Estimating Seismic Force Reduction Factors using Spectral Shape and Duration Intensity Measures

Magnitude 9 Earthquake Scenarios – Probabilistic Modeling, Warning, Response and Resilience in the Pacific Northwest

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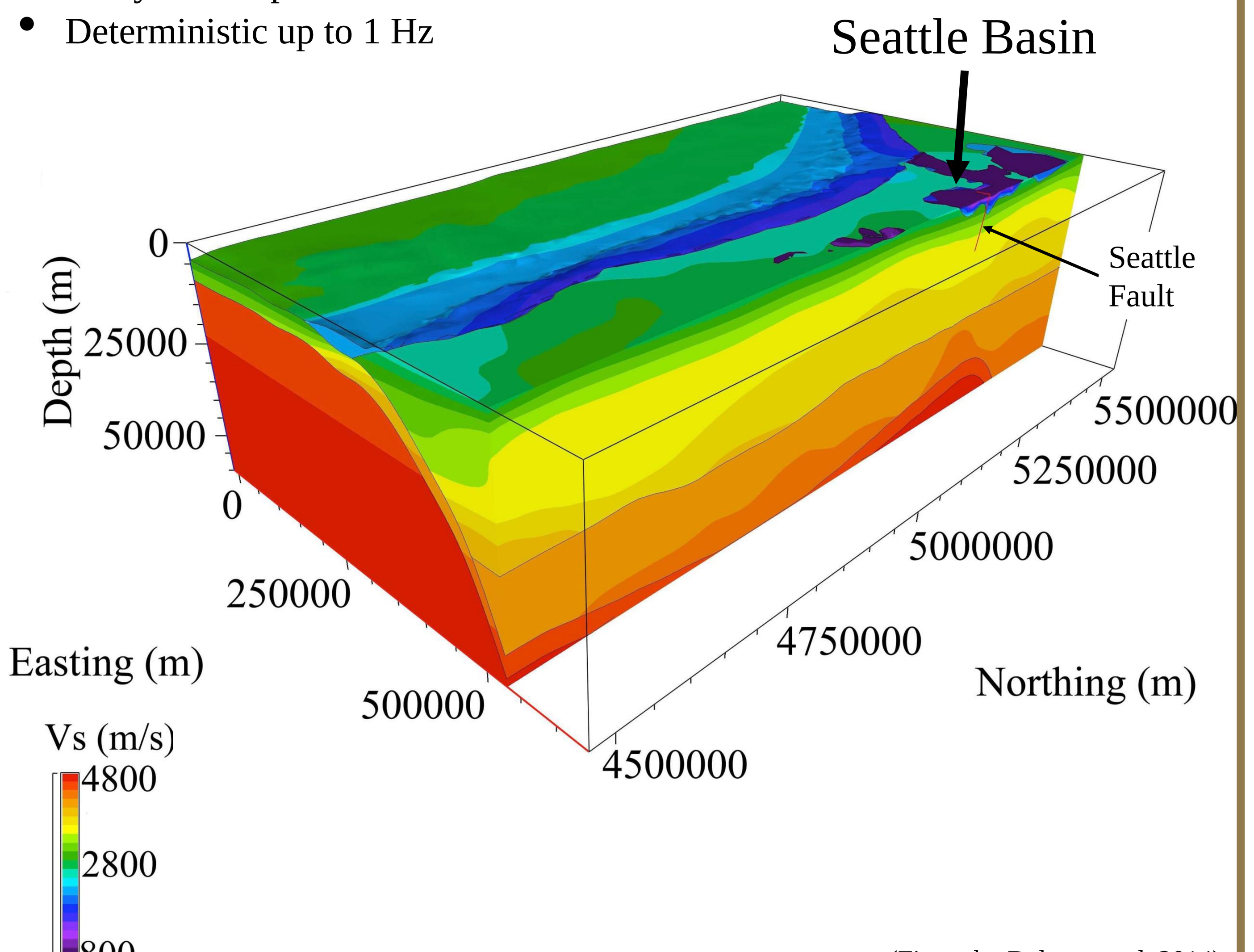
Goals

- To evaluate the possible impacts of generated M9 earthquakes on structures.
  - How do the effects of these ground motions differ?
  - What are the causes of these differences?
  - What kinds of buildings are most affected?
  - How do they affect building/bridges designed to older/newer building codes?

