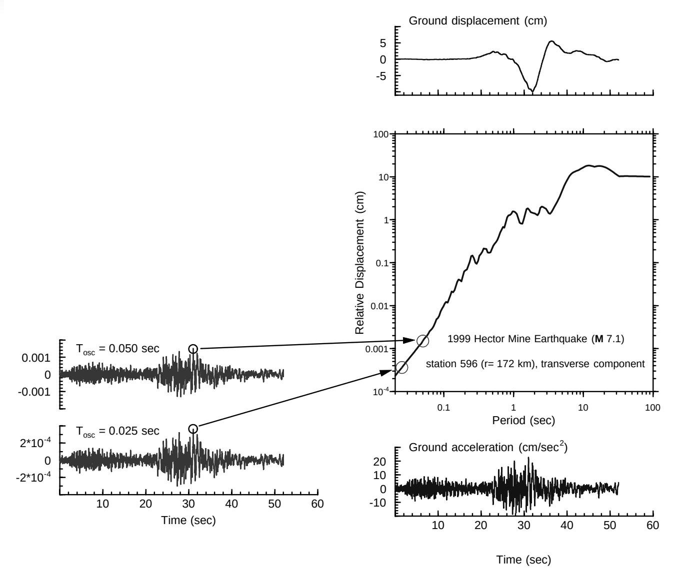

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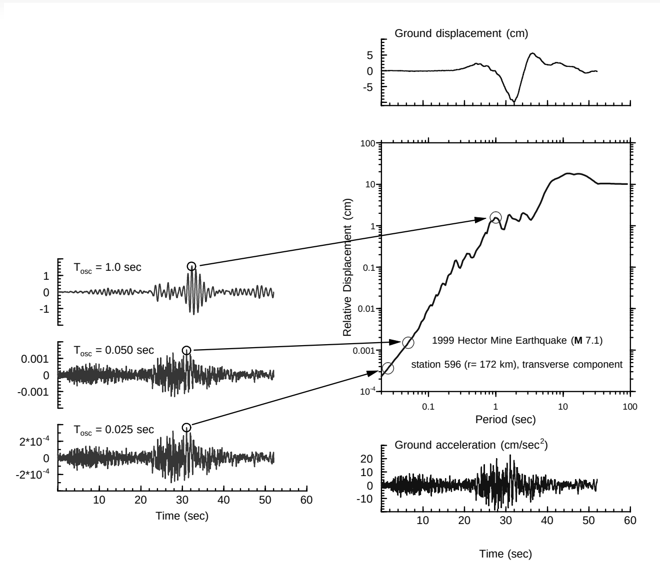

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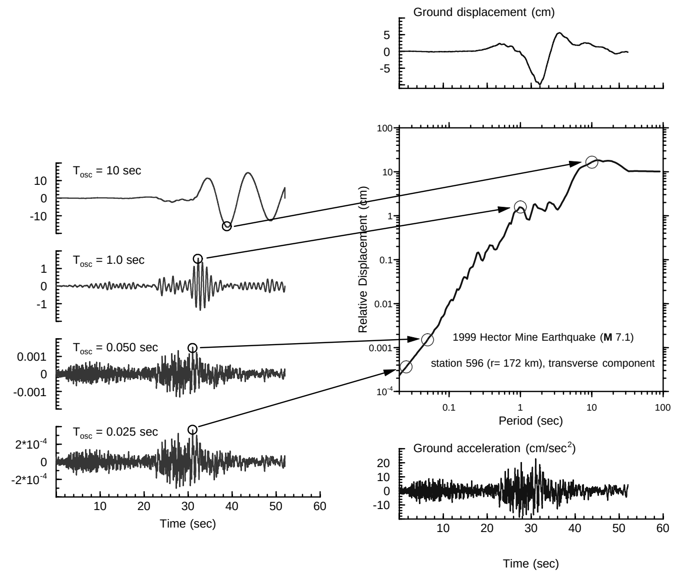

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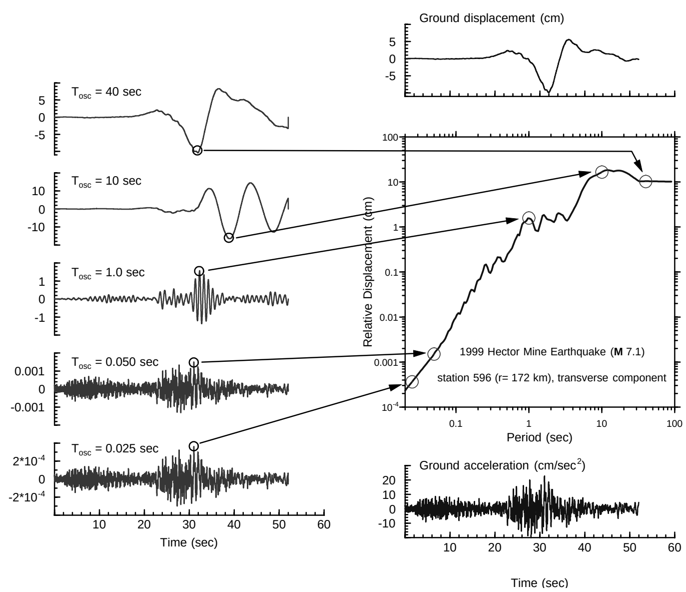

