Selection and Modification of Time-Histories for Southwestern BC

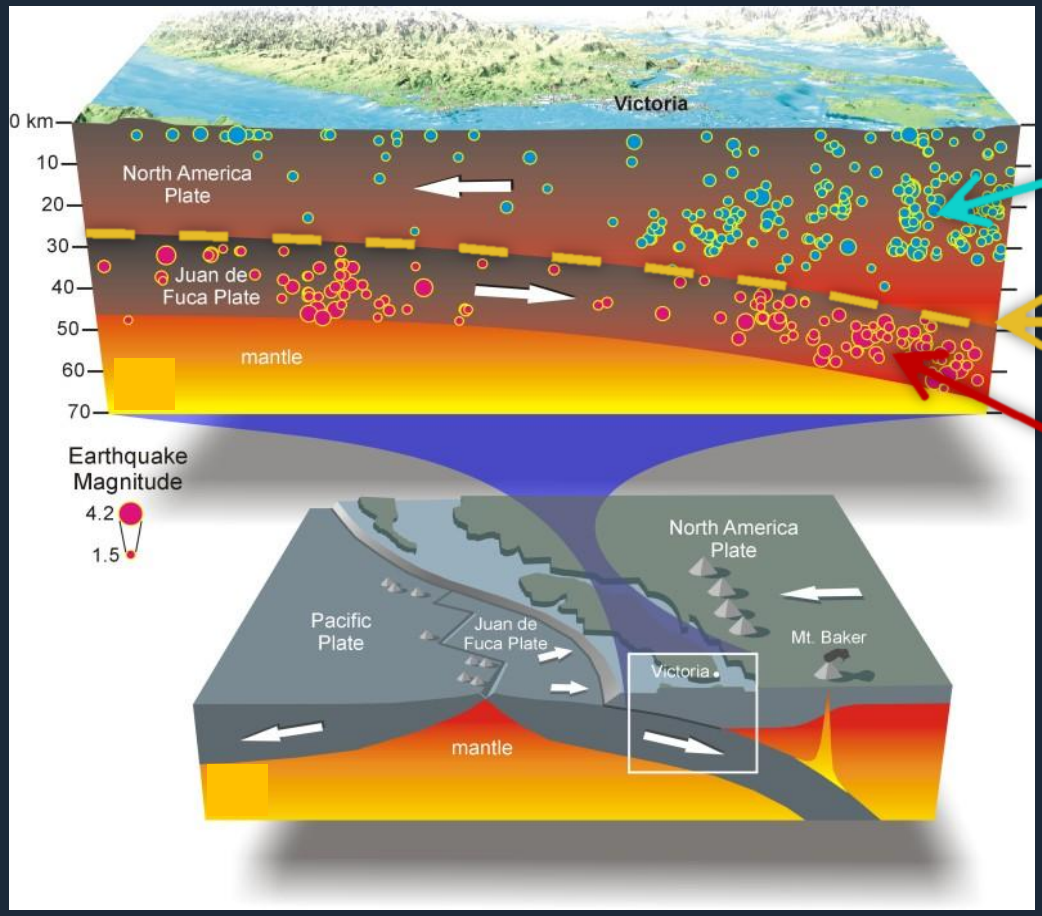
Tuna Onur, Ph.D.

Seismic Hazard and Risk Consultant

Outline

- Overview of Earthquakes in Southwestern BC
- PSHA and Uniform Hazard Spectrum
- Record Selection and Modification

Earthquakes in Southwestern BC



Shallow crustal

Subduction interface

Subducting slab
(subcrustal, inslab, intraslab)

Source: Geoscape Victoria, GSC Miscellaneous Report M41-8/74F, 2001.

T. Onur, Sep 2014

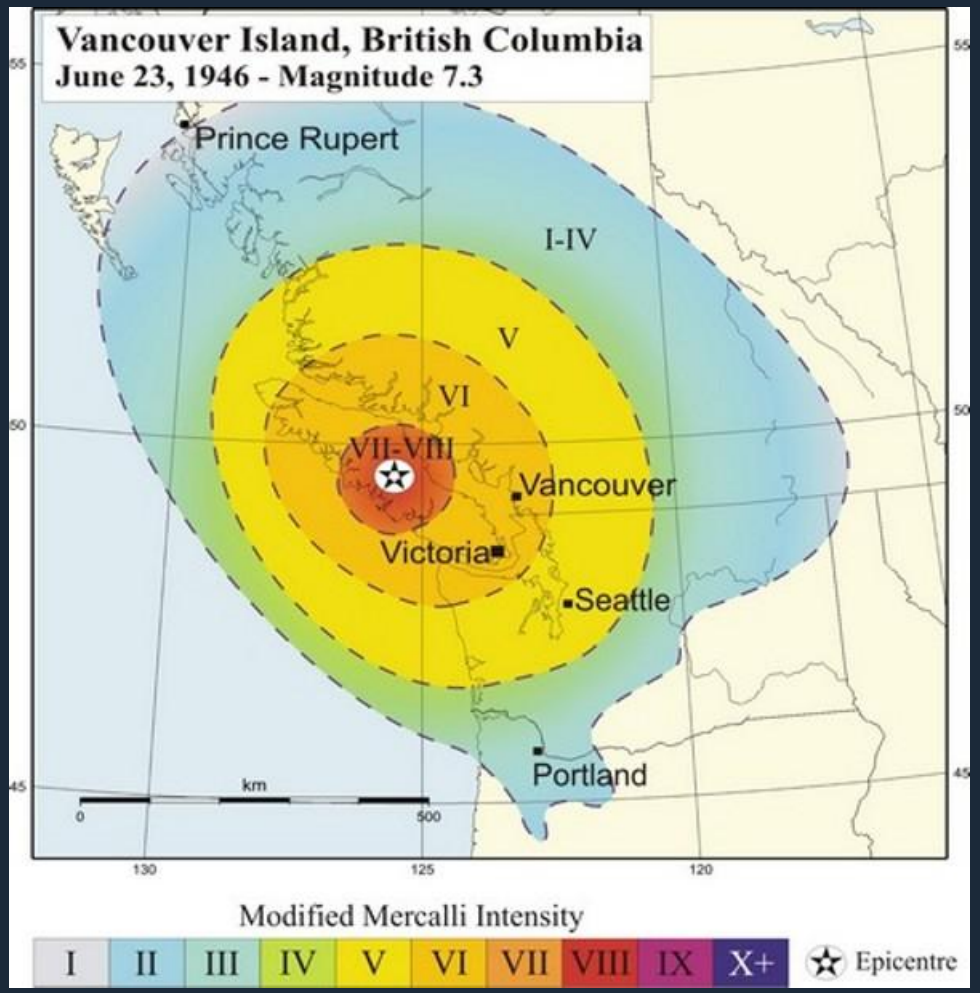
Earthquakes in the Subducting Slab

- Most frequent in southwestern BC
- At ~50km depth under Georgia Strait and Puget Sound
- Felt over a large area
- Examples: 1949 Puget Sound, 1965 Puget Sound, and 2001 Nisqually

T. Onur, Sep 2014

Shallow Crustal Earthquakes

- Major (Mw > 7.0) shallow crustal earthquakes are rare in southwestern BC...
- ... but damaging
- Intense damage close in
- Fast GM attenuation
- 1946 VI earthquake

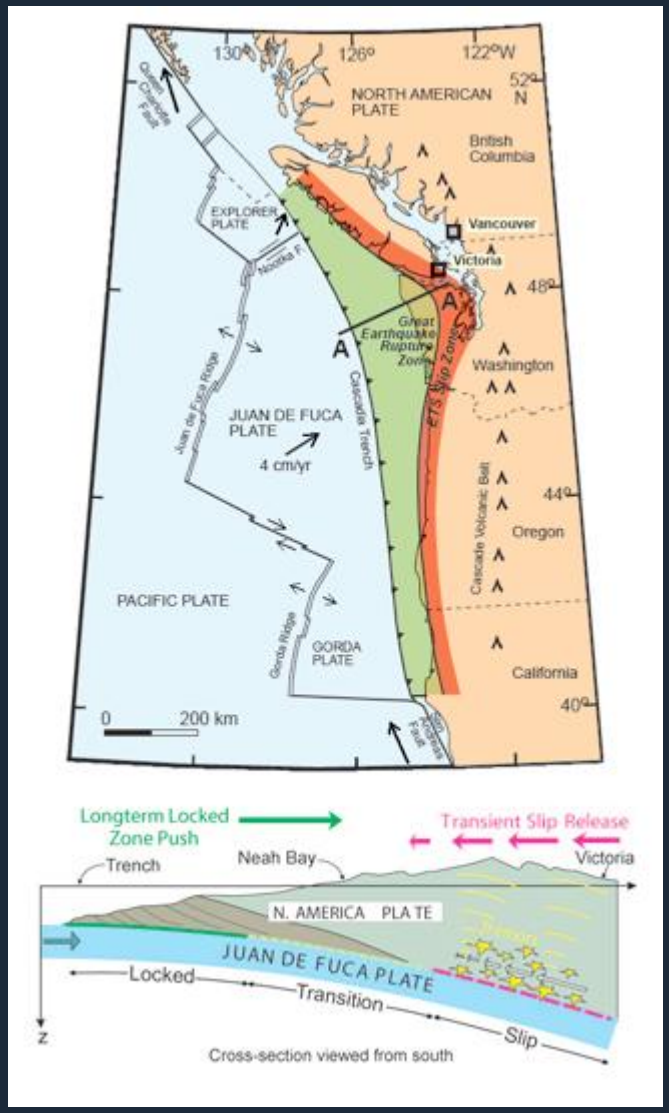


T. Onur, Sep 2014

Source: http://earthquakescanada.nrcan.gc.ca

Subduction Interface Earthquakes

- Average return period: ~550 years
- Last one happened in 1700AD
- Estimated magnitude: ~Mw9.0
- Long-period ground shaking
- Long duration
- Regional shake impact
- Tsunami impact
- Fore- and aftershocks

