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Seismic Risk/Loss Analysis

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Outline of Material

- **How is seismic risk different than seismic hazard, and how is it computed?**
- **Components of seismic risk** (with HAZUS examples)
  - **Hazard**
  - **Exposure/Inventory**
  - **Fragility/Vulnerability**
- **Examples of seismic risk analysis results**

Difference Between Risk and Hazard

- Both probabilities (e.g., annually) of something "bad" happening, but …

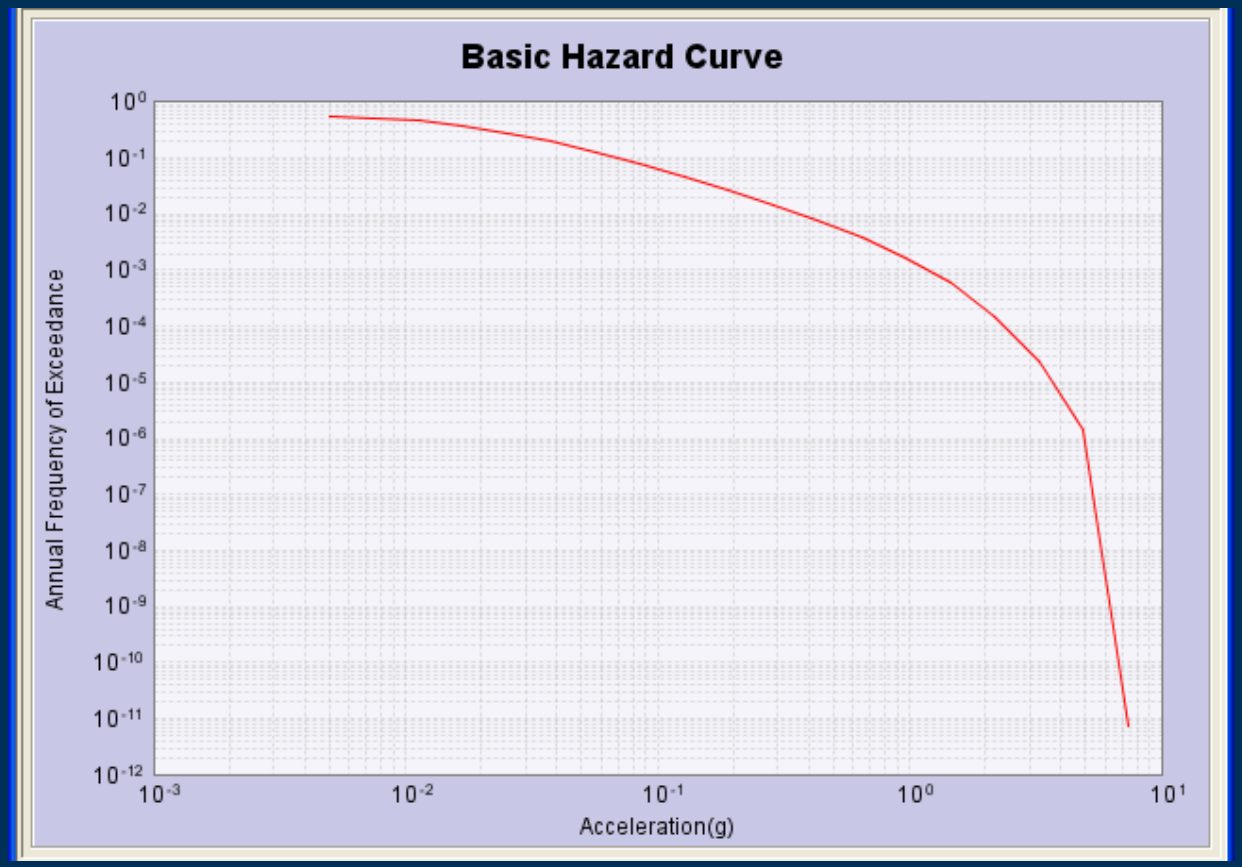
Hazard → Ground Motion

Risk → Structural Damage/Loss

- "Earthquakes don't kill people, buildings do!"
- Risk = Hazard + Inventory + Fragility

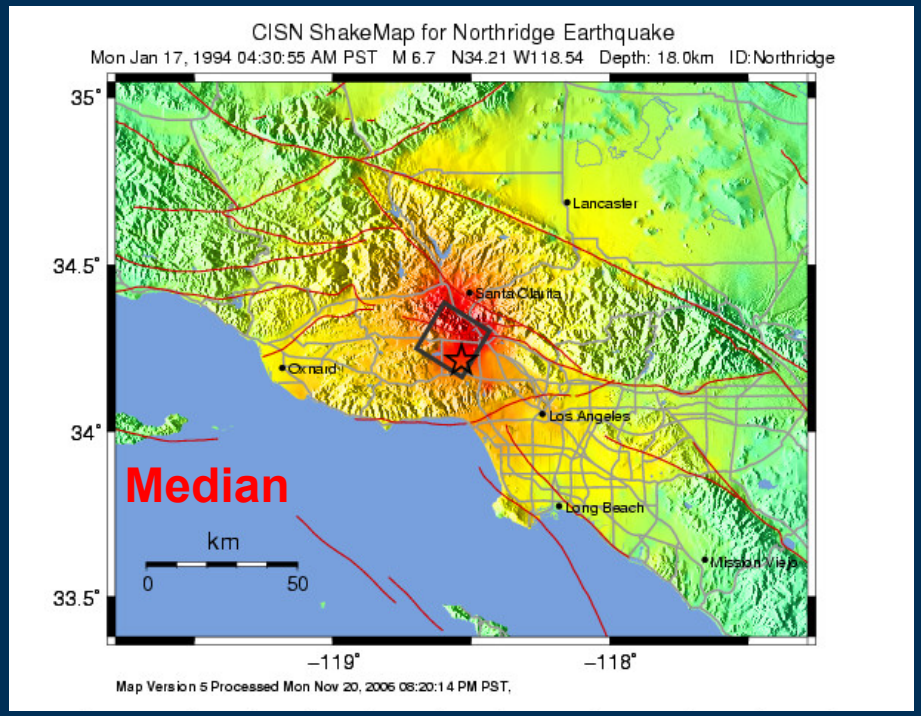
Hazard

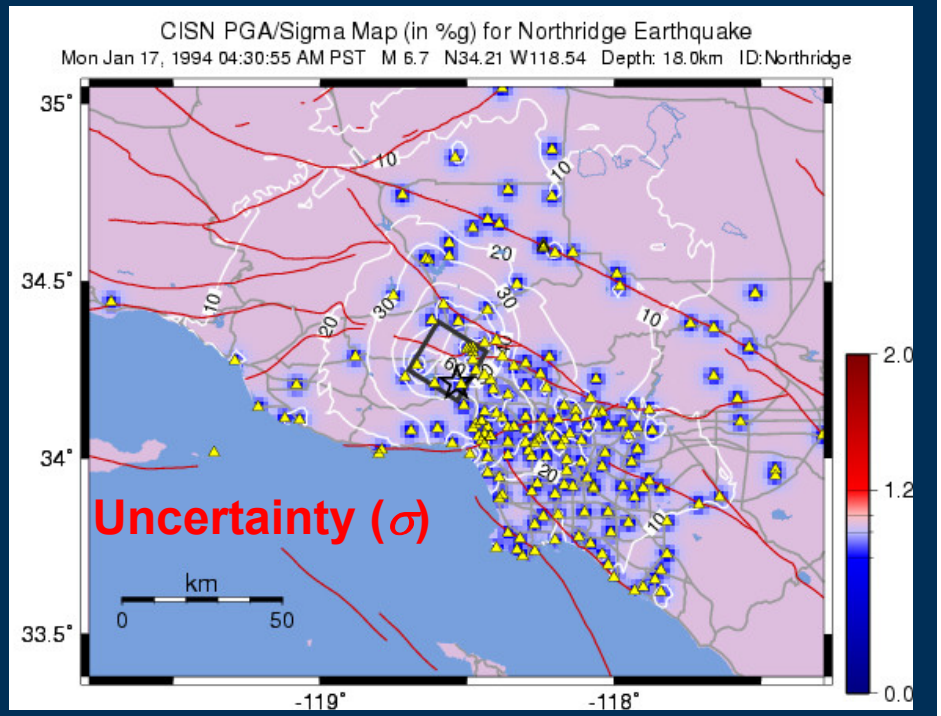
- Hazard Curve (forecast) for each location, e.g., …