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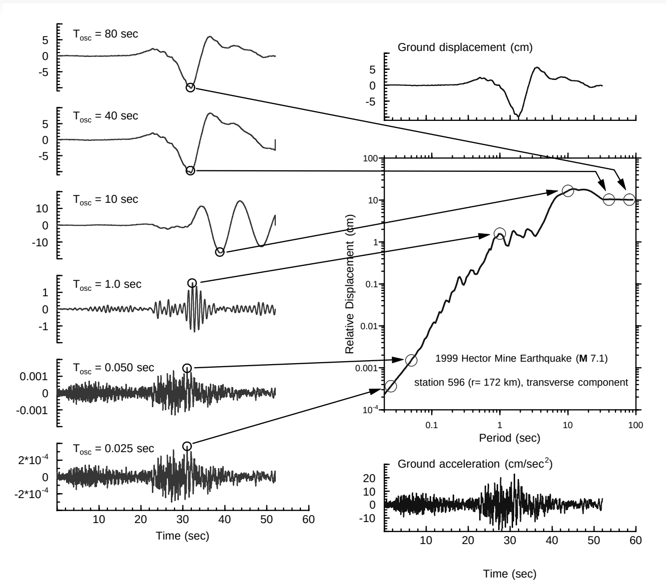

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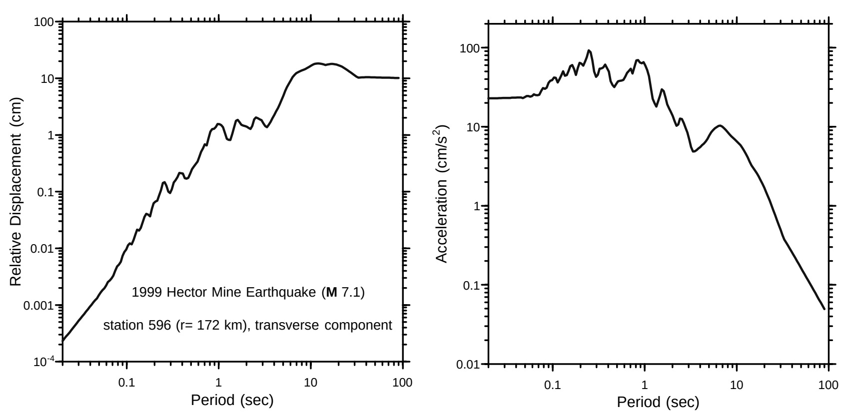
convert displacement spectrum into acceleration spectrum (multiply by $(2 \pi /T)^2$)



Acceleration spectrum usually used in engineering

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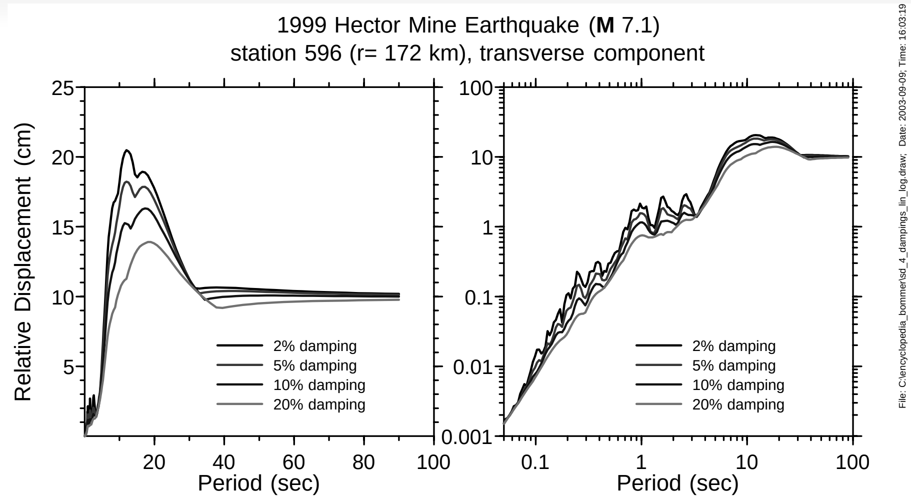

