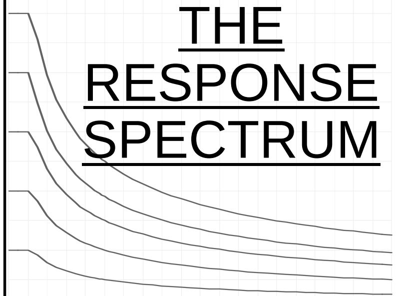
The Canadian Society for Civil Engineering, Vancouver Section

THE RESPONSE SPECTRUM



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

Ground Motion Time-Histories Matching Spectrum

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BC Hydro

1-2 June 2007 Vancouver, BC

Outline

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- Objectives of matching time histories to target spectra
- NBCC 2005 requirements
- Criteria for selection of time histories
- Approaches to matching a target spectrum
- Summary

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Objectives of Spectrum-Matching a Time History
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- Compared to Response Spectrum Analysis, which provides the maximum period-dependent response of the structure, Time History Analysis provides the time-dependent response of the structure.
- Details of the time-dependent response can provide more comprehensive information on the behaviour and progressive deformation of the structure and identification of potential failure modes.
- To allow reasonable comparison between the results from the two methods, the response spectrum and the time histories selected for the analyses should be compatible.
- If the selected time histories are modified to achieve a spectral match, the modified time histories should still be representative of realistic time histories.

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Some Key Issues
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- What makes a time history compatible with a target response spectrum?
- How are appropriate earthquake scenarios determined?
- How are appropriate time histories selected?
- How should the selected time histories be modified to achieve a match with the target response spectrum?

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NBCC 2005

- **4.1.8.12.(3) Dynamic Analysis Procedure**
  - "The ground motion histories used in the Numerical Integration Linear Time History Method shall be compatible with a response spectrum constructed from the design spectral acceleration values, S(T), defined in Sentence 4.1.8.4.(6)" *(i.e. compatible with a Uniform Hazard Spectrum).*
- **Commentary J, Sentence 4.1.8.12.(3)**
  - "A time history is deemed to be spectrum-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 structure".

NBCC 2005 - Commentary J

- The ground motion time-histories used as input should be representative of the seismotectonic environment at the location of the building, i.e. correspond to earthquake ground motions that have been recorded for magnitudes and epicentral distances similar to those that dominate seismic hazard at the particular location.
- In addition to being compatible with a response spectrum constructed from the design spectral acceleration values, S(T), these time histories need to have durations and waveforms that will allow the structural model to respond inelastically with sufficient cycles of load reversal.
- Sufficient time histories need to be used to enable uncertainties in ground motion parameters (e.g. durations) to be reflected in the dispersion of resulting response parameters.

Next Steps

- Ideally, the designer would like to have a suite of representative time-histories that were recorded at the site of the structure being designed.

⇨ **Highly unlikely!**

- The following slides present a systematic process that can be followed to obtain a suite of time histories that are representative of the design scenario(s).

Time History Record Selection Criteria (1)

General	➢ **Records should be free-field.** ➢ **Multiple records should be selected.**
Tectonic conditions	➢ **Records should be from a similar tectonic setting, e.g. plate boundary region, continental interior, subduction zone.** ➢ **Records should be from earthquakes caused by similar styles of faulting, e.g. strike-slip, thrust or normal.** ➢ **For near-fault conditions (≤ 10km), records that show directivity effects (e.g. fault fling or directivity) should be considered.**

