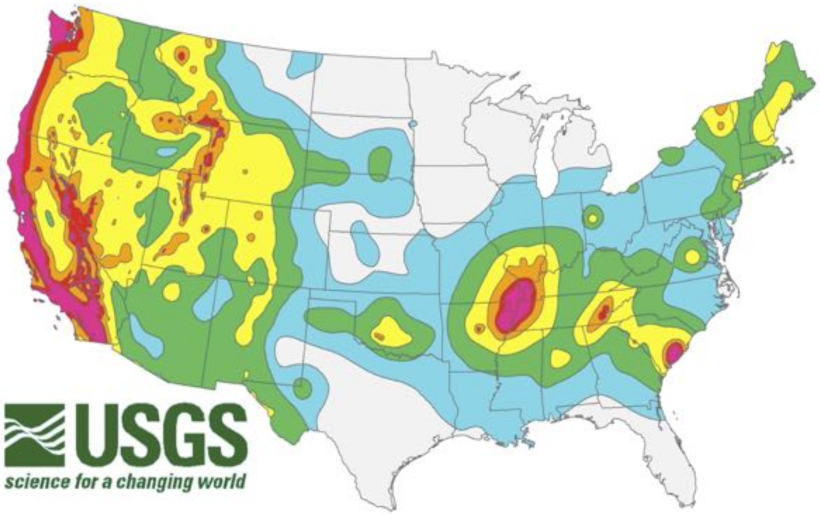
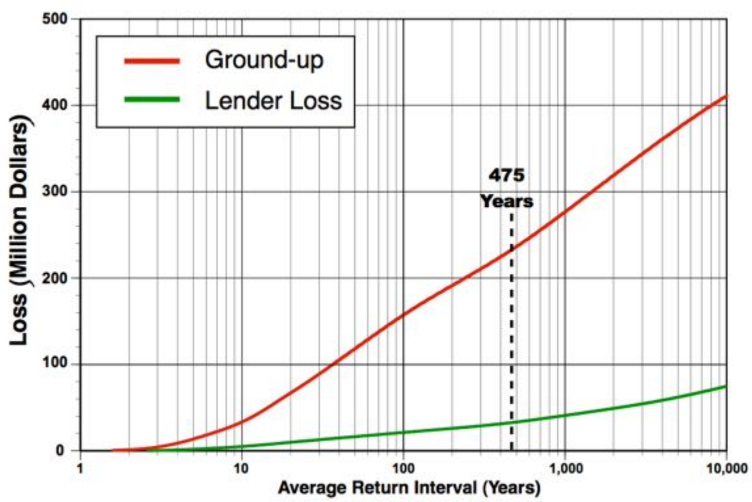
Seismic Risk Assessment of Real Estate Portfolios

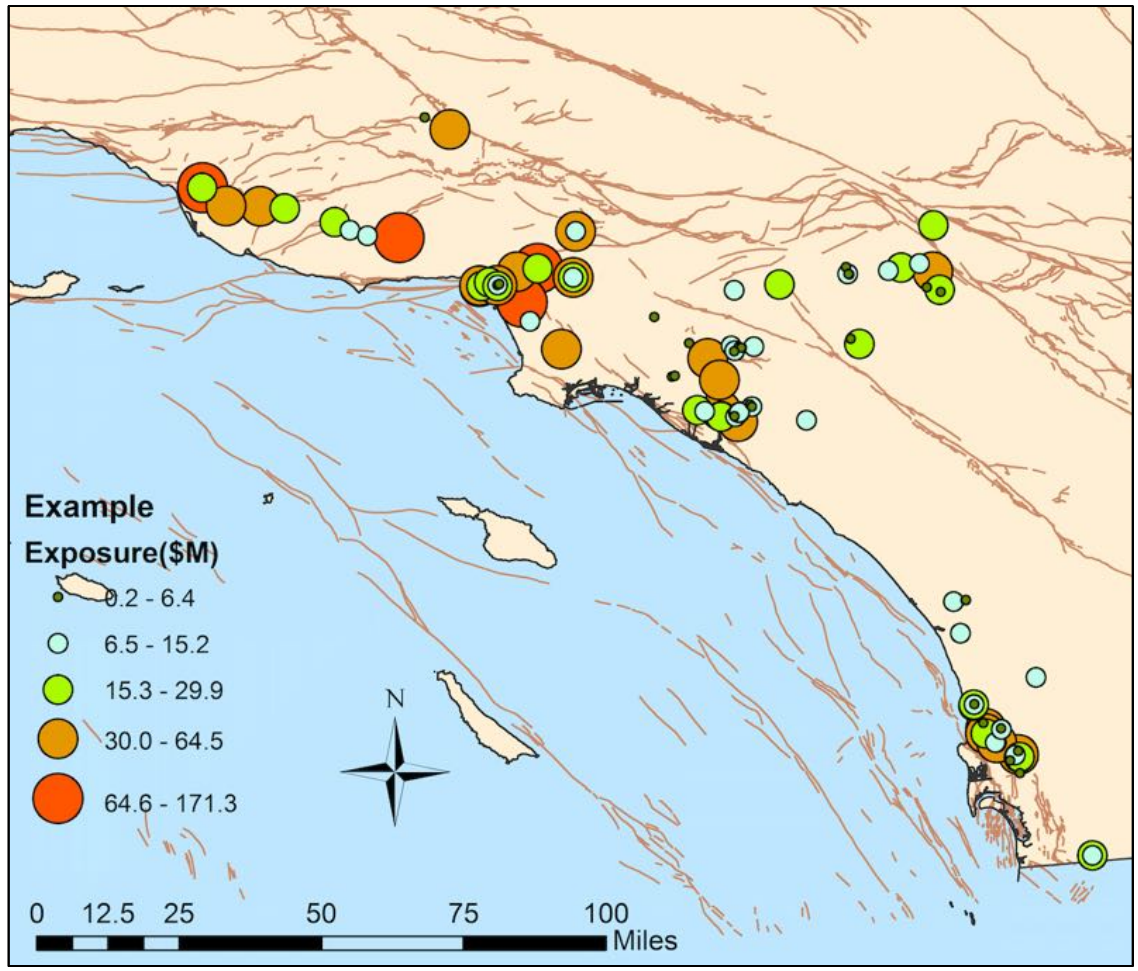
Subcommittee WK55885

Webinar: Overview of Portfolio Seismic Risk Assessment

W.P. Graf and Y.J. Lee, ImageCat, Inc.







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Introduction and Background

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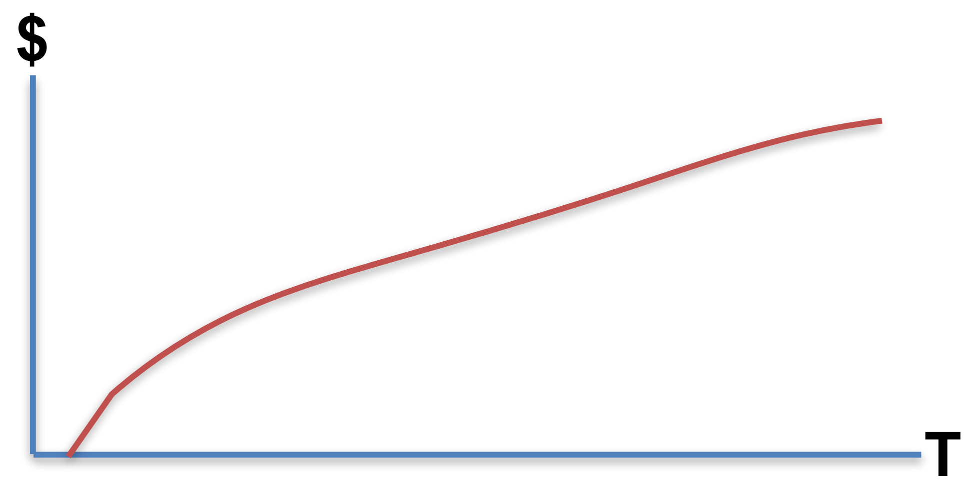
Introduction and Background



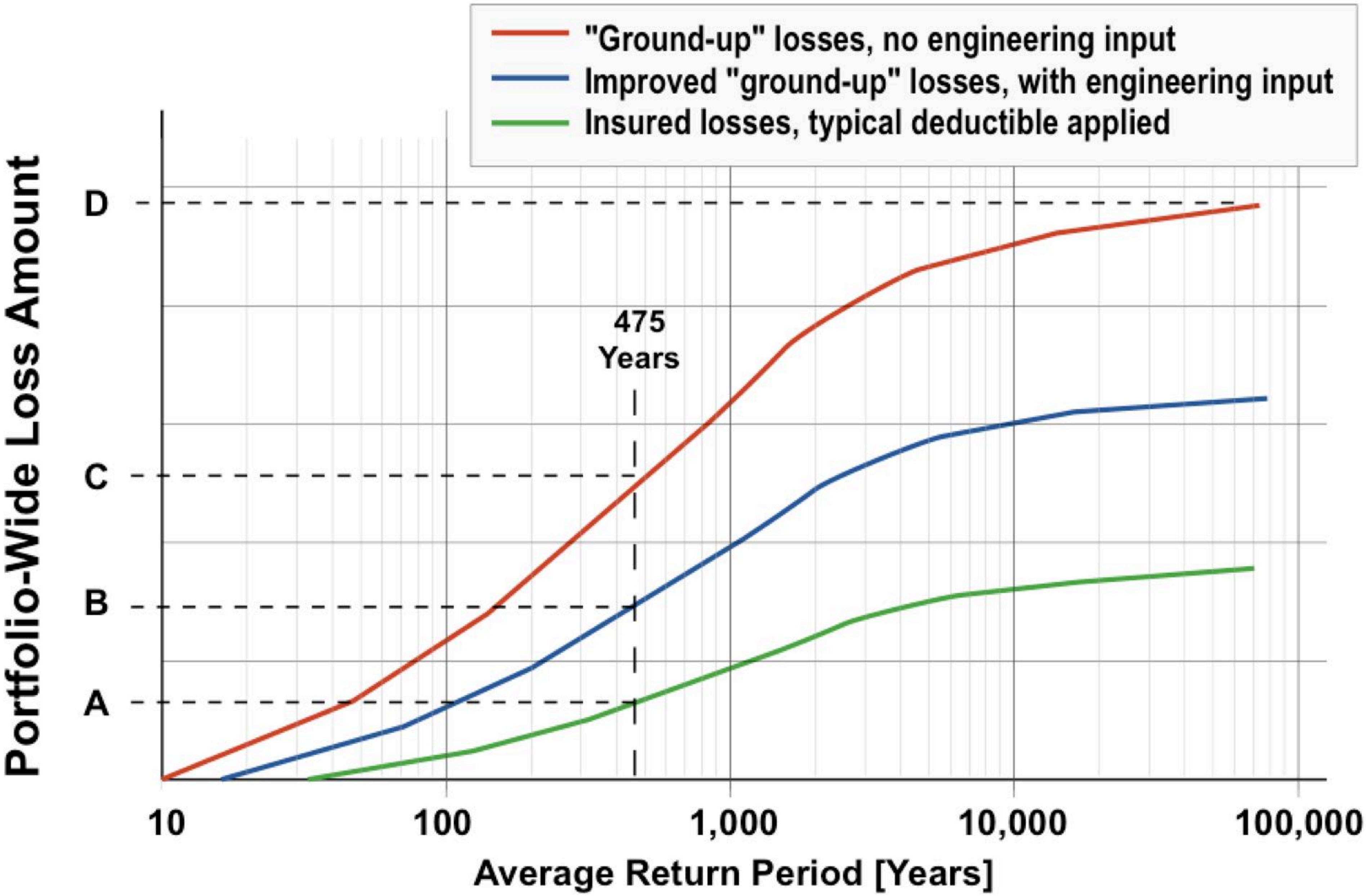
Introduction & Background

Why do portfolio seismic risk analysis?
What are the benefits?

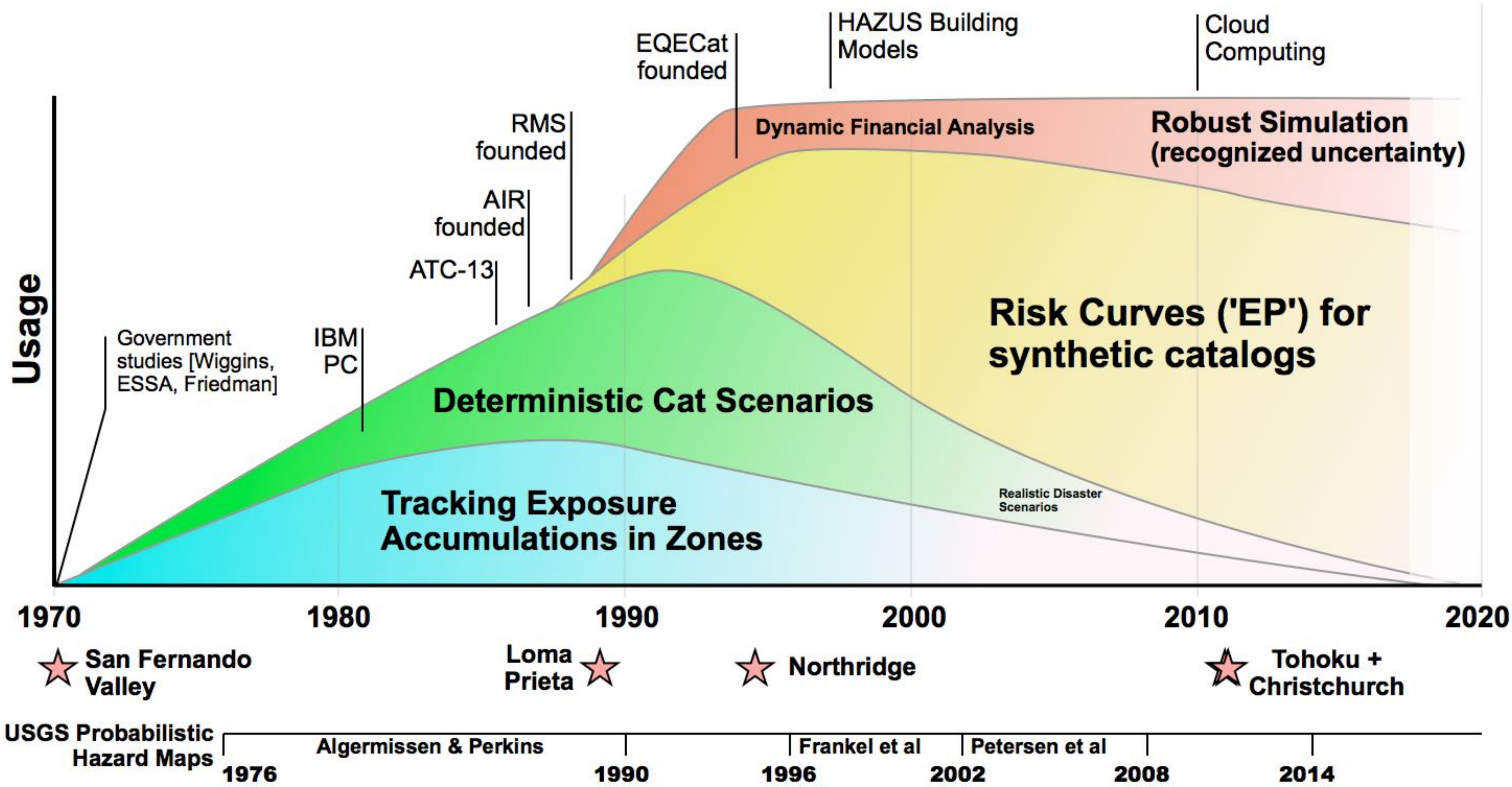
- **To know total, strategic risk, not just site-by-site risks as provided by acquisition due-diligence (PMLs).**
- **To identify the geographic concentrations of risk and other factors contributing to large aggregate losses.**
- **To make better decisions for investment and sale, and to set better policies for acquisition due-diligence.**
- **To manage risks through geographic diversification, earthquake insurance and retrofit.**

Example –

An owner asks: “How much earthquake insurance should I buy?”



A History of Portfolio Risk Methods



Idealized Computational Process

Proceeds Earthquake-by-Earthquake through an "event set"

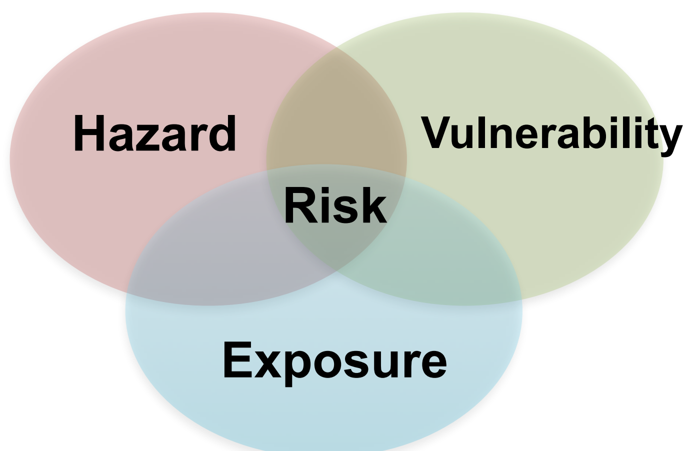
For Each Earthquake Event

- Calculate hazards at each site
- Calculate losses at each site
  - *Building damage*
  - *Contents*
  - *Time-element losses*
- Sum up losses from site to site, all sites
  - *All losses ('ground up' losses)*
  - *Losses to owner*
  - *Losses to lender*
  - *Losses to insurer*
- Link loss to probability

Go to Next Event
(Repeat for all events)

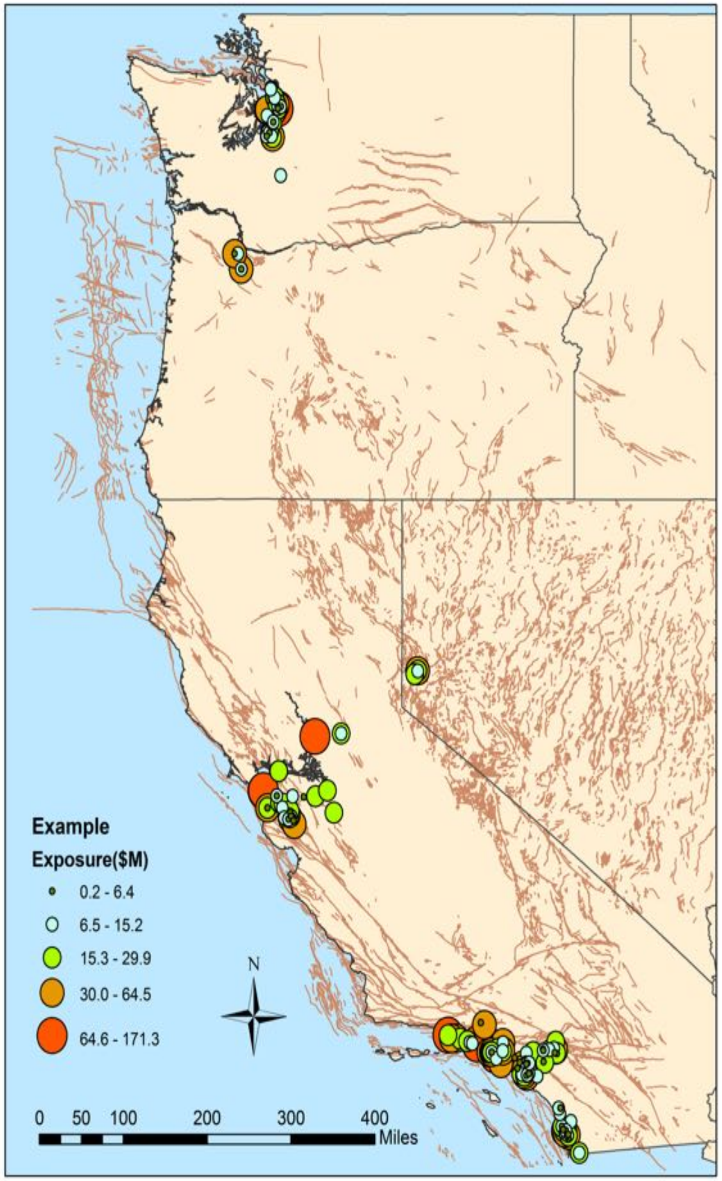
Then:
- **Construct the risk curves, considering uncertainty**
- **Compute Average Annual Losses (AAL)**
- **Identify the sites and buildings driving the losses**

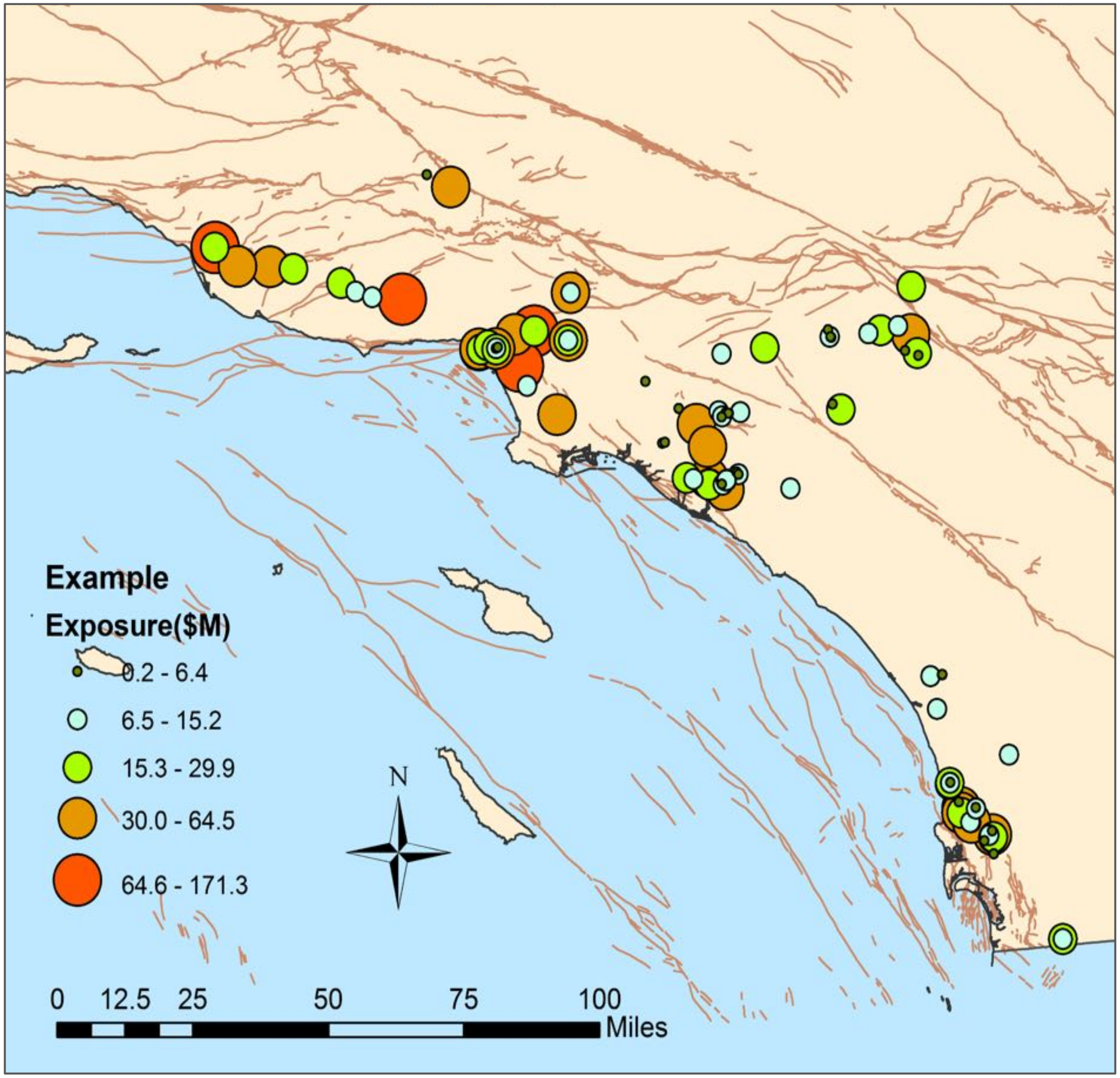
1. Terminology



1. Terminology

Portfolio – A geographically-distributed set of facilities (e.g., real estate properties) or other values-at-risk.