D. Boore, USGS

Linear scale at left

Log scale at right

At short and very long periods, damping not significant

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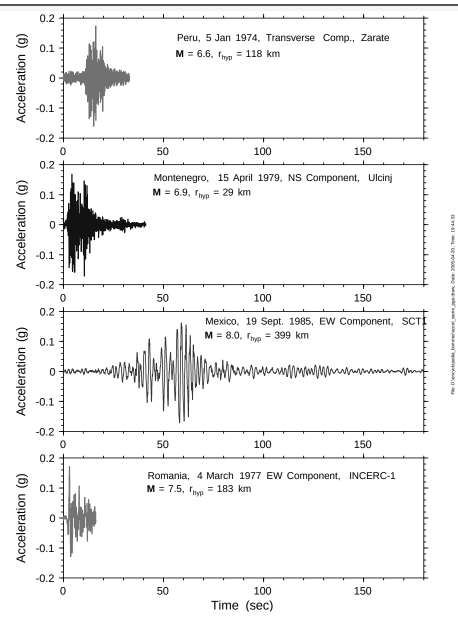
PGA generally a poor measure of ground-motion intensity. All of these time series have the same PGA:



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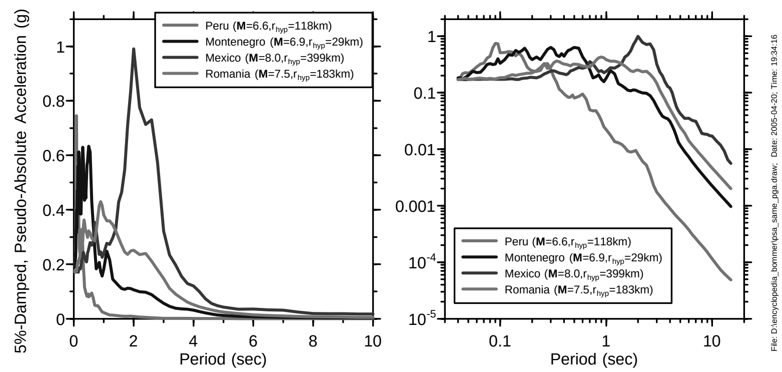
But the response spectra (and consequences for structures) are quite different (lin-lin and log-log plots to emphasize different periods of motion):



D. Boore, USGS Linear scale at left Log scale at right

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Common misconceptions about probabilistic seismic hazard analysis 30

- Low probability hazard estimates are an extrapolation of a short historical record
- Probabilistic hazard analysis are subject to large uncertainties, so deterministic analyses are more reliable

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Example of contributions to hazard at 10**-4 per annum

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- Say p(significant EQ, M>5)=0.1
- Conditional p(M>6)=0.1
- Conditional p(R<20 km) = 0.02
- Conditional p(pga>A) = 0.5
- So p(>A) = (0.1)(0.1)(0.02)(0.5) = 0.0001
- Thus low probability hazard estimates are not an extrapolation, simply a compound probability

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Types of uncertainty in seismic hazard analysis

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- Random (aleatory) uncertainty due to random, natural variability in earthquake processes (eg. scatter in ground motion relations)
- Modeling (epistemic) uncertainty due to imperfect knowledge regarding correct model parameters
- Randomness is accounted for in standard probabilistic analysis
- Modeling uncertainty can be considered through sensitivity analysis or logic tree approaches

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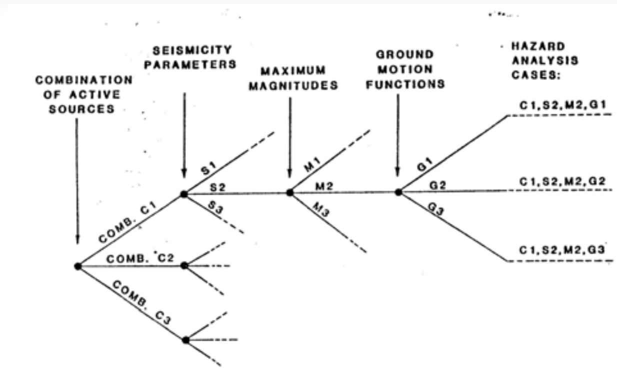
Incorporation of uncertainty in knowledge into the analysis: logic tree approach



Hazard analyses for 2005 NBCC use a logic tree approach to model main uncertainties

FIGURE 4. Logic tree format to represent uncertainty in hazard analysis input. Each branch has an assigned weight; the sum of weights on branches attached to any node is unity. (after NRC, 1988)

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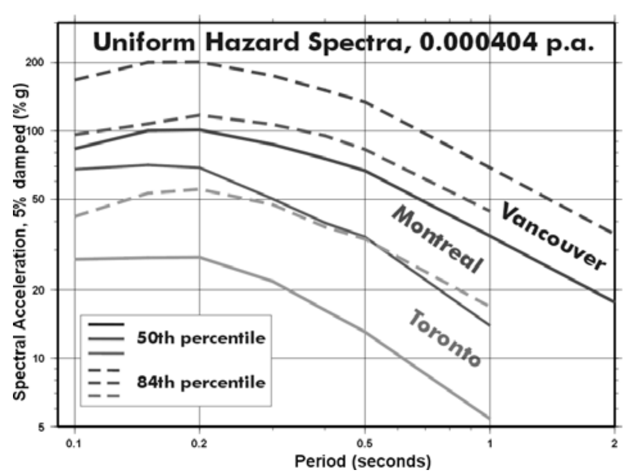
Seismic hazard analysis result is expressed as a Uniform Hazard Spectrum (UHS) for a target probability; uncertainty expressed through confidence levels in results