World Seismicity, 1990 - 2000

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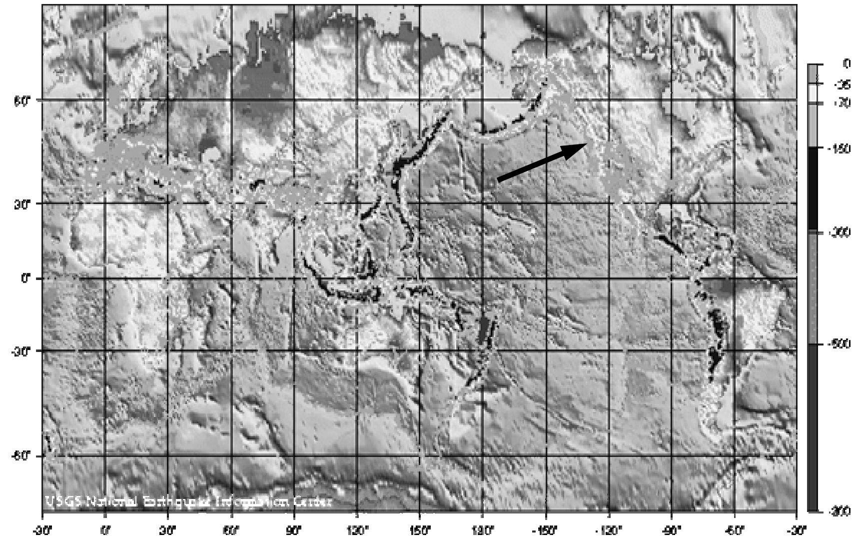

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Earth's Major Tectonic Plates

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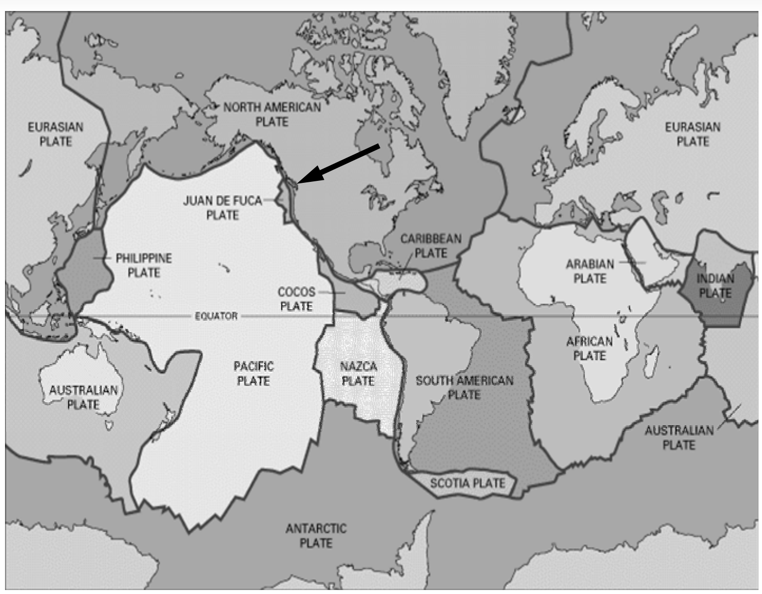

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Cascadia Subduction Zone - Plan

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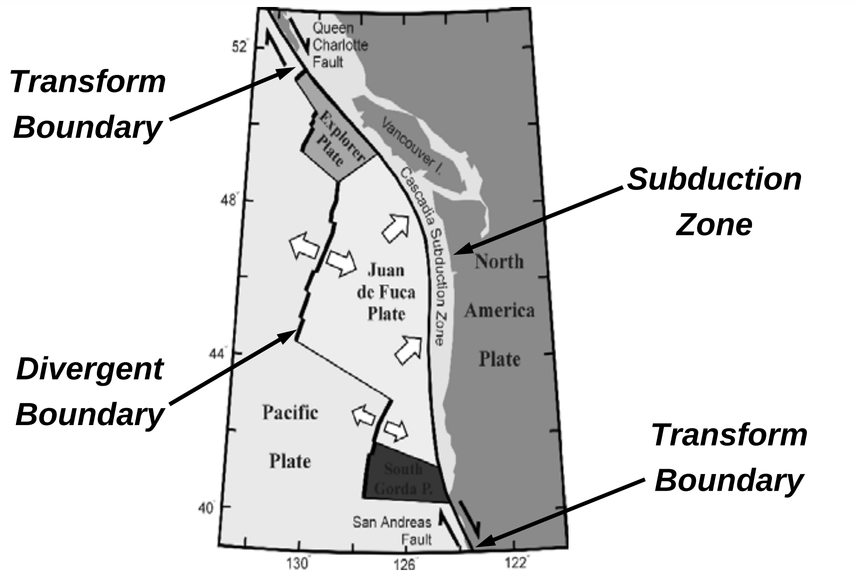