"Hazard" = (EQ Rate=1) * PE(*SA*>*x*)

- **Best estimates of, and uncertainties in, ground motion for a given earthquake, e.g., …**

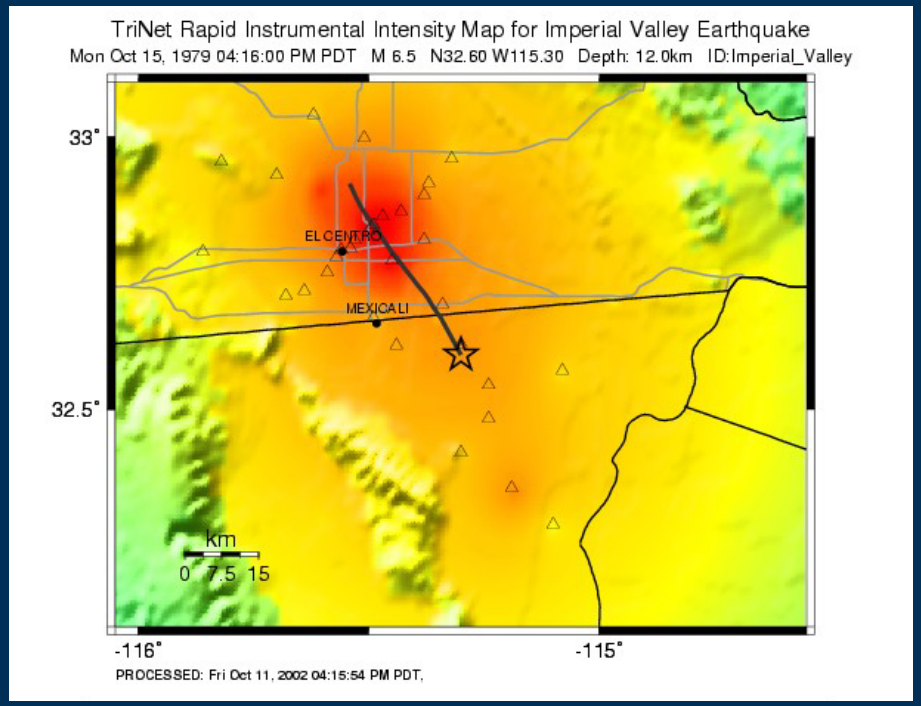




(ShakeMap immediately after an earthquake)

"Hazard"

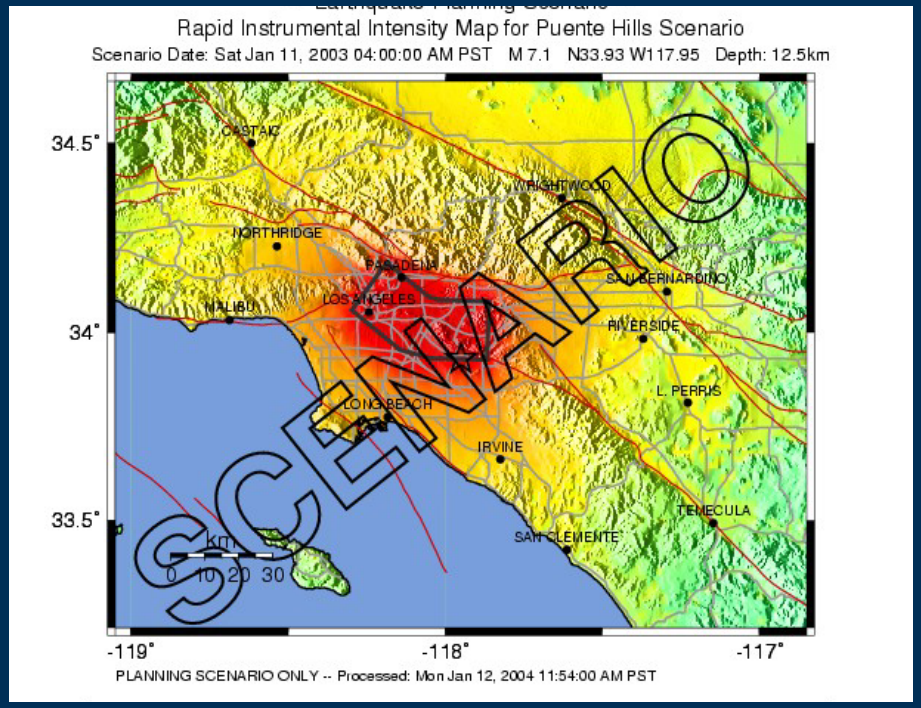
- **Best estimates of, and uncertainties in, ground motion for a given earthquake, e.g., …**



(ShakeMap for a past earthquake)

"Hazard"

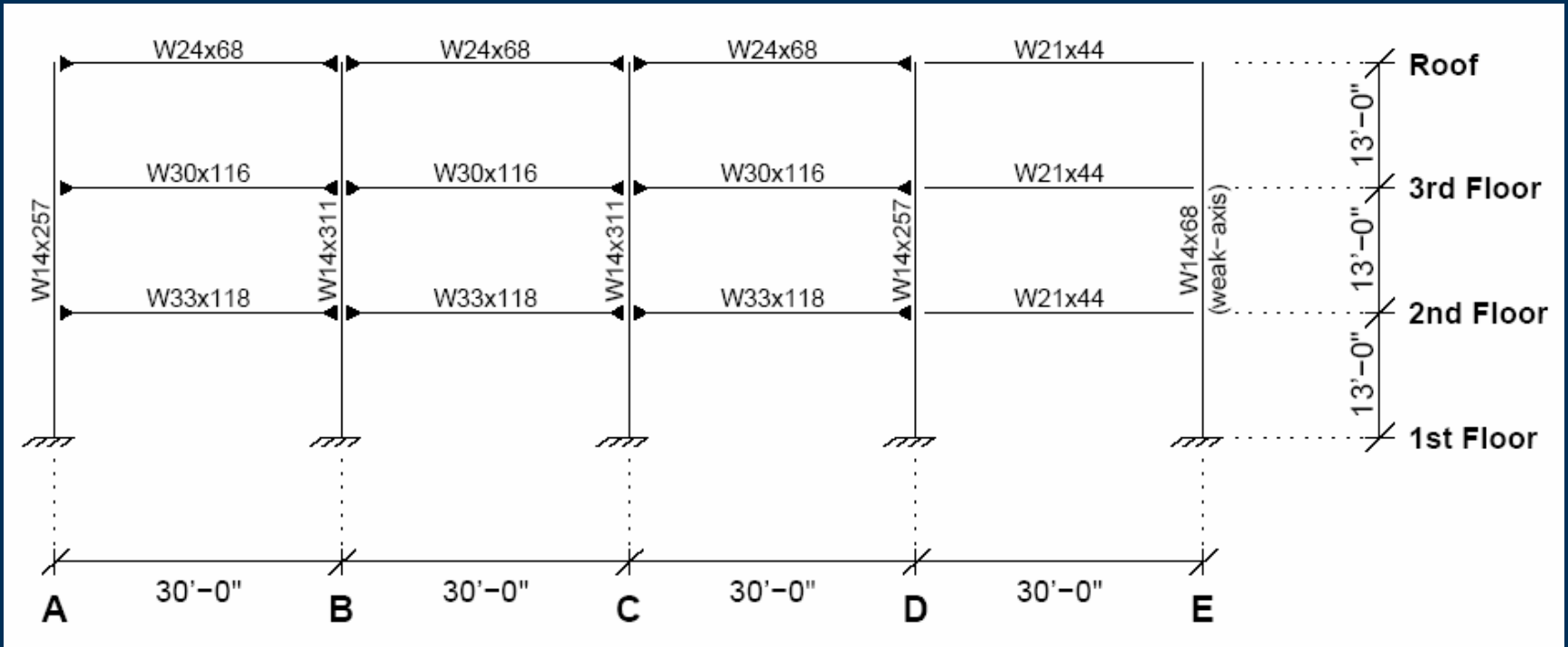
- **Best estimates of, and uncertainties in, ground motion for a given earthquake, e.g., …**