1. Terminology

Event Set – a set of (earthquake) simulations, each with a spatial distribution of ground shaking and annual frequency of occurrence, intended to represent the complete ensemble of future earthquakes for the defined region(s), used for the evaluation of earthquake damage to spatially-distributed real estate properties.

Stakeholder – one of the parties who may suffer damage, loss or injury from an earthquake event. For example, an owner, lender, or insurer may have a stake in an earthquake loss. If an owner retains earthquake insurance, the insurer is then at risk for covered losses above the deductible and below the limit of liability. If the owner defaults on a loan, the lender may face a loss.

1. Terminology

Aggregate Loss – the portfolio-wide loss to the particular stakeholder, in dollars, from an earthquake event.

Ground-up Loss – (Insurance) the total financial loss considered by an earthquake insurance policy, prior to allocation through the application of deductibles and limit of liability. The portions of the ground-up loss retained by the insured are losses below deductible and loss in excess of the limit of liability. The portion paid by the insurer (also called **direct loss or gross insurer loss**) is the loss above the deductible, but below the limit of liability.

Expected Loss – the mean value of loss [$] from a statistical distribution of loss. This can apply to a single building or to portfolio (aggregate) loss.

Probable Loss – earthquake loss to the building or portfolio that has a specified probability of being exceeded in a given time period, or an earthquake loss that has a specified return period for exceedance.

1. Terminology

Lender Loss – the financial risk to a lender from earthquake damage to a property that secures a mortgage, should the owner choose to default on the mortgage. An owner may elect to default on a loan if the cost to make earthquake repairs exceeds the owner's equity in the property (current market value minus mortgage balance). Upon default, the lender may foreclose on the property, make necessary repairs and sell the property. The lender's loss would then be:

Lender Loss = (Mortgage Balance + Repair Cost) – Market Value

Alternatively, the lender may elect to maintain ownership of the property.

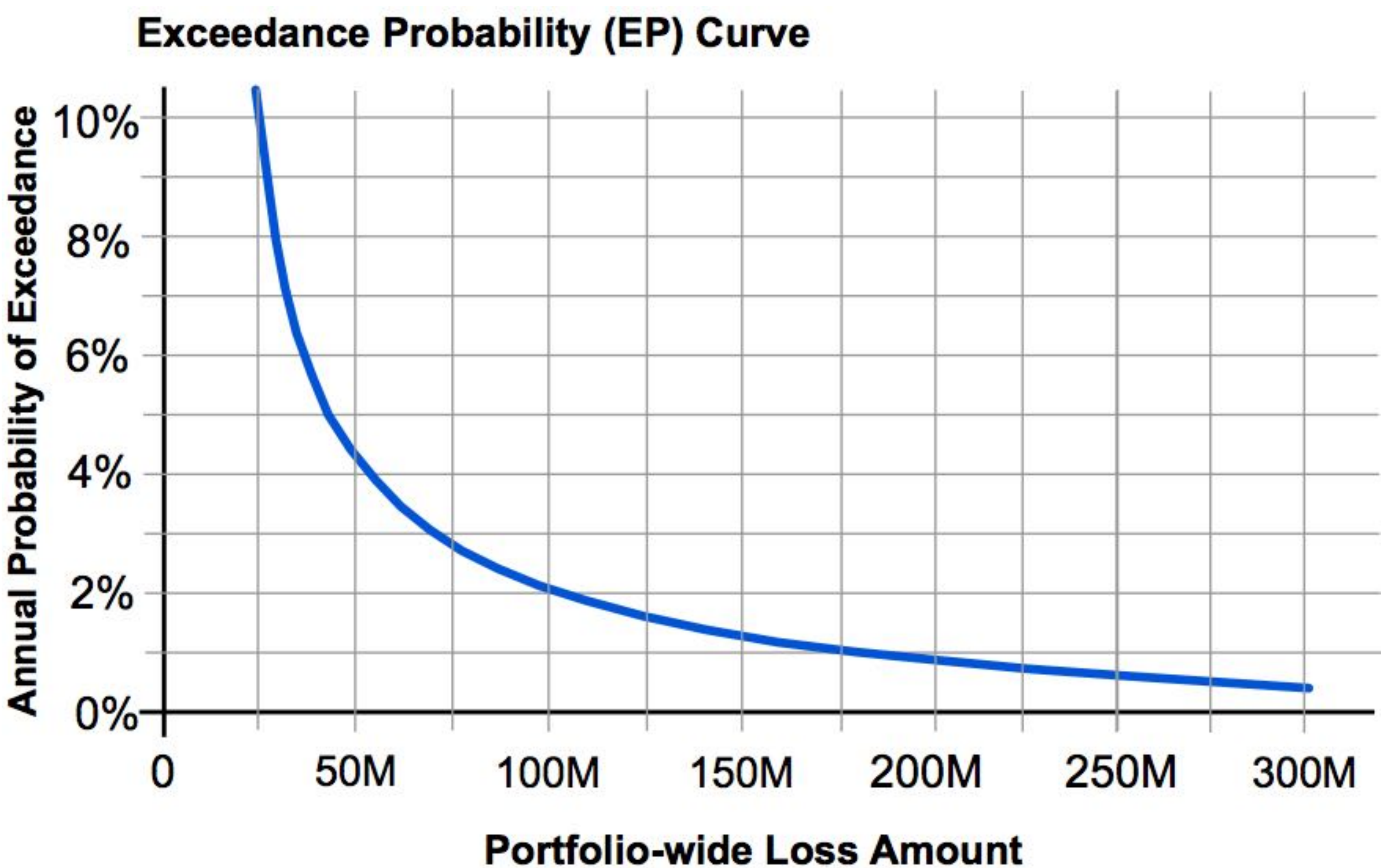
Average Annual Loss (AAL) – the loss per annum due to hazards, calculated from the probabilistic loss contribution of all events. The expected annual loss is the expectation of the probability distribution of loss per annum, and may be calculated as the frequency-weighted average of loss due to all possible hazard events.

$$AAL \approx \sum Loss(i) \times f(i) \text{ for all events, } i$$

Where $f(i)$ is annual frequency of event (i)

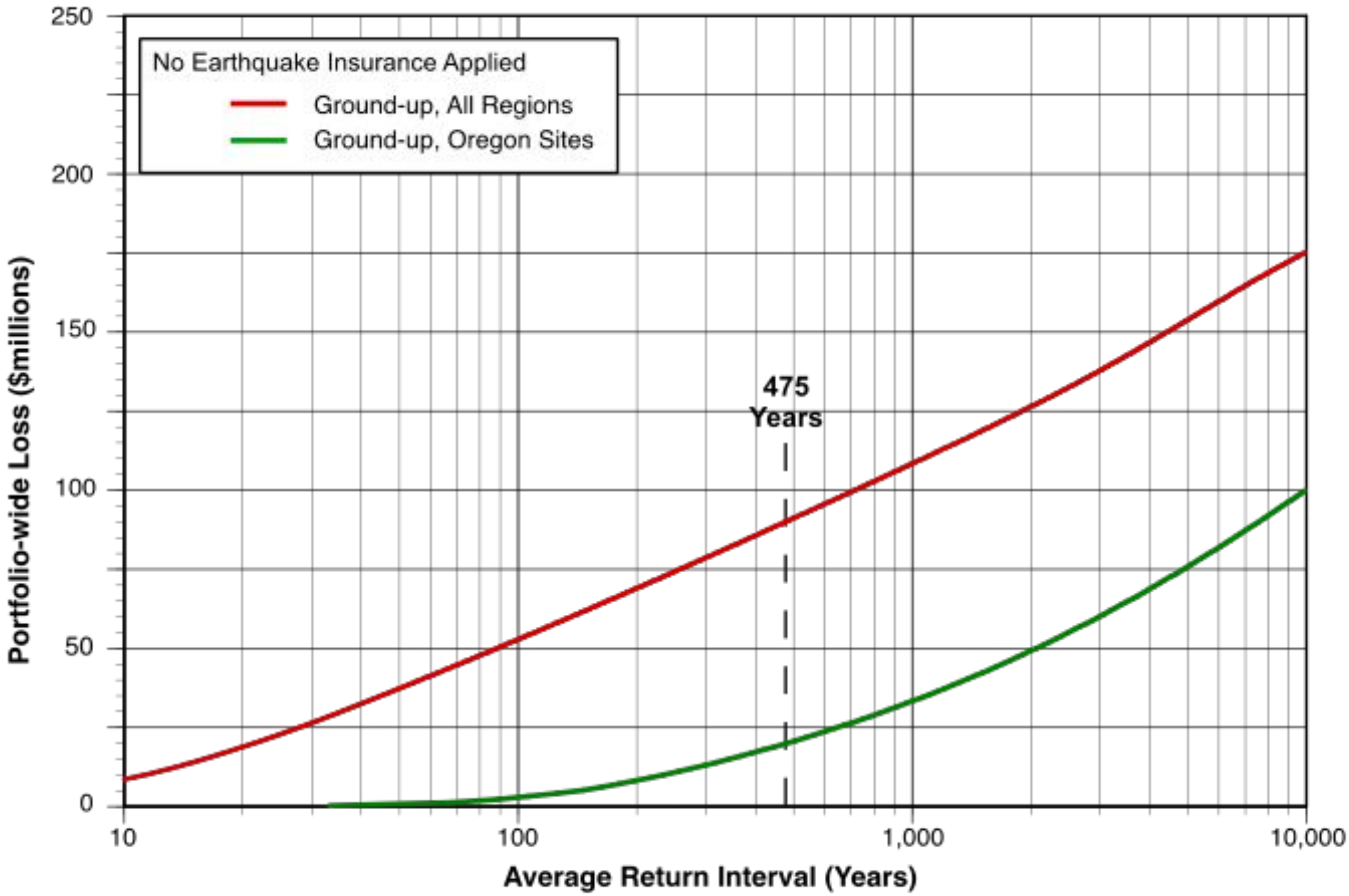
1. Terminology

Risk Curve or Exceedance Probability Curve – a plot of the severity of loss or other consequence as a function of annual exceedance probability or average return period. This is a continuous form of **Probable Loss.**

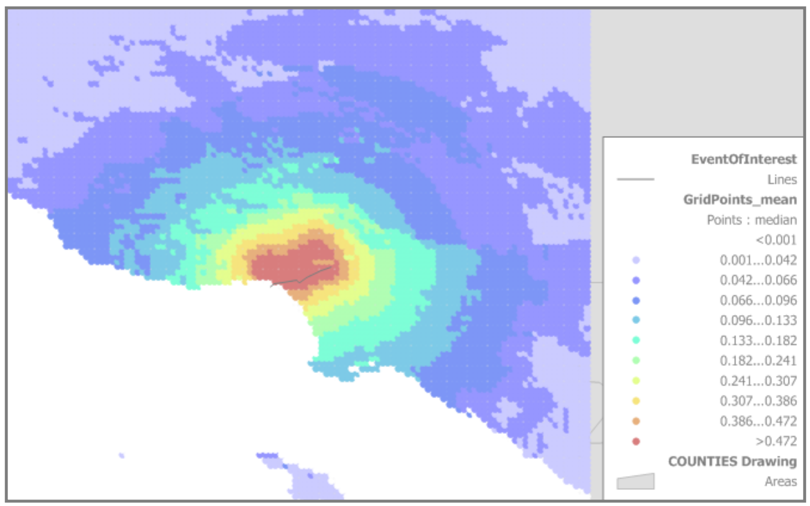


1. Terminology

Risk Curve or Exceedance Probability Curve –



2. Site Hazards and Event Sets



2. Site Hazards and Event Sets

The hazards in play are ground shaking and liquefaction effects. Modeled liquefaction effects are limited to damage from differential settlement on flat sites. Lateral spreading, lurching, etc. are much more difficult to model.

Less important in portfolio seismic risk assessment: surface fault rupture, landslide. These are highly localized and do not typically contribute to high portfolio-wide risks.

2. Site Hazards and Event Sets

In the probabilistic catastrophe models used in insurance (RMS, AIR, CoreLogic, Impact Forecasting, ImageCat, etc.) losses are computed for an "**event set**" -- a large synthetic catalog of earthquake simulations, constructed to reasonably sample all future earthquakes, based on current understanding of the seismic environment.

The Engineering Service Provider has the opportunity to improve the modeling by making sure Site Class and liquefaction susceptibility are correct, using site-specific information (e.g., from a geotechnical report) to over-ride data found from more general digital maps. Where liquefaction may occur, foundation type becomes important.

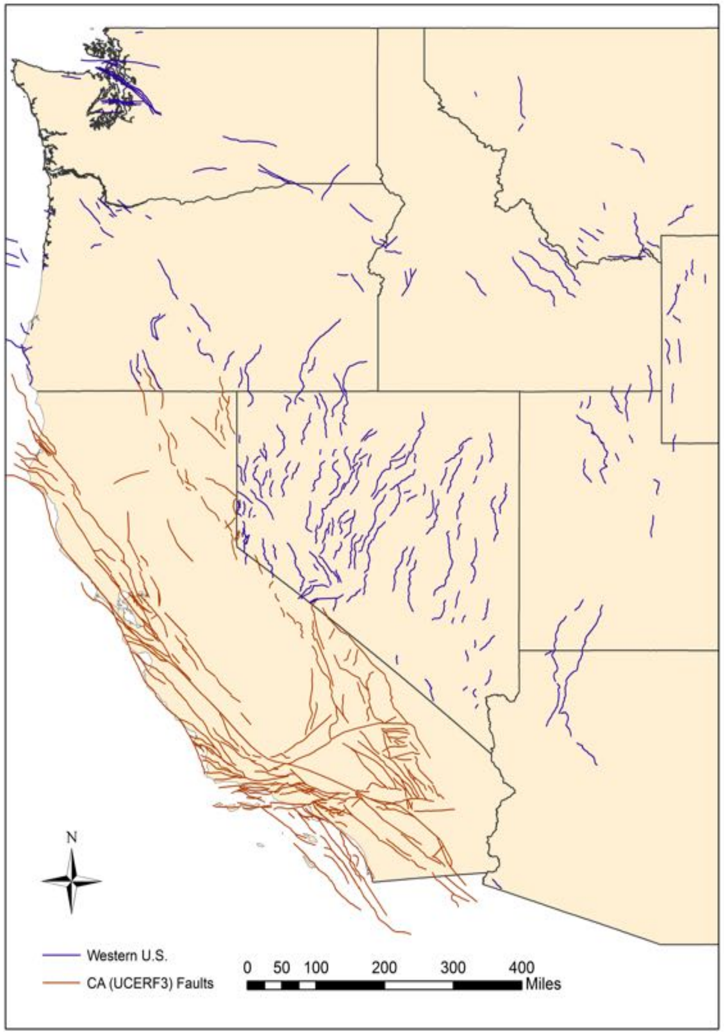
Modeling Seismic Shaking Hazards

Parts:

1. **Seismicity** modeling (accounting for magnitude, location and annual frequency of occurrence)
2. **Ground motion models** (GMMs, GMPEs, attenuation relationships)
3. **Site amplification** (Fa, Fv, or as a function of Vs30 within GMM)
4. **Managing uncertainty**

Modeling Earthquake Occurrence

- ➢ **Exactly when, where and how severely the next earthquake will strike cannot be predicted precisely**
- ➢ **Occurrences, locations and magnitudes must be modeled using stochastic methods to account for uncertainties**



(USGS 2014 NSHMP)

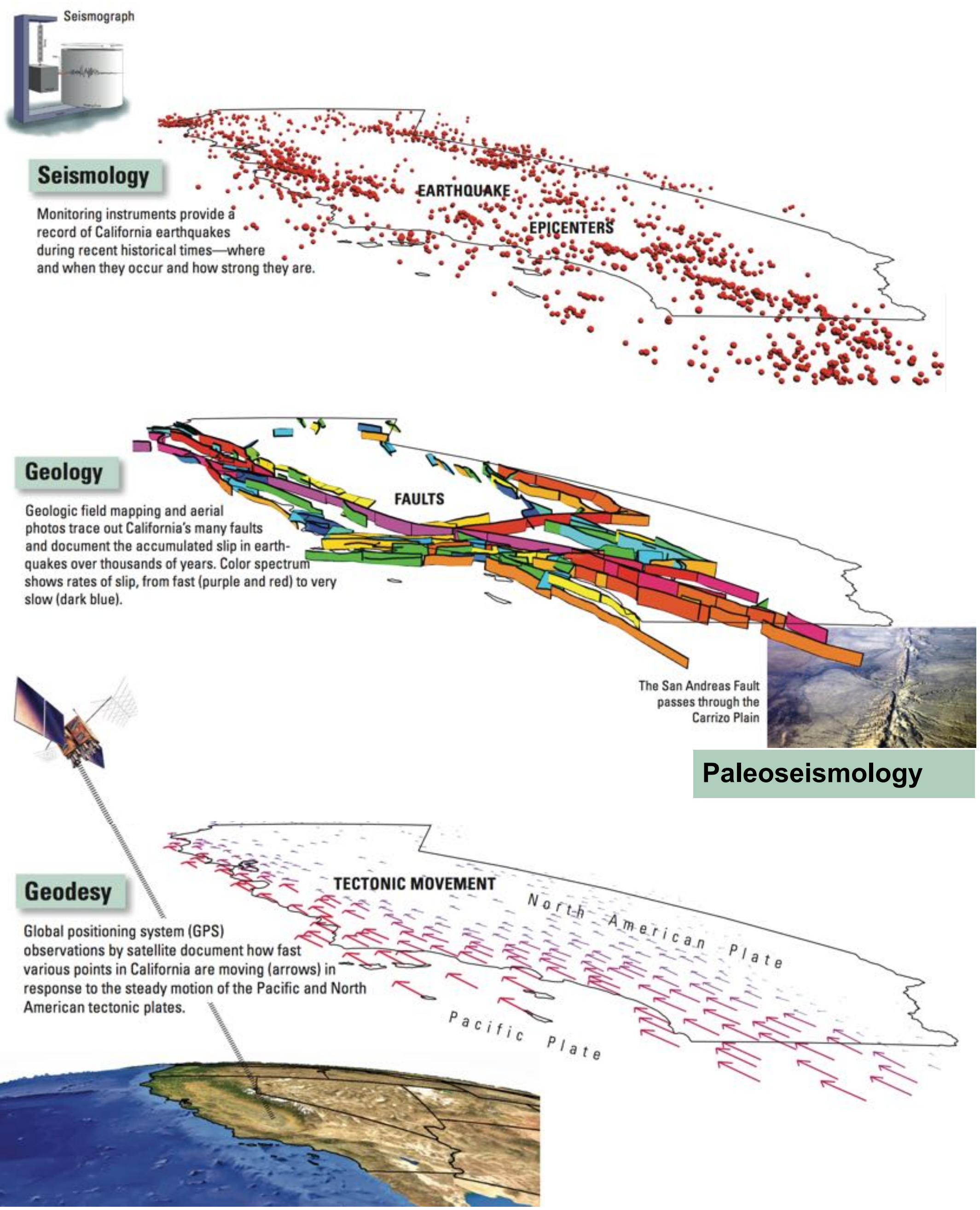
Stochastic 'Event Set'

Ground Shaking – Event Set

- A large set of earthquake simulations that systematically samples the magnitude-frequency distribution and finite rupture locations to account for all possible future earthquakes in a region.
- Each earthquake simulation attempts to accurately reproduce the geographic distribution of ground shaking and other hazards.
- Empirical ground motion models are used with specific fault parameters (depth, dip, style of faulting, etc.), with *Mw* and a defined finite fault rupture . Ground shaking is adjusted for Site Class and other effects. Predicted shaking is a response spectrum Sa(T) which may be a smooth shape or constructed from PGA, Ss and S_1.
- The number of earthquake simulations required for a seismically active region can be <u>large</u> (e.g. hundreds of thousands, or millions).
- The de facto standard is USGS National Seismic Hazard Mapping Project model (1996, 2002, 2008, 2014).