Geological Model

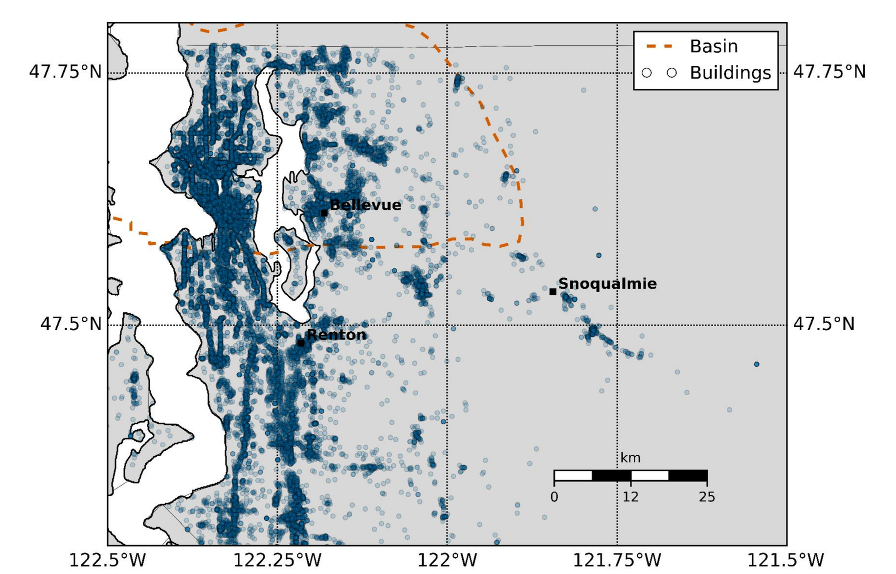
- 3D finite element model
- 1100 km (N-S) by 550 km (E-W) by 60 km deep
- Cascadia Fault
- Many fault rupture simulations
- Deterministic up to 1 Hz



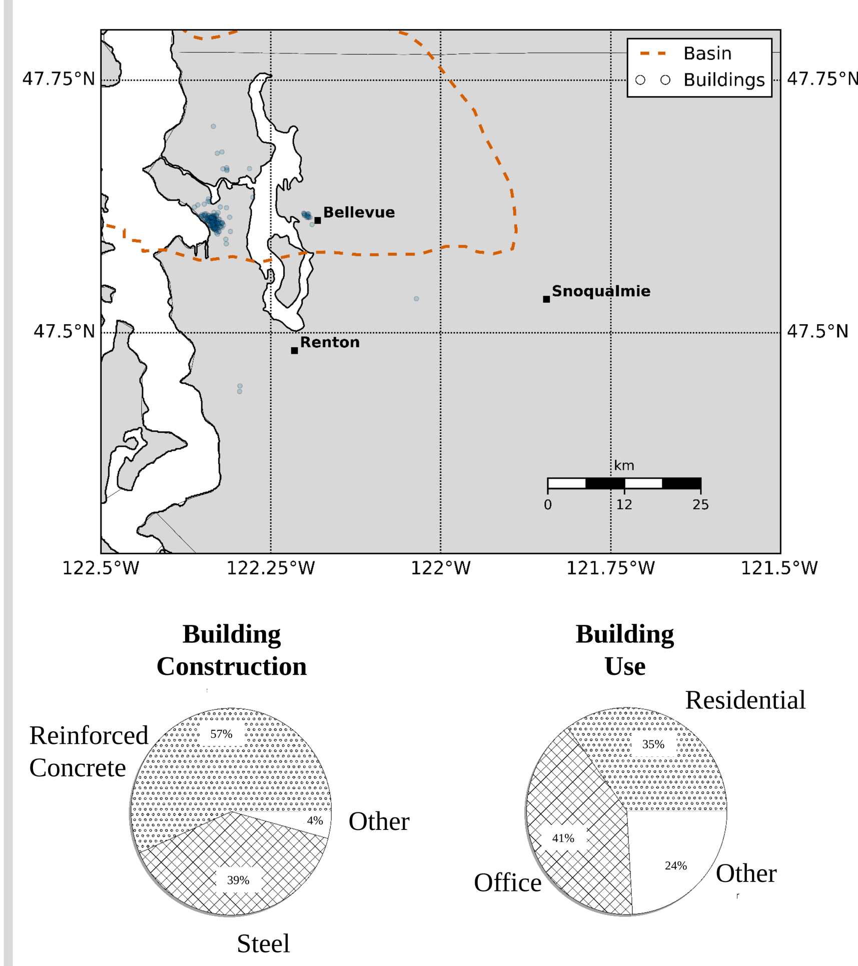
(Figure by Delorey et al. 2014)