(ShakeMap for a potential future earthquake)

Exposure / Inventory

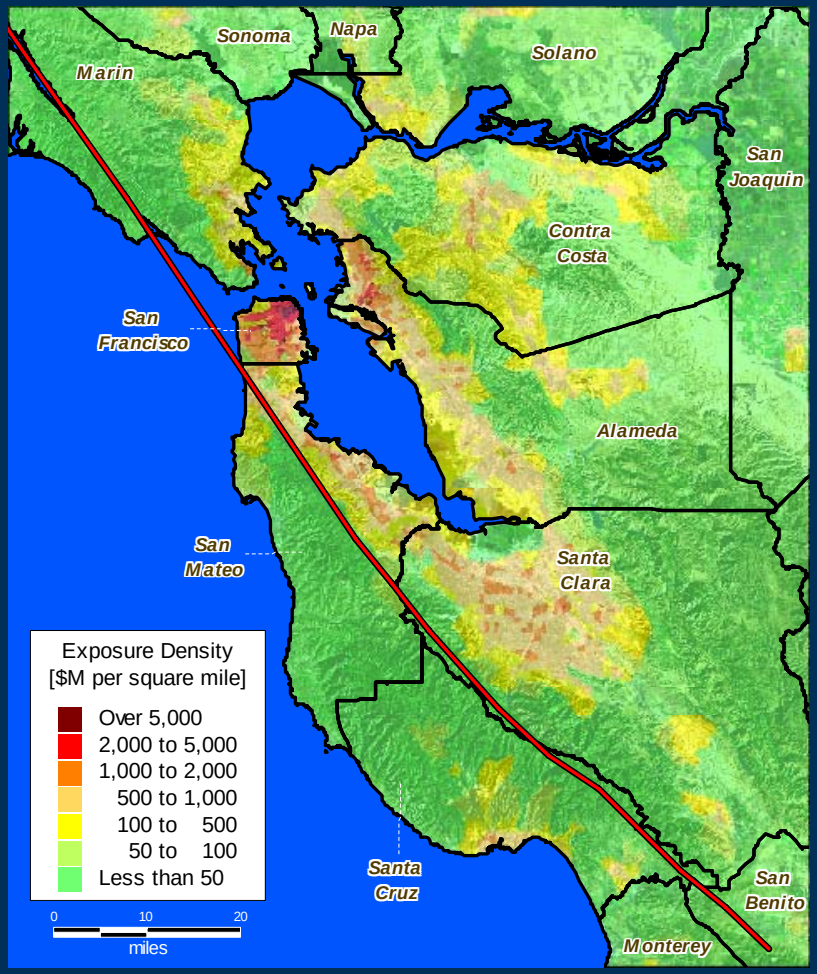
- Individual structure, e.g., …



Exposure / Inventory

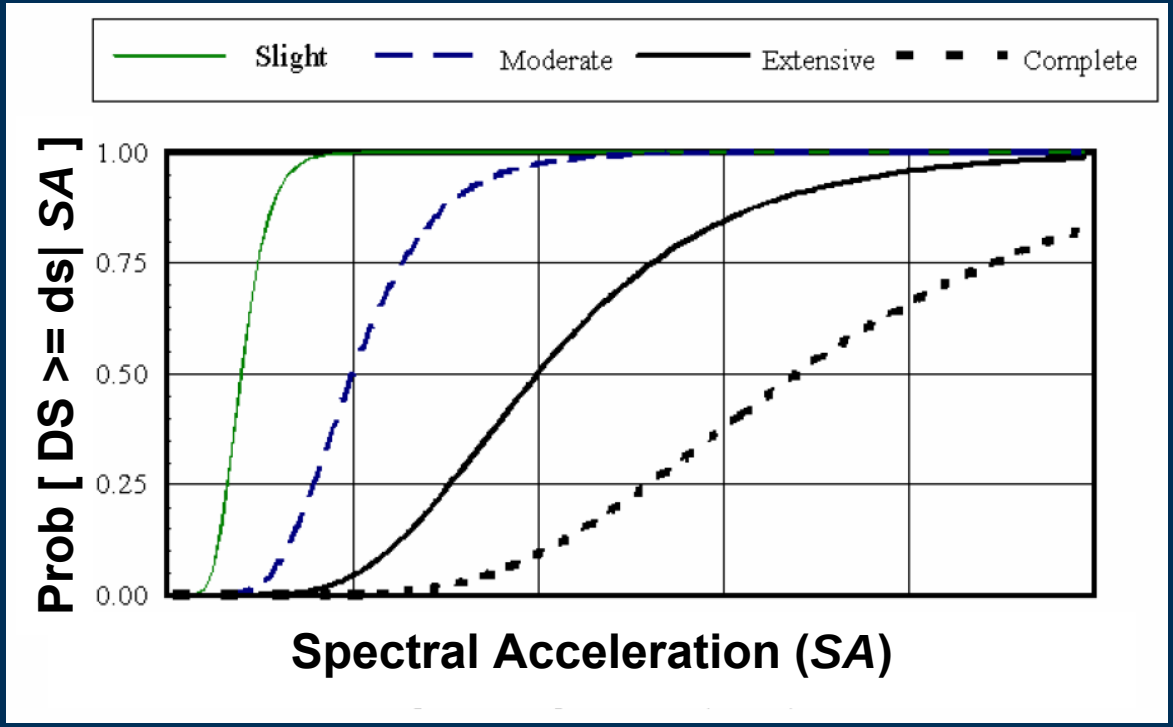
- **All structures in a region, e.g., …**

- 1.1 trillion dollars of building exposure
- 780 Billion dollars of residential exposure
- 204 Billion dollars of commercial exposure
- 43 billion dollars of industrial exposure



Fragility / Vulnerability

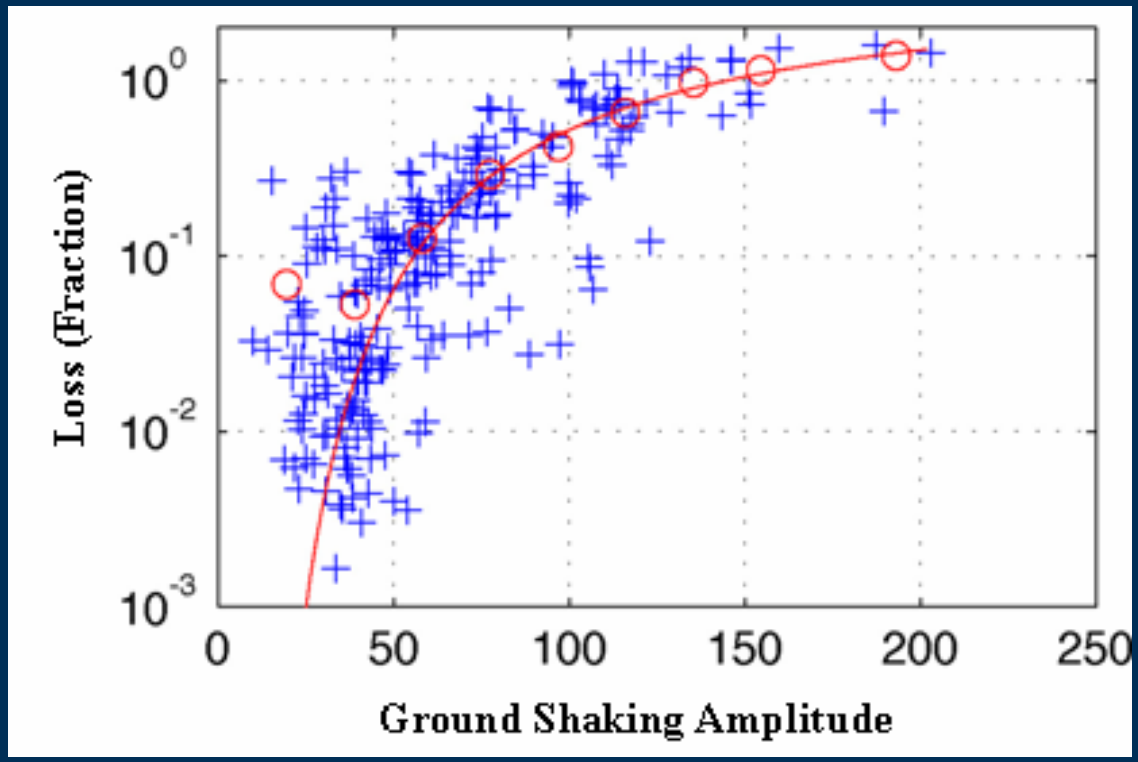
- Conditional probability of exceeding a specified amount of damage (or loss) as a function of the ground motion level, e.g., …