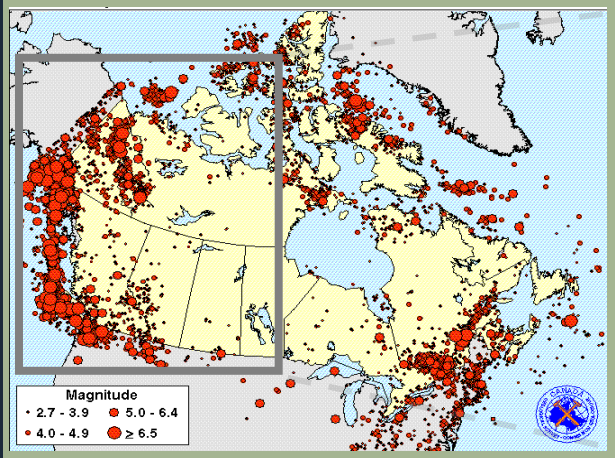


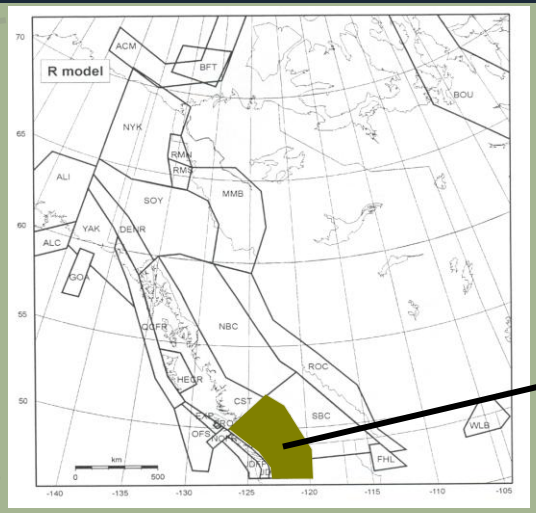
T. Onur, Sep 2014

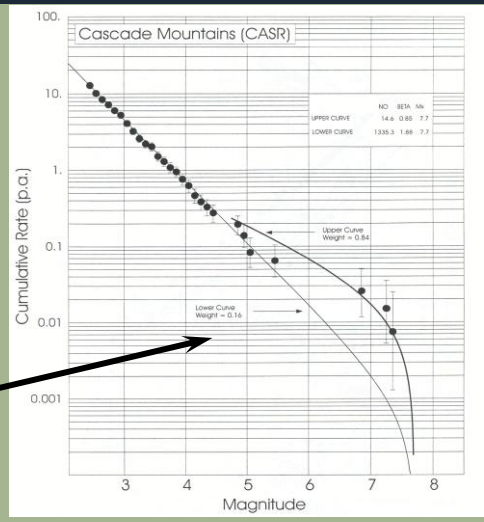
http://xenon.colorado.edu/spotlight/index.php?product=spotlight&station=albh

Magnitude-Recurrence Relations

Cumulative recurrence rate of earthquakes







Earthquake Activity → Seismic Source Zones → Recurrence Relations

Source: Geological Survey of Canada

T. Onur, Sep 2014

Ground Motion Prediction Equations

- GMPEs characterize how ground shaking amplitudes decay by distance for a given:
  - magnitude,
  - fault type (strike-slip, normal, thrust, etc.),
  - near-surface site conditions, typically represented by Vs_{30}
  - sometimes depth

  - macro-scale geology/tectonics of the region (stable craton, subduction zone, etc.)
    - Central and Eastern Canada → Stable Continental Region
    - Western Canada → Active Crustal
    - Cascadia → Subduction Interface and Subducting Slab

Probabilistic Seismic Hazard Assessment

- Probabilistic combination of the contribution of earthquake shaking hazard from various seismic sources

- Answers the question:
  - What is the probability of a given ground shaking intensity being exceeded?

  or
  - What is the ground shaking intensity corresponding to a given probability of exceedance?

PSHA Formulation

- Probabilistic seismic hazard at a site of interest is given by:

$$\lambda(a) = \sum_i v_i \iint P[A > a \mid m, r]\, f_{Mi}(m)\, f_{Ri|Mi}(r;m)\, dr\, dm$$

$\lambda(a)$: annual frequency of earthquakes that produce a ground-motion amplitude A higher than a (PGA, PGV, SA at a given period, MMI, etc).

The summation extends over all source zones, v_i is the annual rate of earthquakes with magnitudes higher than a threshold, m_0 in source i.

$f_{Mi}(m)$ and $f_{Ri|Mi}(r;m)$: probability density functions on m and r, respectively.

$P[A > a \mid m, r]$: the probability that an earthquake of magnitude m at distance r produces a ground motion amplitude A at the site that is greater than a.

From λ to Probabilities

λ: Annual rate of exceedance

Return period: $T_R = \frac{1}{\lambda}$

$p_e = 1 - e^{-\lambda X}$

Probability of at least one event (or exceedance) occurring in a period of X years (Poisson probability distribution), OR

Probability of exceedance

- Poisson probability distribution assumes that occurrence of one event is independent of another

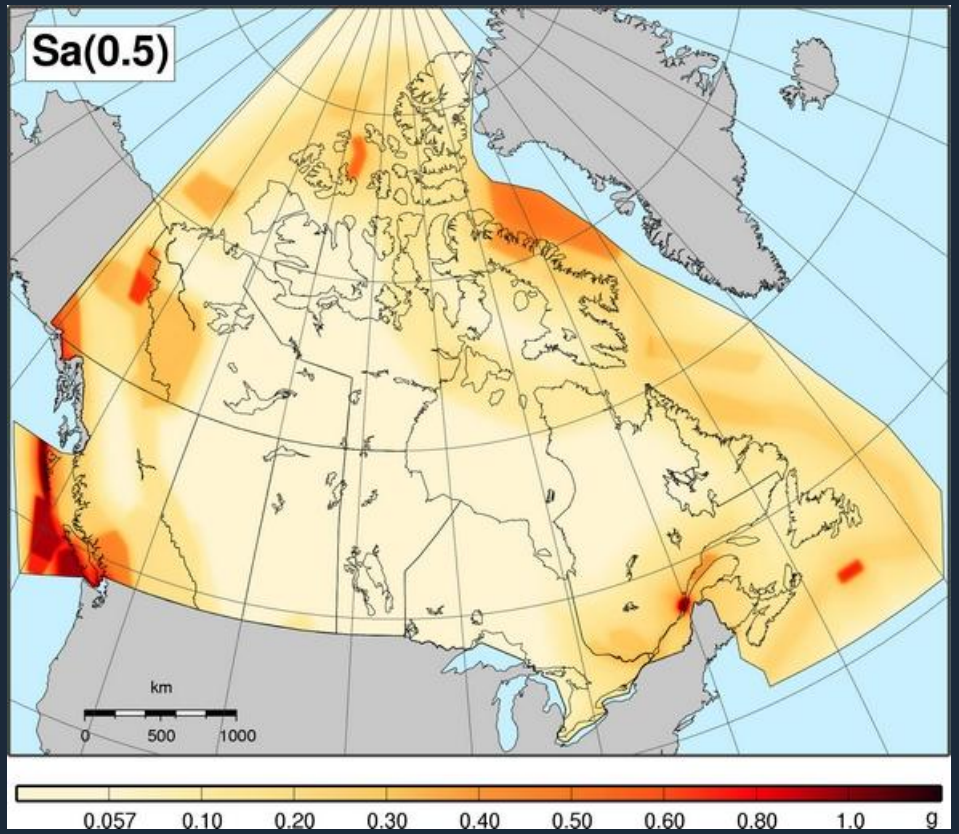
Regional vs. Site-specific PSHA

- Regional (multiple sites over a large area) – e.g. building codes
  - Large geography → seismic sources general in nature
  - Often a reference ground condition is selected, such as Vs30=760m/s