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Cascadia Seismic Sources

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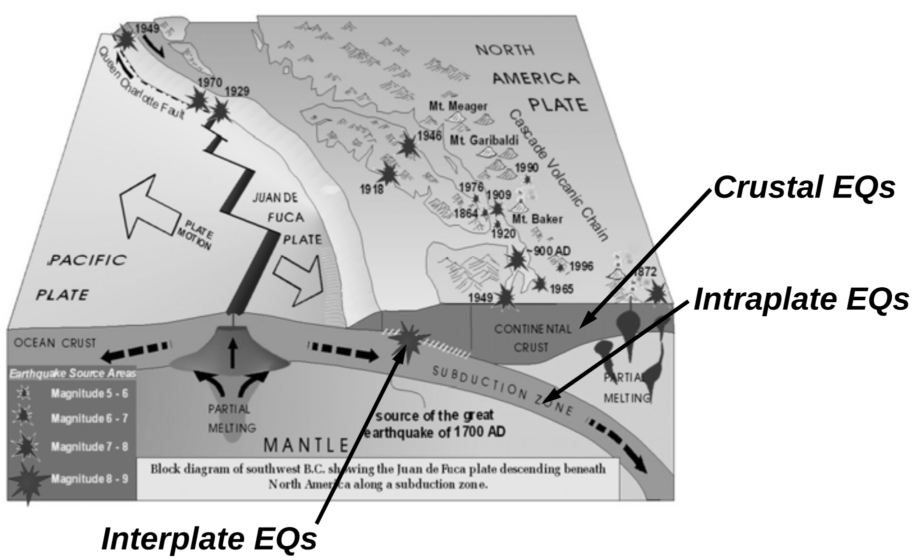

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Types of Faults

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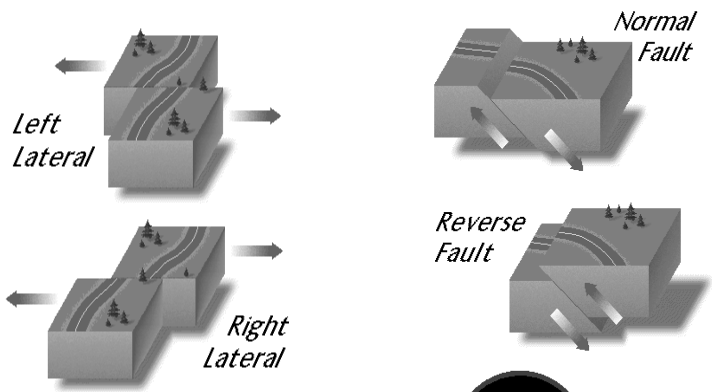

The type of faulting & the characteristics of the earthquakes caused by the fault rupture depend on the tectonic stress conditions in the Earth's crust.

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Time History Record Selection Criteria (2)

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Geologic conditions	➢ **Records should be from rock sites, or sites with soil conditions comparable to those at the structure site.** ➢ **It is often difficult to find time histories from sites with comparable soil conditions. If records from rock sites are selected, then soil effects can be evaluated using the site-specific soil conditions & properties of the structure site.**

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Soil Effects – Time Histories

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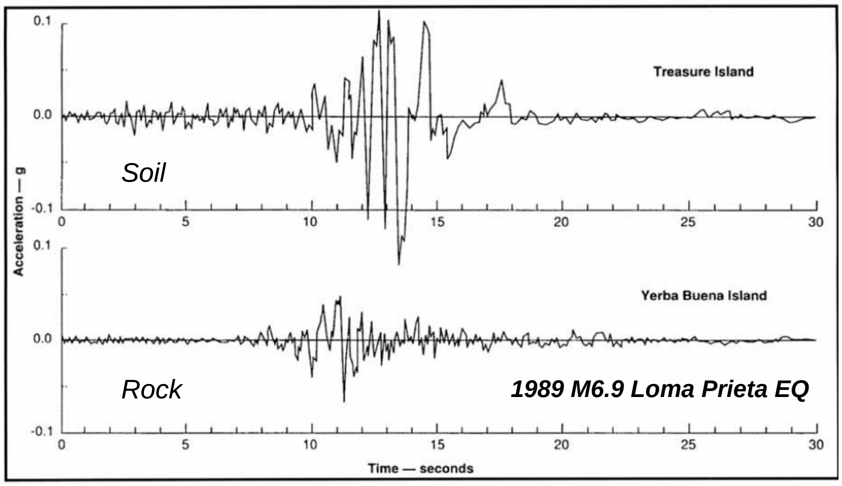

Soil overlying bedrock will cause frequency-dependent amplification of ground motions.