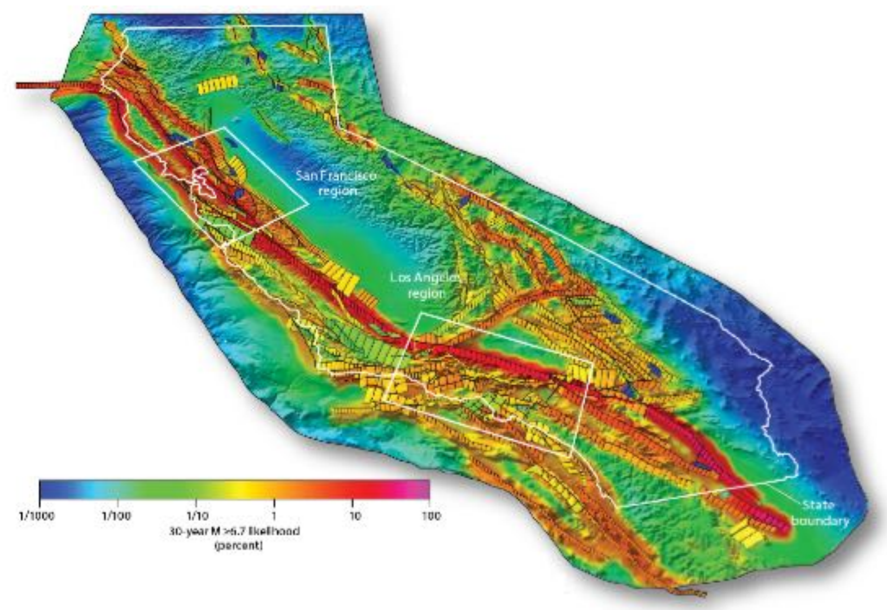
UCERF3

Uniform California Earthquake Fault Rupture Forecast



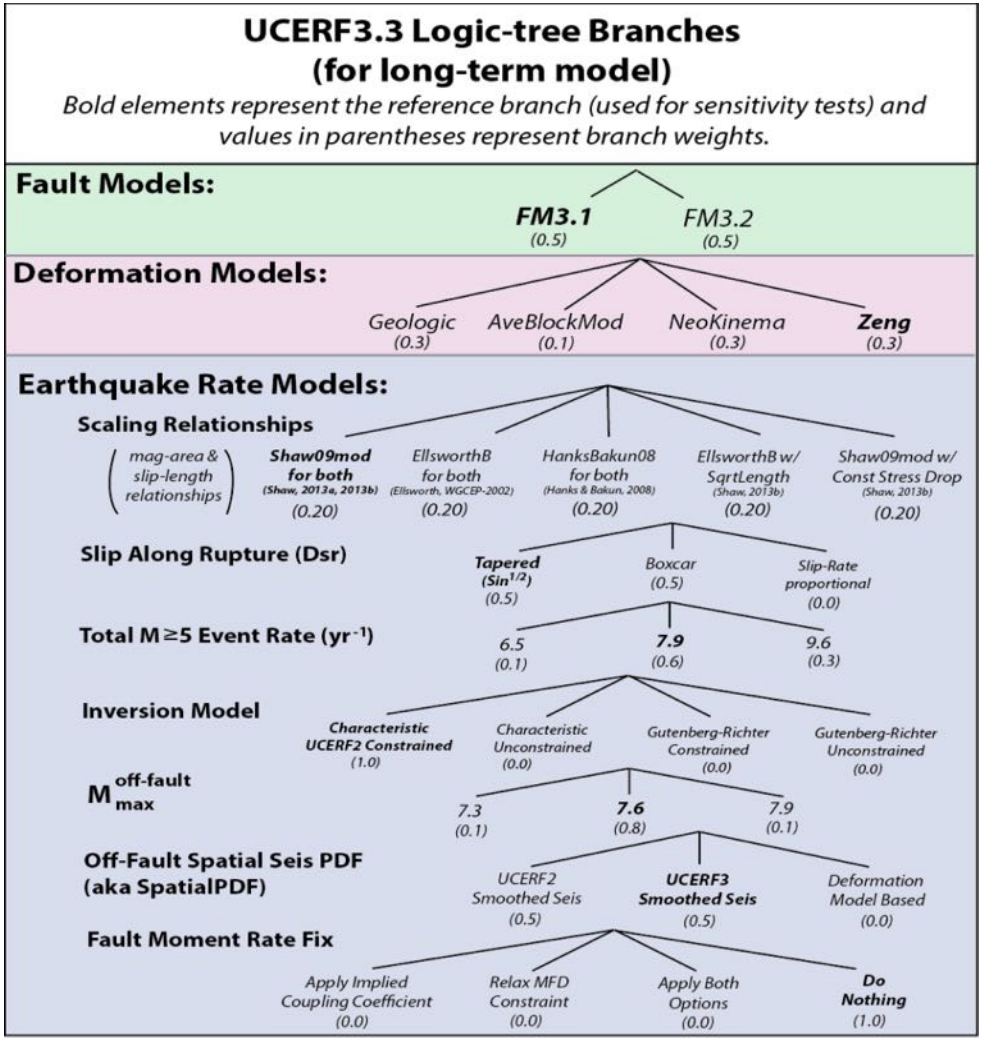
"The new Uniform California Earthquake Rupture Forecast (UCERF) combines information from geodesy (precise data on the slow relative movement of the Earth's tectonic plates), geology (mapped locations of faults and documented offsets on them), seismology (occurrence patterns of past earthquakes), and paleoseismology (data from trenches across faults documenting the dates and offsets of past earthquakes on them). All four kinds of data are combined mathematically to produce the final probability values for future ruptures in the California area, in regions of the State, and on individual faults.

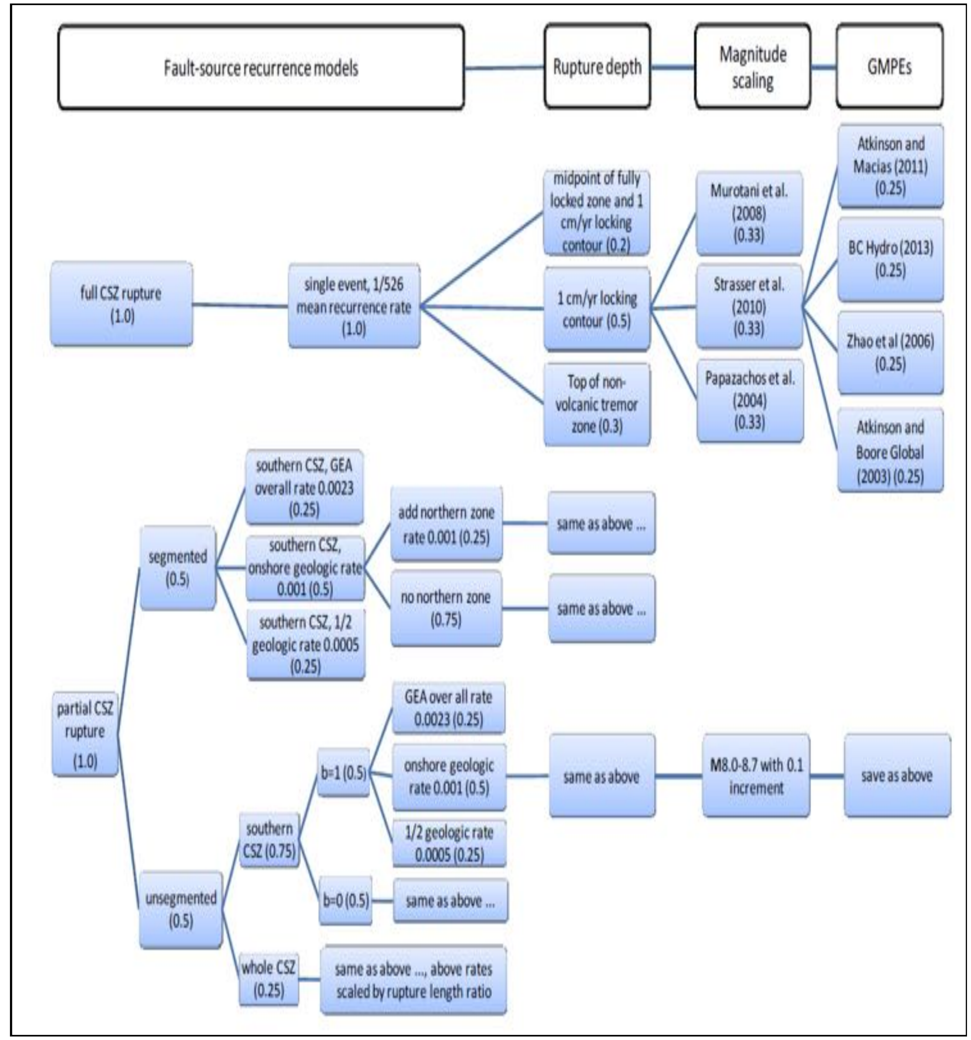
Building on several previous studies and decades of data collection, UCERF was developed by a multidisciplinary group of scientists and engineers, known as the 2007 Working Group on California Earthquake Probabilities. Advice and comment was sought regularly from the broader community of earthquake scientists and engineers through open meetings and workshops. Where experts disagreed on aspects of the forecast, alternative options were accounted for in calculations to reflect these uncertainties. The final forecast is a sophisticated integration of scientific fact and expert opinion."



Modeling Epistemic Uncertainty [USGS]

➢ Seismicity Models



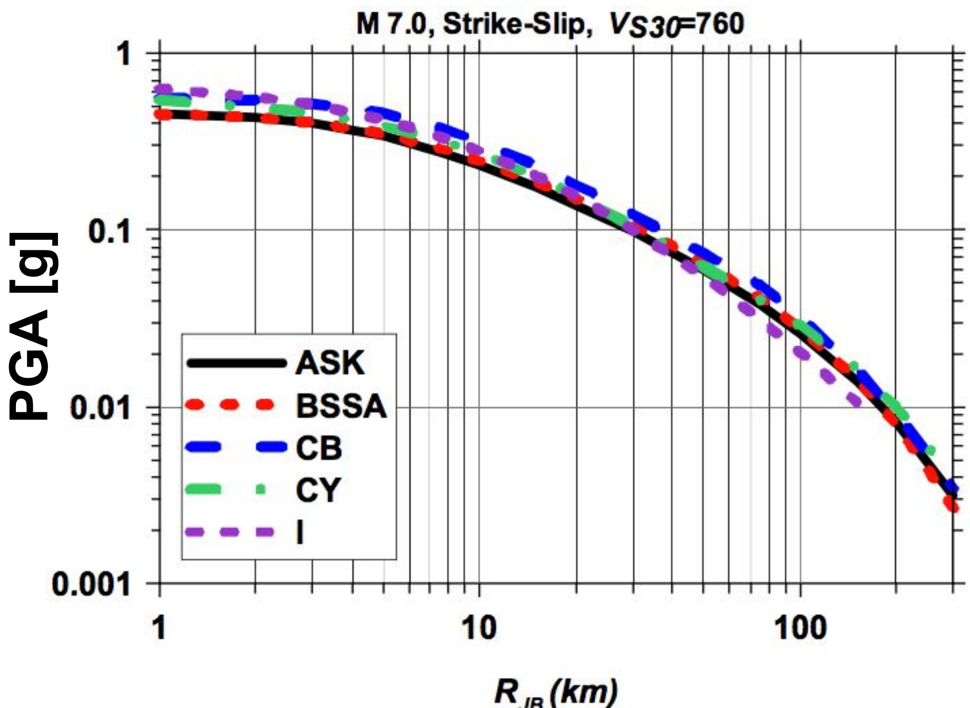


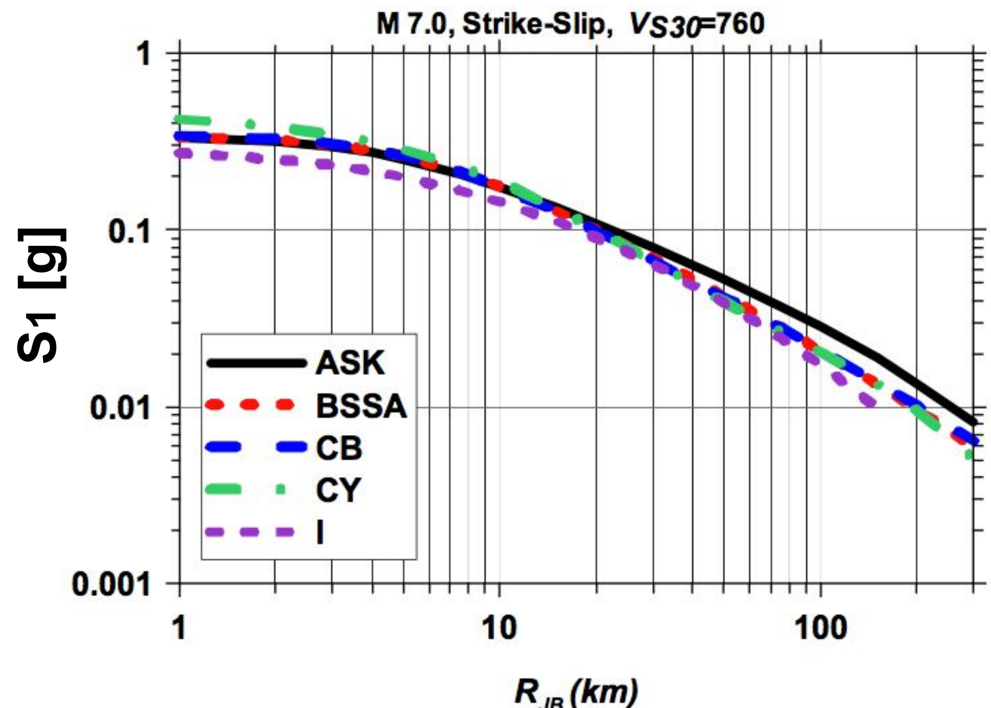
UCERF3 Compound Fault System Solutions - *Time-independent models: 1440 logic branches for earthquakes affecting California*

Another example – Cascadia Subduction Zone *(CSZ): complex rupture location, magnitude and event rate logic tree*

NGA West2 Ground Motion Models (GMMs)

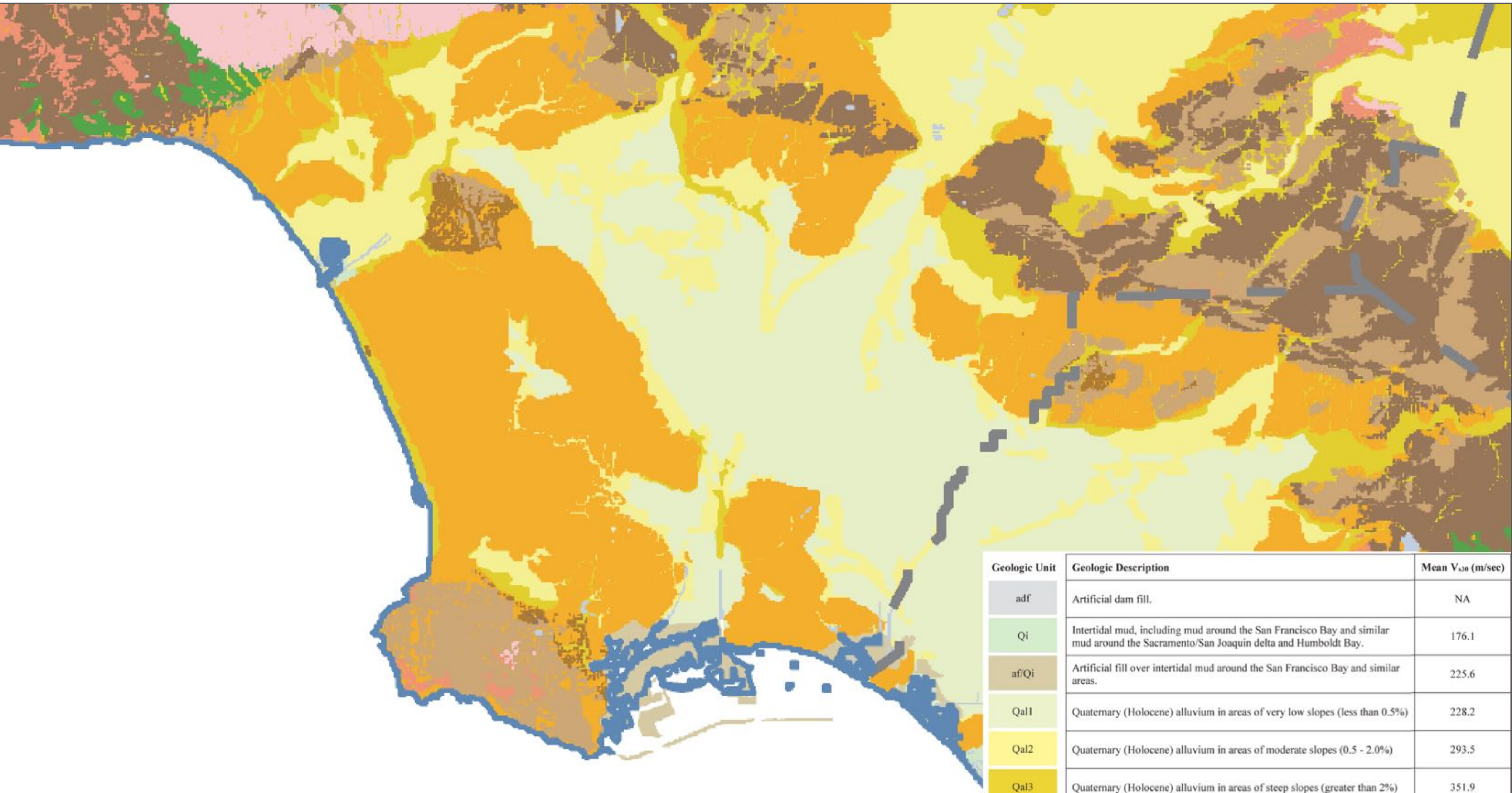
Comparison of NGA-West2 GMMs for PGA, for magnitude 7.0 strike-slip earthquakes and for V_{S30}=760m/sec





ASK = Abrahamson, Silva, and Kamai
BSSA = Boore, Stewart, Seyhan, and Atkinson
CB = Campbell and Bozorgnia
CY = Chiou and Youngs
I = Idriss

Sample V_{S30} / Site Class Map



Geologic Unit	Geologic Description	Mean V_{s30} (m/sec)
adf	Artificial dam fill.	NA
Qi	Intertidal mud, including mud around the San Francisco Bay and similar mud around the Sacramento/San Joaquin delta and Humboldt Bay.	176.1
af/Qi	Artificial fill over intertidal mud around the San Francisco Bay and similar areas.	225.6
Qal1	Quaternary (Holocene) alluvium in areas of very low slopes (less than 0.5%)	228.2
Qal2	Quaternary (Holocene) alluvium in areas of moderate slopes (0.5 - 2.0%)	293.5
Qal3	Quaternary (Holocene) alluvium in areas of steep slopes (greater than 2%)	351.9
Qoa	Quaternary (Pleistocene) alluvium.	386.6
Qs	Quaternary (Pleistocene) sand deposits, including the Merritt Sand in the Oakland area.	307.6
QT	Quaternary to Tertiary (Pleistocene - Pliocene) alluvial deposits, including the Saugus Formation of Southern CA, the Paso Robles Formation of the central Coast Ranges, and the Santa Clara Formation of the San Francisco	444

Wills, Gutierrez, Perez, and Branum, A Next Generation VS30 Map for California Based on Geology and Topography, BSSA, 2015.

Verification of Event Set Conformance to USGS Model

U.S. Geological Survey's National Seismic Hazard Maps are a *de-facto* standard for seismic hazard in the U.S.

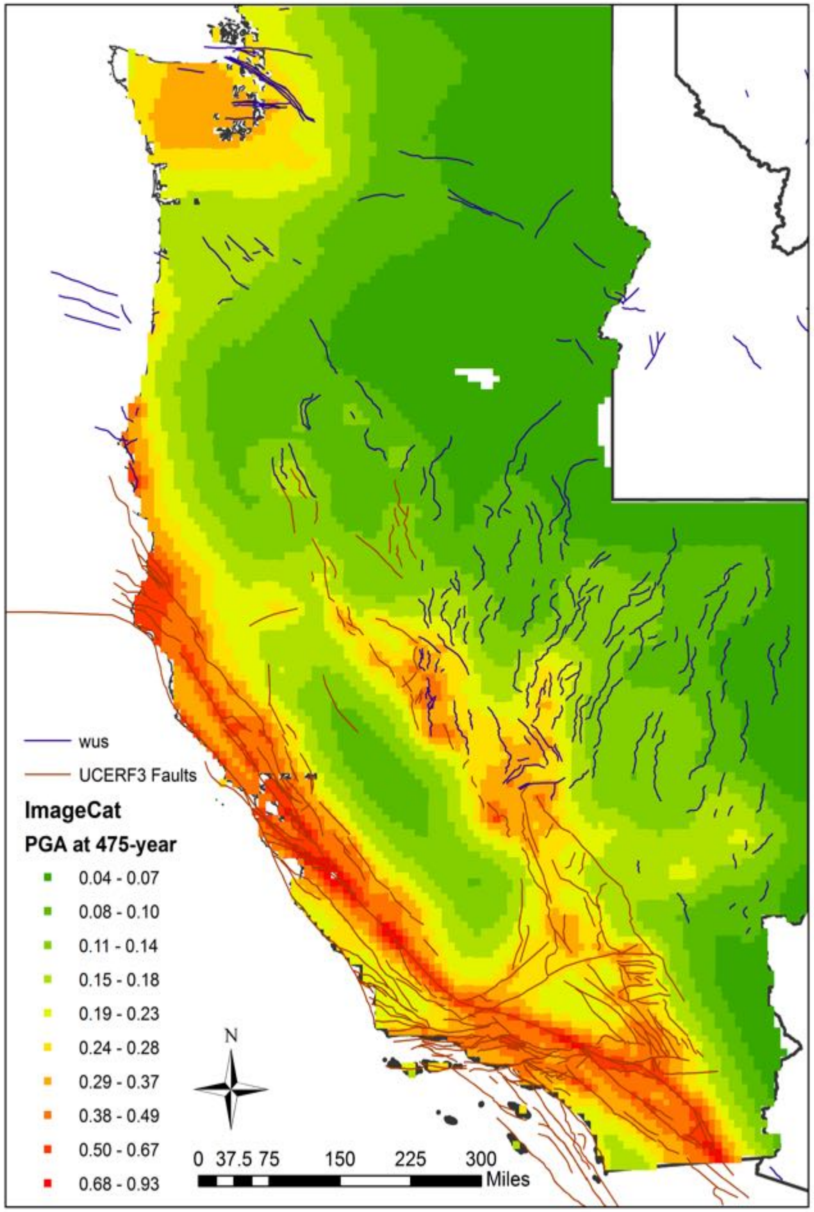
Any catastrophe modeler's event set can be used to construct hazard curves (*Sa* versus return period) to compare with the values published by the USGS. Typical comparisons may be made for *PGA, Ss (Sa @ T*=0.2s) and *S1*. The range of match should be good over the return periods of interest, e.g.72 years < *T* < 1,000 years.