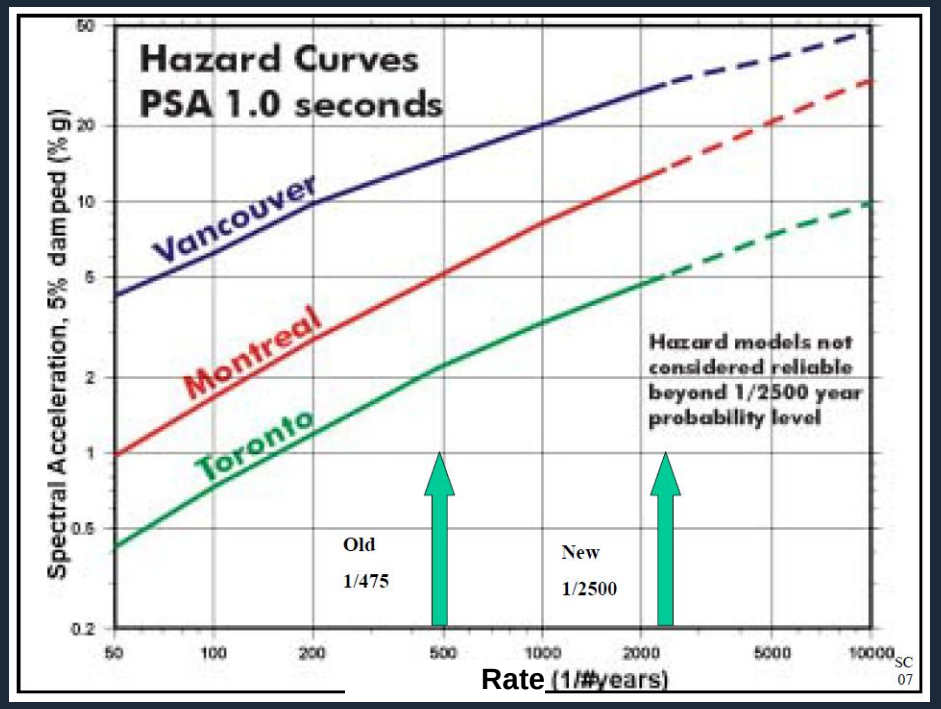
- Site-specific (one or a few sites)
  - Specific area → Thorough analysis of nearby seismic sources
  - Detailed site response analyses (integrated into PSHA or separate) carried out for a well-characterized site

PSHA Output

Hazard Maps



Hazard Curves

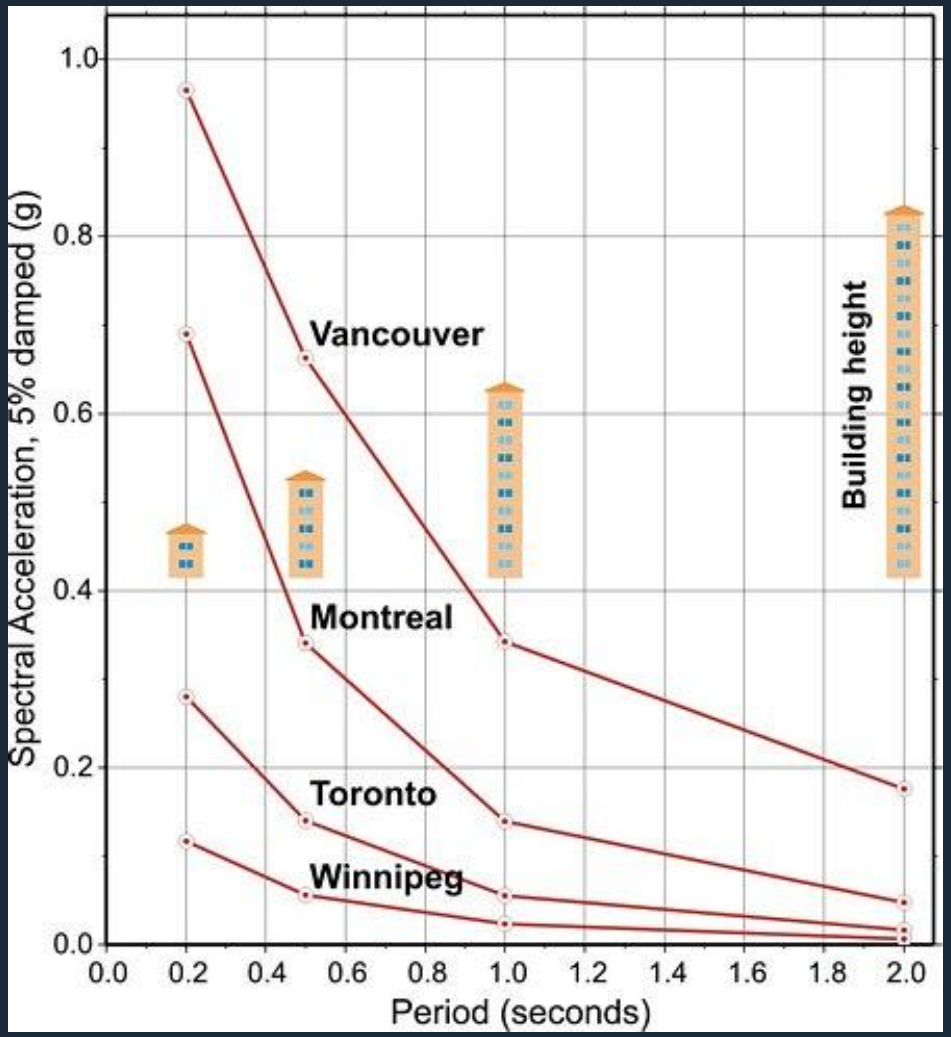


Source: John Adams, Geological Survey of Canada

2010 National Building Code of Canada seismic hazard map for Sa(0.5s) from:
http://earthquakescanada.nrcan.gc.ca/hazard-alea/zoning-zonage/NBCC2010maps-eng.php

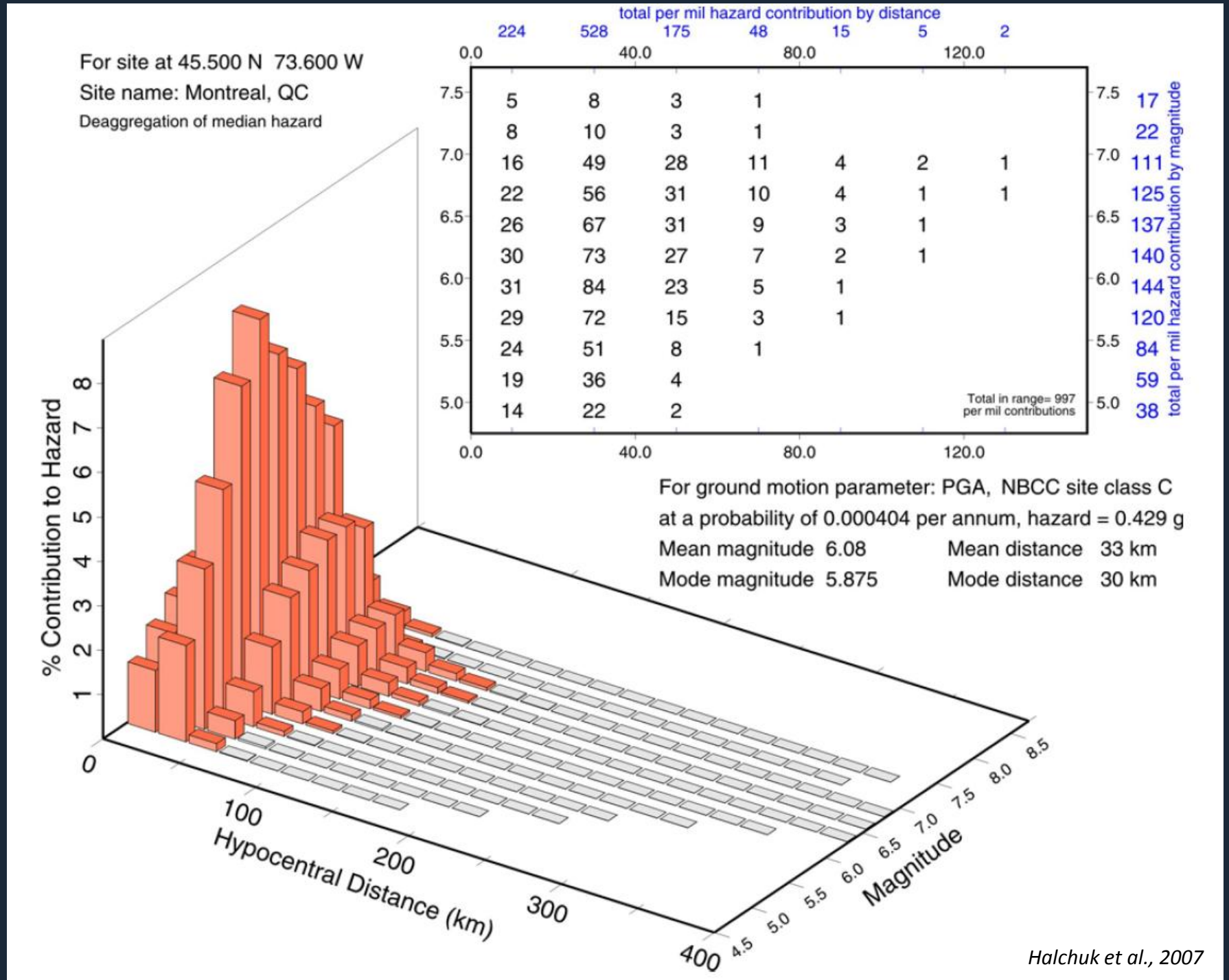
Uniform Hazard Spectra (UHS)