Seattle's Building Inventory

- King County Department of Assessments Database



≥ 10 Stories

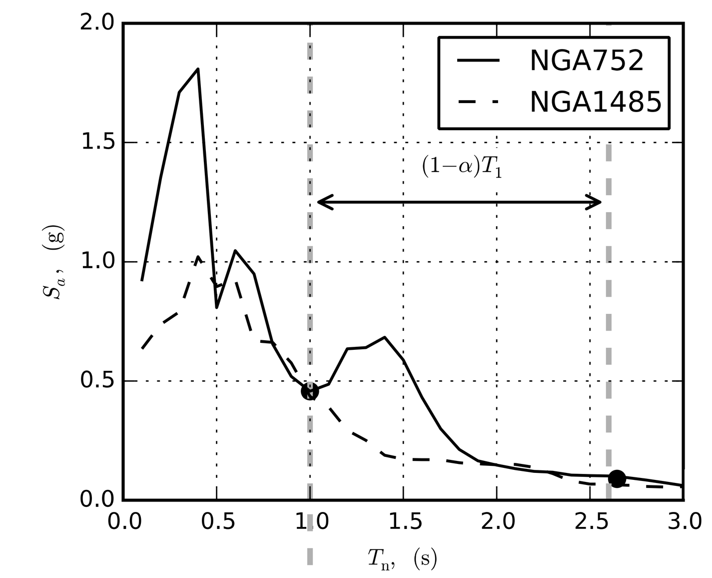


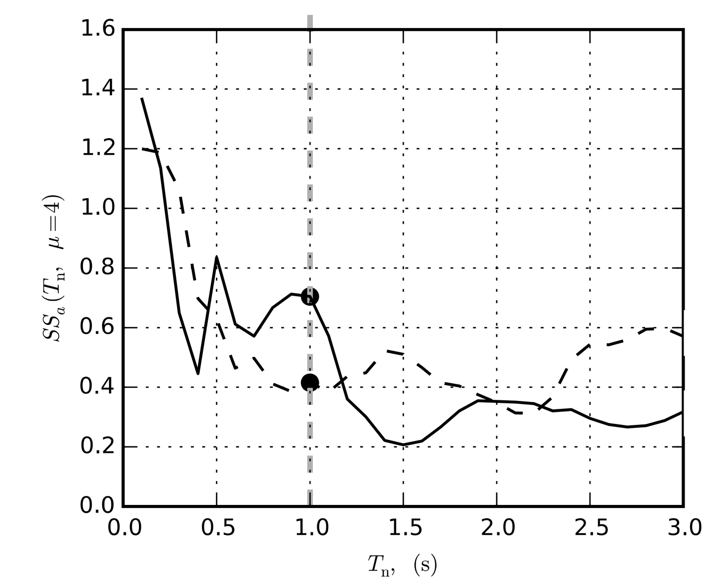
Defining Spectral Shape Intensity Measure

- Explicitly captures spectral shape
- Unaffected by ground motion scaling
- Period range dependent
- Independent of other ground motion IMs

$$SS_a(T_1,\alpha) = \frac{\int_{T_1}^{\alpha T_1} S_a(T_n)\,dT_n}{S_a(T_1)(\alpha-1)T_1}$$