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Soil Effects – Response Spectra

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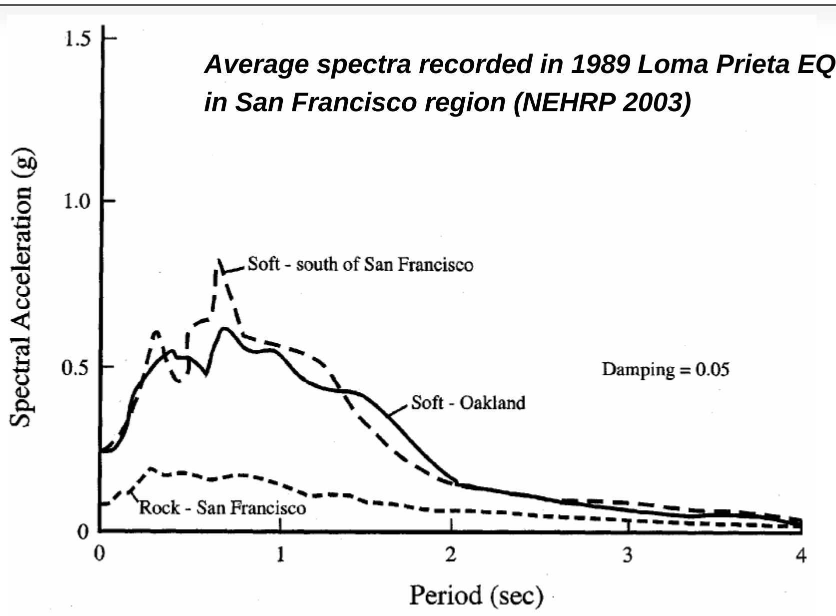

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Time History Record Selection Criteria (3)

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Earthquake scenario(s)	➢ **Magnitude should be similar to that of design scenario(s), typically within about ± 0.5M.** ➢ **Distance should be similar to that of design scenario(s), typically within about ± 50%.** ➢ **De-aggregation of hazard provides a method for selecting appropriate magnitude/distance scenarios.** ➢ **Duration should be similar to that typically expected for the scenario magnitude.**
Basis of hazard de-aggregation	➢ **PGA or Sa hazard corresponding to primary vibration mode of the structure.**

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Magnitude-Distance De-Aggregation

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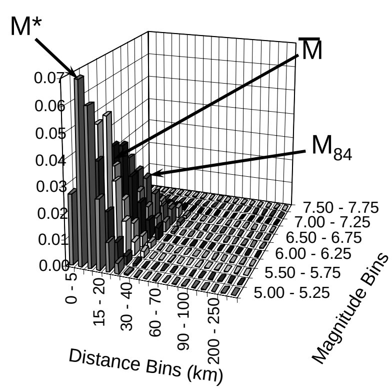
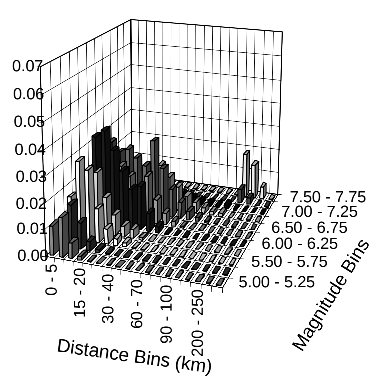
Contributions to PGA hazard



Contributions to 1.5s Sa hazard



Example from SE B.C.

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Earthquake Duration

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Magnitude	Duration of Strong Shaking (sec)
4.0 to 4.9	<5
5.0 to 5.9	2 to 15
6.0 to 6.9	10 to 30
7.0 to 7.9	20 to 50
8.0 to 8.9	30 to 90

Ref. Gere and Shah, 1984

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Time History Record Selection Criteria (4)

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Comparison of unscaled spectrum to target spectrum	➢ General response spectrum shape should be similar to that of the target response spectrum. ➢ Sa corresponding to primary vibration mode of the structure should be similar to the target Sa at that period, typically within a factor of about 2 to 3.