2% in 50 year probability of exceedence

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Engineering application of the UHS for the chosen probability 35

- Dynamic analysis using a response spectrum method (generally linear): in this case we have everything needed
- Time history analysis using accelerograms (eg. many nonlinear analysis methods): in this case we need time histories that are "compatible" with the UHS

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GSC's national hazard maps (NBCC, 2005) (for summary see Adams and Atkinson, 2003 CJCE): Main inputs 36

- seismic source zones (for each of the sources, the seismicity is used to calculate magnitude-recurrence relations)
- Ground-motion prediction equations
- treatment of uncertainty

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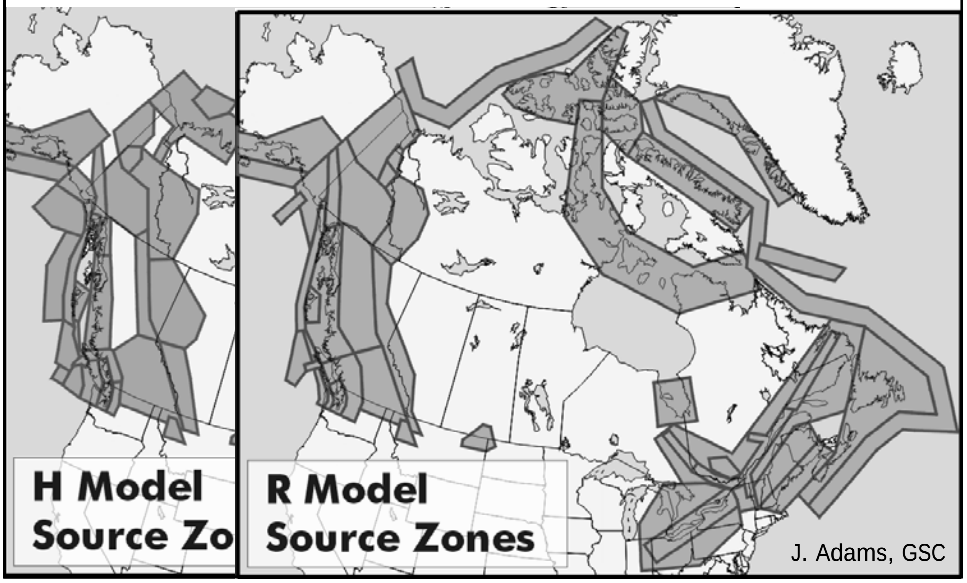
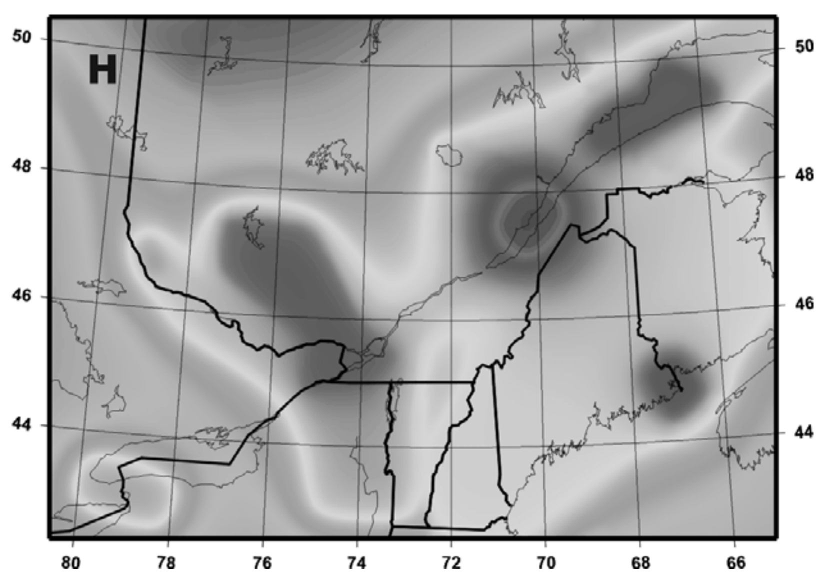
Two source zones span range in knowledge



Expected ground motions when historical clusters define the seismic source zones 38