(*SA* → Structural Response → Structural Damage and/or Loss)

Vulnerability / Fragility

- **Expected amount of loss as a function of the ground motion level, e.g., …**



(*SA* → Structural Response → Structural Damage and/or Loss)

Objectives of Risk Analysis

- **Probability of exceeding a particular amount of damage or loss in some time period**

  e.g., P[collapse] or P[Loss>$x] in 50 years

- **Expected amount of loss in some time period**

  e.g., Expected Annual Loss (EAL)

- **Probability of exceedance or expected amount of loss *for a particular earthquake***

Reasons for Risk Analysis

- Communication of earthquake hazard
- Mitigation decisions, e.g., …
  - Do we need stricter building codes?
  - Should we retrofit certain types of buildings?
  - Do we need insurance, and at what cost?
  - How much damage do we need to prepare for?
- For individual structures or a whole region

Seismic Risk Analysis Models

- Private Sector ($$$$$)
  - AIR Worldwide Corporation
    (formerly Applied Insurance Research)
  - RMS (Risk Management Solutions)
  - ABS (formerly EQE International)
  - Others

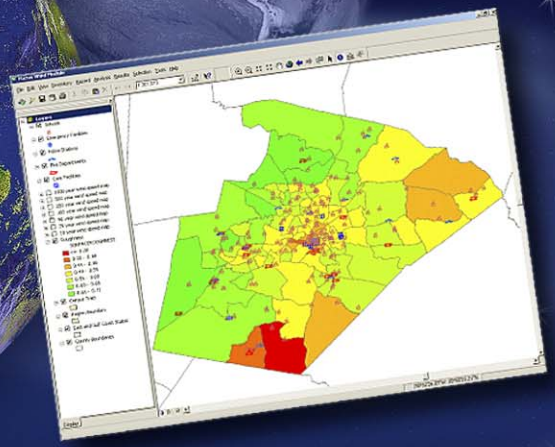
Seismic Risk Analysis Models

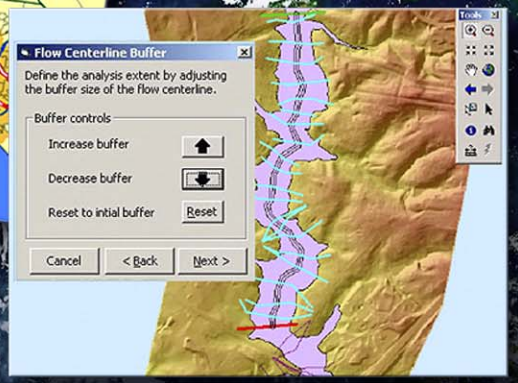
- Public Sector (Free!)
  - Federal Emergency Management Agency (FEMA) → HAZUS
  - National Science Foundation (NSF) Earthquake Engineering Centers: PEER, MAE, MCEER
  - "OpenRisk"?
  - Others