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Example

- Location – Vancouver Island
- Design AEF = 1/10,000
- Dominant scenario earthquake:
  - Crustal EQ
  - M = 7.5
  - D < 15km
  - PGA = 0.8g on rock; 5% damped UHRS defined
- Few candidate records that match these criteria
- One time history being considered:
  - 1999 Kocaeli, Turkey; $M_w = 7.4$
  - Station GBZ, 000 component
  - D = 47 km
  - Firm ground
  - PGA = 0.25g

Spectrum-Matching Methods

- Linear scaling

Frequency content modification approaches:

- Time domain scaling
- Frequency domain scaling

Other approaches:

- Artificial time histories

Linear Scaling

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- The entire acceleration time history is scaled by a constant factor.
- Scaling factor is typically selected to achieve a match to target PGA or Sa at fundamental period of structure.
- Frequency content and original phasing of the record are preserved.
- “Large” scaling factors should be avoided.

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Kocaeli EQ – GBZ000 Record

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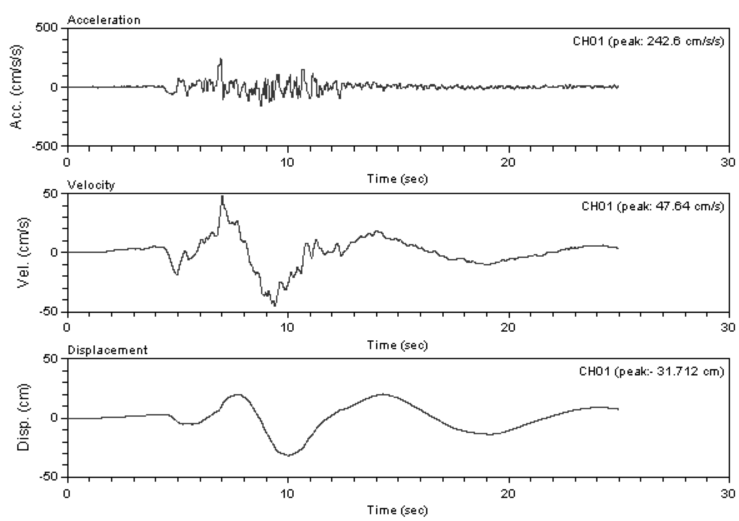

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Linear Scaling – Target UHRS

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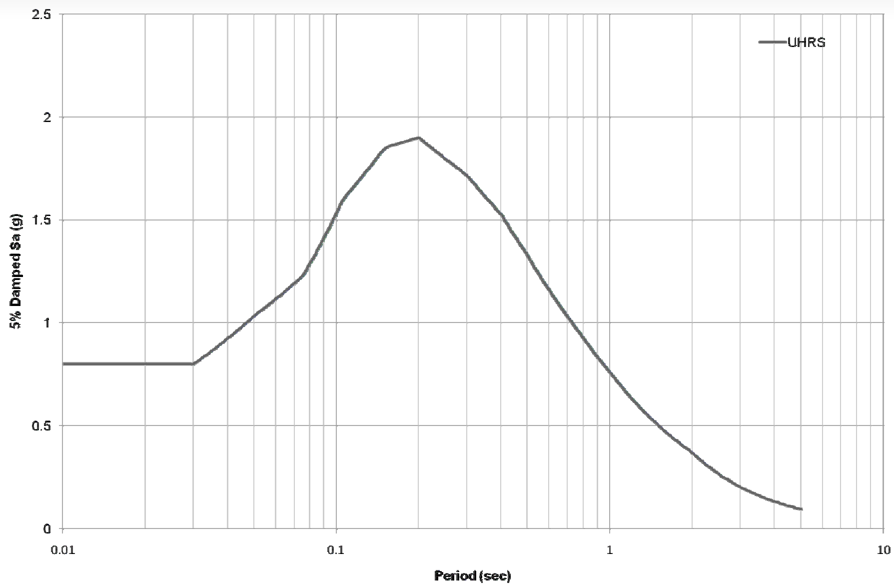