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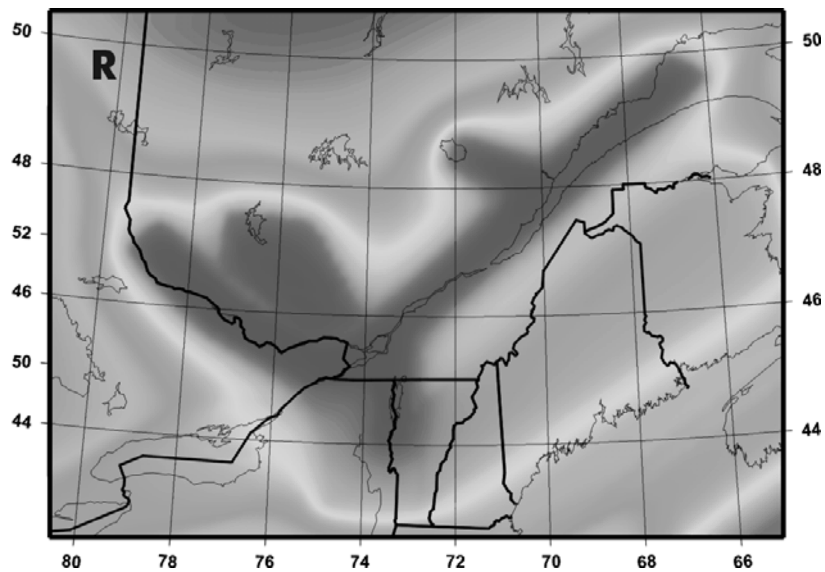
Expected motions when a larger regional area is a single source zone 39



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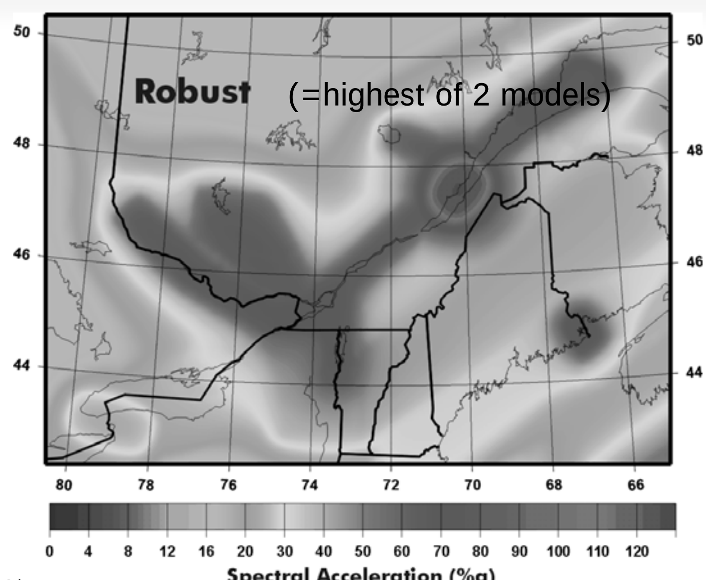

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Full Robust Hazard Model

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- Highest value of:-
  - Probabilistic H model
  - Probabilistic R model
  - Deterministic Cascadia model
  - Probabilistic Stable craton model (Floor model, will not discuss today)

Note: all calculations for 'firm ground' = NEHRP C

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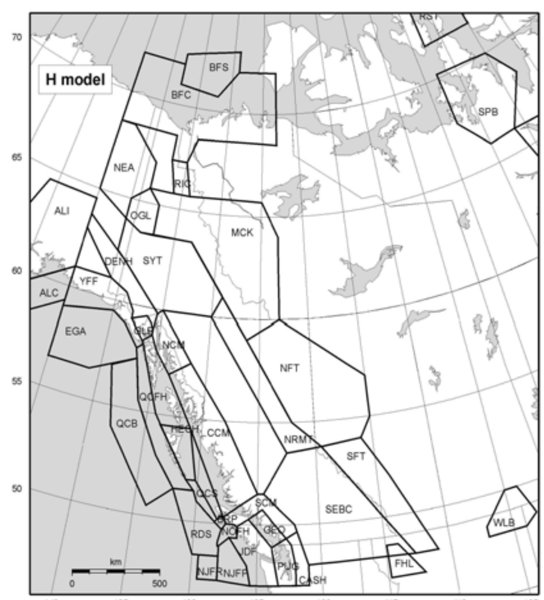
Western H-model source zones



From GSC Open-file 4459, 2003

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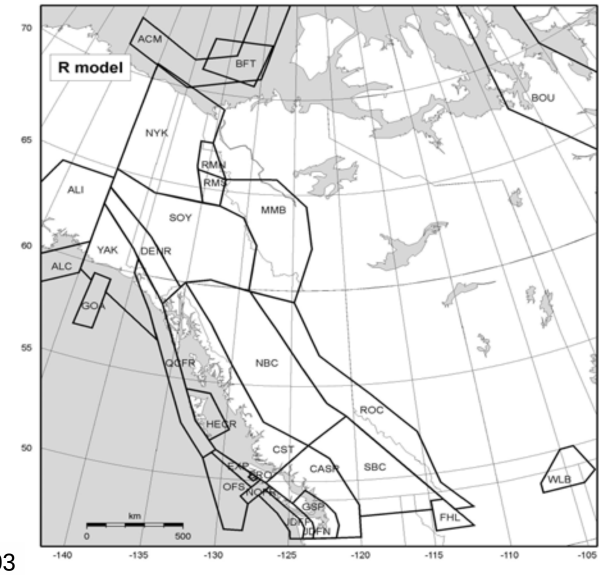
Western R-mode source zones