HAZUS® MH

EARTHQUAKE • WIND • FLOOD

FEMA's Software Program for Estimating Potential Losses from Disasters

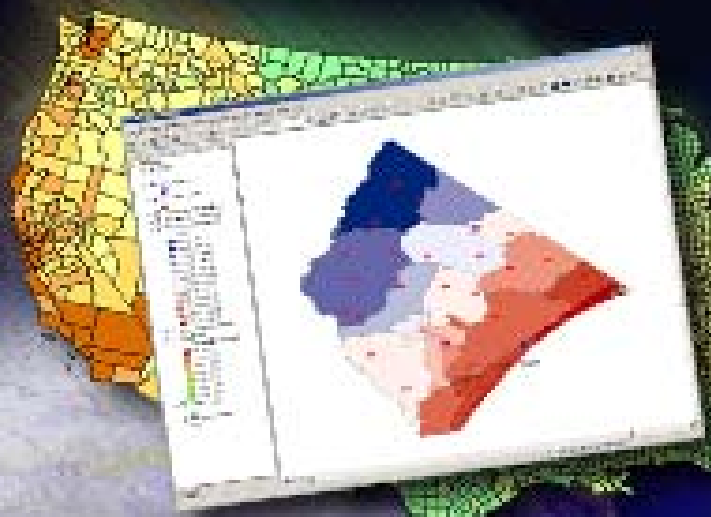




FEMA

HAZUS-MH: FEMA'S SOFTWARE PROGRAM FOR ESTIMATING POTENTIAL LOSSES FROM DISASTERS

HAZUS-MH: Features



Physical Impacts

Economic Impacts

Social Impacts

GIS Technology

Nationwide Databases

Nationally Standardized Loss Estimation and Risk Assessment Methodology

FEMA

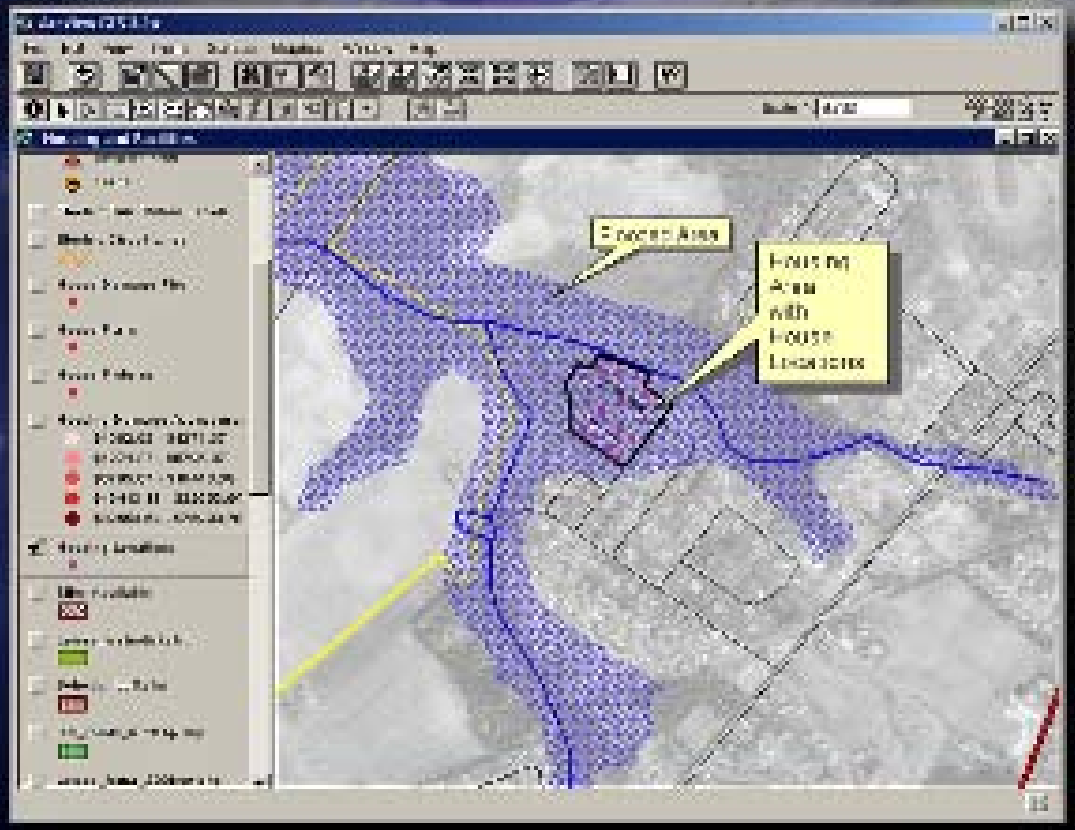
GIS Technology

Spatial Relationships

- Layers
- Computations

Risk Communication

- Risks
- Solutions



FEMA

Nationwide Databases

Demographics – Population, Employment, Housing

Building Stock – Residential, Commercial, Industrial

Essential Facilities – Hospitals, Schools, Police Stations, Fire Stations

Transportation – Highways, Bridges, Railways, Tunnels, Airports, Ports and Harbors, Ferry Facilities

Utilities – Waste Water, Potable Water, Oil, Gas, Electric Power, Communication Facilities

High Potential Loss Facilities – Dams and Levees, Nuclear Facilities, Hazardous Material Sites, Military Installations

FEMA

HAZUS-MH: Analysis Levels

Parameter Modification

InCAST – Inventory Collection and Survey Tool

BIT – Building data Import Tool

FIT – Flood Information Tool

Level 1 and 2 analyses can usually be performed by emergency services or planning staff

Level 3 analysis typically requires technical expertise

FEMA

HAZUS-MH: Models

	Earthquake Ground Motion Ground Failure	Flood Frequency Depth Discharge Velocity	Hurricane Winds Pressure | Missile | Rain
Direct Damage			
General Building Stock	✓	✓	✓
Essential Facilities	✓	✓	✓
High Potential Loss Facilities	✓	✓	✓
Transportation Facilities	✓	✓	
Lifelines	✓	✓	
Induced Damage			
Fire Following	✓		
Hazardous Materials Sites	✓	✓	✓
Debris Generation	✓	✓	✓
Direct Losses			
Cost of Repairs/Replacement	✓	✓	✓
Income Loss	✓	✓	✓
Crop Damage		✓	
Casualties	✓		
Shelter and Recovery Needs	✓	✓	✓
Indirect Losses			
Supply Shortages	✓	✓	
Sales Decline	✓	✓	
Opportunity Costs	✓	✓	
Economic Loss	✓	✓	

FEMA

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- **Components of seismic risk** (with HAZUS examples)
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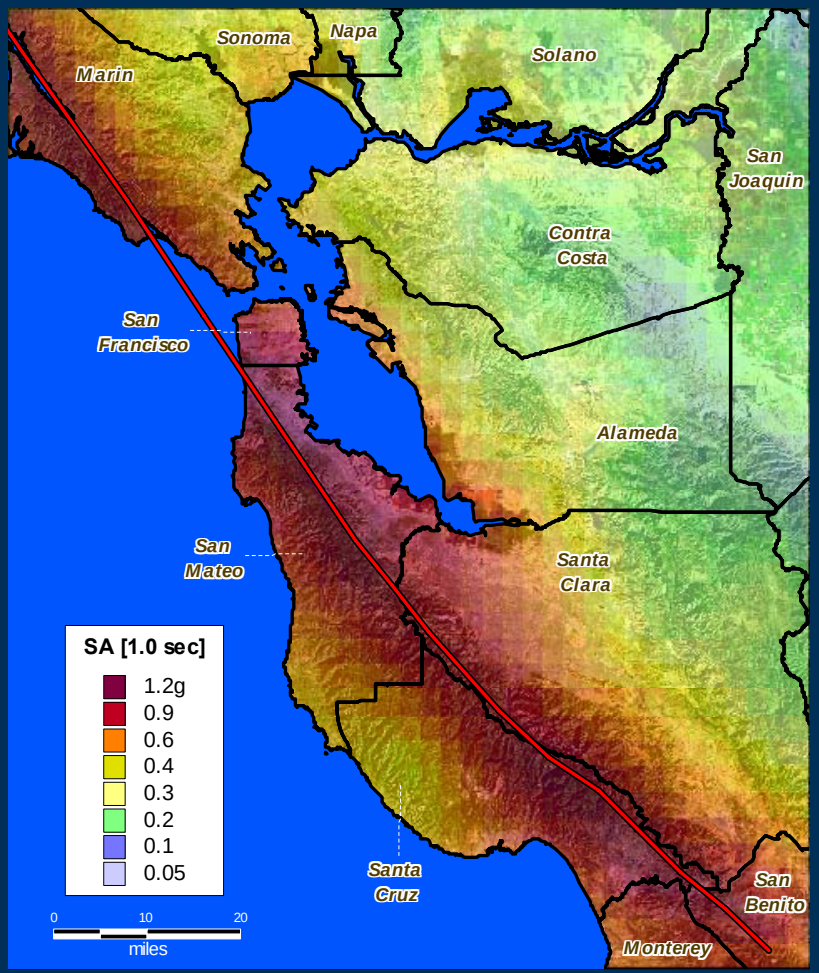
Seismic Hazard Input (HAZUS)

- **Earthquake scenario**

  e.g.,

  M=7.9 on
  San Andreas Fault
  (repeat of 1906
  San Francisco
  Earthquake)