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Linear Scaling – UHRS & Unscaled Spectrum

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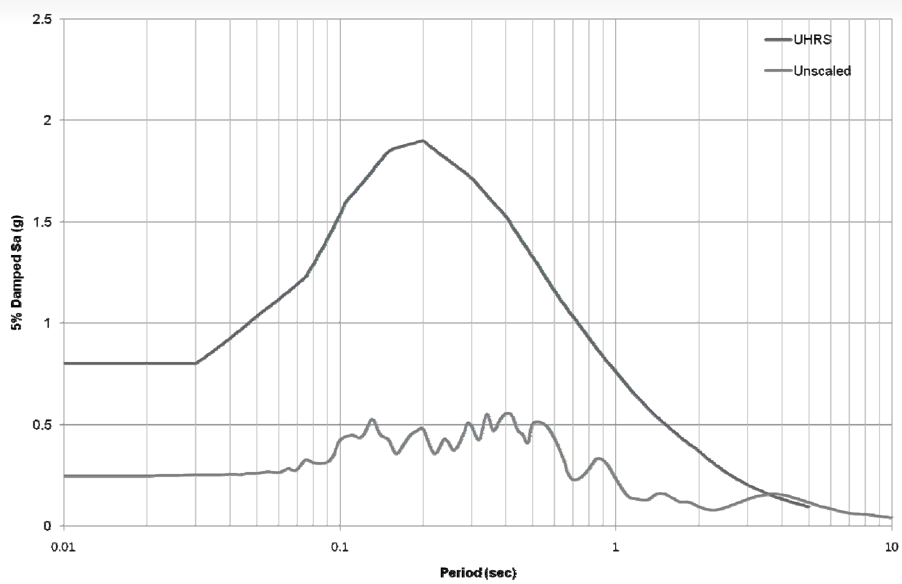

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Linear Scaling – UHRS & PGA Scaling

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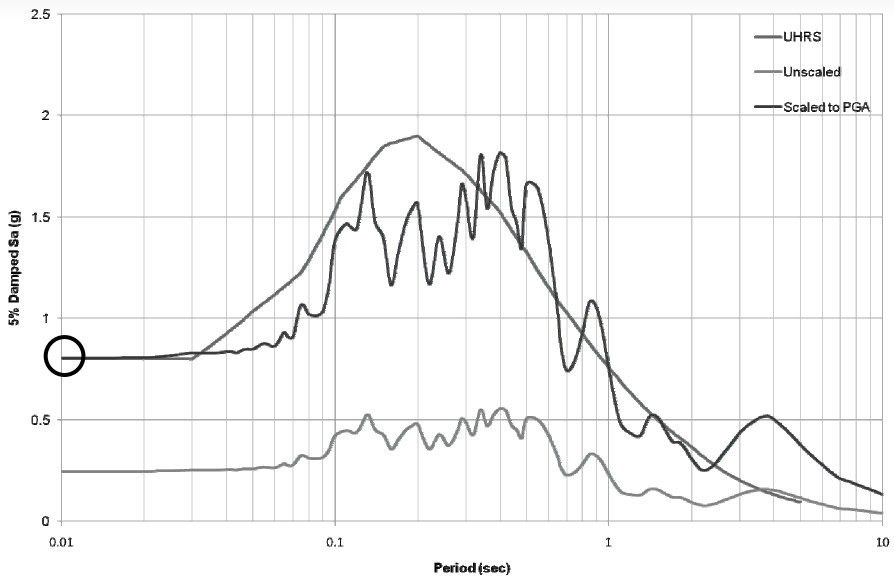

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Linear Scaling – UHRS & Sa(0.2s) Scaling