- Each spectral amplitude on the UHS has the same probability of exceedance
- Contributions from various seismic sources, not just one earthquake



http://earthquakescanada.nrcan.gc.ca/hazard-alea/zoning/UHSsample-eng.php

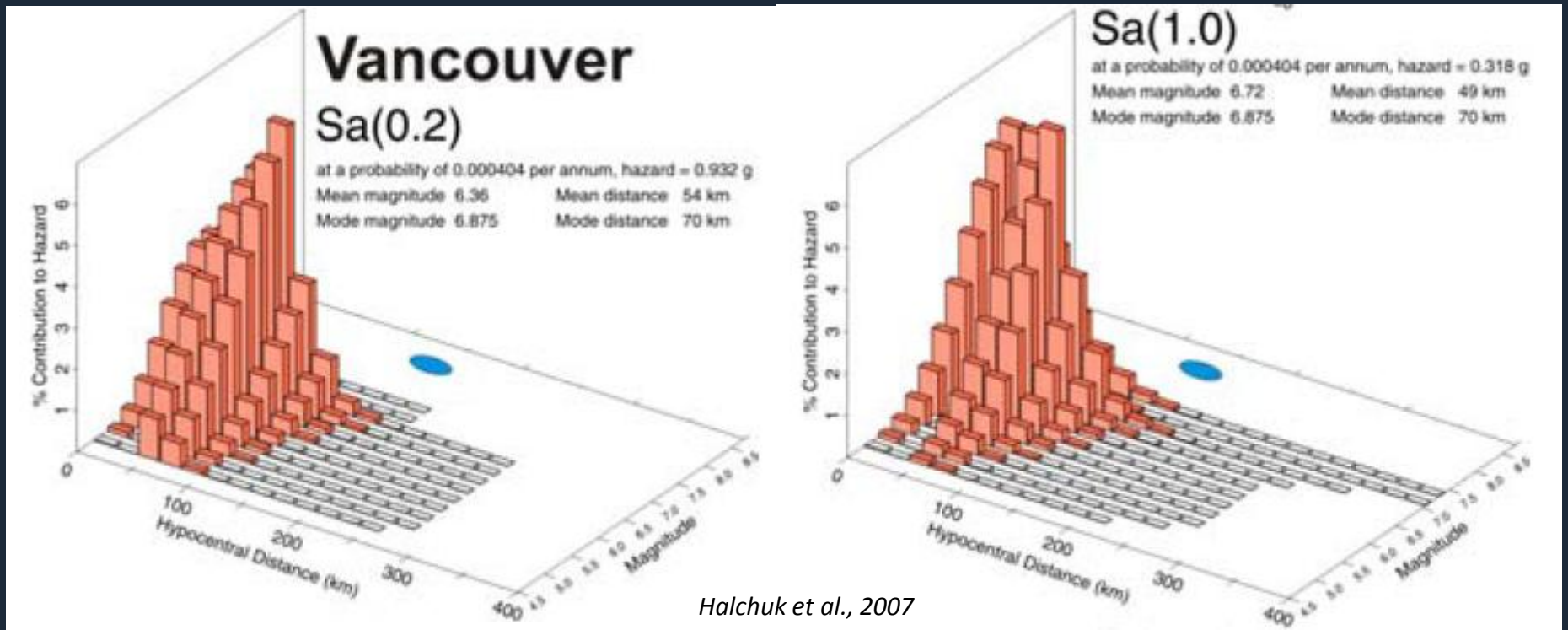
T. Onur, Sep 2014



Halchuk et al., 2007

Deaggregation for Vancouver

- GSC model (2010 NBC): 2% in 50-year hazard
- Deterministic Cascadia subduction interface EQ
- Deep subducting slab earthquakes contribute most



Halchuk et al., 2007

NBC and "Compatible" Records

NBC 2010 requires that "the ground motion histories be compatible with a response spectrum constructed from the design spectral acceleration values"

(Commentary J, paragraph 32)

Ground motion time history is compatible "if its response spectrum equals or exceeds the target spectrum throughout the period range of interest, i.e. the periods of the modes contributing to the response of the particular structure"

(Commentary J, paragraph 177)

Selecting Records

- {M, R} from deaggregation

- Other considerations?
  - Tectonic environment: Seismically active regions, subduction zones, stable continental regions, etc.
  - Type of earthquake: Shallow crustal, subduction interface, subducting slab, etc.
  - Focal mechanism: Strike-slip, normal, thrust, etc.
  - Site conditions: Not just Vs30! Right frequency content...

Fully Synthetic Records

- e.g. CJCE paper by Gail Atkinson: "Earthquake time histories compatible with the 2005 National building code of Canada uniform hazard spectrum"
  http://www.nrcresearchpress.com/doi/abs/10.1139/L09-044

- Pros:
  - Matches the UHS perfectly
  - Practical when little or no real records are available
  - No need for signal processing

- Cons:
  - May not be realistic (non-stationarity)
  - May not differentiate between tectonic environments, etc.

Real Records

- Select records
  - {M, R}, tectonic environment, earthquake type, etc.
- Perform basic signal processing if records are "unprocessed" (or "raw" or "uncorrected")
- Check frequency range for which they can be used (filtering, instrument range, etc)
- Modify records to be compatible with the target UHS (if necessary)

Example Strong Motion Record Sites

- Geological Survey of Canada:
  http://www.earthquakescanada.nrcan.gc.ca/stndon/NWFA-ANFO/sm/index-eng.php
- COSMOS:
  http://www.strongmotioncenter.org/vdc/scripts/earthquakes.plx
- USGS – National Strong Motion Program:
  http://nsmp.wr.usgs.gov/data.html
- PEER Ground Motion Database:
  http://www.strongmotioncenter.org/vdc/scripts/earthquakes.plx
- Center for Engineering Strong Motion Data:
  http://www.strongmotioncenter.org/
- Japanese K-Net and KiK-Net Networks:
  http://www.kyoshin.bosai.go.jp/

Geological Survey of Canada

Government of Canada | Gouvernement du Canada

Canada.gc.ca | Services | Departments | Français

Natural Resources Canada

Canada

Search

Energy | Mining/Materials | Forests | Earth Sciences | Hazards | Explosives | The North | Environment

Natural Resources Canada » Hazards » Natural Hazards » Earthquakes

Earthquakes Canada

- Recent Earthquakes
- Historic Events
- Earthquake Hazard
- Be Prepared!
- Stations and Data
- General Information
- Products / Research
- Earthquake Resources
  - Earthquake Search
  - Hazard Calculator
  - Station Book
  - Seismogram viewer
  - Waveform Data
  - External Links
- Contact EqCan
- Follow @CanadaQuakes

Strong Motion Data Sets

Strong Motion Records are available of the Val-des-Bois, Quebec Earthquake of June 23, 2010.

Processed numerical acceleration, velocity, and displacement data from the following Kinemetrics SMA-1 Strong Motion Accelerograph deployments are available for review and download from the NWFA.

You can contact us at EarthquakeInfo@NRCan.gc.ca for any of the sets listed below.

- Miramichi, NB 1982
- Nahanni, NT 1985-86
- Saguenay, QU 1988

Val-des-Bois, QC 2010
Miramichi, NB 1982
Nahanni, NT 1985-86
Saguenay, QC 1988

Date modified: 2013-04-26

Terms and Conditions | Transparency

http://www.earthquakescanada.nrcan.gc.ca/stndon/NWFA-ANFO/sm/index-eng.php

COSMOS: Consortium of Organizations for Strong Motion Observation Systems

STRONG-MOTION VIRTUAL DATA CENTER (VDC)

Global Component of the Center for Engineering Strong Motion Data

Home · Login/Logoff · Download · About Us · Contact ·
Earthquakes · Stations · Search · Map · Adv. Search

Earthquakes within each Region

Jump within page to:

[Choose a region]

- [Choose a region]
- Canada:British Columbia
- Canada:NW Territories
- Canada:New Brunswick
- Canada:Quebec
- Central America:Costa Rica
- Central America:El Salvador
- Central America:Mexico
- East Asia:China
- East Asia:India
- East Asia:Japan
- East Asia:Russia
- East Asia:Taiwan
- Europe:Greece
- South America:Chile
- South America:Peru
- South Pacific:Indonesia
- South Pacific:New Zealand
- US:Alaska
- US:Arkansas
- US:California
- US:Hawaii
- US:Illinois
- US:Indiana
- US:Montana
- US:New Hampshire
- US:New Mexico
- US:Oklahoma
- US:Oregon
- US:Puerto Rico