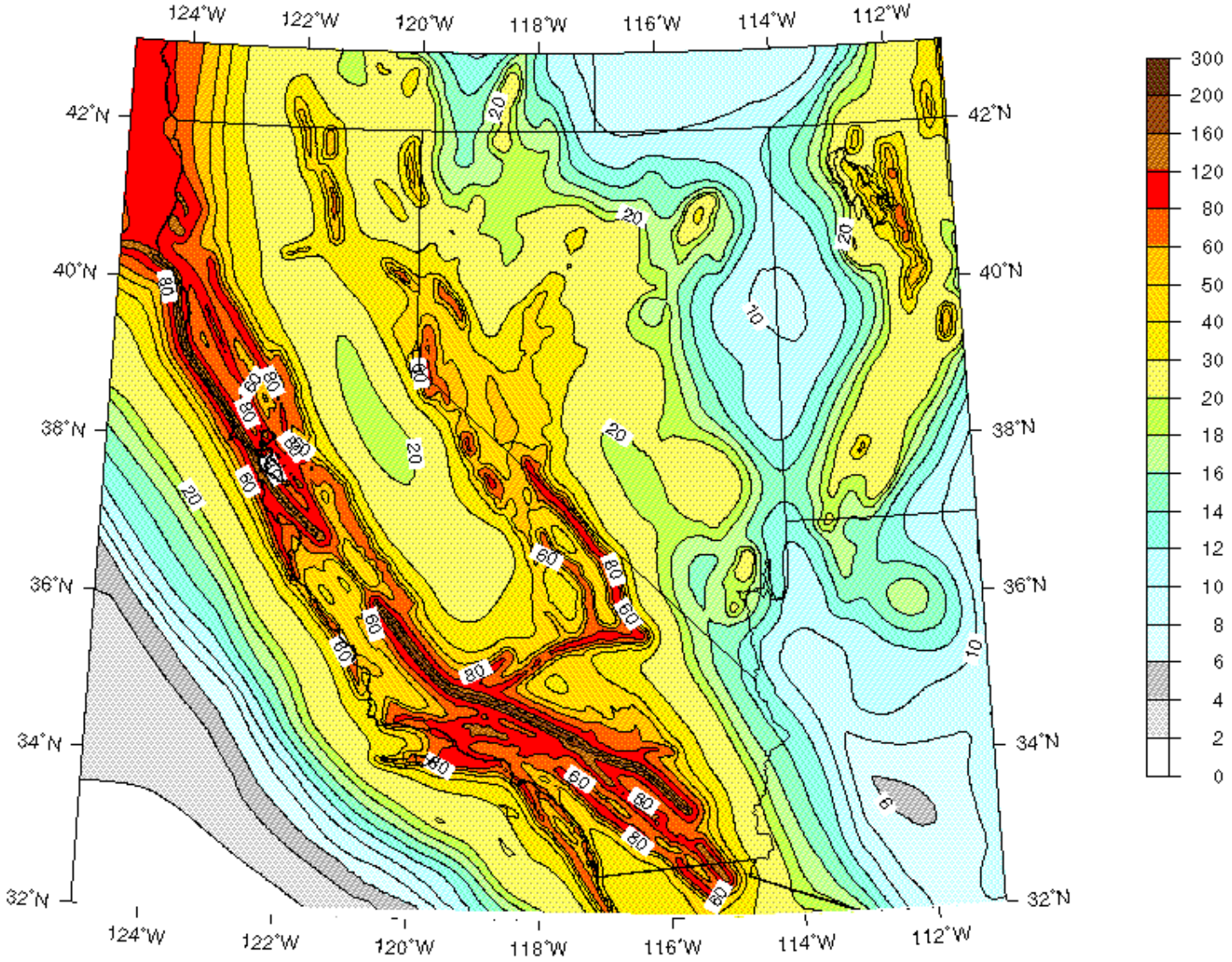
- **E[Loss | Earthquake]**



Seismic Hazard Input (HAZUS)

- Probabilistic ground motions maps from USGS, for E[Loss] / year, e.g., …

1.0 sec SA (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002rev

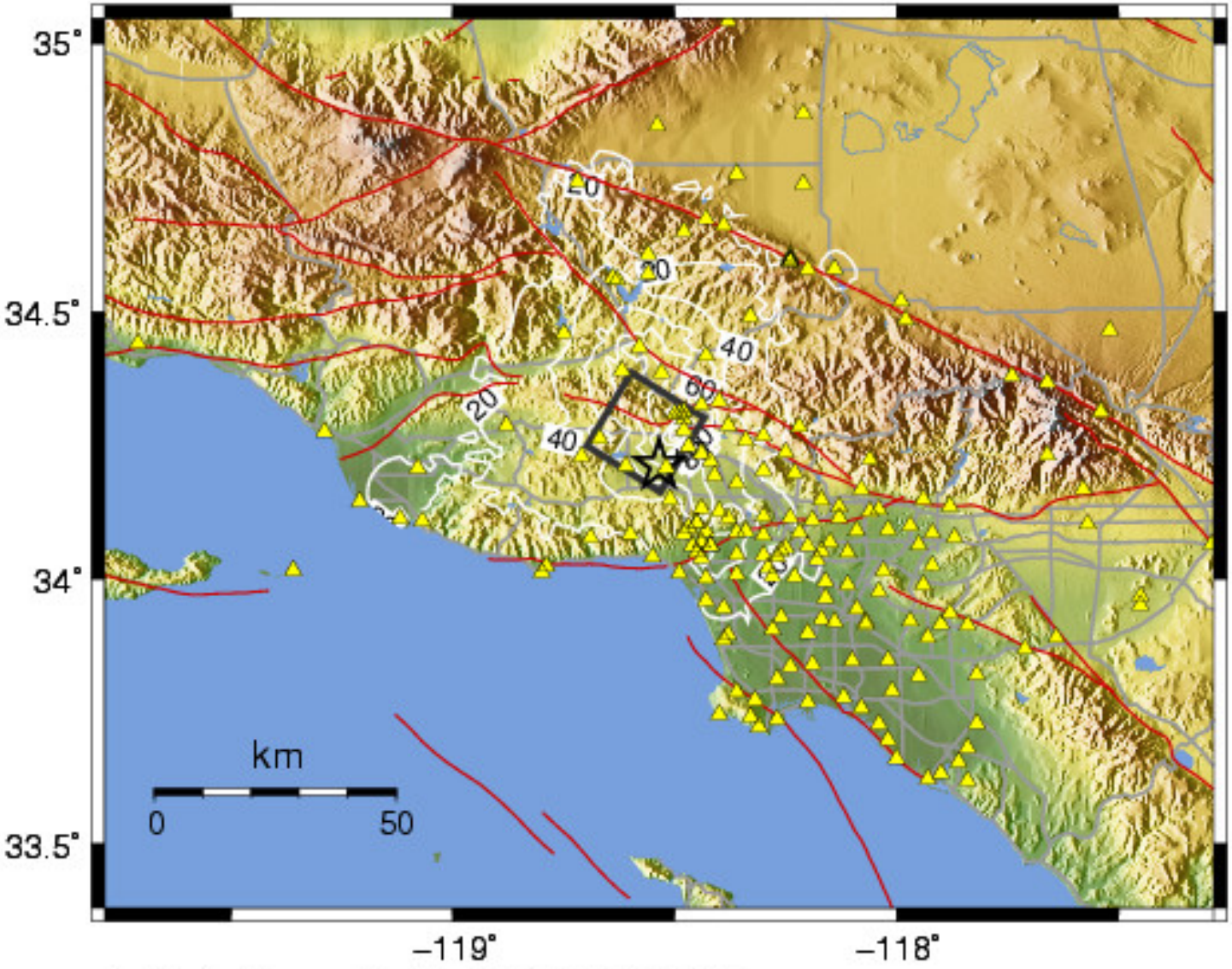


Seismic Hazard Input (HAZUS)

- Other user-supplied ground motion maps, e.g., ShakeMaps, …

CISN 1.0 s Pseudo–Acceleration Spectra (%g) for Northridge Earthquake

Mon Jan 17, 1994 04:30:55 AM PST M 6.7 N34.21 W118.54 Depth: 18.0km ID:Northridge