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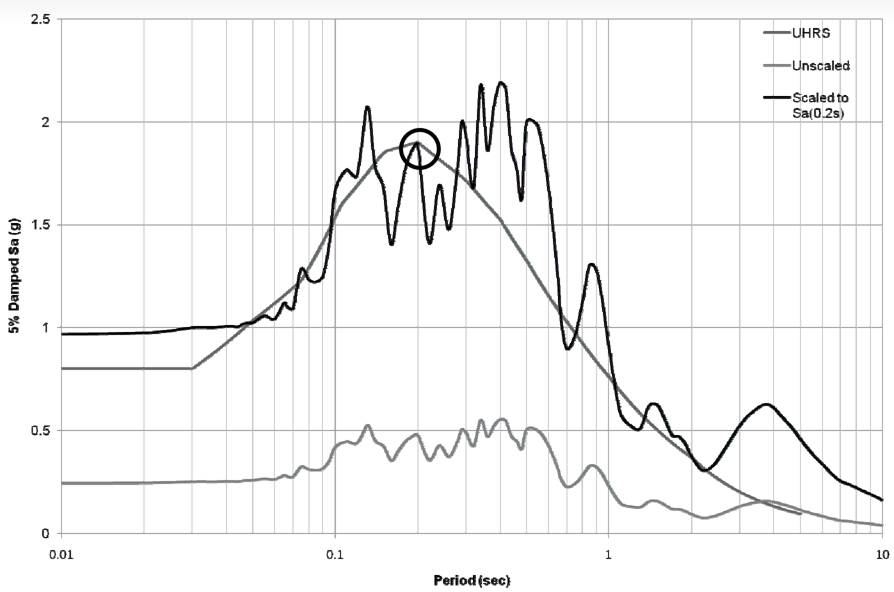

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Frequency Domain Scaling

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- Involves adjusting Fourier amplitudes while maintaining Fourier phases.
- Similar to addition or subtraction of sinusoidal waves of different periods to the full length of the original time history.
- Several iterations are usually required to achieve a match.
- May produce modified time histories that significantly differ in appearance from the original time histories (especially the velocity & displacement time histories).

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Time Domain Scaling

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- “Wavelets” of finite duration are added to or subtracted from the time history.
- Wavelets are selected to provide a match to the target spectrum at specific periods.
- Several iterations are usually required to achieve a match.
- Currently is the generally preferred approach for matching to a target spectrum.

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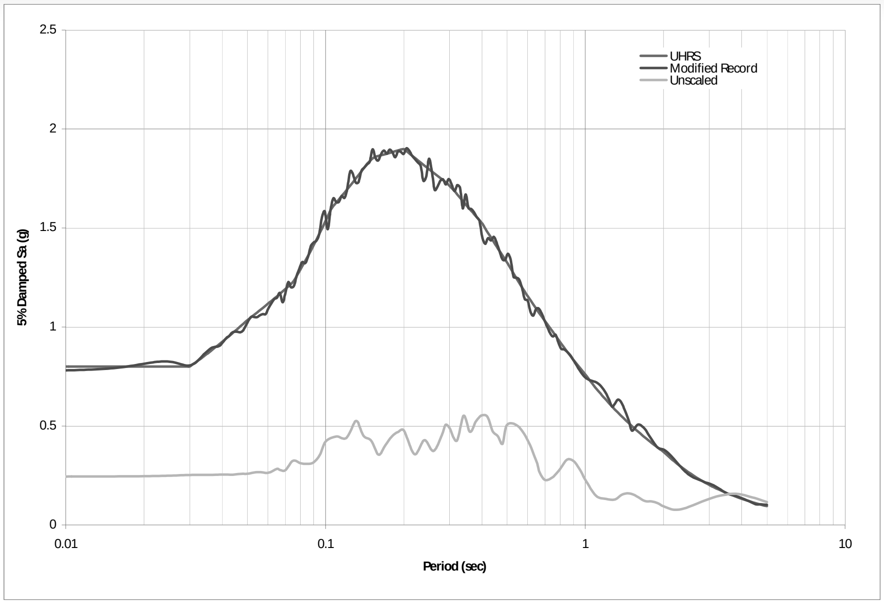
Time Domain Modified Record



Artificial Time Histories

- A possible approach when no appropriate scenario earthquake time histories are available.
- Based on numerical modeling of the fault rupture process and the source-to-site propagation of seismic waves.
- Several theoretical approaches are available.
- Seismologist required!

Time History Record Selection Criteria (5)

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After time histories have been spectrum-matched	➢ Check the PGV, PGD and the velocity & displacement time histories of the modified records for reasonableness. ➢ Check other parameters such as Arias Intensity and Power Spectral Density to ensure that the energy content & distribution of the modified records is reasonable.