Deviations in modeling from the USGS standard should be explained and justified. *For example, special modeling may be needed to address topographical irregularity, soft soils (Site Class E) or soil failures (Site Class F), basins, directivity or near-fault effects.*

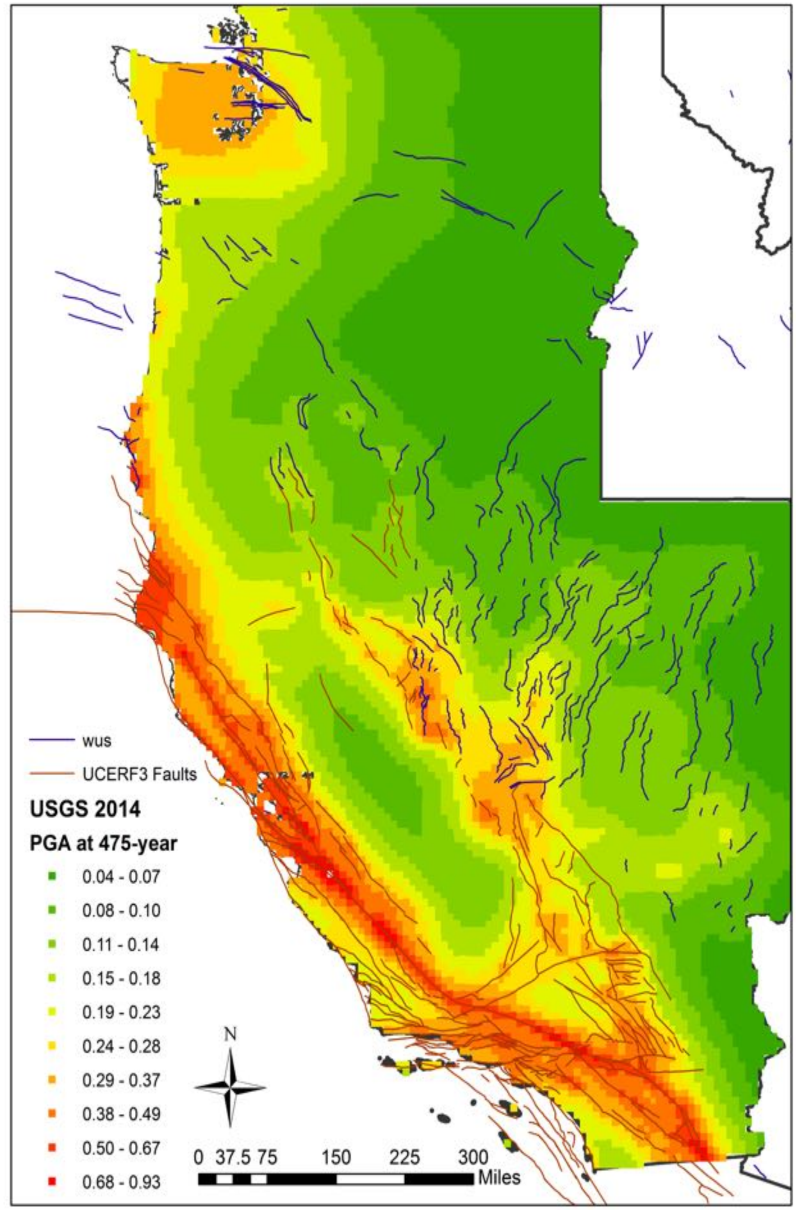
Verification of Event Set

PGA 475-year

ImageCat

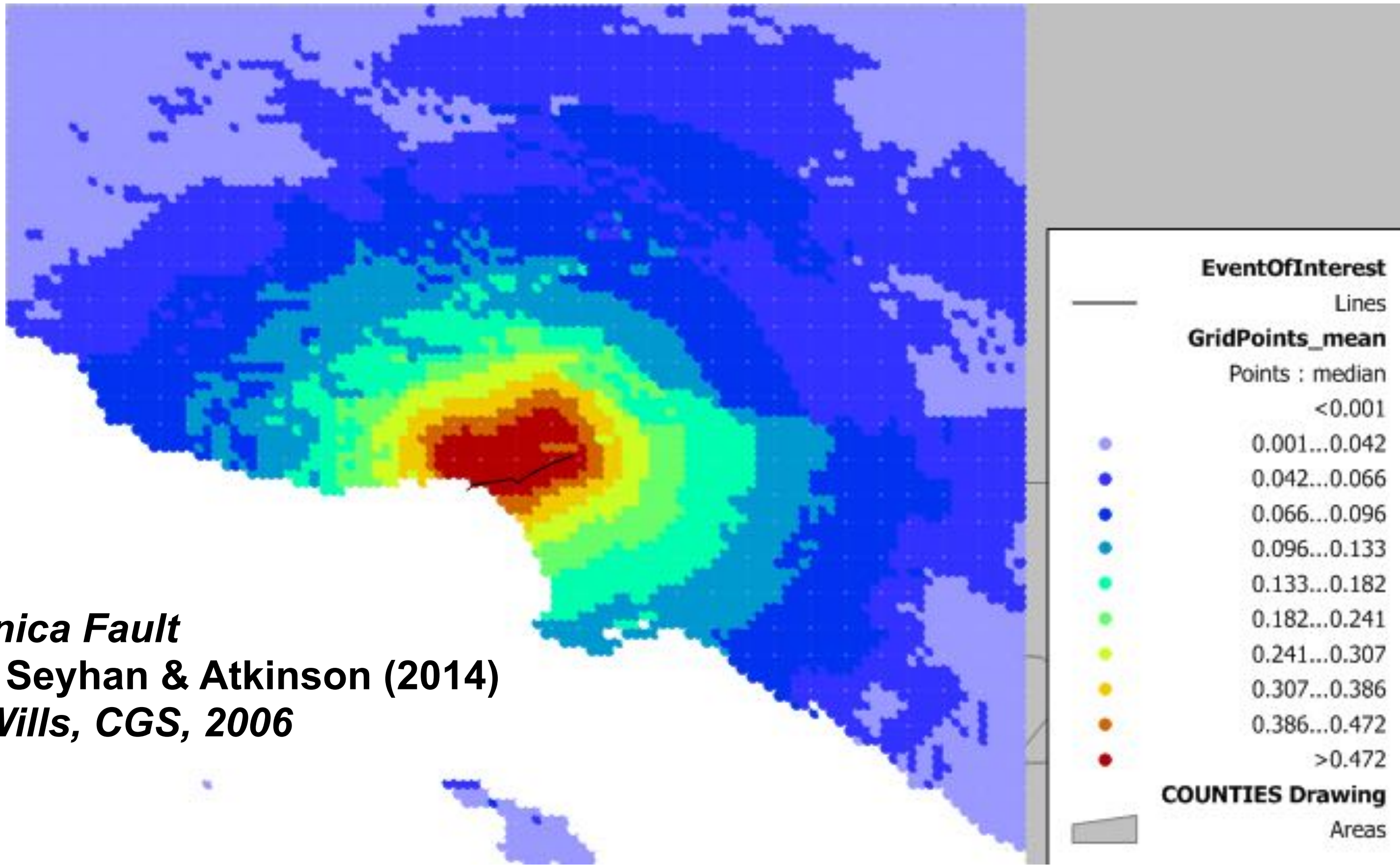


USGS 2014



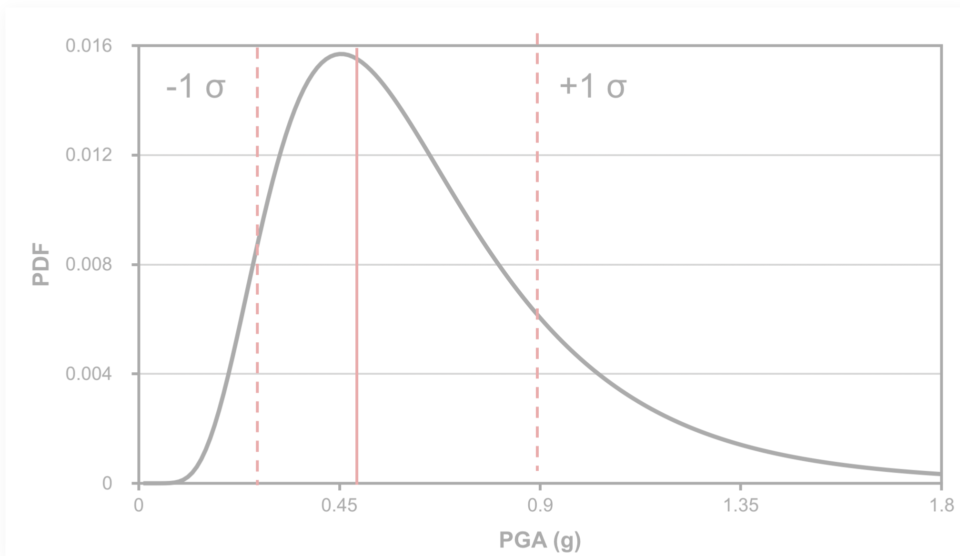
Points to Consider

- The event set is produced by model venders and is <u>not modifiable by users</u>. Particular events and their effects can be examined in more detail.
- Site hazards include shaking effects and liquefaction effects.
- The area affected by maximum shaking is small, and as ***Sa*** diminishes, greater and greater area is affected. As a result, portfolio losses typically include a few highly damaged sites, and many sites with lower damage levels — but these add up.



<u>Sample Event</u>
M6.7, Santa Monica Fault
Boore, Stewart, Seyhan & Atkinson (2014)
Site Class per Wills, CGS, 2006

3. Modeling Uncertainties in Seismic Hazard

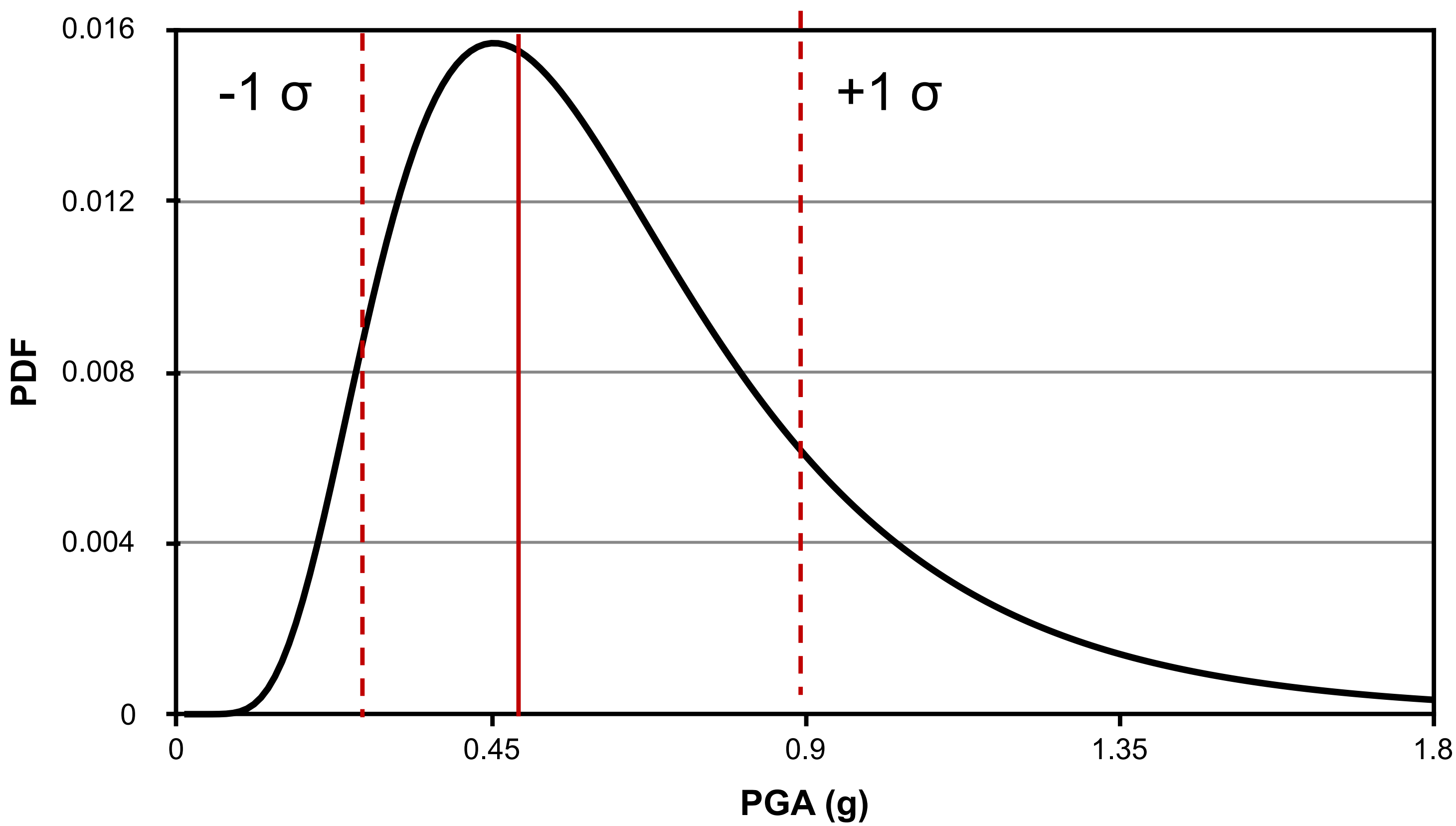


3. Modeling Uncertainties in Seismic Hazard

- Two types of uncertainty
  - **aleatory** uncertainty: “randomness”
    - Model intrinsic randomness - the stochastic nature of the natural phenomena or a response that is not being addressed by the model in question but is instead represented stochastically
    - The Law of Large Numbers and Central Limit Theorem impact aggregation
    - Easier to quantify and manage
  - **epistemic** or scientific uncertainty (choice of model)
    - Accounts for lack of knowledge
    - Has systematic effects on risk
    - More difficult to quantify and manage.
    - Typically addressed using multiple models with a logic tree

Uncertainty in Ground Motion Models (GMMs) Lognormal Distribution

M6.7, R_{jb} = 0, Vs30 = 256 m/s (Site Class D)
PGA_{median} = 0.5g, σ = 0.58 [BSSA, 2014]



Uncertainty in GMMs – Between- and within-event variability

- Random terms in empirical ground motion models –

$$\ln(y) = f(m,r) + \eta + \varepsilon$$

y : ground motion parameter such as *PGA, PGV, SA*, etc.

***η* : between-event** (also called inter-event) term *(std: σ)*

– Earthquake-to-earthquake, e.g., randomness in source process, stress drop, etc.

***ε* : within-event** (also called intra-event) term *(std: τ)*

– Site-to-site within an event, e.g., directivity, wave propagation path, local site effect, etc.

- Assuming independence of two terms, combined (total) variability (std) :

$$\tilde{\sigma} = \sqrt{\tau^2 + \sigma^2}$$

Model Spatial Correlation of Shaking Intensity for Portfolio Losses

- Spatial correlation of shaking intensities due to location proximity (geographical clustering) affects intra-event term
- Correlation coefficient ($\tilde{\rho}$) is represented through two uncertainty terms (Park et. al, 2007) -

$$\tilde{\boldsymbol{\rho}}(\boldsymbol{T},\boldsymbol{h}) = \frac{\boldsymbol{\tau}^2 + \boldsymbol{\sigma}^2\boldsymbol{\rho}(\boldsymbol{T},\boldsymbol{h})}{\tilde{\boldsymbol{\sigma}}^2}$$

ρ(T, h) = correlation coefficient of ground shaking within event

h = distance between two locations

T = building period

Distance- and Period-Dependent Spatial Correlation of Intra-event Variability of Sa

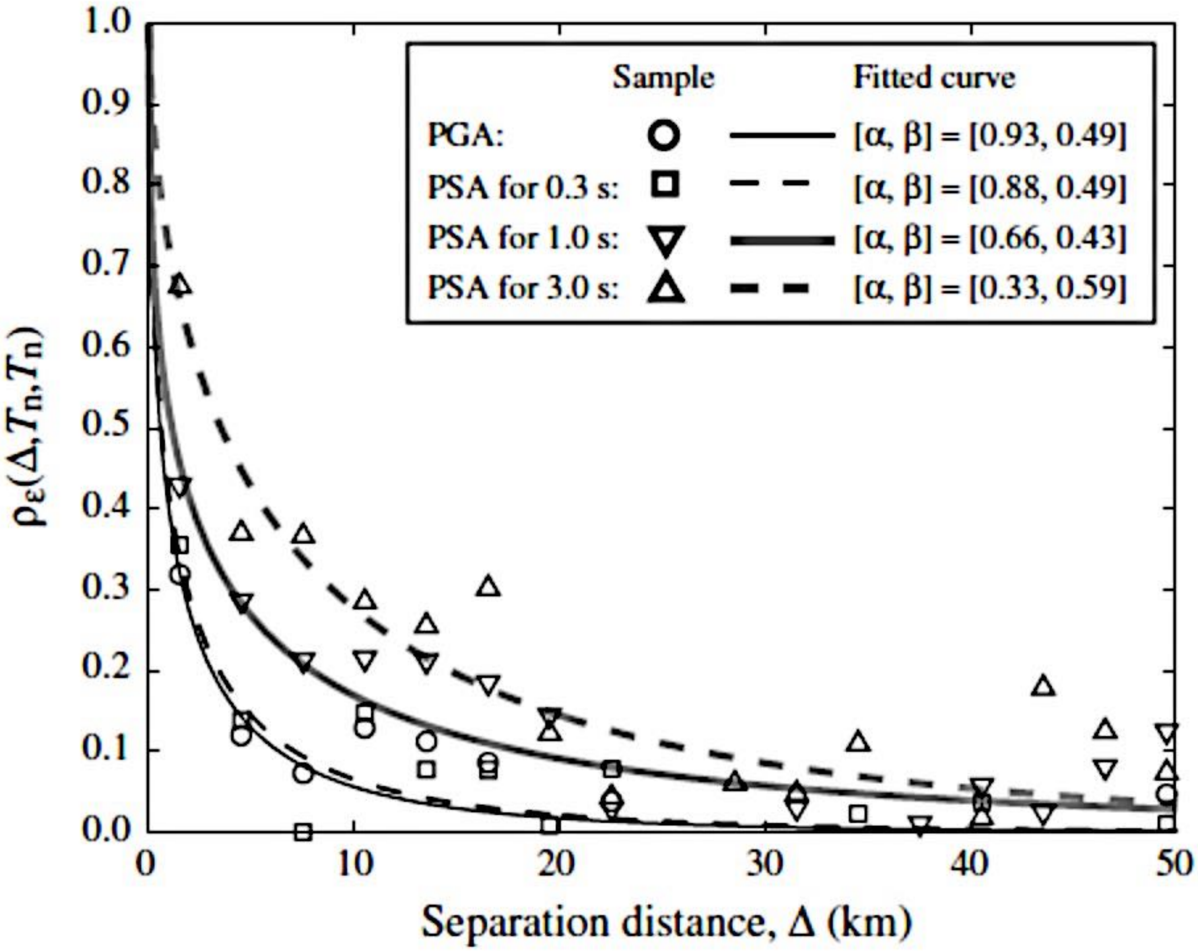
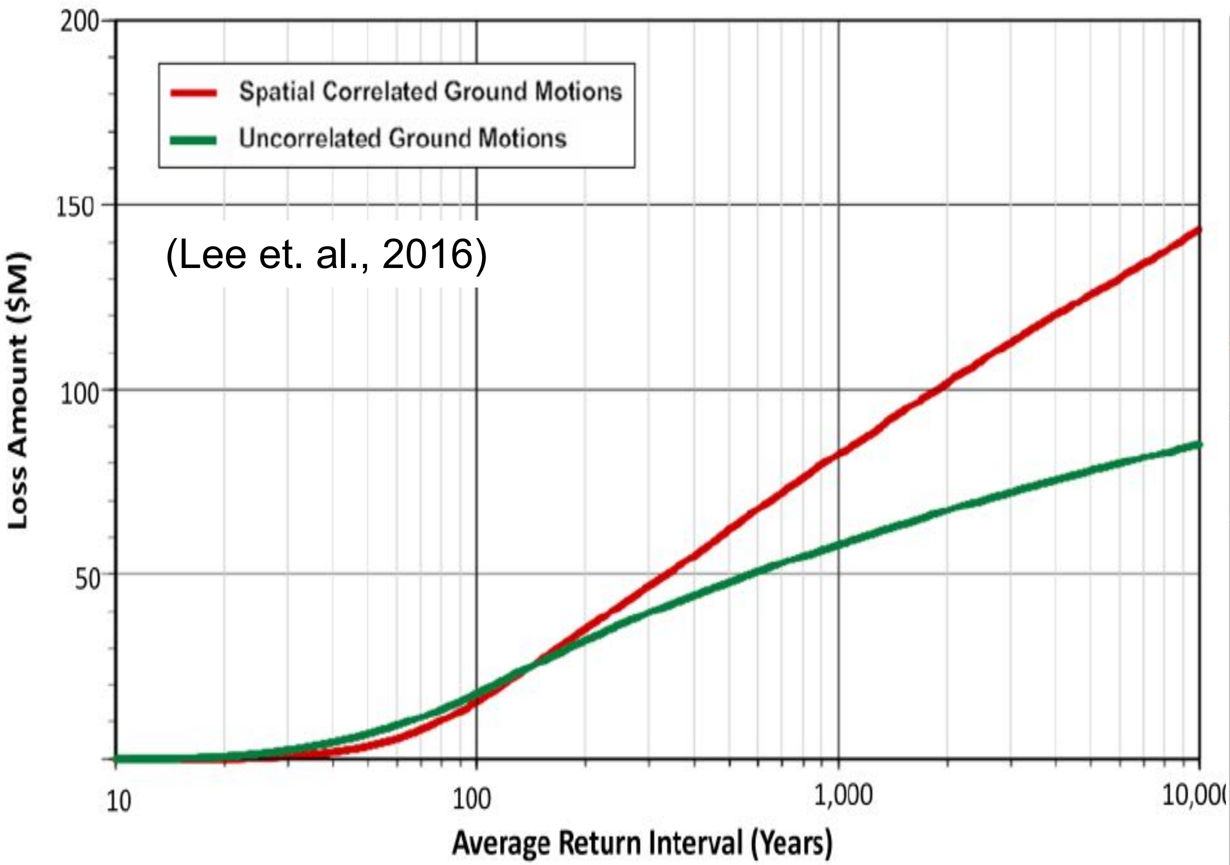
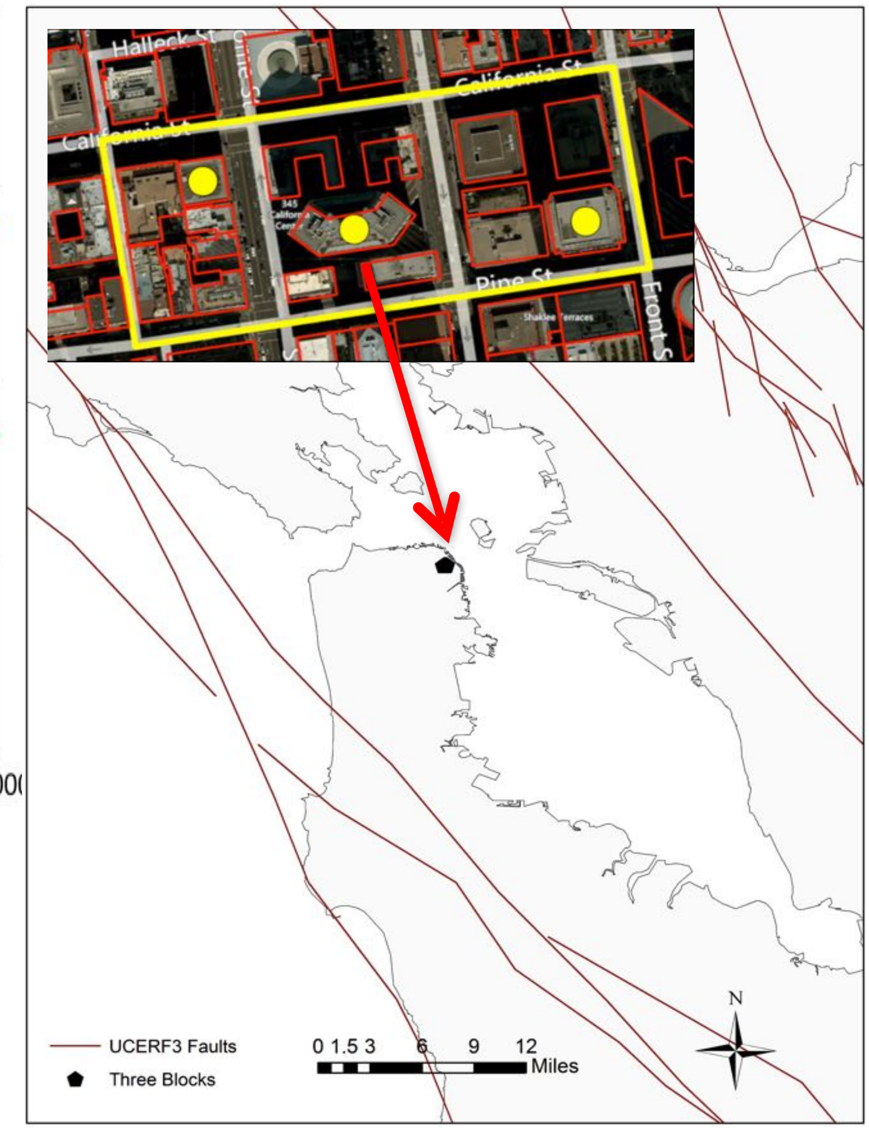


Figure 1. Estimated spatial intraevent correlation $\rho_\varepsilon(\Delta, T_n, T_n)$ of the PGAs and PSAs for T_n equal to 0.3, 1.0, and 3.0 sec using the California records.