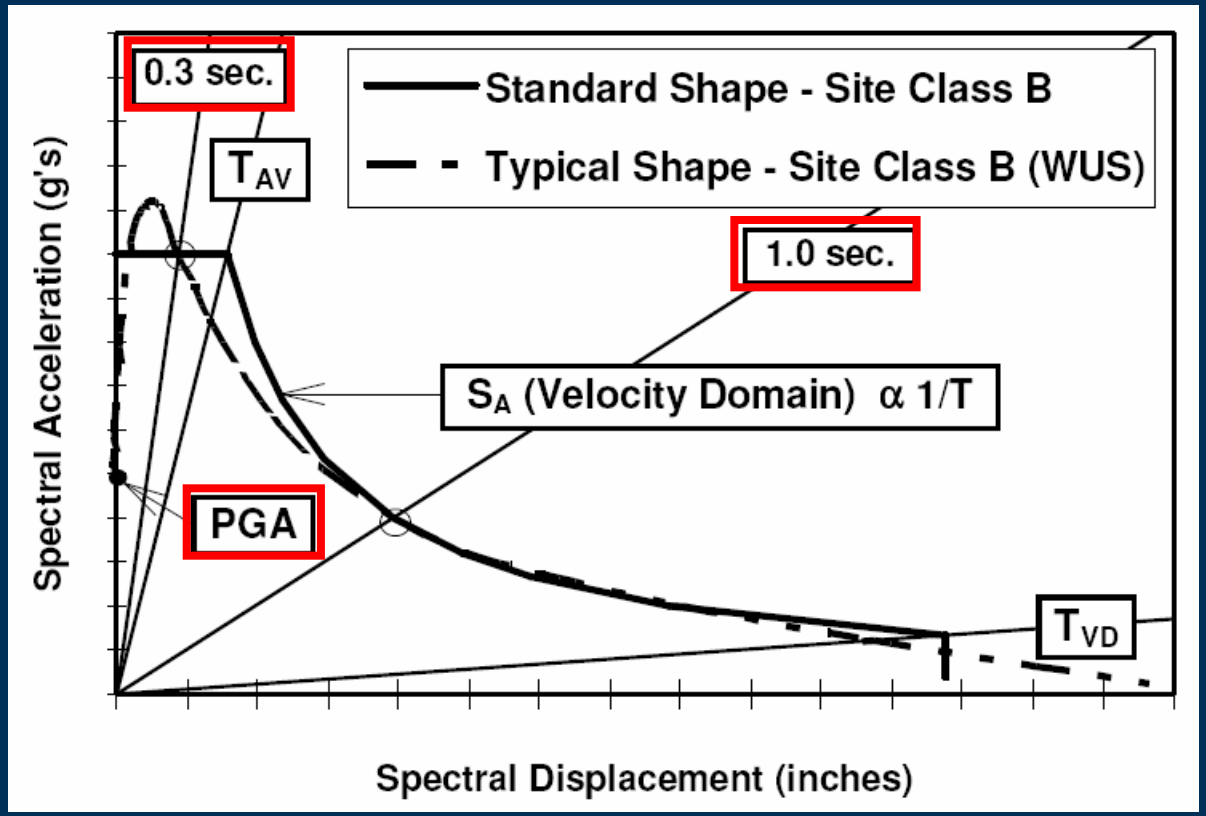


Map Version 5 Processed Mon Nov 20, 2006 08:20:14 PM PST,

NOTE: These are automated maps based on instrumental response spectra, and may not be appropriate for comparison with design spectral values.

Seismic Hazard Input (HAZUS)

- Ground motion response spectrum



PGA

SA(0.3sec)

SA(1.0sec)

Seismic Hazard Input (HAZUS)

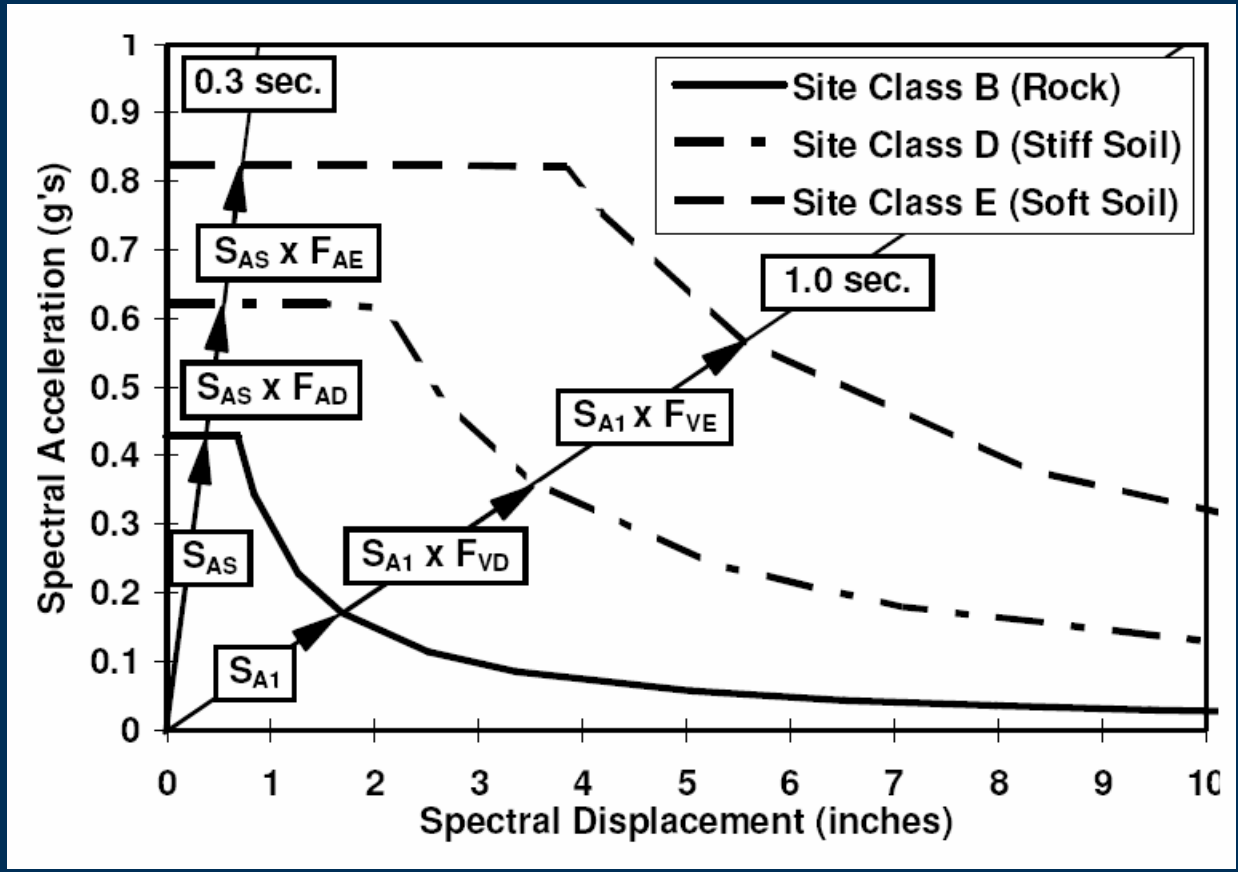
Table 4.9 Soil Amplification Factors

Site Class B Spectral Acceleration	Site Class				
	A	B	C	D	E
Short-Period, S_{AS} (g)	**Short-Period Amplification Factor, F_A**				
≤ 0.25	0.8	1.0	1.2	1.6	2.5
0.50	0.8	1.0	1.2	1.4	1.7
0.75	0.8	1.0	1.1	1.2	1.2
1.0	0.8	1.0	1.0	1.1	0.9
≥ 1.25	0.8	1.0	1.0	1.0	0.8*
1-Second Period, S_{A1} (g)	**1.0-Second Period Amplification Factor, F_V**				
≤ 0.1	0.8	1.0	1.7	2.4	3.5
0.2	0.8	1.0	1.6	2.0	3.2
0.3	0.8	1.0	1.5	1.8	2.8
0.4	0.8	1.0	1.4	1.6	2.4
≥ 0.5	0.8	1.0	1.3	1.5	2.0*

* Site Class E amplification factors are not provided in the *NEHRP Provisions when* $S_{AS} > 1.0$ *or* $S_{A1} > 0.4$. Values shown with an asterisk are based on judgment.

Seismic Hazard Input (HAZUS)

- Soil-amplified response spectrum



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- **Components of seismic risk** (with HAZUS examples)
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Building Inventory Classification (HAZUS)

Classify by parameters influencing damage & loss

- Structural parameters affecting structural capacity and response
  - Basic structural system (steel moment frame)
  - Building height (low-rise, mid-rise, high-rise)
  - Seismic design criteria (seismic zone)
- Nonstructural elements affecting nonstructural damage
- Occupancy (affecting casualties, business interruption and contents damage)
- Regional building practices
- Variability of building characteristics within the classification

Exposure/Inventory (HAZUS)

- Buildings and Facilities
  - General building stock, essential facilities, high potential loss facilities, …
- Transportation Systems
  - Highway systems, railways, light rail, bus system, ports and harbors, ferry, airports, …
- Lifeline Utility Systems
  - Potable water, waste water, oil systems, gas systems, electric power, communication, …
- Hazardous Materials Facilities

General Building Stock Database (HAZUS)

- includes:
  - Square footage by occupancy
  - Full replacement value by occupancy
  - Building count by occupancy
  - General occupancy mapping
  - Demographics

General Building Stock Database (HAZUS)

- developed from:
  - Census of Population and Housing, 2000
  - Dun & Bradstreet, Business Population Report, 2002
  - Department of Energy, Housing Characteristics
  - Department of Energy, A Look at Residential Energy Consumption in 1997,
  - Department of Energy, A Look at Commercial Buildings in 1995