where, $\alpha = C_\alpha\sqrt{\mu}$

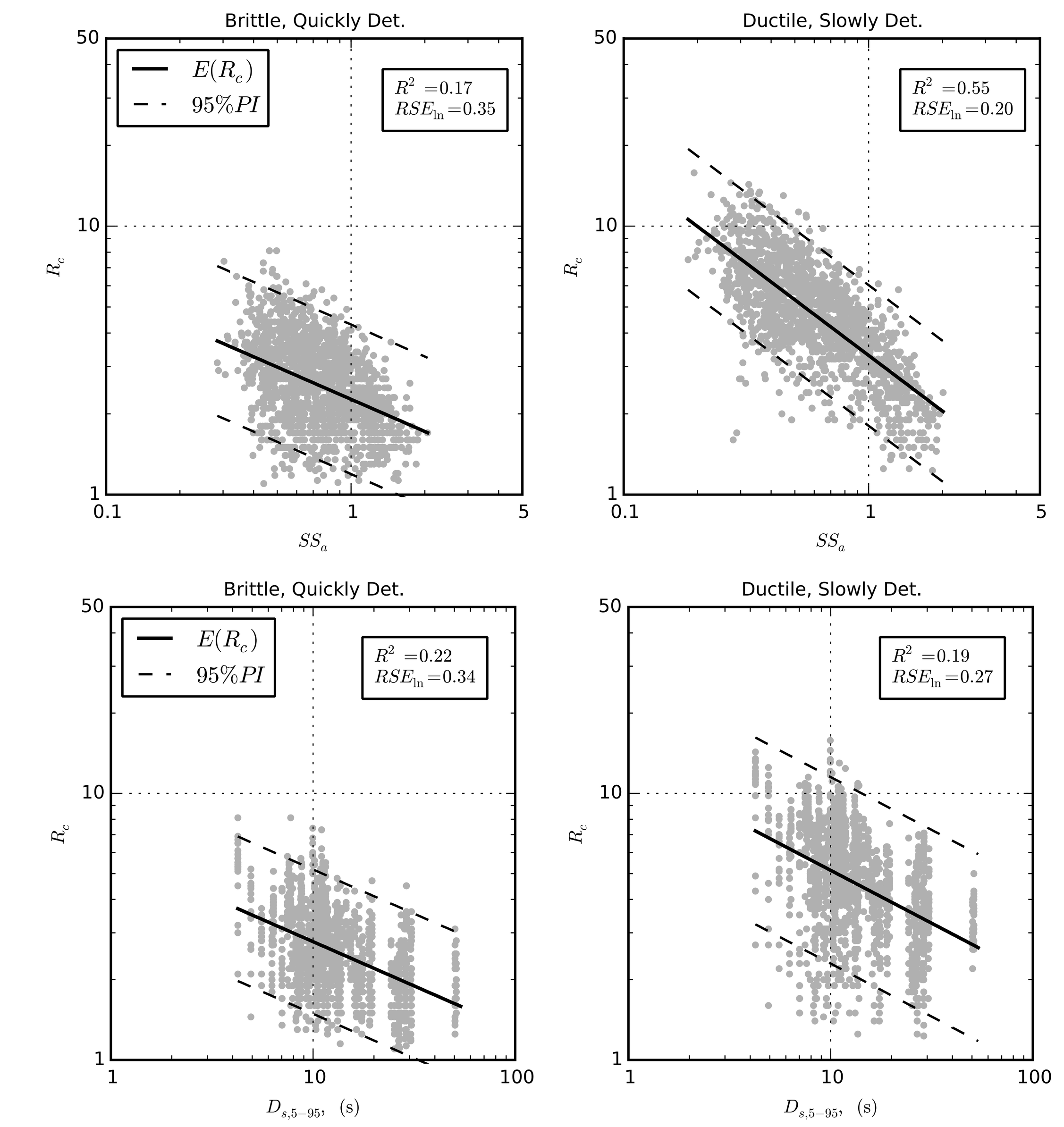




Estimating Collapse using Spectral Shape and Duration

- Computed collapse capacities using:
  - SDOF oscillators in OpenSees
  - Modified Ibarra-Medina-Krawinkler deterioration model
  - Two representative systems with properties matching experimental results
    - Brittle, quickly deteriorating
    - Ductile, slowly deteriorating
  - Periods ranging from 0.1 to 5s
- Normalized collapse capacity using relative intensity (R_c)

  $R_c = \frac{S_{a,c}}{\eta}$, where $\eta = \frac{F_y}{mg}$.
- Correlated R_c with SS_a and significant duration (D_s)