(Goda and Hong, 2008)

Portfolio Losses With and Without Considering Spatial Correlation of Shaking Intensity





<u>**Example:**</u> **3-blocks of 18 steel and concrete buildings in San Francisco, from 3 to 48 stories**

4. Loss Estimation in Buildings

Types of Damage Relationships

We can distinguish three types of damage relationships:

- **Expert-based damage functions**, as exemplified by ATC-13 [Applied Technology Council, 1985]; [Wiggins, 1987]; [Steinbrugge, 1982, 1990, etc.]

- **Statistical and actuarially-based damage relationships** – such as the study of wood-framed dwellings from Northridge Earthquake damage claims [Wesson et al, EERI Earthquake Spectra Journal, 2004]

- **Engineering damage models** – these are largely physics-based, with heuristic elements. HAZUS-MH is an example.

Adequate statistics upon which to create actuarially sound damage relationships are rare. Fortunately, expert-based empirical models and engineering damage models can be used when good statistical data is not available.

Each type of model has its own area of competency.

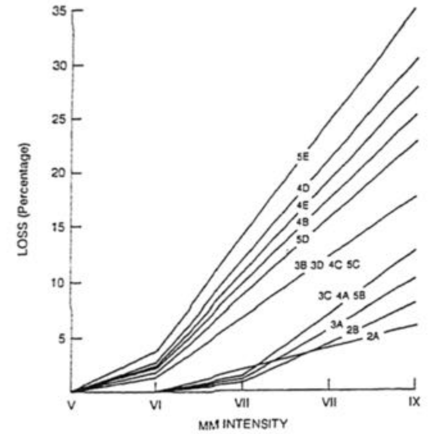
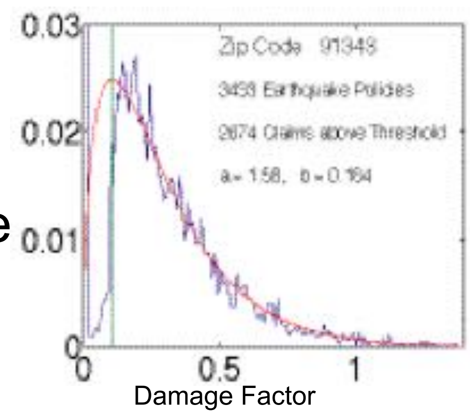


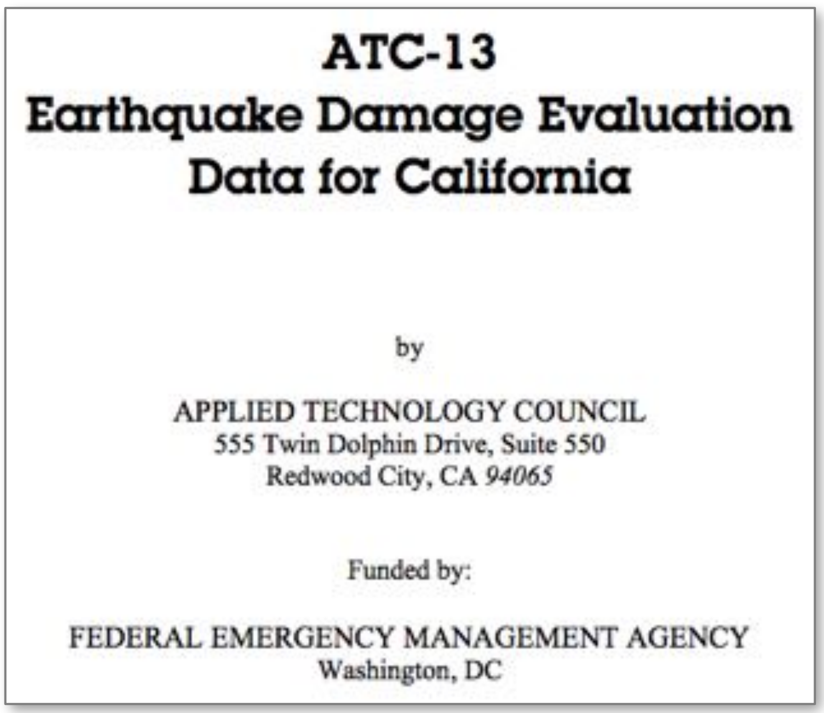
Figure 1. Mean damage ratio versus Modified Mercalli Intensity for different construction classes (from Algermissen and Steinbrugge, 1984)



Wesson et al, Spectra, 2004

Expert-based Damage Relationships
ATC-13 (1985)

- 40 California building types
- Engineering-related classes
- Consensus expert opinion (from Engineers)

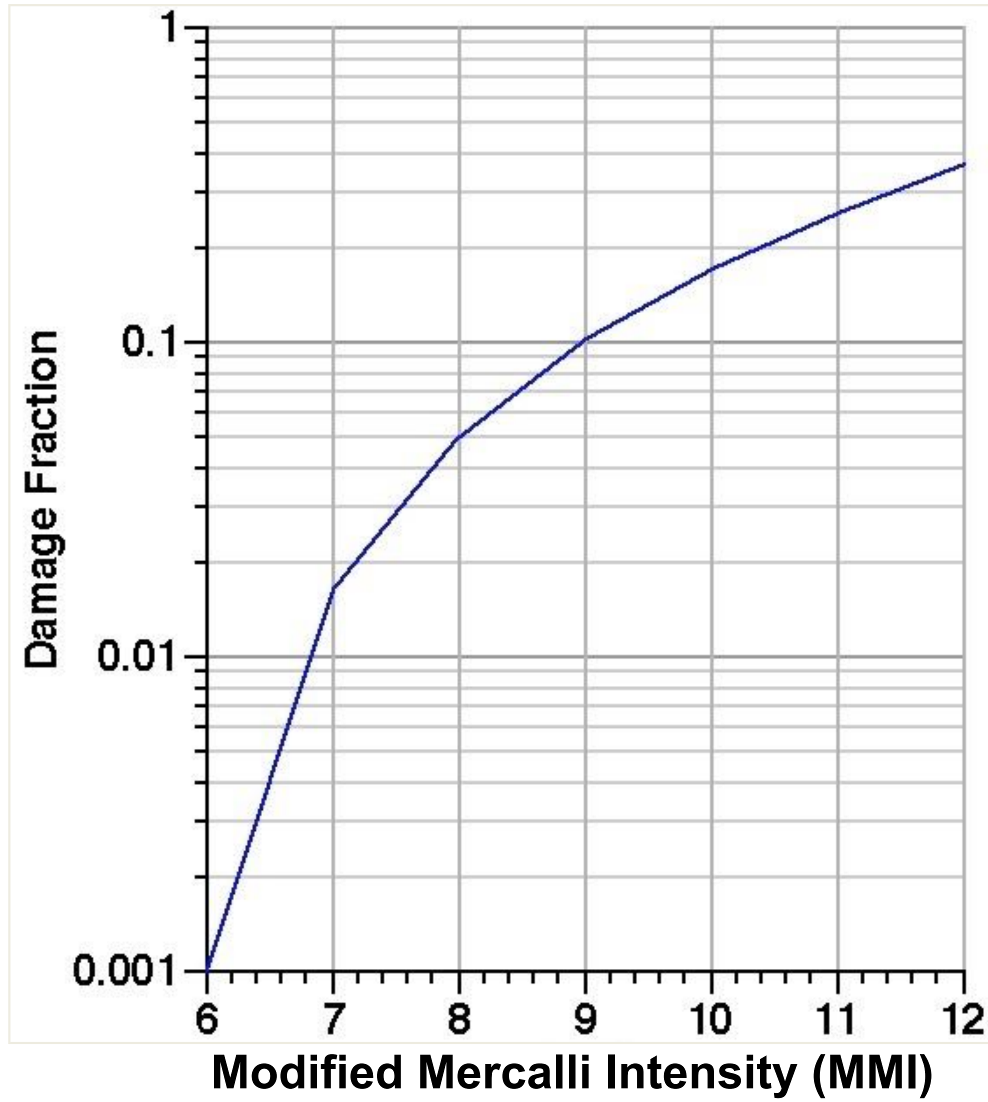

ATC-13
Earthquake Damage Evaluation Data for California

by

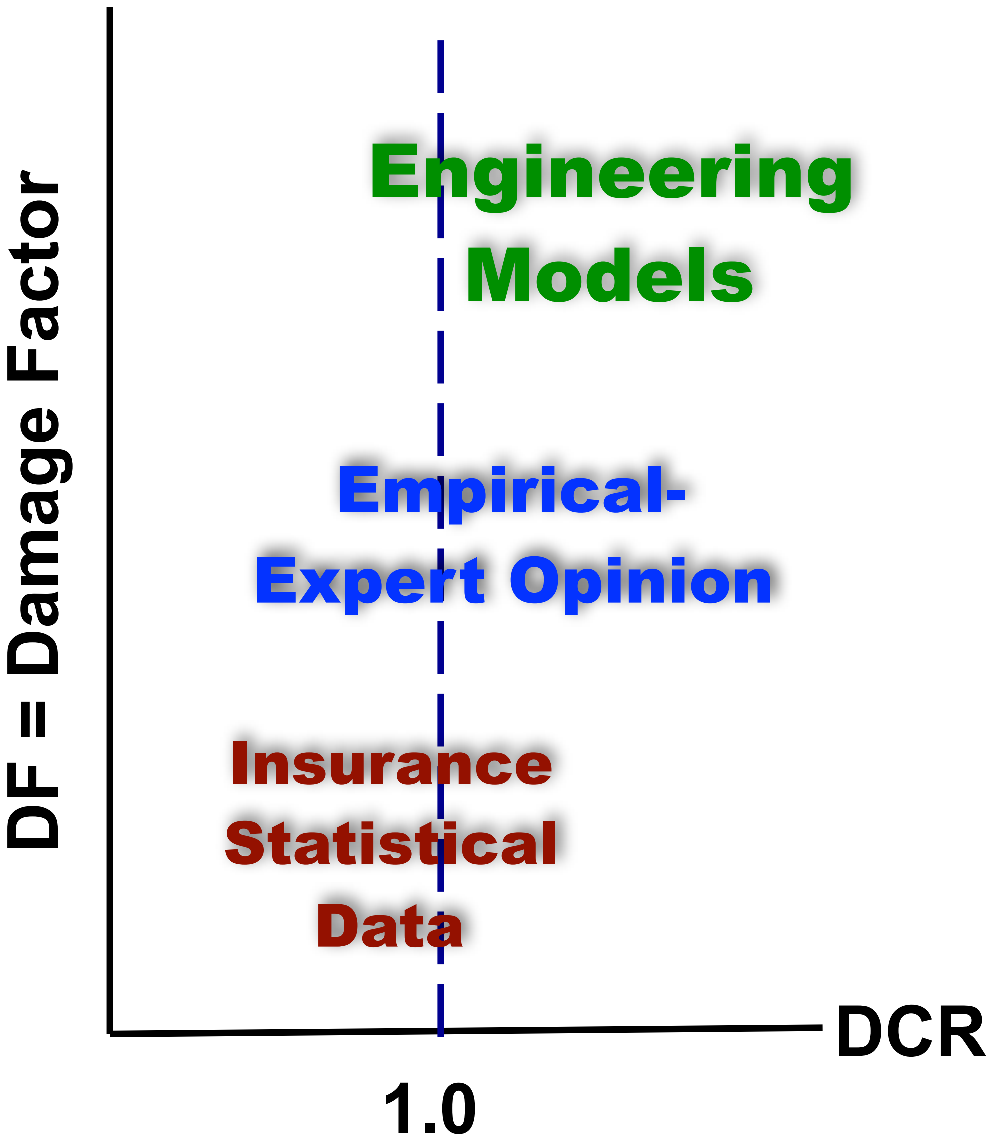
APPLIED TECHNOLOGY COUNCIL
555 Twin Dolphin Drive, Suite 550
Redwood City, CA 94065

Funded by:

FEDERAL EMERGENCY MANAGEMENT AGENCY
Washington, DC



Code-Oriented Damage Assessment (CODA)
[Graf & Lee, EERI Spectra Journal, 2009]



DCR = Demand-to-Capacity Ratio

Demand = $Sa_{actual}(T)$ for earthquake

Capacity = $Sa_{code}(T)$ for "design event"

Capacity = R x Cs

Sa = Spectral Acceleration at period T

T = Fundamental period for building

R = Response Modification Factor (ASCE)

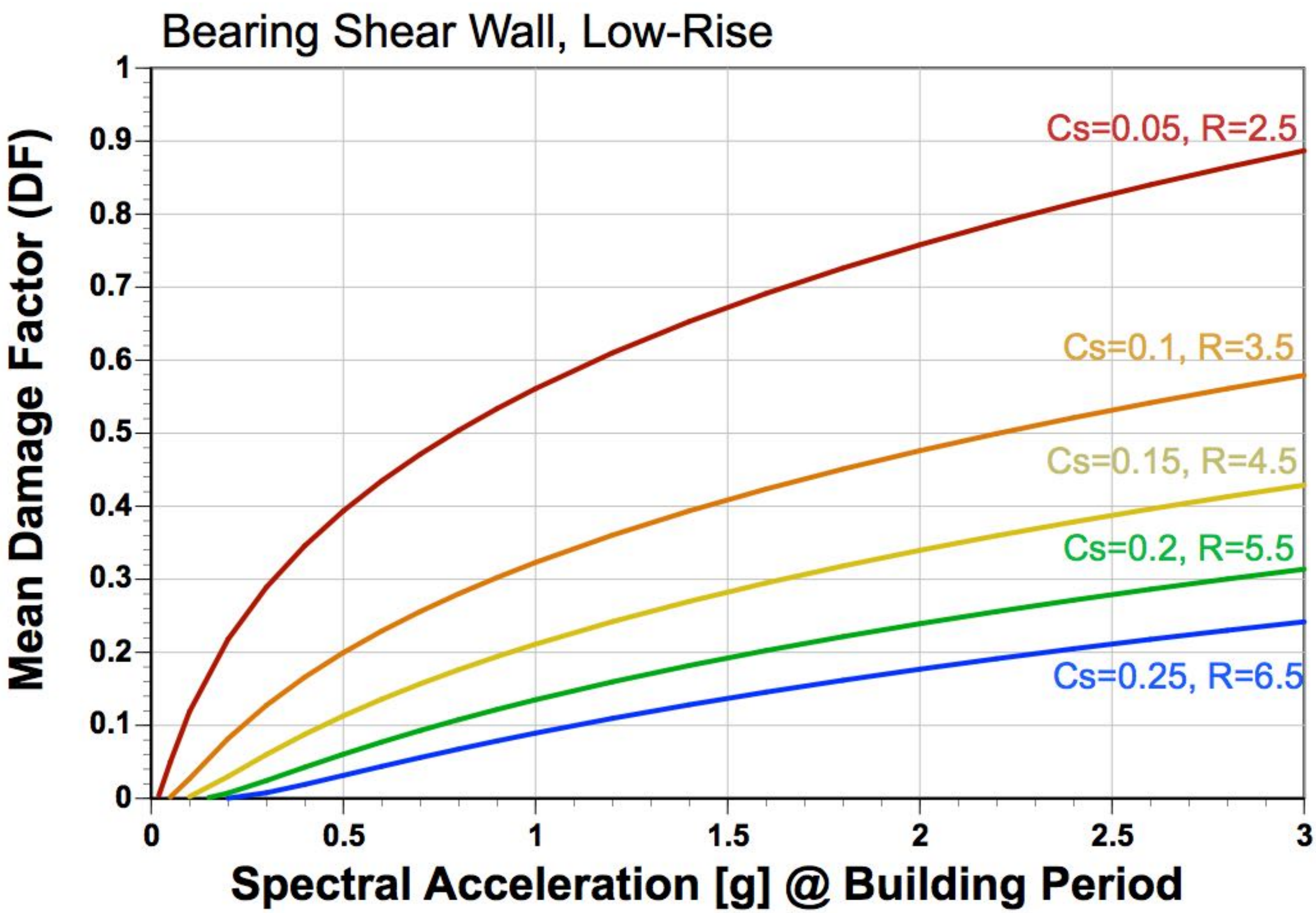
Cs = Design Base Shear = Sa_{code} / R

DCR = 1.0 for "Design Event"

DF = Damage Factor

$$DF = \frac{\text{Repair Cost}}{\text{Replacement Value}}$$

Code-Oriented Damage Assessment for Buildings (CODA) *[Graf & Lee, 2009]*



HAZUS-MH ®

- Developed by C. Kircher et al., through NIBS, for FEMA
- Vulnerability varies by model building type, height and Seismic Design Level
- Adjust value allocation (STR, NSD, NSA)
- Adjust capacity parameters (period Te, strength Cs)
- Adjust fragility parameters (STR, NSD, NSA)
- Outputs – expected damage (SEL), downtime and probability of collapse