British Columbia

Earthquake	Date	Magnitude
British Columbia	2007-01-09 15:49:33 UTC	5.6

Return to Top

http://www.strongmotioncenter.org/vdc/scripts/earthquakes.plx

US Geological Survey
NSMP: National Strong Motion Program

USGS nsmp

http://nsmp.wr.usgs.gov/data.html

DATA SETS

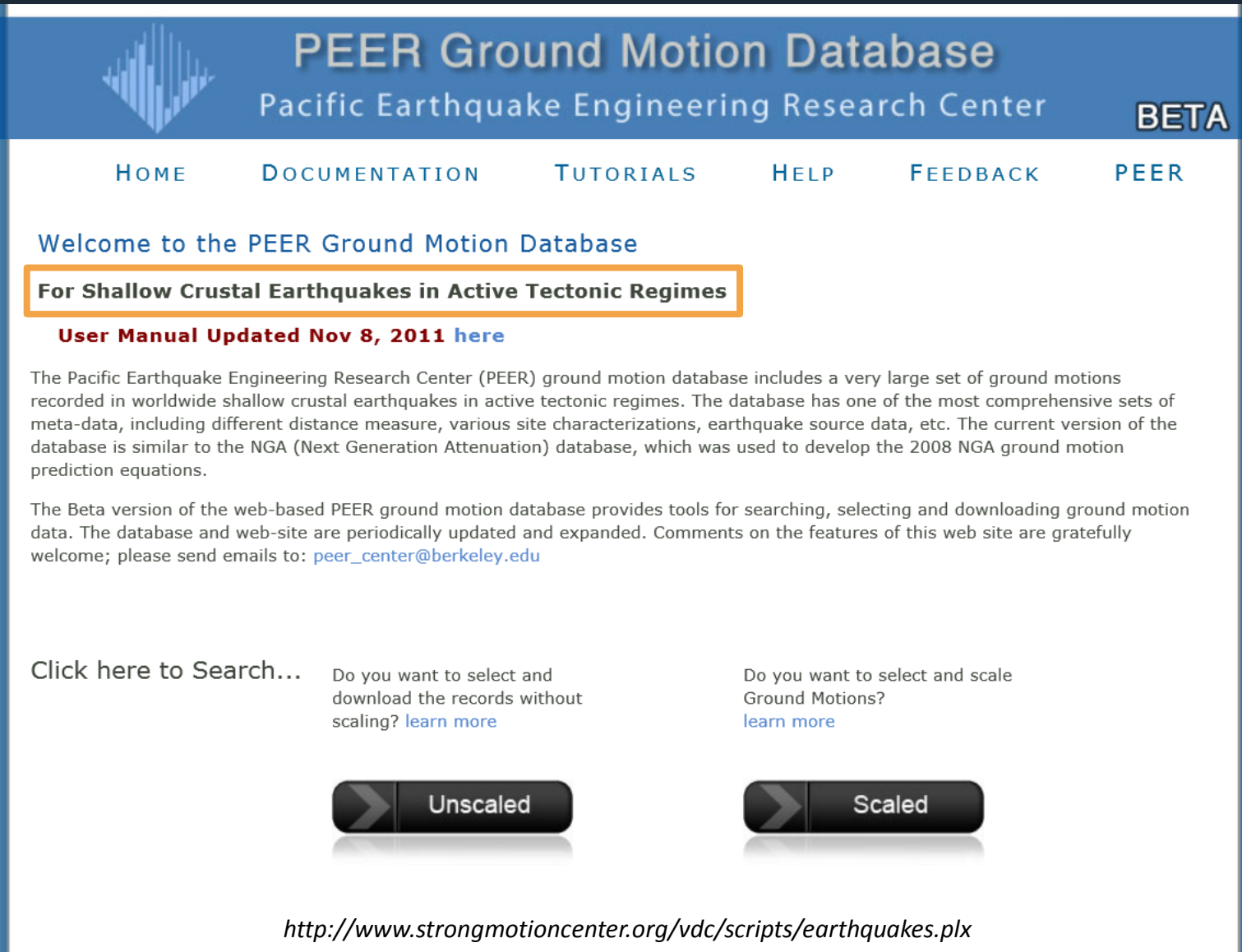
The following digital data sets are available from the NSMP:

- 1986 - Current Earthquake Time Series Data **(updated 03/10/2014)**.
- 1933 - 1986 North and Central American Earthquakes - a collection of 1,477 mostly three-component station recordings from about 500 earthquakes. These data represent all of the avai Hawaiian records written by ground-level instruments.
- General Earthquake Observation System (GEOS) Accelerograms - recordings collected by the NSMP GEOS project for aftershock studies, long-term deployments, and short-term expe
- Special Studies - recordings collected by the NSMP from non-earthquake sources.

Terminology, processing software, data formats, and download instructions:

- **Uncorrected vs Corrected data -** the term "uncorrected" indicates that a digitized (or digitally recorded) time series has received no processing that involves any hypotheses as to the chara content of the ground motions or recording instruments. An "uncorrected" analog-recorded time series has been corrected only for uneven film transport with time and for transverse motion longitudinally through the recorder; it has been shifted to have zero mean; and it has been translated from digitization units to units of cm/sec/sec (ordinates) and seconds (abscissas). The " applies bandpass filters (removing noise contamination) and instrument correction (removing the effects of frequency-dependent instrument response) to a time series. For a more complete processing steps for corrected data see DATA PROCESSING].
- The first line of each data file contains an integer in the first column followed by text that indicates what type of data are contained in the file: "1 UNCORRECTED ACCELEROGRAM" (some 1), "2 CORRECTED ACCELEROGRAM" (Vol 2), "3 CORRECTED VELOCITY" (Vol 3), "4 CORRECTED DISPLACEMENT" (Vol 4), "5 RESPONSE SPECTRA" (Vol 5), or "6 FOURIER AMP CORRECTED ACCELERATION" (Vol 6).
- Software, named "BAP", that will correct the time series is also available from the NSMP web site.
- SMC data format - a general description of the SMC data format currently used for NSMP time series.
- **Download Instructions**: Compressed data files from different earthquakes but from the same station have the same names. Download files from different earthquakes to different directorie You will need a program that decompresses and "unzips" the data.

PEER Ground Motion Database



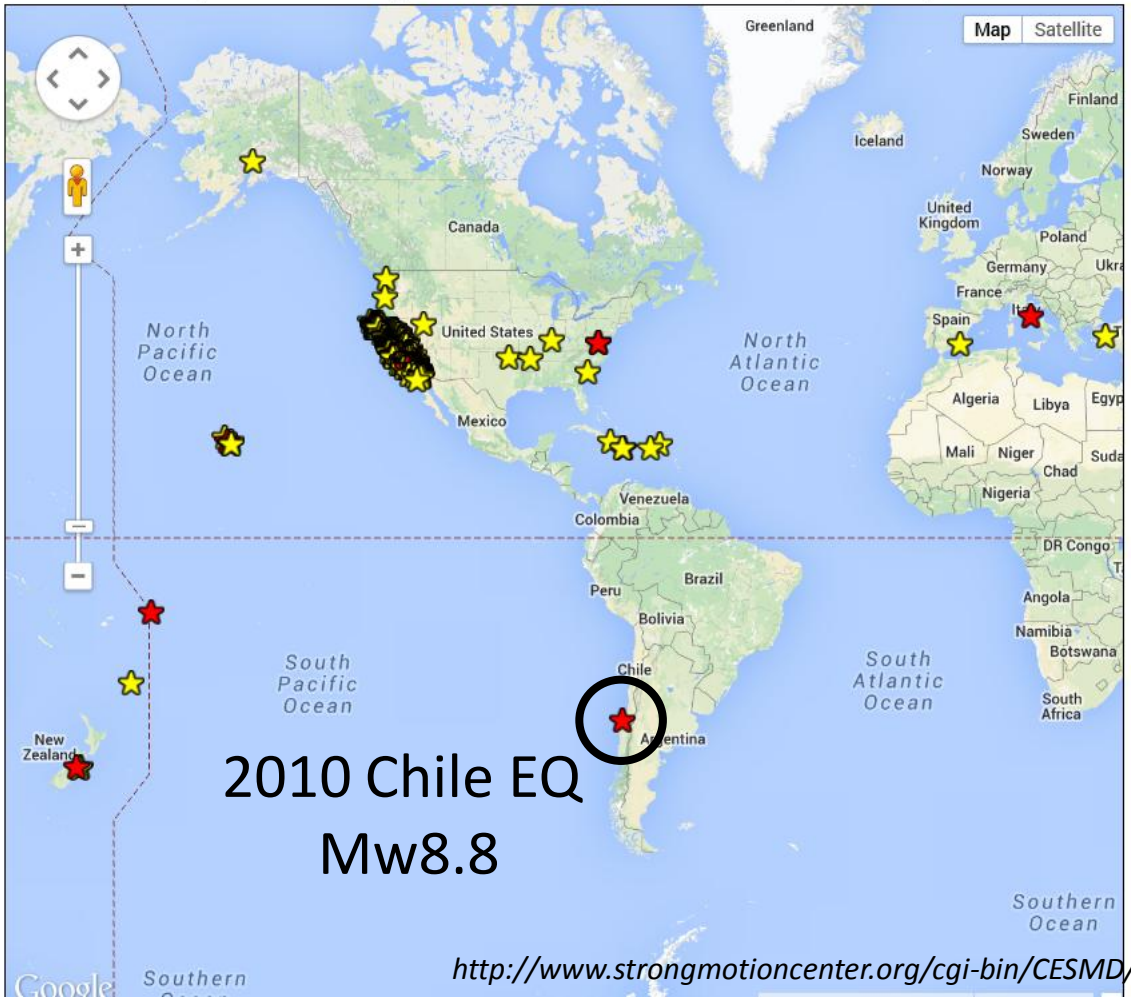
http://www.strongmotioncenter.org/vdc/scripts/earthquakes.plx

Center for Engineering Strong Motion Data

Earthquakes with Strong Motion Records in CESMD

Use polygon to display and list earthquakes within area of interest:

1. Start Polygon | 2. Close Polygon | 3. Show Result | Start Over



Significant Strong-Motion Earthquakes

Other

Hover over star to reveal earthquake name and information.