From GSC Open-file 4459, 2003

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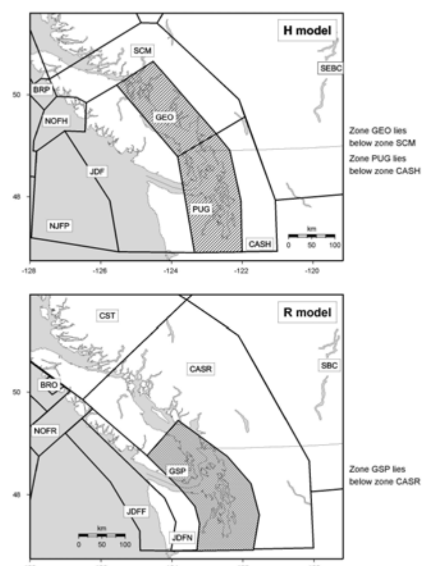
Source zones in Lower Mainland region: shaded zones are in-slab sources that lie beneath crustal sources



From GSC Open-file 4459, 2003

The R model zones are also shown for comparison

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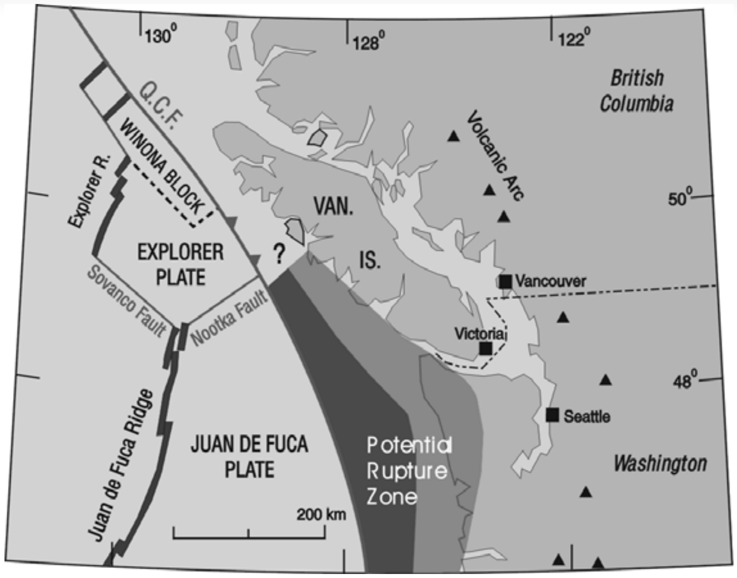
Cascadia Subduction Zone: expected motions for M9 calculated separately (deterministically) 45



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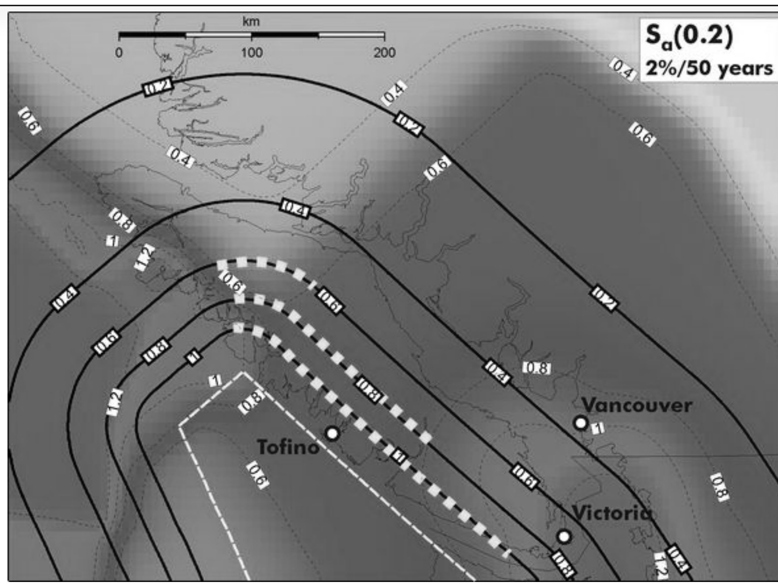
Deterministic Cascadia plus Probabilistic hazard: take higher of the two 46