STR: Structural Drift-Sensitive

NDS: Nonstructural Drift-Sensitive

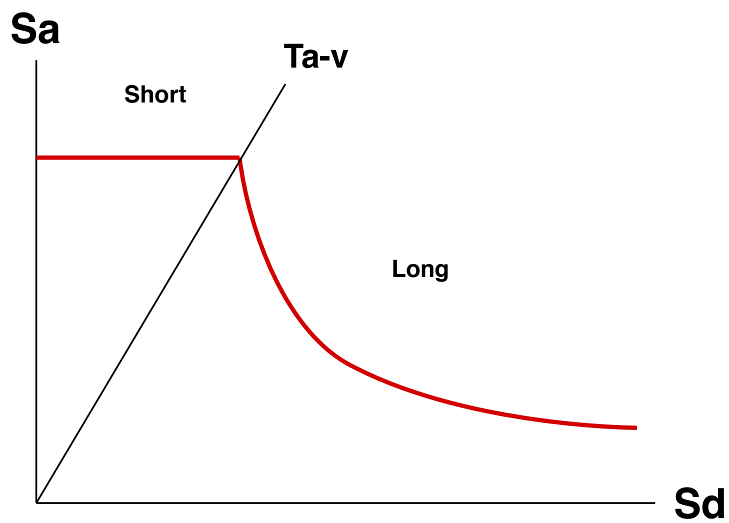
Cladding and Partition Failures

NSA: Nonstructural Acceleration-Sensitive

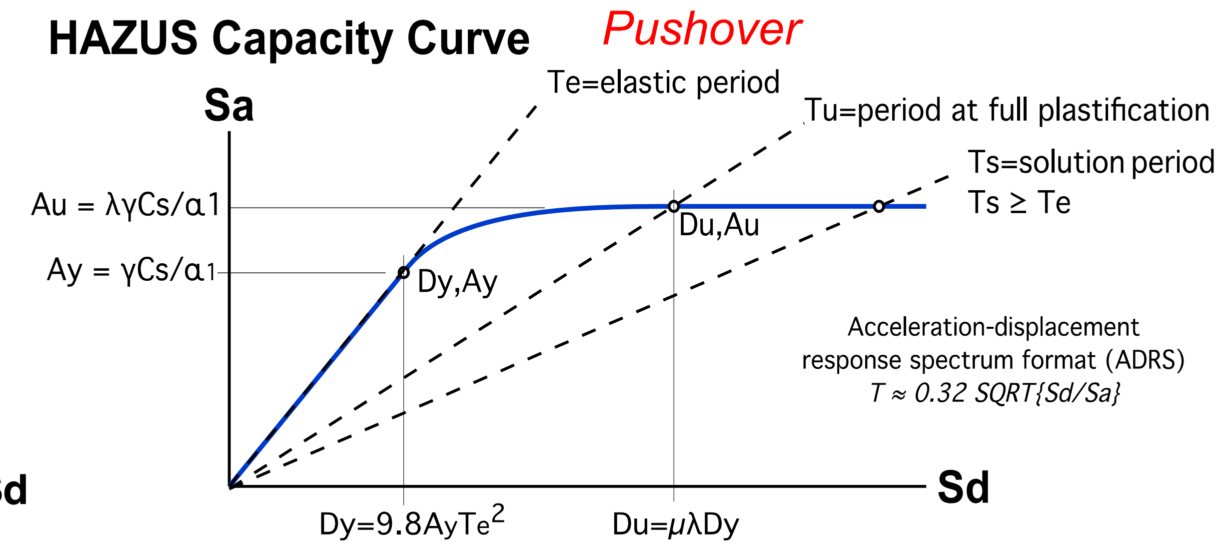
Ceilings, Equipment, Contents

HAZUS Models

Provide an engineering-based alternative to statistical / empirical models

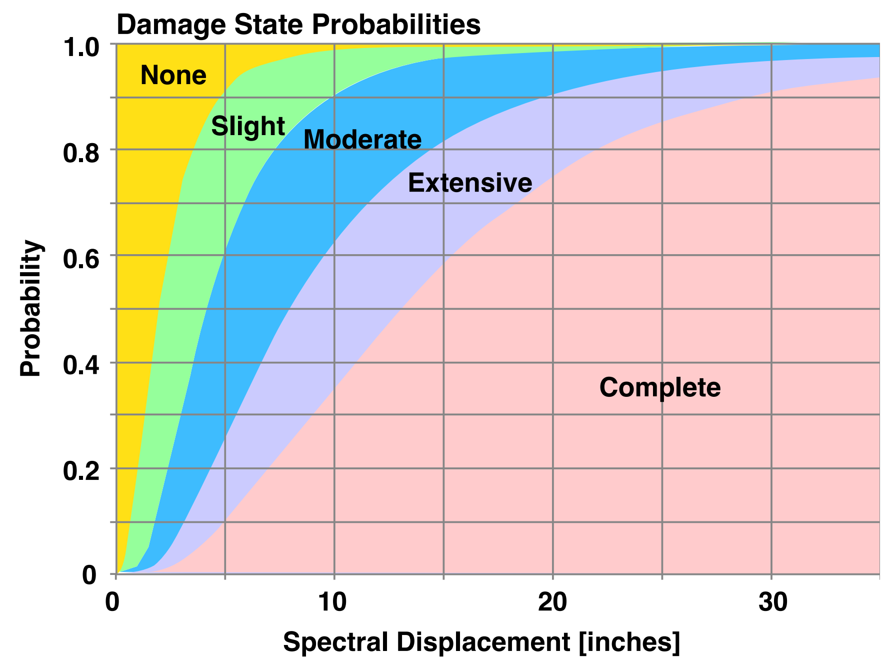


HAZUS Demand Curve

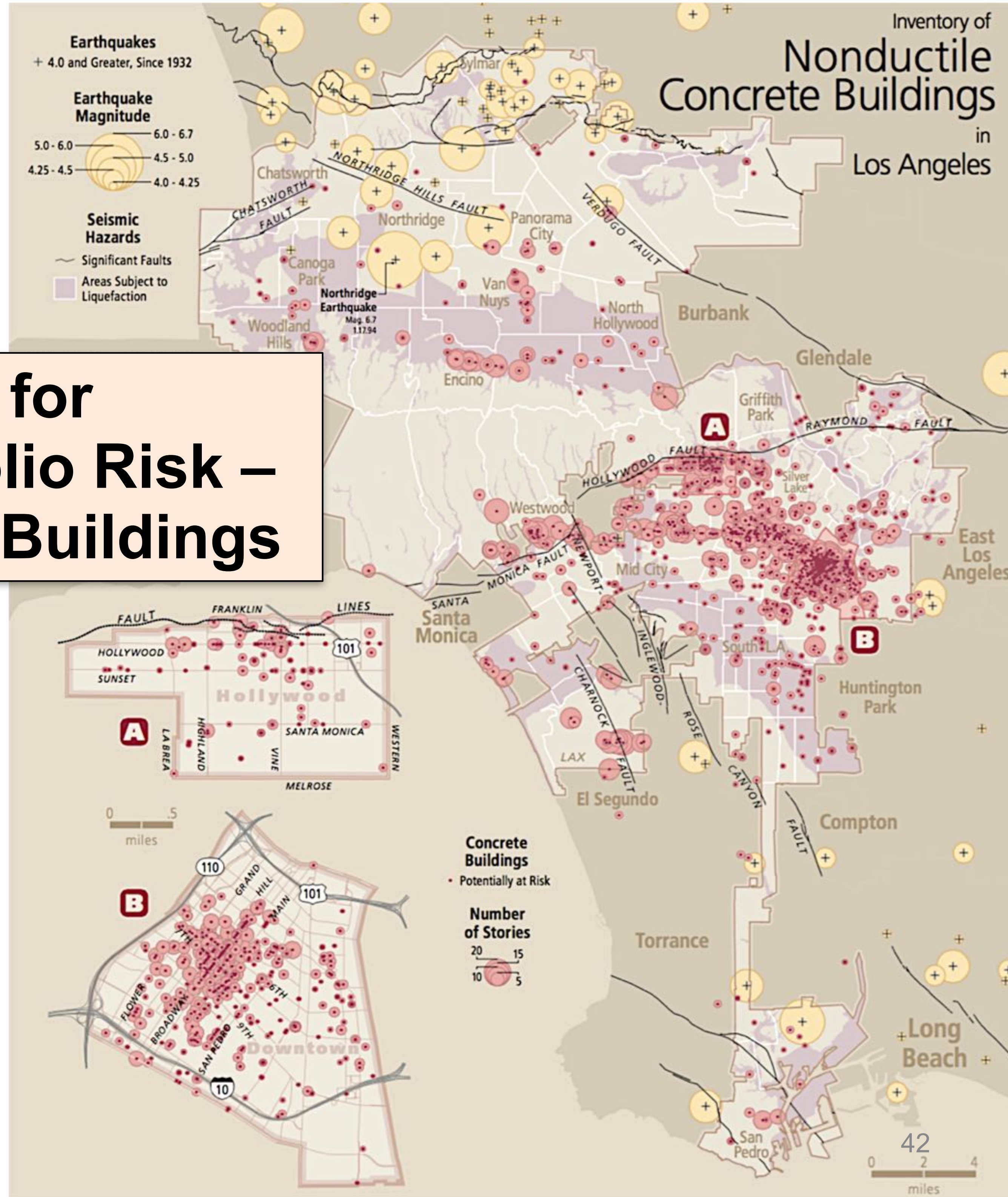


Nonlinear SDOF model for drift and floor accelerations

Fragility model for drift-sensitive and acceleration-sensitive components

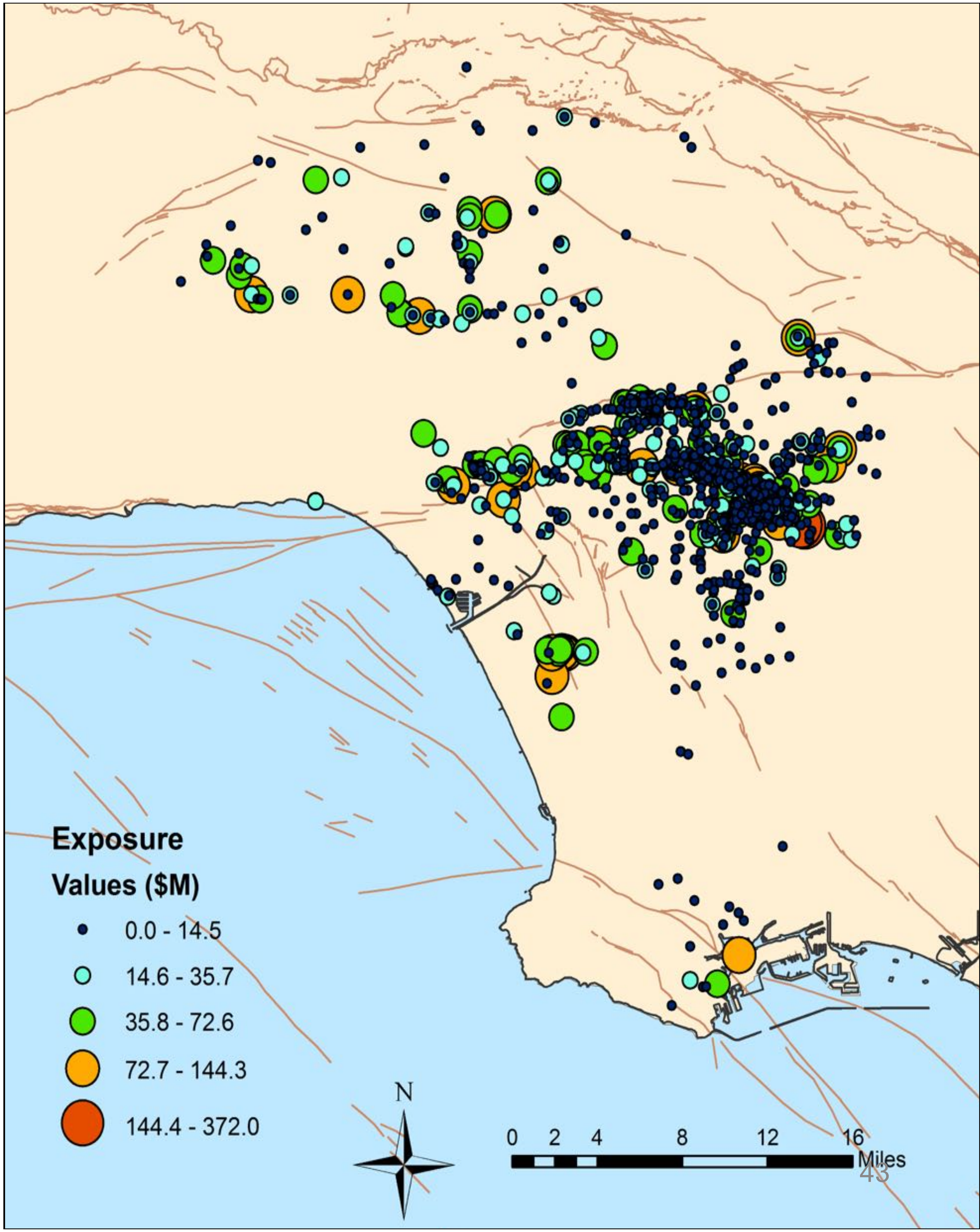


Example of HAZUS for Probabilistic Portfolio Risk – Concrete Coalition Buildings



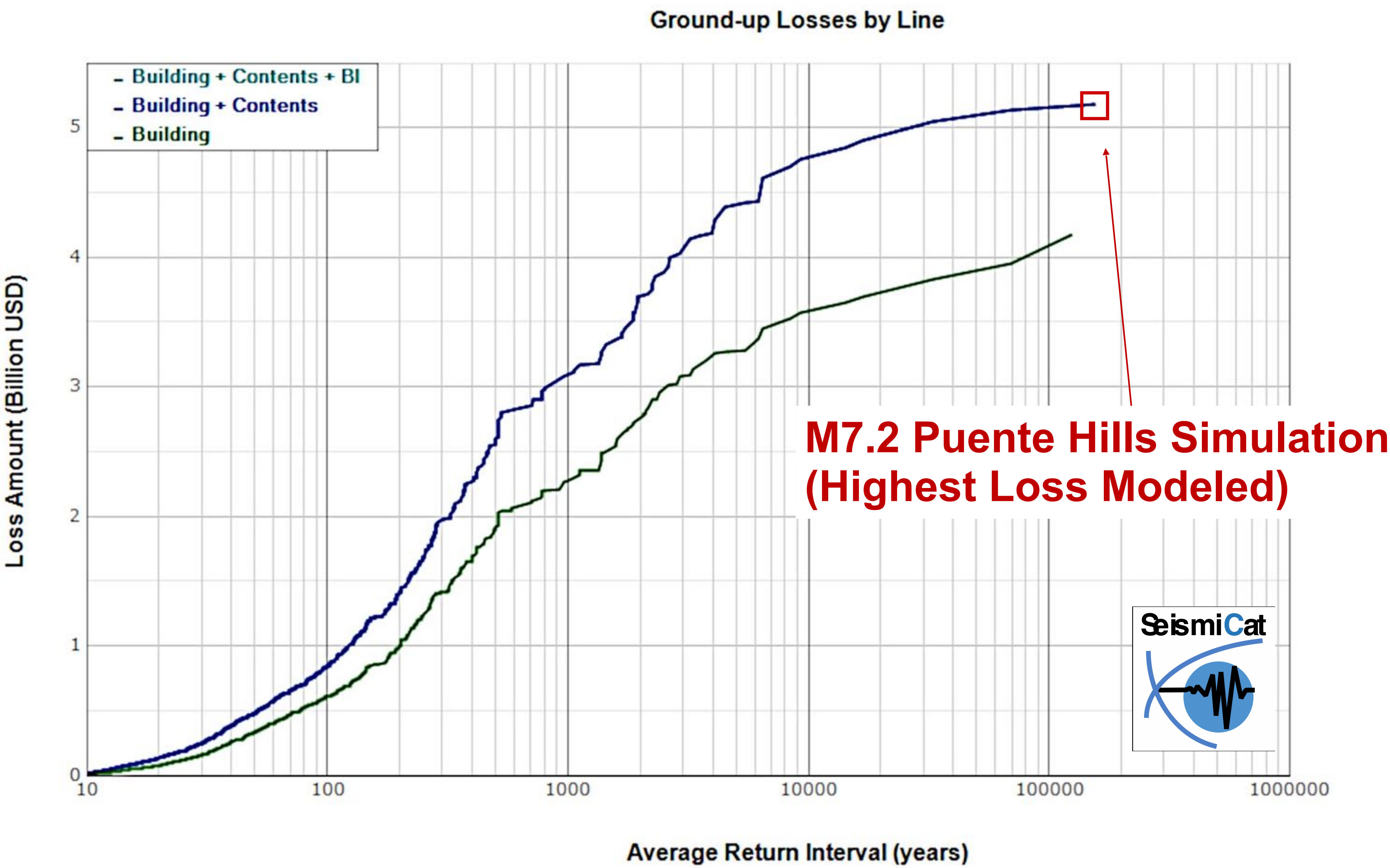
Site Locations and Fault Map

Inventory from Prof. T. Anagnos Concrete Coalition -- 1454 Buildings



SeismiCat

Expected Loss by Line of Coverage



HAZUS Limitations

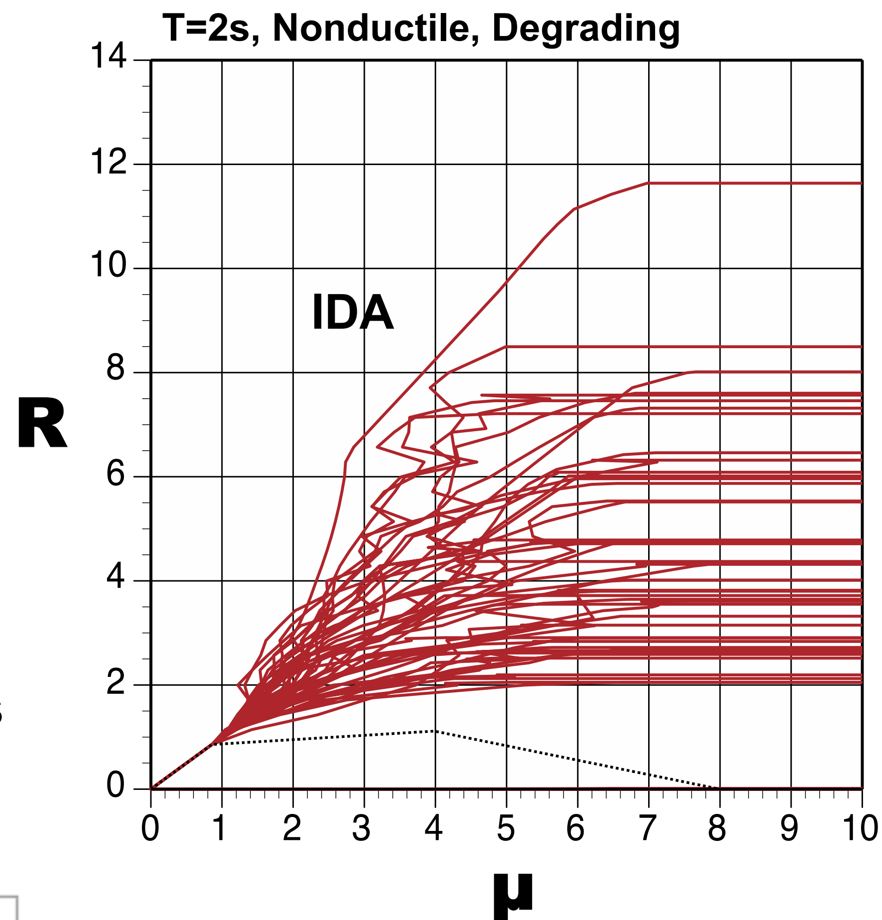
- Comes from FEMA as a part of a GIS system
- Computes expected losses only (no loss distribution)
- Computes portfolio losses for individual scenarios (e.g., ShakeOut)
- β-values need adjustment for ground motion and building performance uncertainties

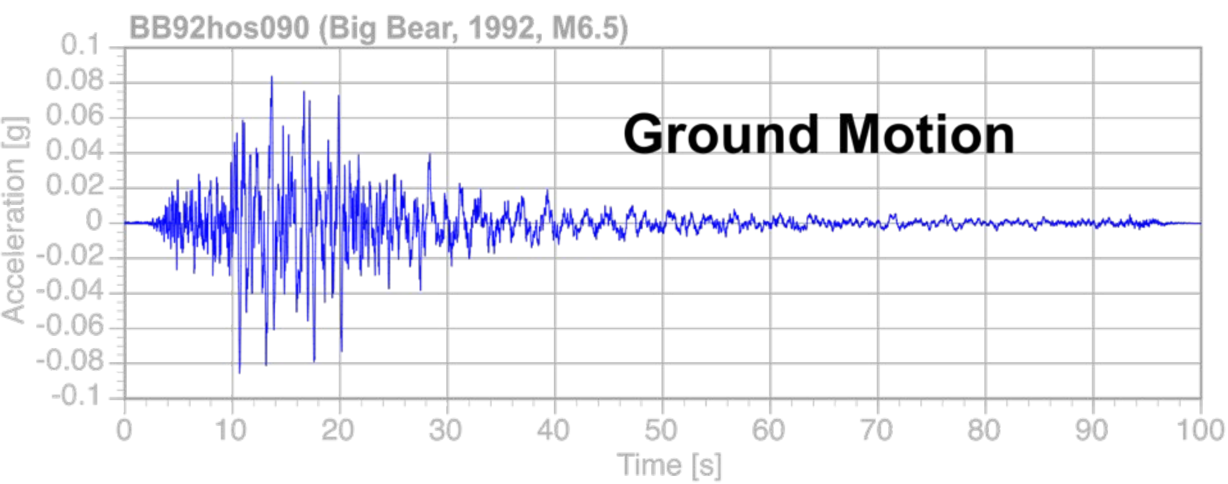
➢ **HAZUS models can be adapted for use in probabilistic analysis and insurance applications**

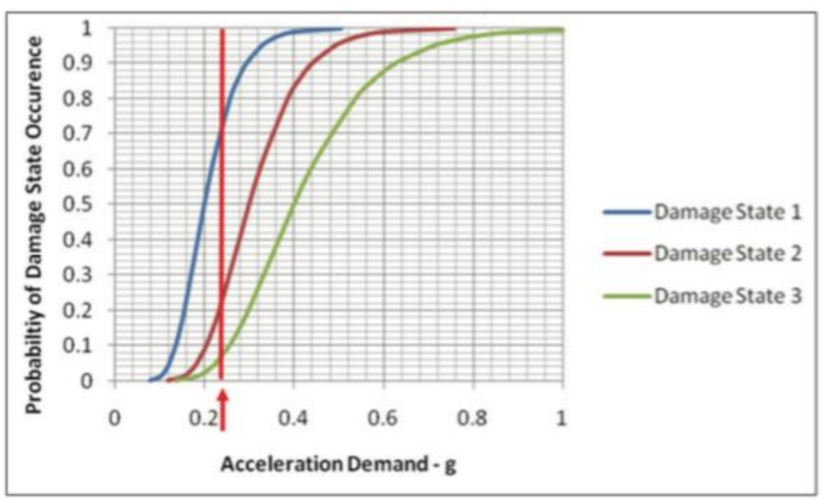
FEMA P-58

Not applicable to Portfolio Seismic Risk

- Models use nonlinear dynamic procedure, rather than (Sa, Mw) as ground motion input
- Models require many times the computational effort as empirical damage models or HAZUS
- Models require much more building-specific information – OK for new construction, but this is a challenge for existing construction



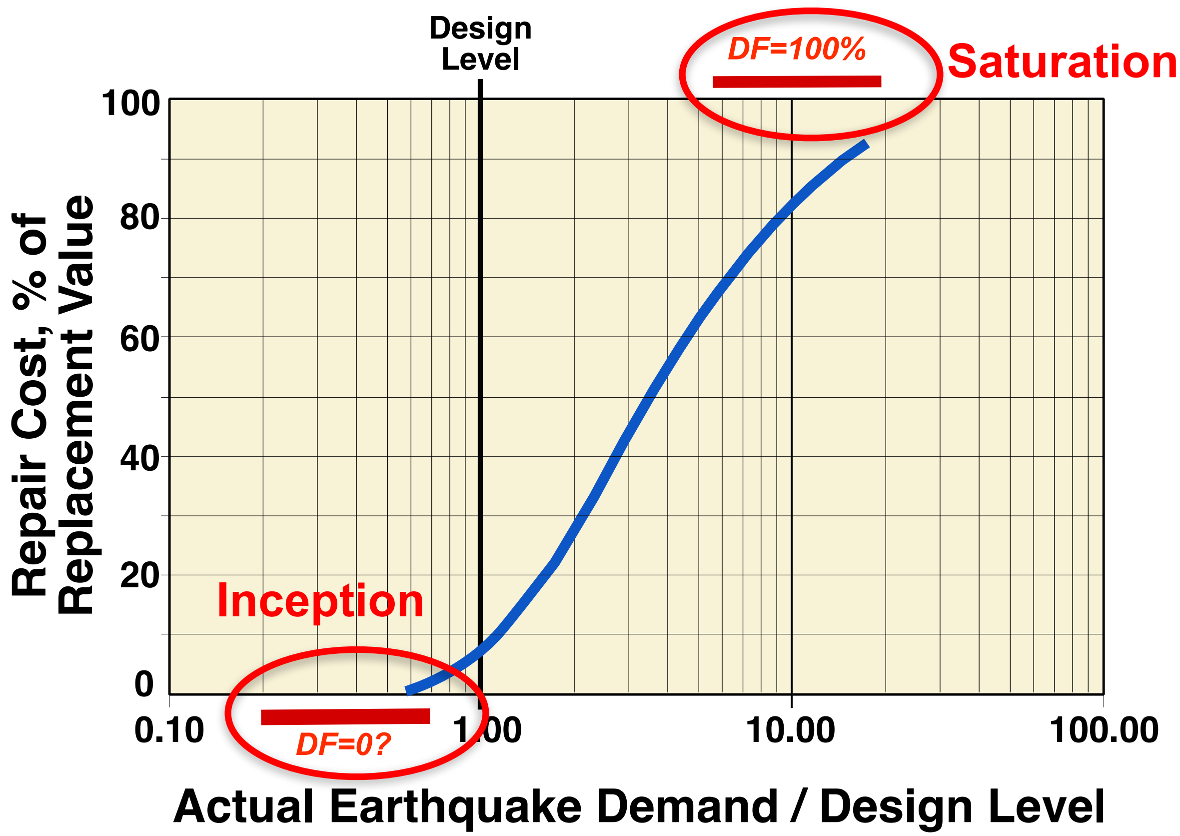




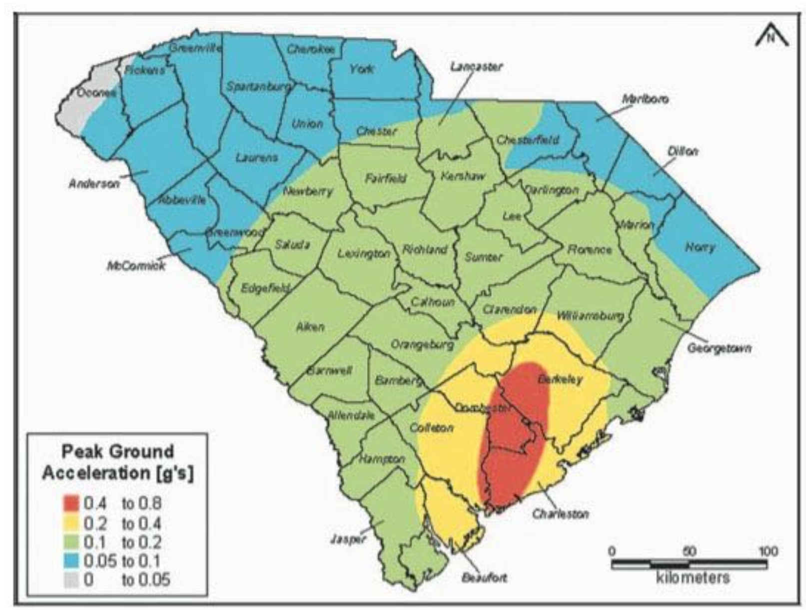
Damage Inception and Saturation

Damage inception is important in estimates of Average Annual Loss and hence earthquake premiums. Damage inception is also important in setting quake deductible.