Note: Event Epicenters are approximate when viewed at high zoom levels.

Click earthquake for more information

Click on an earthquake below to see details

- **Choose an Earthquake** -
Alamo, 05 Sep 2008, 4.0Mw
Alum Rock Area, 30 Oct 2007, 5.4Mw
Alum Rock, 09 May 2013, 3.5ML
Anderson Springs, 12 Feb 2012, 4.4ML
Anderson Springs, 15 Apr 2013, 3.5ML
Anderson Springs, 27 Aug 2013, 3.8ML
Angwin, 05 Dec 2013, 3.6ML
Anza, 11 Mar 2013, 4.7M
Anza, 12 Jun 2005, 5.2ML
Anza, 12 Mar 2013, 3.5ML
Anza, 30 Oct 2001, 5.1 ML
Arkansas, 27 Feb 2011, 4.7M
Aromas, 02 Jul 2007, 4.3Mw
Aromas, 13 Apr 2012, 3.5ML
Atascadero, 29 Apr 2008, 3.9ML
Banning Area, 11 Jan 2010, 4.3ML
Barstow Area, 05 Dec 2008, 5.1MW
Barstow, 27 May 2012, 3.8ML
Bayview, 11 Oct 2013, 4.9ML
Beaumont Area, 16 Jan 2010, 4.3ML
Beaumont, 09 Jul 2006, 3.8 ML
Beaumont, 14 Sep 2011, 4.1ML
Bellmont IL, 18 Apr 2008, M5.2
Berkeley, 04 Sep 2003, 3.9 ML
Berkeley, 20 Oct 2011, 4.0Mw
Berkeley, 20 Oct 2011, 3.8Mw
Berkeley, 27 Oct 2011, 3.6ML
Beverly Hills, 09 Sep 2001, 4.2 ML
Big Bear City, 05 Jul 2012, 3.5ML
Big Bear City, 22 Feb 2003, 5.4 ML
Big Bear, 28 Jun 1992, 6.5 ML

http://www.strongmotioncenter.org/cgi-bin/CESMD/iqrEventMap.pl

K-Net and KiK-Net

Signal Processing

- If records are already processed:
  - What processing was done? Base-line correction? Filtering? What are the filter parameters?

- If unprocessed records are being used:
  - Basic signal processing needs to be done
  - What are the frequency ranges of the accelerometers?

Modification of Records

- Amplitude scaling
  - Scale the entire record in time-domain by a constant
- Frequency content modification (generally referred to as “spectrum matching”)
  - Time-domain methods
  - Frequency-domain methods

PEER Database – Scaling

PEER Ground Motion Database

Pacific Earthquake Engineering Research Center

BETA

HOME DOCUMENTATION TUTORIALS HELP FEEDBACK PEER

Target Spectrum

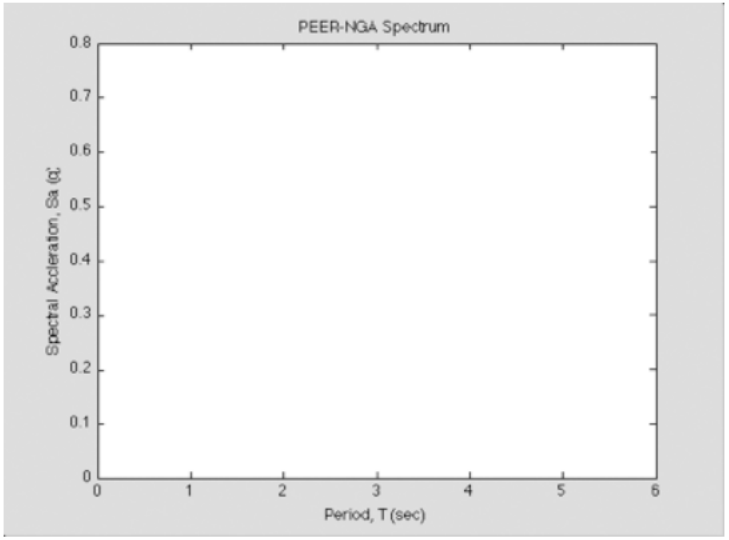
Select Spectrum Model

Select models to generate target spectrum : PEER-NGA Spectrum / User Defined Spectrum / ASCE Code Spectrum

User Defined Spectrum

Filename: Upload File

Download Example file(.csv)



Show notations

Show chart controls

Create

Spectrum Matching

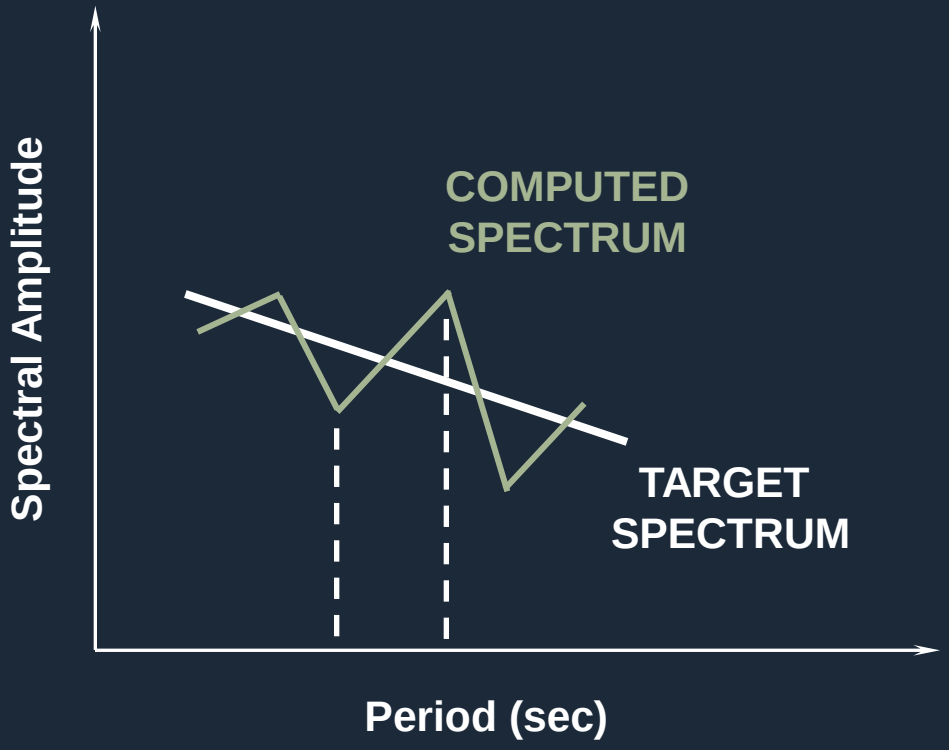
- UHS is a smooth curve derived as a result of PSHA with contributions from many earthquakes

- How much to match? The whole spectrum? Part of it?
  - Depends on how well the natural period(s) of vibration of the structure is constrained
  - Elastic, post-yield, AND contribution of higher modes

- The more you "match" the smooth UHS, the more unrealistic the records become

Frequency-domain Methods

- Example: SYNTH (Naumoski, 2001). This program iteratively modifies the Fourier coefficients until a match with the target spectrum is obtained.



1. For each period, the ratio between the target and computed spectral ordinates is calculated.

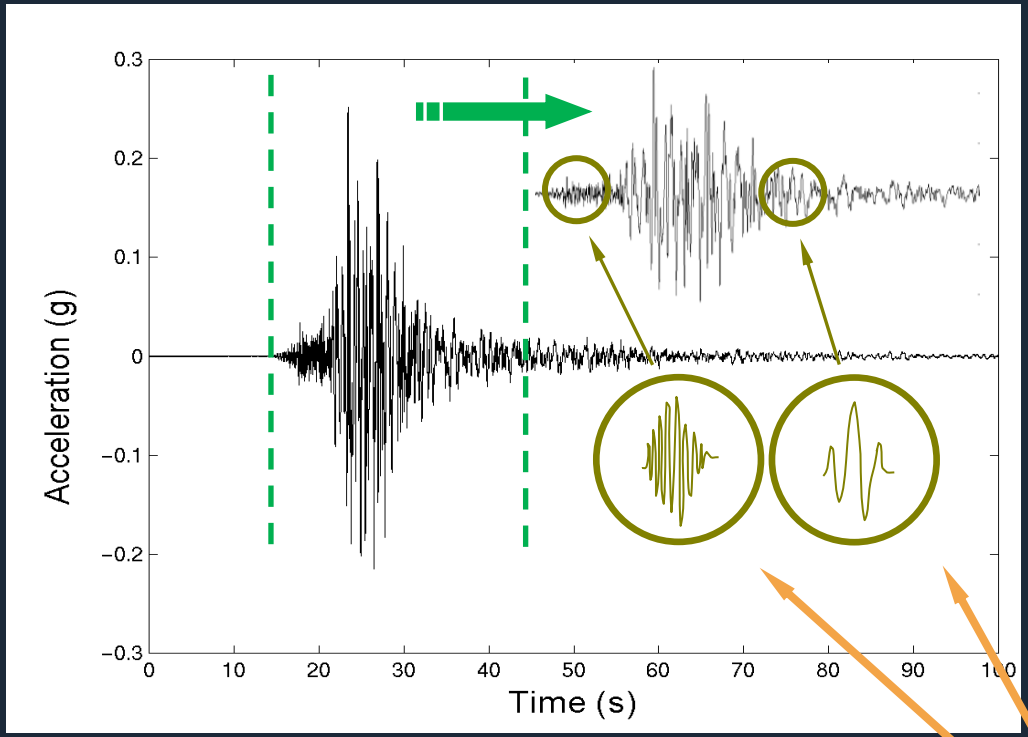
$$R(j) = \frac{SP_{TARGET}(j)}{SP_{COMPUTED}(j)}$$