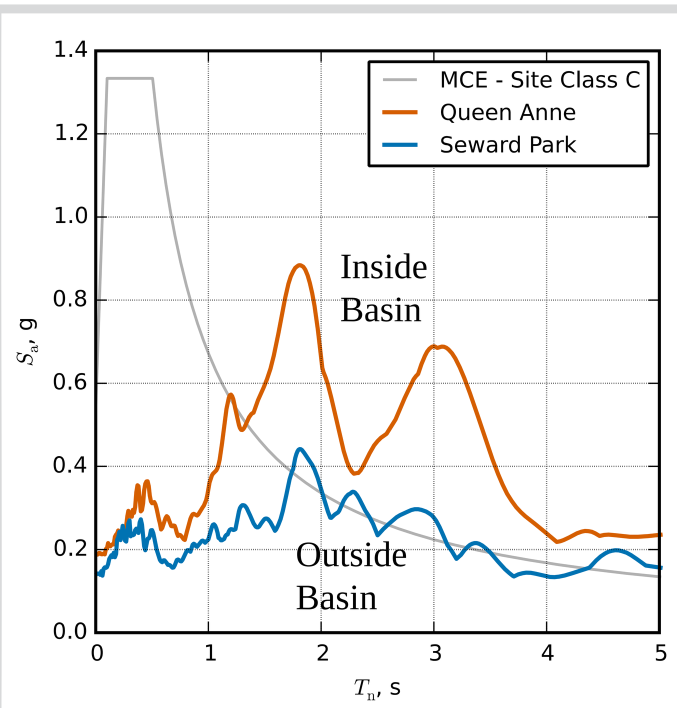


- Estimating R_c with SS_a and D_s

  $R_c = C_0 SS_a^{C_1} D_s^{C_2}$, where the constants are determined using an OLS optimization with a multiple linear regression analysis