Damage saturation is important for damage estimates for areas with large faults and with many existing buildings not designed for earthquakes (Memphis, Charleston, Port-au-Prince, …). Damage saturation is important in setting limit.



Charleston M7.3 1886



PGA map of the M 7.3 earthquake scenario

Damage Relationships

Published Relationships:

ATC-13 (1985)
HAZUS-MH
Code-Oriented Damage Assessment [Graf & Lee, 2009]
Wesson et al., Northridge Dwellings, 2004
Steinbrugge
Thiel & Zsutty

Proprietary Relationships:

AIR WORLDWIDE
RMS
CoreLogic
AON Empower Results
Impact Forecasting
Aon Benfield Analytics

4. Loss Estimation for Buildings

Damage Relationships in Insurance Cat Models

Damage relationships in insurance catastrophe models (RMS, AIR Worldwide, CoreLogic, Impact Forecasting) are proprietary, and not directly inspectable. There is at present no direct way to calibrate damage models to the results of engineering studies (PMLs or other studies).

Engineering Damage Relationships

Damage models that make direct use of engineering parameters (e.g., HAZUS, CODA, etc.) and that allow direct inspection of damage relationships make it possible to calibrate to the results of engineering studies (PMLs or other).

Estimating Consequences – *"Death, Damage and Downtime"*

Loss ($) = Damage Factor x Replacement Value

- Values-at-risk for structures, equipment, contents
- Loss rates for time-element losses (e.g., monthly rents)
- Consequences to occupants and surrounding populations (injury, death)

Errors in exposure values translate directly into errors in losses ($).

4. Loss Estimation for Buildings

Commercial catastrophe models used by insurance brokers and insurers typically use occupancy-based damage relationships. These are ambiguous as to the structural framing system, and so have higher uncertainty in damage.

Occupancy

Permanent Dwelling
Retail Trade
Wholesale Trade
Personal and Repair Services
Professional, Technical, and Business Services
Health Care Services
Entertainment and Recreation
Parking
Heavy Fabrication and Assembly
Light Fabrication and Assembly
Food and Drugs Processing
High Technology
Agriculture
Mining
Religion and Non-profit
General Services
Emergency Response Services

Structural Class

Wood-framed residence
Wood-framed commercial
Steel moment frame
Steel braced frame
Light metal
Concrete shear wall
Concrete moment frame
Masonry shear wall
Precast concrete tilt-up
Unreinforced masonry
Mobile home

Other known attributes:

Location and age (design code)
Number of stories

4. Loss Estimation for Buildings

Commercial catastrophe models also accommodate direct assignment of structural class, reducing uncertainty in damage prediction. Beyond that, secondary modifiers may help refine damage prediction:

Structural Class

Wood-framed residence
Wood-framed commercial
Steel moment frame
Steel braced frame
Light metal
Concrete shear wall
Concrete moment frame
Masonry shear wall
Precast concrete tilt-up
Unreinforced masonry
Mobile home

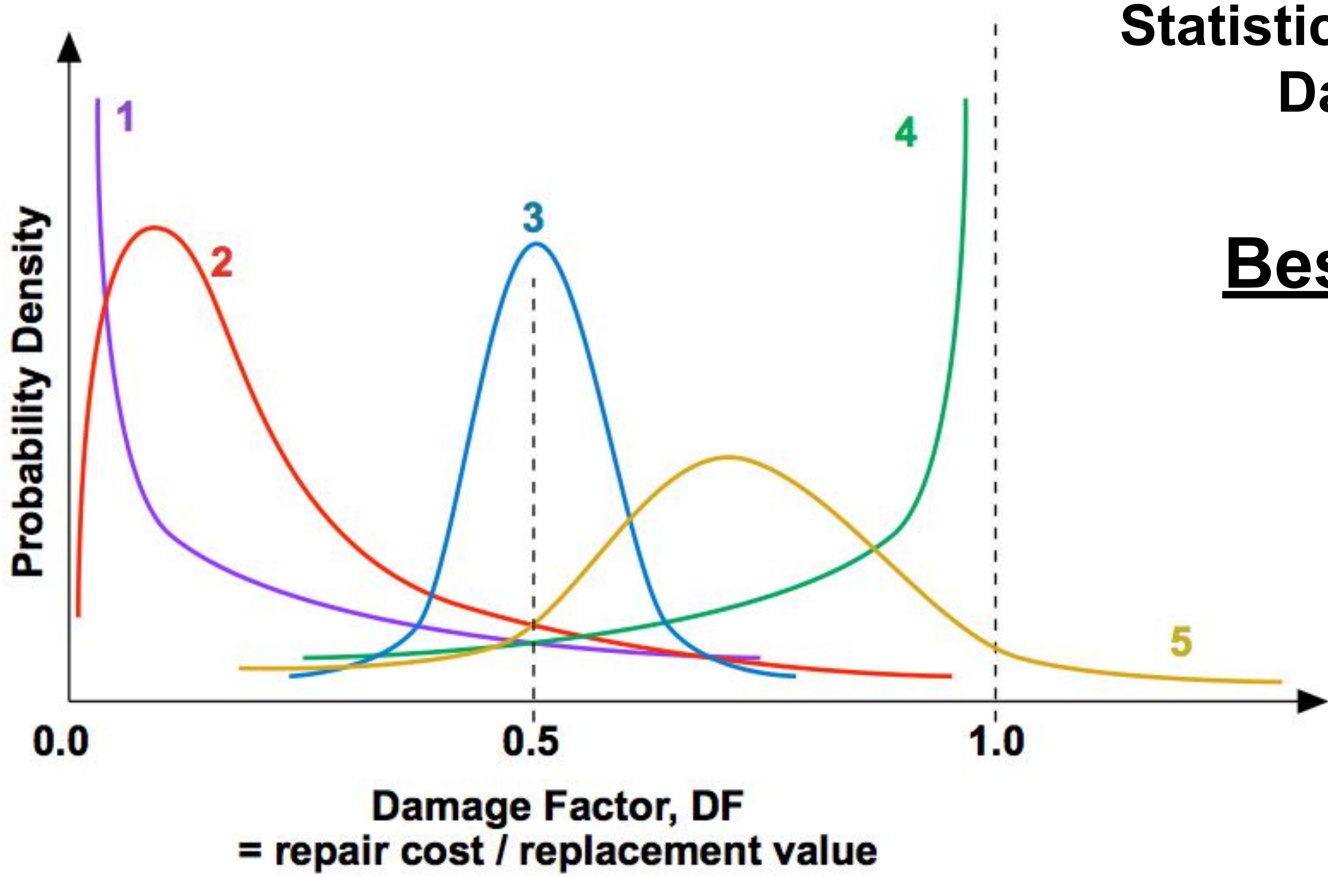
Other known attributes:

Location and age (design code)
Number of stories

Secondary Modifiers

Shape or Configuration
Soft Story
Setbacks & Overhangs
Redundancy
Torsion
Cladding Type
Building Exterior
Short Column
URM Chimney/ Partition
Ornamentation
Cripple Walls
Frame Bolted
Anchoring
URM Retrofit
Structural Upgrade
Engineered Foundation
Equipment
Construction Quality
Fatigue / Damage
Pounding
Base Isolation
Hazardous Exposures
Year Upgraded

4. Loss Estimation for Buildings



Statistical Distributions for Damage Factor

<u>Best Candidates</u>:

- **Beta**
- **Gamma**
- **Lognormal**

Well-behaved, unimodal loss data (structures of similar vulnerability subjected to relatively uniform hazard)

1. (L-shape, highly skewed) Very low-level losses, with many properties experiencing zero or near-zero loss.
2. (Skew central unimode) Low-level losses, with a defined mode greater than zero
3. (Symmetric central unimode) Mean losses with a well-defined symmetric model near 50%
4. (J-shape, highly skewed) High losses, saturating as DF approaches 1.0
5. (Nonsymmetric central unimode) High losses not saturating at 1.0

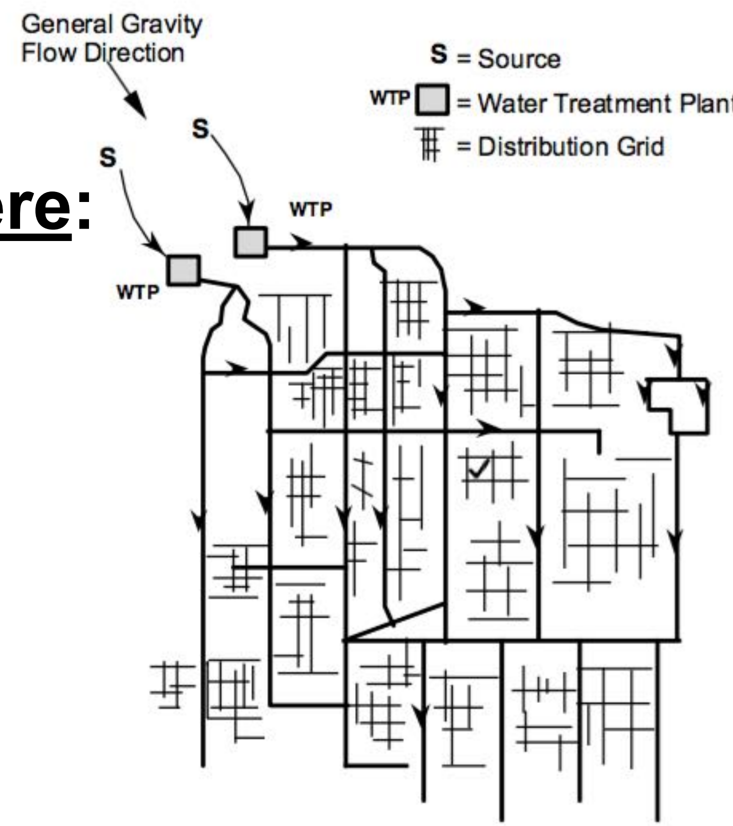
4. Loss Estimation for Buildings

<u>Other losses, not discussed here</u>:

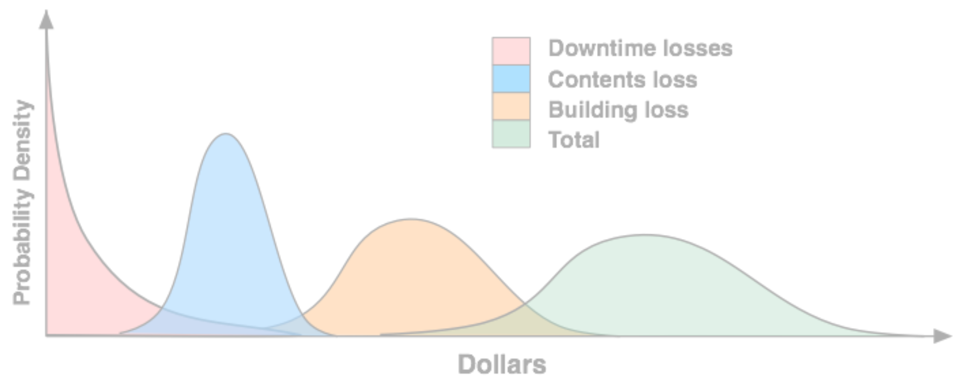
- contents damage
- cost of downtime
- pipe breakage and water damage to contents and nonstructural elements (EQSL)
- "demand surge"
- earthquake-initiated fire

<u>Other study types, not discussed here</u>:

- Network Models
- Business Interruption Models



5. Loss Aggregation for Each EQ Simulation



5. Loss Aggregation for Each EQ Simulation

Aggregation is the addition of <u>distributions</u>.

Aggregate losses within each building (Building+Contents+Downtime)

Aggregate losses at each site (locally correlated hazard)

Aggregate losses across portfolio

Aggregation methods include:

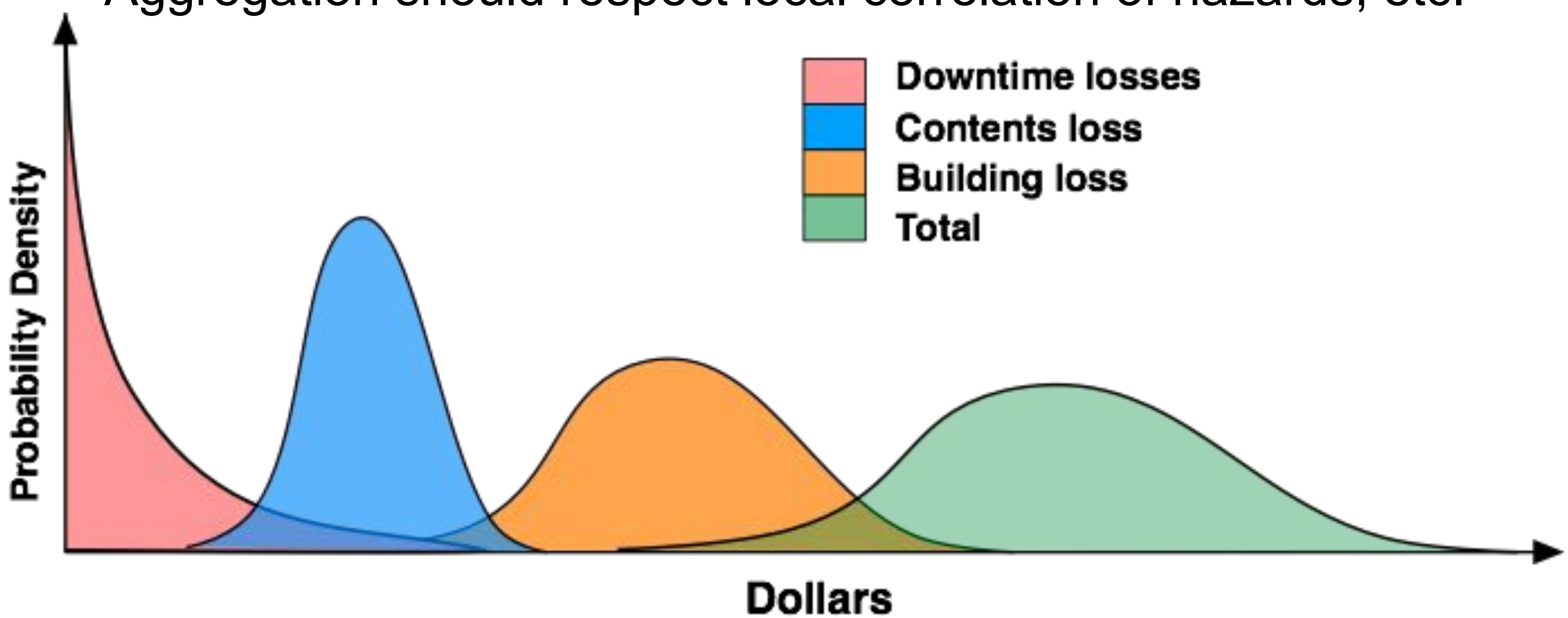
Closed-form methods (e.g., sum of mean$)

OK for ground-up, but may introduce errors in insurer or lender loss

Monte-Carlo methods

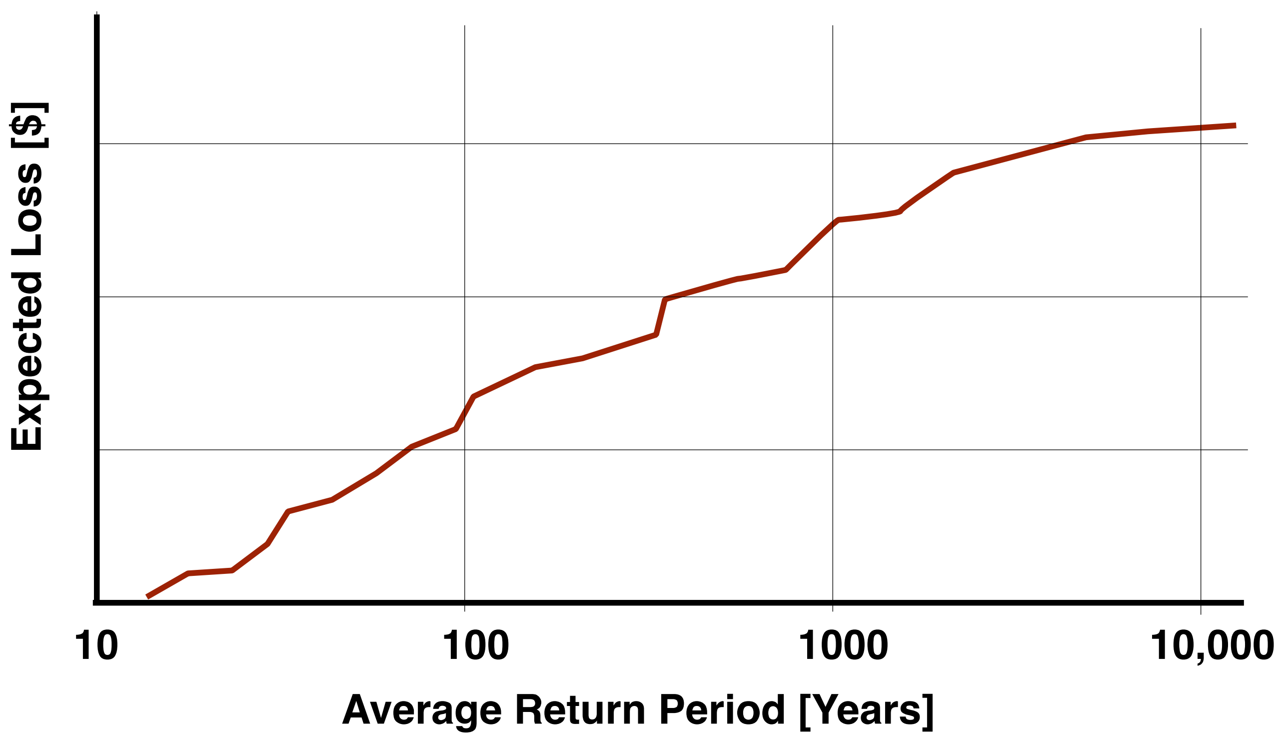
Robust Simulation – smart sampling strategies

Aggregation should respect local correlation of hazards, etc.