2. If $R(j) < 1$, the computed spectral ordinate is suppressed. If $R(j) > 1$, the computed spectral ordinate is raised.

Time-domain Methods

- Example: RSPMATCH (Abrahamson, 1993/2009).
- This program first finds where different frequencies appear throughout the reference time-history.
- Then it adjusts the record by adding wavelets to the reference time-history where that frequency is encountered.
- Tolerance for spectral match can be set in fractions, i.e. 0.05 means 5% maximum deviation

RSPMATCH



1. For each frequency, the difference between the target and computed spectrum is calculated, including the polarity, *P* (+1 or –1):

$$\Delta R(j) = \left(SP_{TARGET}(j) - SP_{COMPUTED}(j)\right) \cdot P(j)$$

2. Then the program "seeks" points in time at which a particular frequency is observed within the time history.

3. Wavelets (adjustment function) with the desired frequency are added to the points in the reference time-series where that frequency is encountered.

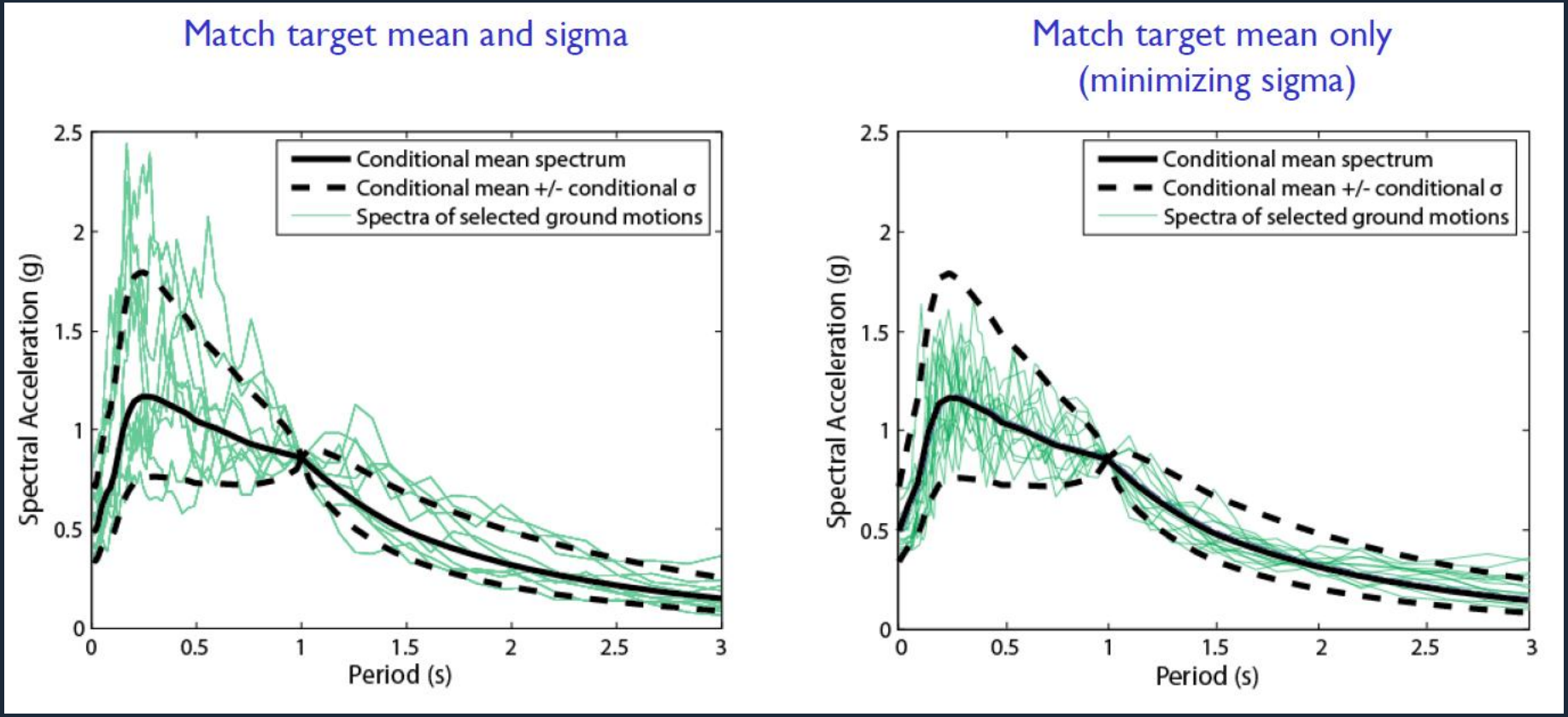
Adjustment Function : (Tapered Cosine Wave)

$$f_j(t) = \cos\left\{\omega'_j(\tau_j)\right\} \cdot e^{-|\tau_j| \cdot \alpha_j}$$

T. Onur, Sep 2014

Conditional Mean Spectrum (CMS)

- UHS → Deaggregation for T* → {M, R, ε}



Baker, J. (2011). Conditional mean spectrum: Tool for ground motion selection, J. of Struct. Eng. 137(3): 322–331.

http://www.stanford.edu/~bakerjw/gm_selection.html

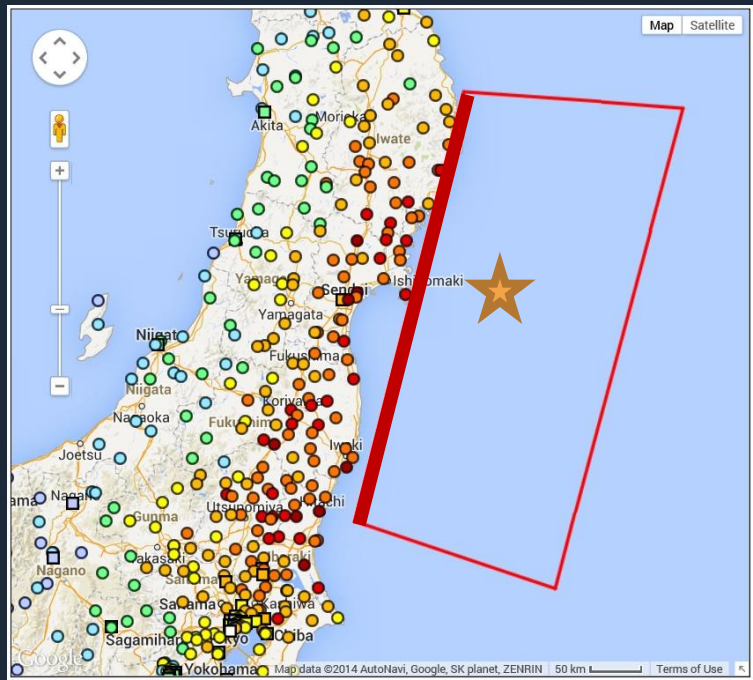
Back to Southwestern BC...