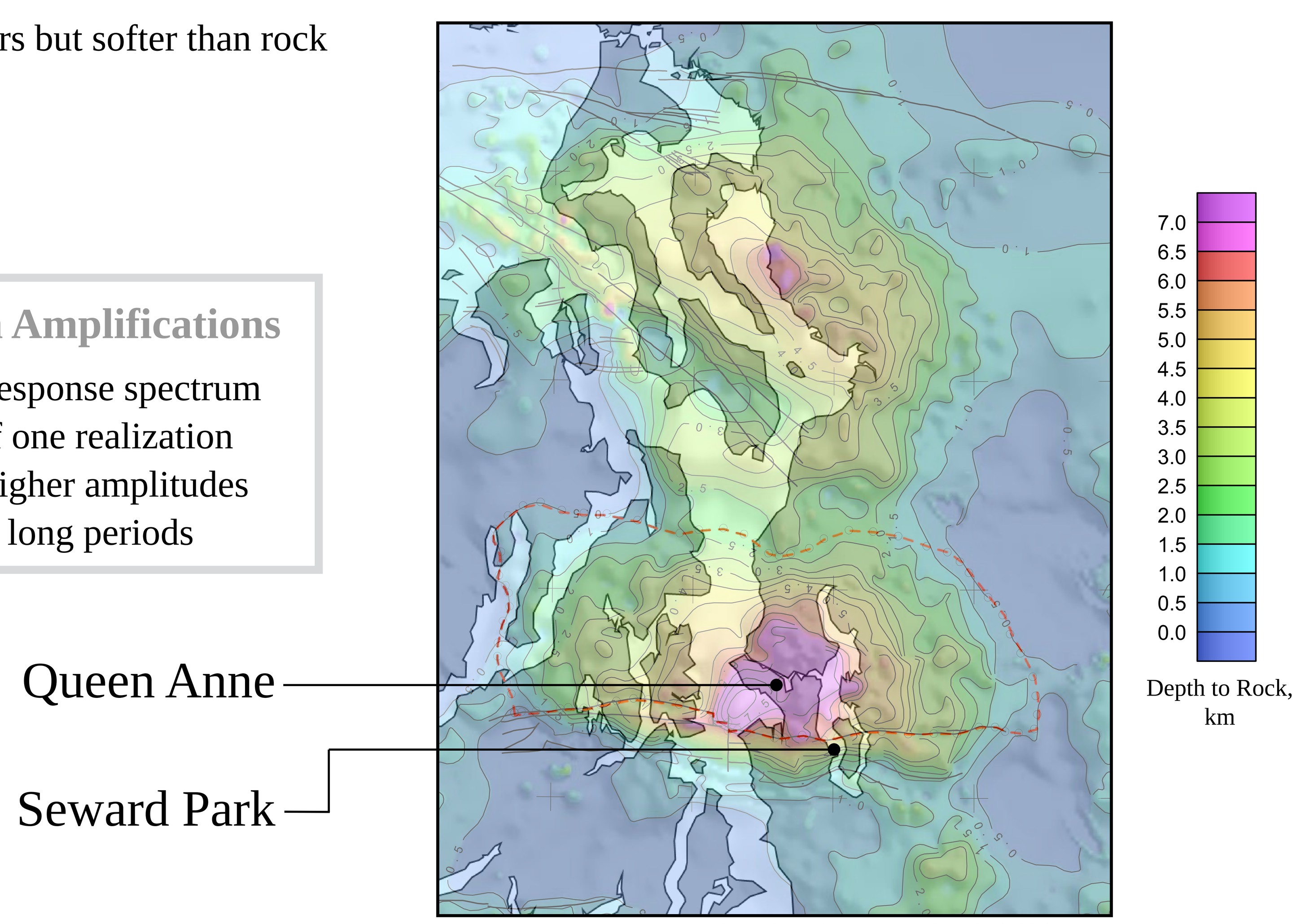
Seattle Basin

- Deep layers of sediment that are densified by glaciers but softer than rock
- Amplifies long period content of ground motion
- Mapped through research:
  - Offshore explosions and shaking recording
  - Nisqually shaking record



Basin Amplifications

- Response spectrum of one realization
- Higher amplitudes at long periods

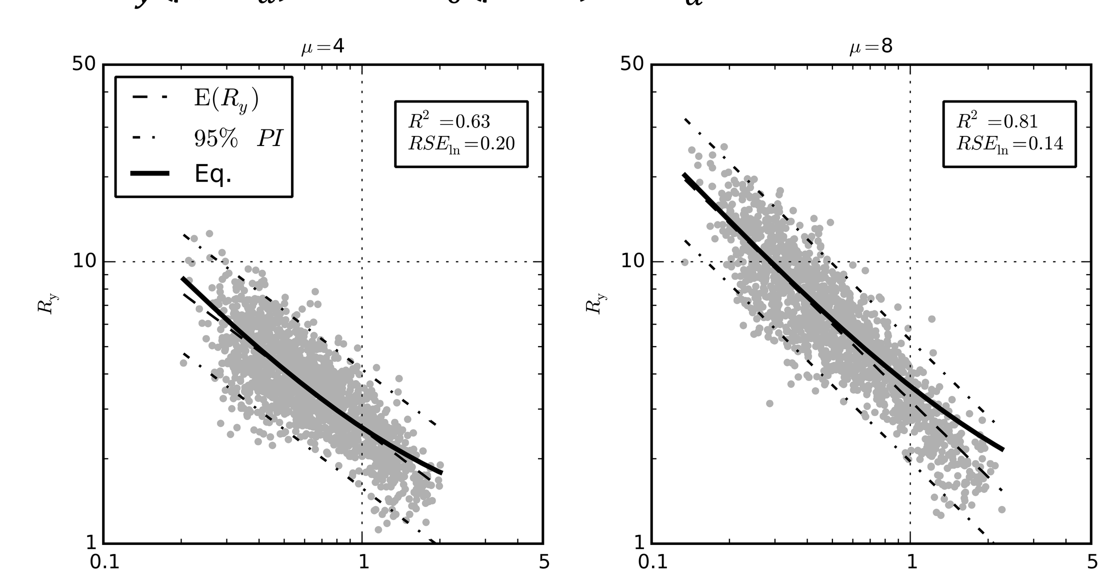


(Basin extent by Brocher et al. 2004, contours by Richard Blakely, USGS)

Estimating R_y with SS_a

- Various R_y factors were computed using:
  - Expanded FEMA P695 record set
  - Elasto-plastic SDOF Oscillators
  - Periods ranging from 0.1 to 5s
  - Various ductility factors (μ)
- Correlated R_y factors with SS_a
- Prediction model for R_y using:

$$R_y(\mu, SS_a) = 1 + C_0(\mu-1)^{C_1}\, SS_a^{C_2}$$



Summary

- Basin effects amplify long period content making spectral shape important
- Structures undergoing non-linear behavior are more prone to spectral shape effects
- Force reduction factors that cause yielding in elasto-plastic systems and collapse in deteriorating systems depend on:
  - System ductility
  - Spectral shape
  - Duration

References

Brocher, T. M. (2004). "Interpretation of the Seattle Uplift, Washington, as a Passive-Roof Duplex." *Bulletin of the Seismological Society of America*, 94(4), 1379–1401.

Delorey, A. A., Frankel, A. D., Liu, P., and Stephenson, W. J. (2014). "Modeling the Effects of Source and Path Heterogeneity on Ground Motions of Great Earthquakes on the Cascadia Subduction Zone Using 3D Simulations." *Bulletin of the Seismological Society of America*, 104(3), 1430–1446.

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