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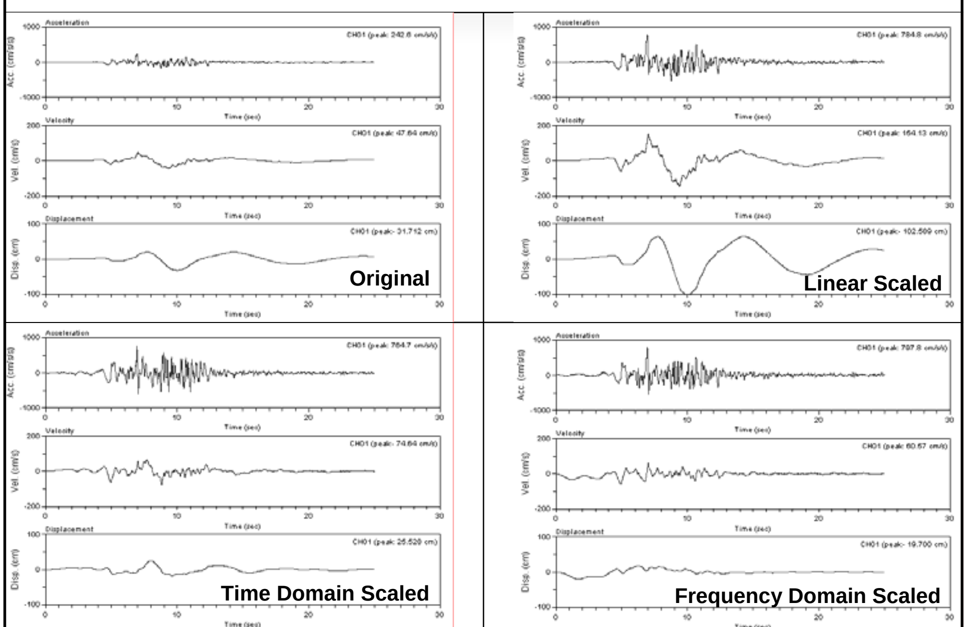
Comparison of Scaled Records



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How Many Time Histories Are Enough?

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- **1 is never enough.**
- Scatter and variability are always observed in earthquake ground motions.

A typical practice:

- Take maximum response of 3 records.
- Take average response of ~7 records.
- Use spectrum-compatible records to reduce scatter.

- Consider other sources of conservatism in the structural response analysis. Is the conservatism in selecting time histories consistent with the level of conservatism in the rest of the analysis?

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Summary

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- Time histories selected for dynamic analysis of a structure should be from seismotectonic & geologic settings comparable to those at the site of interest.
- The time histories selected should be consistent with the magnitude/distance/duration scenario developed for the analyses.
- Linear scaling or time-domain spectral matching are the preferred approaches to matching a time history to a target response spectrum.
- Multiple time histories should always be used in dynamic analyses.

NOTE – In the end it may be necessary to relax some of the selection criteria if insufficient candidate time histories are identified.

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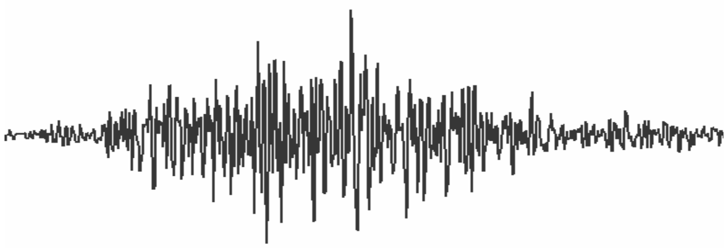
Thanks for your attention



Acknowledgements

Some of the images presented in these slides were obtained from web pages of the:

- Geological Survey of Canada:
  - http://earthquakescanada.nrcan.gc.ca/index_e.php
- US Geological Survey:
  - http://earthquake.usgs.gov/
- USGS National Earthquake Information Centre:
  - http://earthquake.usgs.gov/regional/neic/

Thanks to Kofi Addo and Michael Lee for the computer analyses that provided data files required to produce some of the plots.