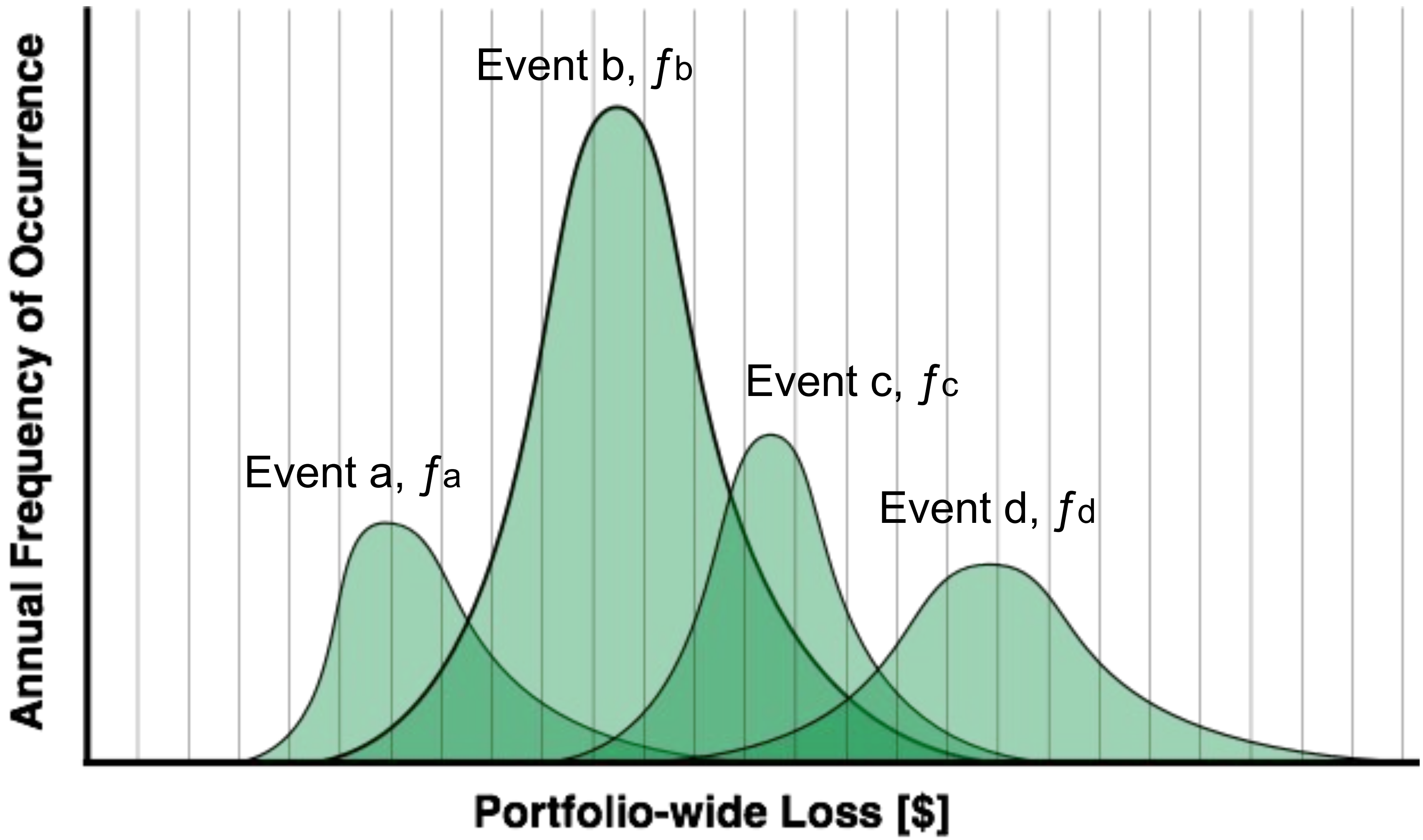
Constructing a Risk Curve

Portfolio Expected Loss: Starting with the list of earthquake simulations, each with an associated mean loss and annual frequency of occurrence, we can sort the losses from maximum to minimum. The frequency of exceedance for the maximum modeled loss is equal to its frequency of occurrence. The frequency of exceedance for each remaining loss is equal to the sum of the frequencies of occurrence for all events with higher losses. Return period is found as *1/ƒe*, where *ƒe* is frequency of exceedance. The plot below shows expected loss for the portfolio as a continuous function of return period. It is something like SEL, but for all of the scenarios affecting the portfolio, and we can see the return period for any level of loss. This process can be followed for the losses from any stakeholder position – Ground-up, Gross (Insurer) Loss, Lender Loss, or Owner's (Retained) Loss.

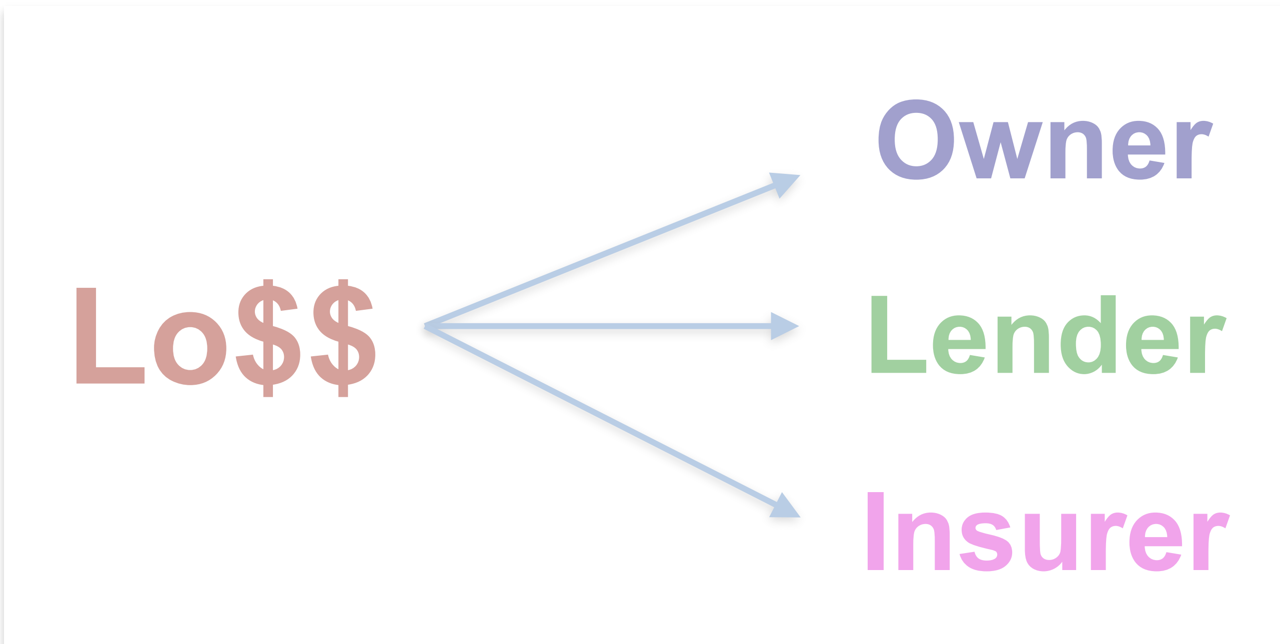


Building a 'Probable Loss' Curve

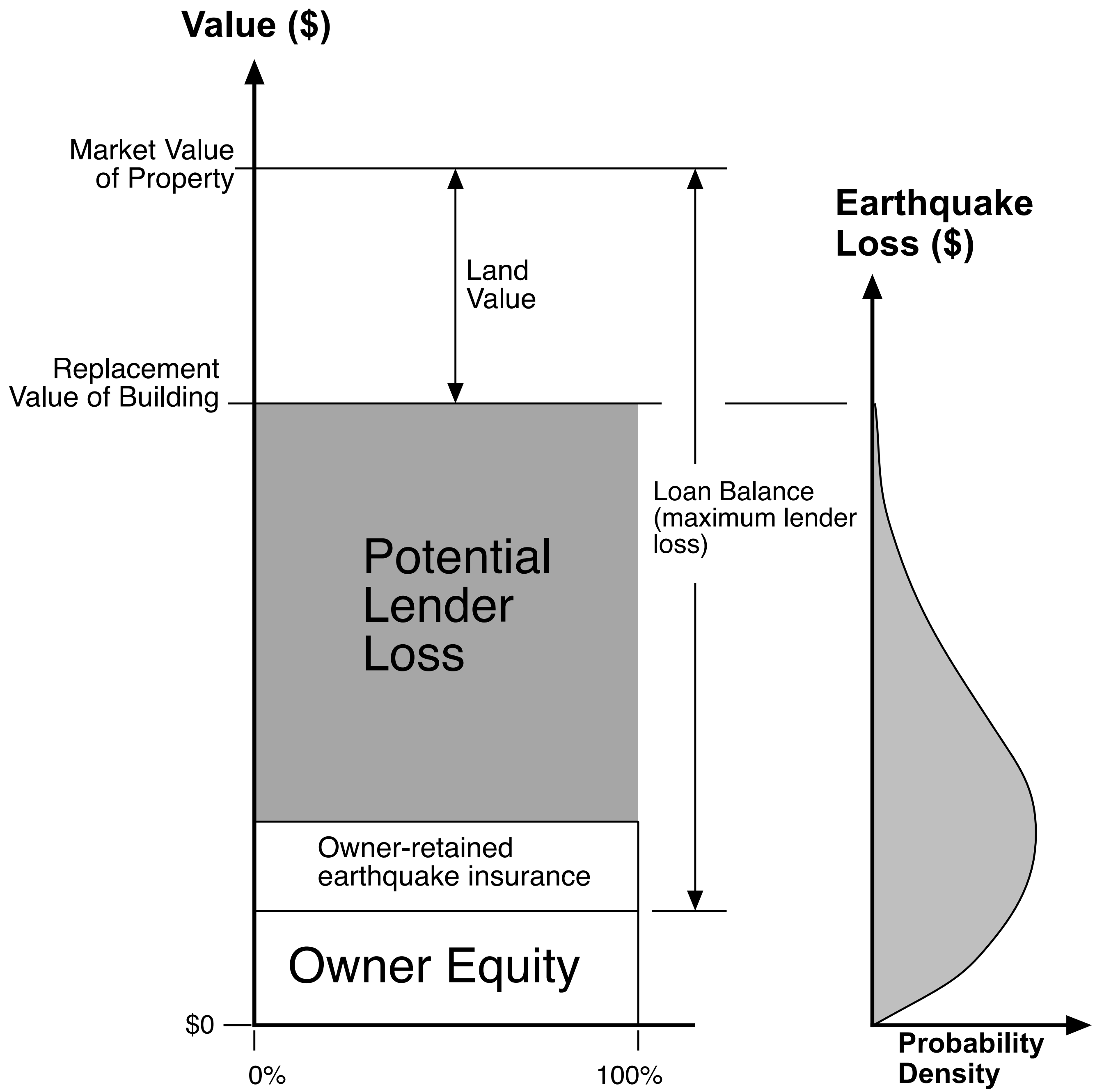
<u>Probable Loss for a Portfolio</u>: For each earthquake in the event set, the losses and their uncertainties produce a statistical distribution of loss. We can go through a binning process, whereby we account for the event frequency of occurrence and the statistical distribution of loss, and construct the risk curve



6. Stakeholder Models

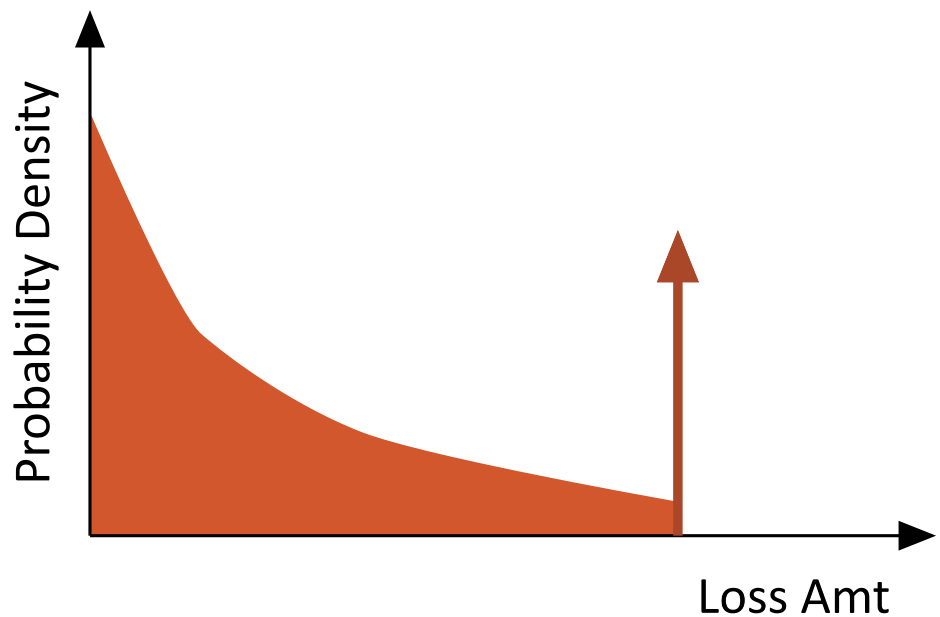


6. Stakeholder Models – Lender Loss Model

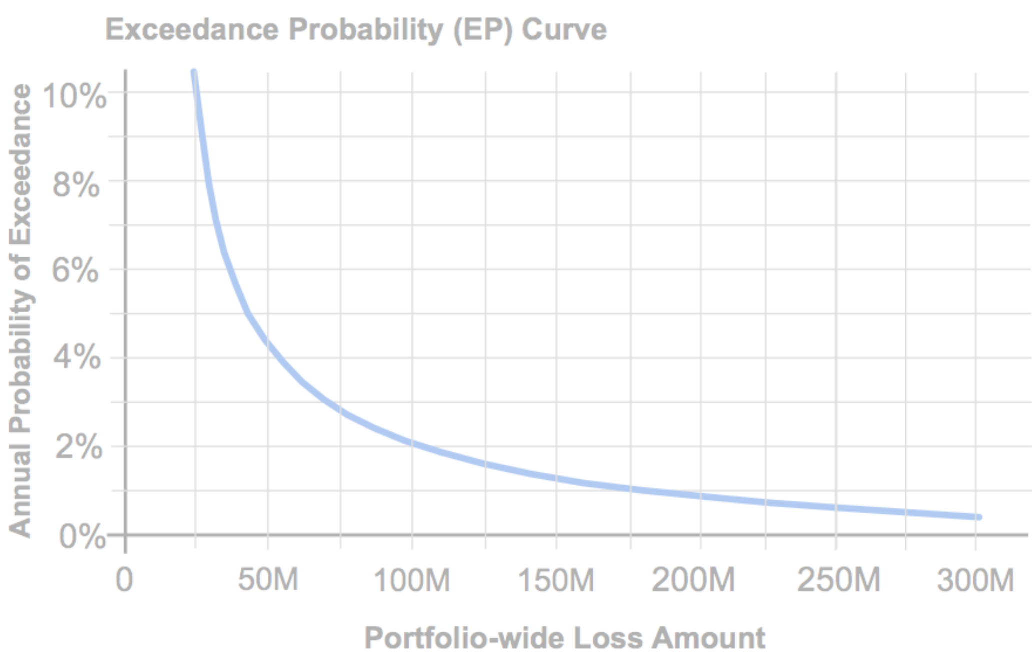


6. Stakeholder Models – Lender Loss Model

Stakeholder models produce truncated distributions, making aggregation more complex and difficult.



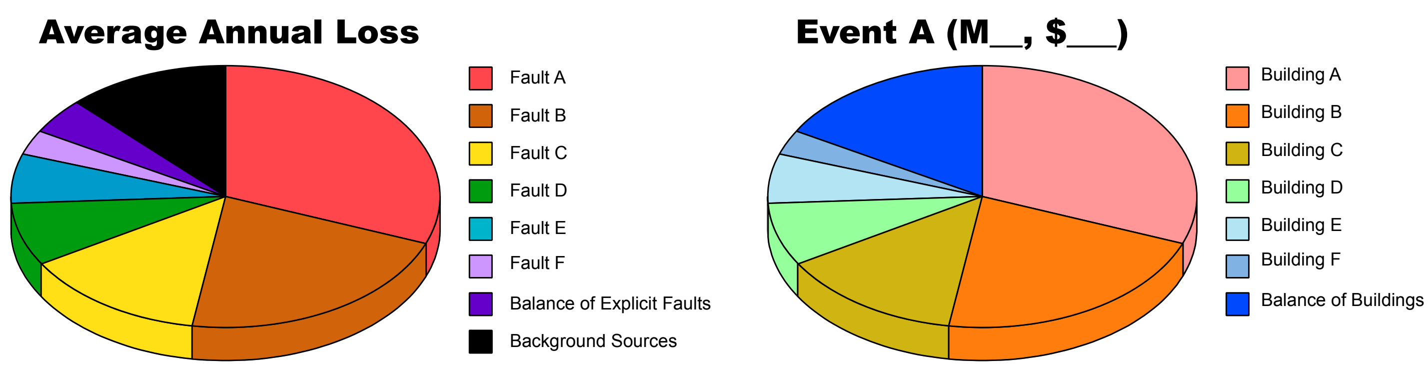
7. Outputs

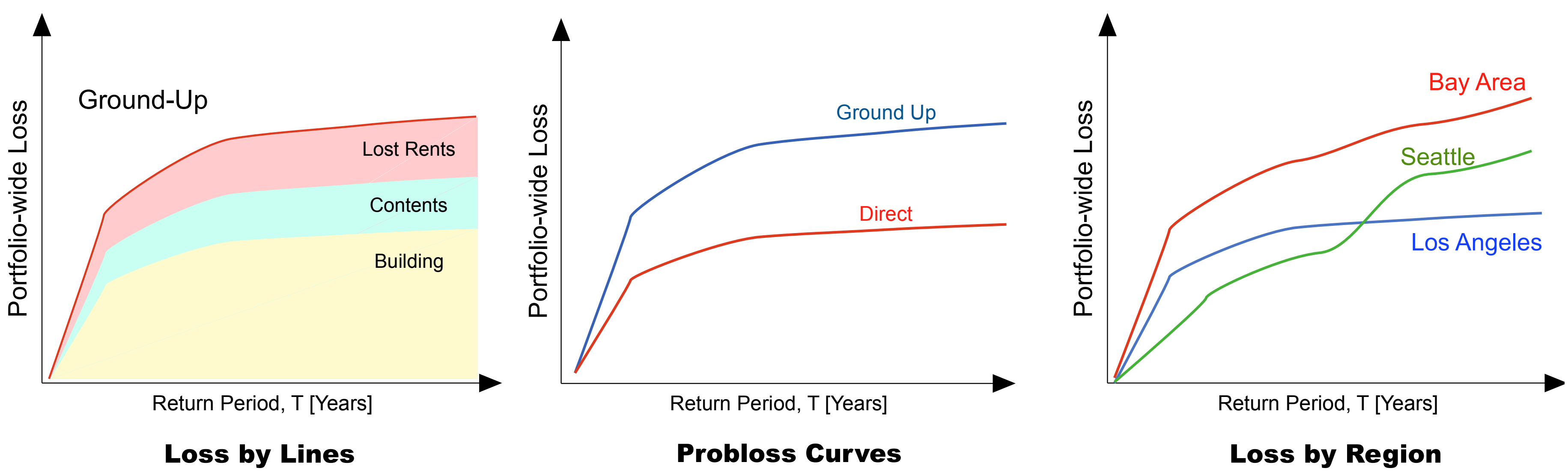


Exceedance Probability (EP) Curve
Annual Probability of Exceedance
10%
8%
6%
4%
2%
0%
0
50M
100M
150M
200M
250M
300M
Portfolio-wide Loss Amount

7. Outputs: EP or Risk Curves; Risk De-aggregations

- Risk Curves (EP Curves) and equivalent tables
- Whole portfolio, and region by region
- Stakeholder curves : Ground-up, Direct, Lender
- Sub-portfolio Analysis (e.g., for pooled loans)
- Average Annual Loss (AAL) or Annual Expected Loss (AEL)
- De-aggregation of AAL by source





8. Recommendations for Best Practice

8. Recommendations for Best Practice

1. Compare models, choose the best suited to User's needs and learn the model
  Check hazards – compare event set to USGS
  Run a "stripped down" single-site analysis to compare to a good PML
  Ask questions of the Cat model provider and knowledgeable users

2. Get high-quality Statement of Values (COPE – Construction, Occupancy, Protection, Exposure). Check that values are reasonable.

3. Sift through past PML reports and use information deemed reliable

4. Focus on important sites, gather data, make site visits, review drawings as permitted by scope, budget and schedule

5. Improve site and building modeling data
  Site Class and liquefaction susceptibility from soils reports
  Assign structural classes where info is available
  Add secondary modifiers where info is available
  Calibrate if possible

6. Save all site data and building modeling and improve the quality of data through time

9. Bibliography and Resources – Portfolio Seismic Risk Assessment

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Anderson, J.G., Special Issue on the 2014 National Seismic Hazard Maps, *Earthquake Spectra Journal,* Volume 31, Number S1, December 2015.

Goda, K., and Hong, H. P., Spatial Correlation of Peak Ground Motions and Response Spectra, Bulletin of the Seismological Society of America, Vol. 98, No. 1, pp. 354–365, February 2008.

Graf, W.P., and Y. Lee, "A Geographic Correlation Index For Portfolio Seismic Risk Analysis," 7th U.S. National Conference on Earthquake Engineering, Boston, July, 2002.

Graf, W.P., and Y. Lee, "Code-Oriented Damage Assessment," *EERI Spectra Journal,* Vol. 25, No. 1, February, 2009.

Grossi, P. and Kenreuther, H., **Catastrophe Modeling: A New Approach to Managing Risk**, Springer, 2005.

Kircher, C.A., Nassar, A.N., Kustu, O., and Holmes, W.T., 1997. "Development of Building Damage Functions for Earthquake Loss Estimation," *Earthquake Spectra Journal*, Vol. 13, No. 4, Earthquake Engineering Research Institute.

Pacific Earthquake Engineering Research Center, NGA-West2, Enhancement of Next Generation Attenuation Relationships for Western US (NGA-West2), http://peer.berkeley.edu/ngawest2/

Porter, K., 2016, A Beginner's Guide to Fragility, Vulnerability, and Risk. University of Colorado Boulder, 86 pp., http://spot.colorado.edu/~porterka/Porter-beginners- guide.pdf

Rojahn, C., ATC-13, Earthquake Damage Evaluation Data for California, Redwood City, California, Applied Technology Council, 1985.

Steinbrugge, K. V., 1982, **Earthquakes, Volcanoes, and Tsunamis: An Anatomy of Hazards**, New York City: Skandia American Group.

Taylor, C.E., **Robust Simulation for Mega-Risks**, Springer, 2015.

Taylor, C.E., Hayne, R., and Tillman, C.W., "Seismic Risk Methods for Earthquake Insurance," Proceedings of the Fourth US National Conference on Earthquake Engineering; Palm Springs, California, EERI, 1990.

Taylor, C.E., Tillman, C.W., and W. P. Graf, "Lenders, Insurers, and Earthquake Loss Estimation", Fourth Annual National Earthquake Hazards Reduction Program Workshop, Puget Sound, Washington, April, 1990

Taylor, C. E., VanMarcke, E., and Davis, J., 1998. Evaluating Models of Risks from Natural Hazards for Insurance and Government, in Paying the Price: The Status and Role of Insur- ance Against Natural Disasters in the United States, Joseph Henry Press, 239–249.

Thiel, C. C., and Zsutty, T. C., Earthquake characteristics and damage statistics, Earthquake Spectra Journal, 1987.

U.S. Geological Survey, National Seismic Hazard Mapping Project, 1996-2014 [Petersen et al, USGS Open File Report 2014-1091, 2014].

Wesson, R. L., Perkins, D. M., Leyendecker, E. V., Roth, R. J., and Petersen, M. D., Losses to single-family housing from ground motions in the 1994 Northridge, California, earthquake, Earthquake Spectra Journal, 2004.

Woo, G., **The mathematics of natural catastrophes**, Imperial College Press, London, 1999.

FAQs

- Why not just examine a single scenario, or a few maximum scenarios, in each region?
- Why not just use correlation methods with single-site loss-recurrence relationships?
- How do I calibrate a damage model in an insurance Cat model to past PML results?
- What effects do secondary modifiers have?
- What is the best Catastrophe model to use?