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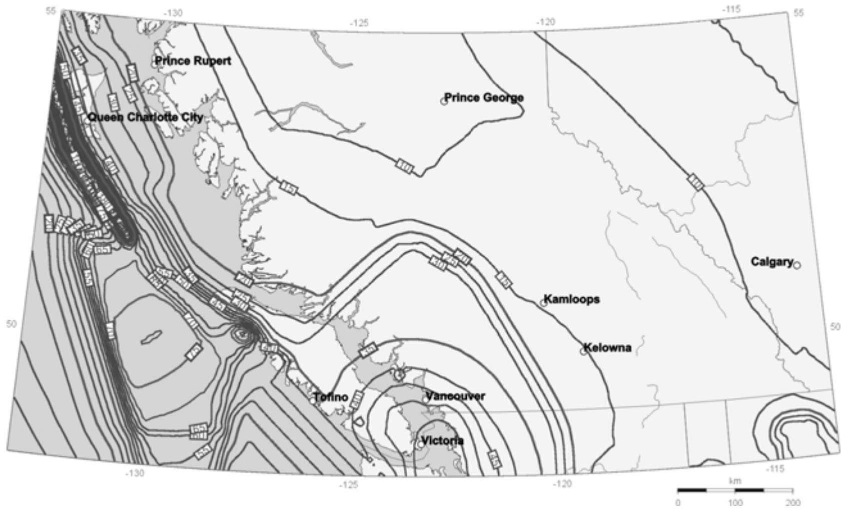
PSA 0.2 sec - robust firm ground 2%/50 year values (%g)



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Ground-motion prediction equations

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- Key input in seismic hazard analysis
- Eastern Canada relations are from Atkinson and Boore (1995) with estimate of epistemic uncertainty
- Western Canada relations are from Boore, Joyner and Fumal (1993) for crustal earthquakes with estimate of epistemic uncertainty; Youngs et al. (1997) for in-slab and interface subduction events
- All relations converted to NEHRP C (firm-ground reference condition)

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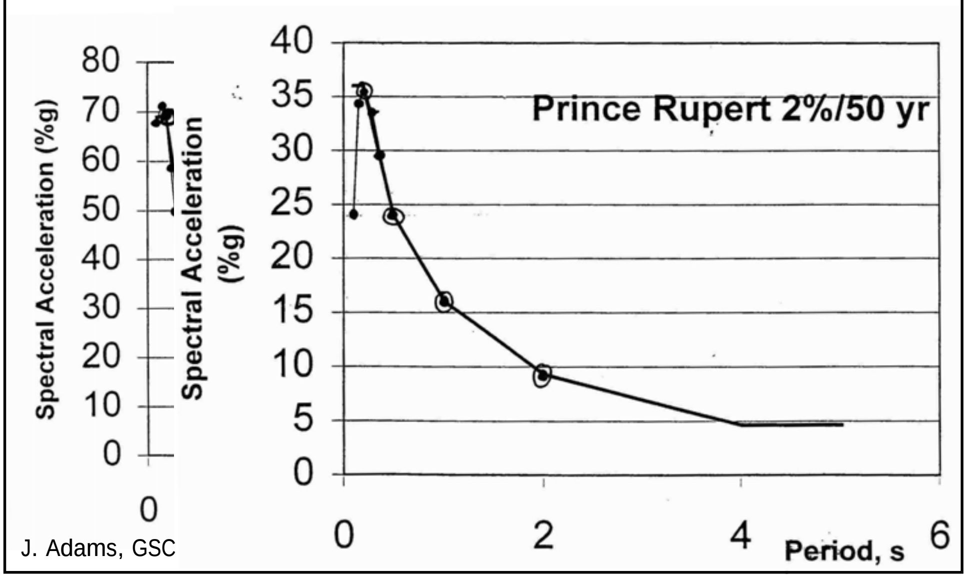
Approximation of UHS on NEHRP Site Class C by four spectral parameters:-



Mapped ground-motion parameters for national seismic hazard maps

50

5% damped PSA on firm ground

(NEHRP C) units = g

periods of 0.2, 0.5, 1, and 2 s

plus

Peak Ground Acceleration
Peak Ground Velocity (in east)

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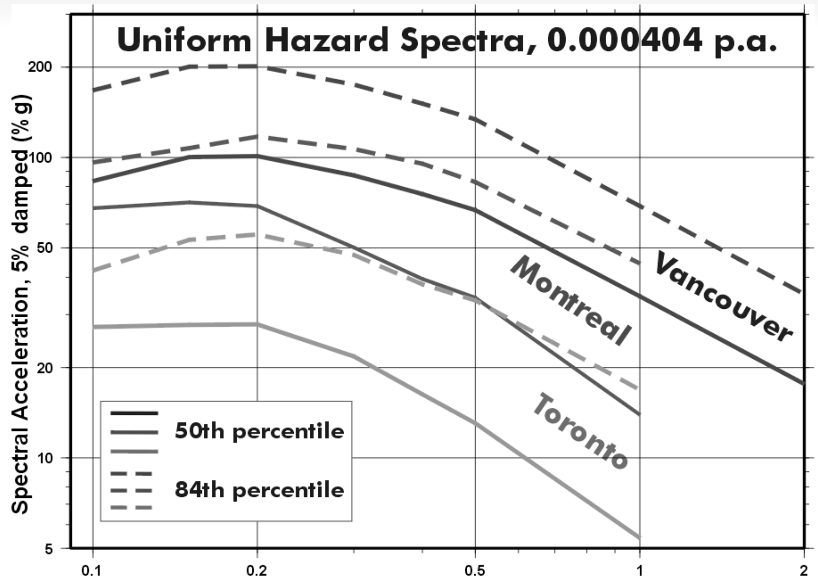