- Shallow Crustal:
  - At ~20km depth in Southwestern BC
  - Surface rupture is rare
  - Crustal structure different from CA but some CA records are OK, e.g. Northridge (1994); Loma Prieta (1989)

- Subducting Slab:
  - Greatest contribution to hazard in Southwestern BC (GSC)
  - Depth: 40-60km
  - Mostly normal faulting
  - e.g. Nisqually, WA (2001); Geiyo, Japan (2001)

Back to Southwestern BC…

- Subduction Interface:
  - Mw~9.0
  - Distance to inland edge of rupture (NOT to epicenter)
  - Until 2010, records from Mw<8.5 earthquakes were used:
    - 1985 Michoacán, Mexico – Mw8.0
    - 2001 Arequipa, Peru – Mw8.4
    - 2003 Tokachi-oki, Japan – Mw8.3
  - Since 2010:
    - 2010 Maule, Chile – Mw8.8
    - 2011 Tohoku, Japan – Mw9.0



T. Onur, Sep 2014

When Using Records from Japan…

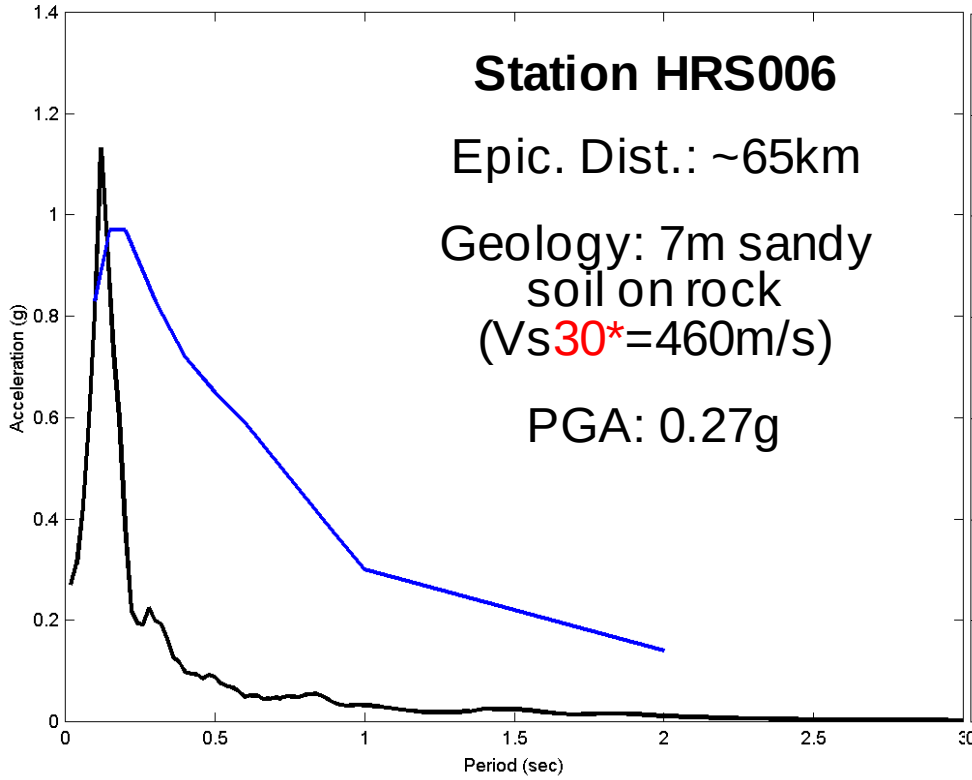
- Dynamic site characteristics not fully captured by Vs30-based site classification
- Typical Site Class C in Japan:
  - Thin layer of soft sediments on very stiff rock
- Typical Site Class C in Vancouver
  - Glaciated sediments (till)

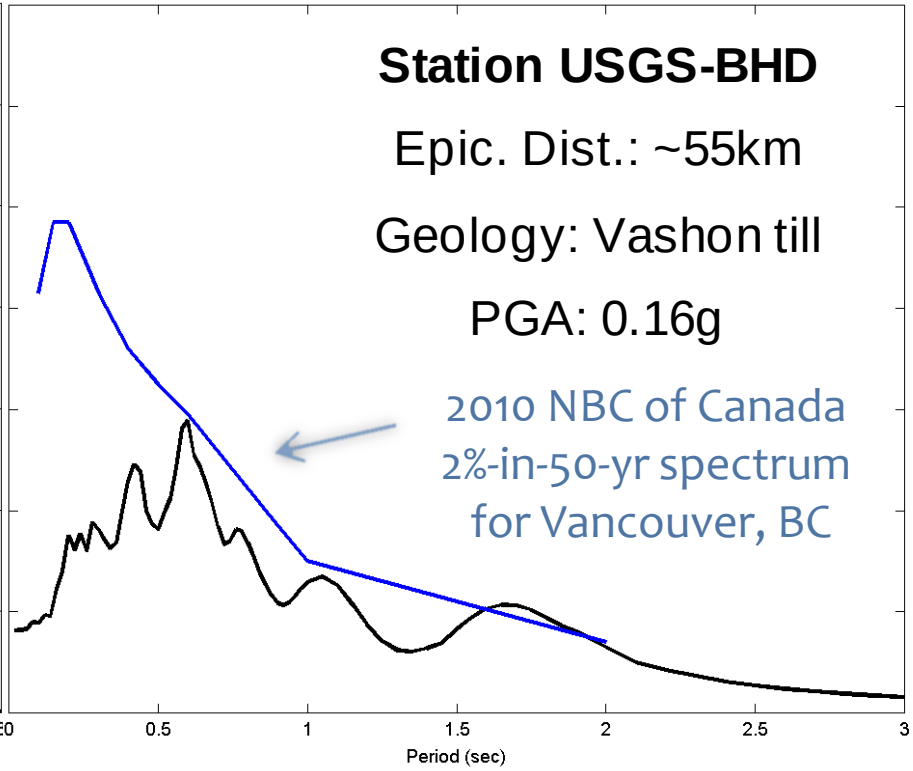
T. Onur, Sep 2014

Two Example Class C Sites

K-Net Station HRS006 (Site Class C)
2001 Geiyo (Inslab; Mw6.8)

USGS Station BHD (Site Class C)
2001 Nisqually (Inslab; Mw6.8)



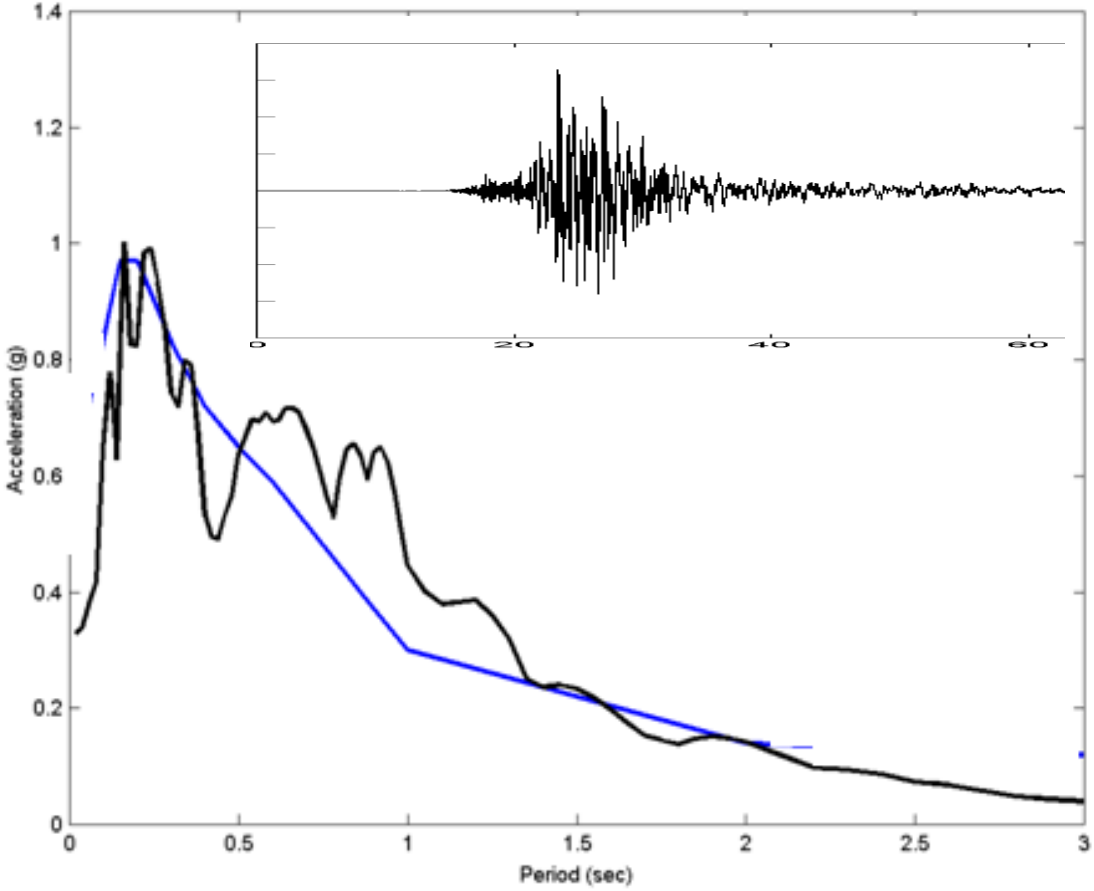


T. Onur, Sep 2014

Remarks

- Records from all three types of earthquakes in southwestern BC
- Vs30 alone does not capture spectral shape, which is key to site/structural response
- Start with a real record that has a spectral shape that is as similar as possible to the target UHS; even if that means choosing records from a different Vs30-based site class

Example for Vancouver



Earthquake: Geiyo, Japan

Date: March 2001

Magnitude: Mw 6.7

Depth: ~50km

Mechanism: Normal faulting

K-Net Station: EHM016

Epic. Distance: ~40km

Geology: Sand, silt & gravel on clay (Site Class D)

Component: E-W

PGA: 0.33g (scaled: 1.3x)

T. Onur, Sep 2014

Period Range and Number of Records

- ASCE 7-10:
  - Period range: 0.2T to 1.5T
  - If seven or more pairs of ground motions are used, average of the response parameter can be used for design

- NBC 2010:
  - "Period range of interest"
  - Seven or more records

- New guidance in NBC 2015 Commentary

Questions? Comments?

Onur.OSC@gmail.com