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Appropriate probabilities in codes will lead to more uniform protection (2% in 50 years NBCC)

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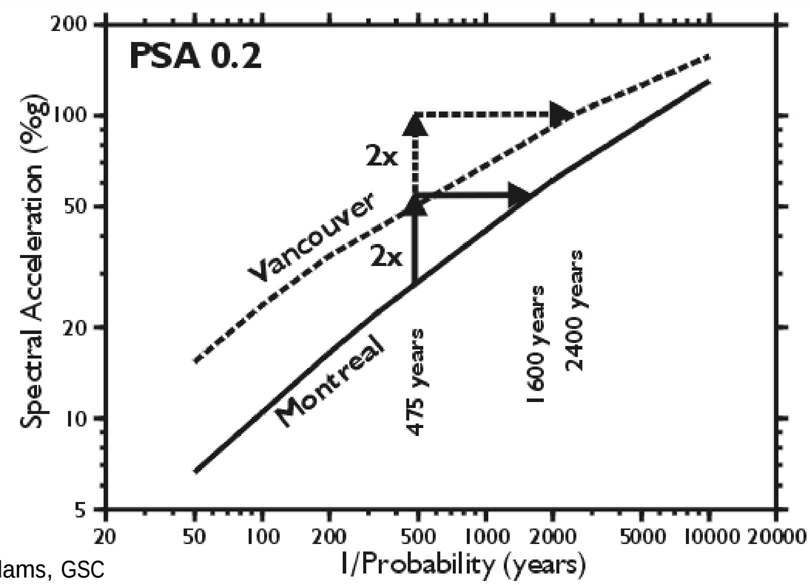

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Spectral acceleration zoning map: GSC 1999 (4 mapped response spectra parameters)
Values downloadable from www.earthquakescanada.ca

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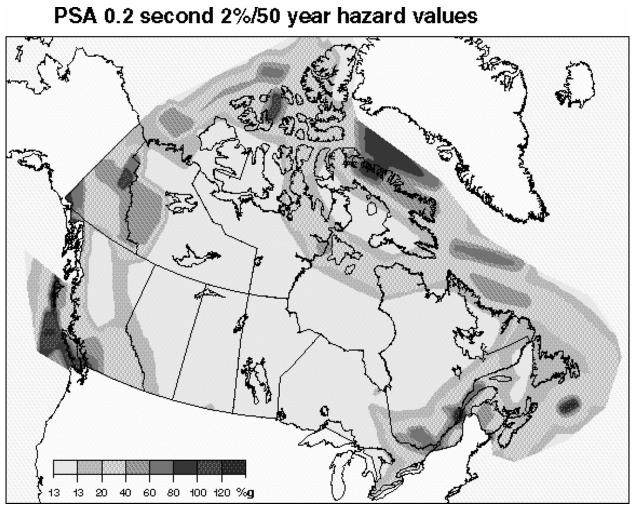

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Deaggregation of hazard contributions by magnitude and distance

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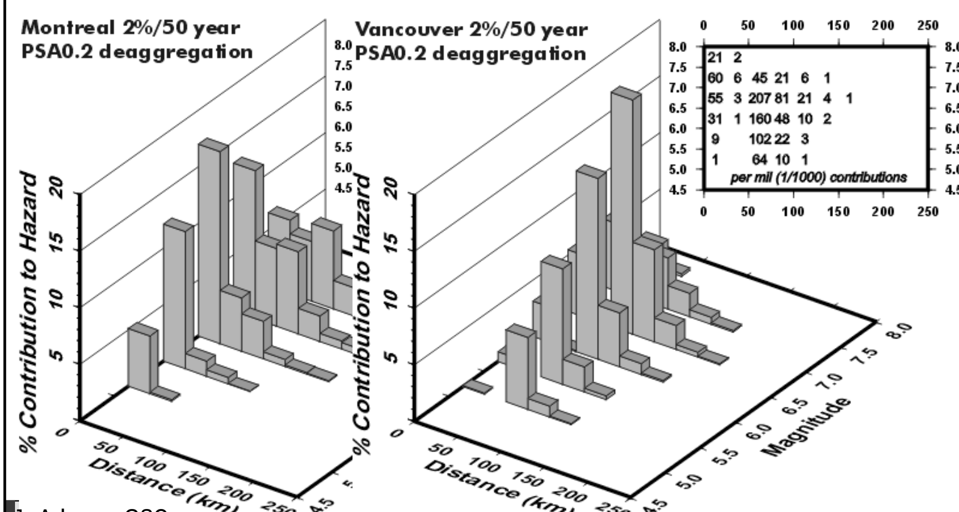

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Thank-you

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