Building Inventory Classification (HAZUS)

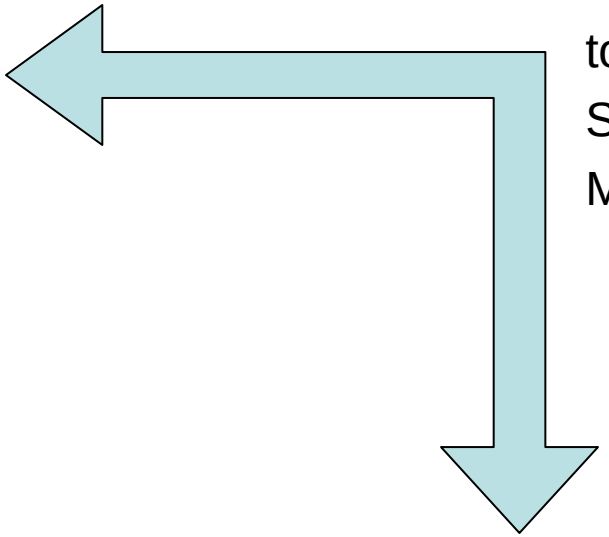
Building Occupancy Class

Square footage

Value

Demographics

…



Occupancy Class
to
Structure Type
Mapping

Building Structure Type

Structural characteristics

Response

Damage functions

…

Building Occupancy Classes (HAZUS)

Table 3.2: Building Occupancy Classes

Label	Occupancy Class	Example Descriptions
	Residential	
RES1	Single Family Dwelling	House
RES2	Mobile Home	Mobile Home
RES3	Multi Family Dwelling RES3A Duplex RES3B 3-4 Units RES3C 5-9 Units RES3D 10-19 Units RES3E 20-49 Units RES3F 50+ Units	Apartment/Condominium
RES4	Temporary Lodging	Hotel/Motel
RES5	Institutional Dormitory	Group Housing (military, college), Jails
RES6	Nursing Home	
	Commercial	
COM1	Retail Trade	Store
COM2	Wholesale Trade	Warehouse
COM3	Personal and Repair Services	Service Station/Shop
COM4	Professional/Technical Services	Offices
COM5	Banks	
COM6	Hospital	
COM7	Medical Office/Clinic	
COM8	Entertainment & Recreation	Restaurants/Bars
COM9	Theaters	Theaters
COM10	Parking	Garages
	Industrial	
IND1	Heavy	Factory
IND2	Light	Factory
IND3	Food/Drugs/Chemicals	Factory
IND4	Metals/Minerals Processing	Factory
IND5	High Technology	Factory
IND6	Construction	Office
	Agriculture	
AGR1	Agriculture	
	Religion/Non/Profit	
REL1	Church/Non-Profit	
	Government	
GOV1	General Services	Office
GOV2	Emergency Response	Police/Fire Station/EOC
	Education	
EDU1	Grade Schools	
EDU2	Colleges/Universities	Does not include group housing

Building Replacement Costs (HAZUS)

Table 3.6 Default Full Replacement Cost Models (Means, 2002)

HAZUS Occupancy Class Description		Sub-category	Means Model Description (Means Model Number)	Means Cost/SF (2002)
RES1	Single Family Dwelling	See Table 14.2		
RES2	Manufactured Housing	Manufactured Housing	Manufactured Housing (N/A)[1]	$30.90
RES3	Multi Family Dwelling – small	Duplex	SFR Avg 2 St., MF adj, 3000 SF	$67.24
		Triplex/Quads	SFR Avg 2 St., MF adj, 3000 SF	$73.08
	Multi Family Dwelling – medium	5-9 units	Apt, 1-3 st, 8,000 SF (M.010)	$125.63
		10-19 units	Apt., 1-3 st., 12,000 SF (M.010)	$112.73
	Multi Family Dwelling – large	20-49 units	Apt., 4-7 st., 40,000 SF (M.020)	$108.86
		50+ units	Apt., 4-7 st., 60,000 SF (M.020)	$106.13
			Apt., 8-24 st., *145,000 SF* (M.030)	$111.69
RES4	Temp. Lodging	Hotel, medium	Hotel, 4-7 st., 135,000 SF(M.350)	$104.63
		Hotel, large	Hotel, 8-24 st., 450,000 SF (M.360)	$93.47
		Motel, small	Motel, 1 st., 8,000 SF (M.420)	$94.13
		Motel, medium	Motel, 2-3 st., *49,000 SF* (M.430)	$110.03
RES5	Institutional Dormitory	Dorm, medium	College Dorm, 2-3 st, *25,000 SF* (M.130)	$118.82
		Dorm, large	College Dorm, 4-8 st, *85,000 SF* (M.140)	$113.31
		Dorm, small	Frat House, 2 st., 10,000 SF (M.240)	$99.50
RES6	Nursing Home	Nursing home	Nursing Home, 2 st., 25,000 SF (M.450)	$104.62
COM1	Retail Trade	Dept Store, 1 st	Store, Dept., 1 st., 110,000 SF (M.610)	$71.54
		Dept Store, 3 st	Store, Dept., 3 st., 95,000 SF (M.620)	$88.73
		Store, small	Store, retail, 8,000 SF (M.630)	$79.23
		Store, medium	Supermarket, *44,000 SF* (M.640)	$69.09
		Store, convenience	Store, Convenience, 4,000 SF (M.600)	$83.59
		Auto Sales	Garage, Auto Sales, 21,000 SF (M.260)	$70.84
COM2	Wholesale Trade	Warehouse, medium	Warehouse, 30,000 SF (M.690)	$61.91
		Warehouse, large	Warehouse, 60,000 SF (M.690)	$56.58
		Warehouse, small	Warehouse, 15,000 SF (M.690)	$70.43
COM3	Personal and Repair Services	Garage, Repair	Garage, Repair, *10,000 SF* (M.290)	$86.81
		Garage, Service sta.	Garage, Service sta., 1,400 SF (M.300)	$113.91
		Funeral Home	Funeral home, 10,000 SF (M.250)	$97.66
		Laundromat	Laundromat 3,000 SF (M.380)	$135.64
		Car Wash	Car Wash, 1 st., 800 SF (M.080)	$198.28

Building Structure Types (HAZUS)

Table 3.1: Building Structure (Model Building) Types

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1	W1	Wood, Light Frame (≤ 5,000 sq. ft.)		1 - 2	1	14
2	W2	Wood, Commercial and Industrial (> 5,000 sq. ft.)		All	2	24
3	S1L	Steel Moment Frame	Low-Rise	1 - 3	2	24
4	S1M		Mid-Rise	4 - 7	5	60
5	S1H		High-Rise	8+	13	156
6	S2L	Steel Braced Frame	Low-Rise	1 - 3	2	24
7	S2M		Mid-Rise	4 - 7	5	60
8	S2H		High-Rise	8+	13	156
9	S3	Steel Light Frame		All	1	15
10	S4L	Steel Frame with Cast-in-Place Concrete Shear Walls	Low-Rise	1 - 3	2	24
11	S4M		Mid-Rise	4 - 7	5	60
12	S4H		High-Rise	8+	13	156
13	S5L	Steel Frame with Unreinforced Masonry Infill Walls	Low-Rise	1 - 3	2	24
14	S5M		Mid-Rise	4 - 7	5	60
15	S5H		High-Rise	8+	13	156
16	C1L	Concrete Moment Frame	Low-Rise	1 - 3	2	20
17	C1M		Mid-Rise	4 - 7	5	50
18	C1H		High-Rise	8+	12	120
19	C2L	Concrete Shear Walls	Low-Rise	1 - 3	2	20
20	C2M		Mid-Rise	4 - 7	5	50
21	C2H		High-Rise	8+	12	120
22	C3L	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise	1 - 3	2	20
23	C3M		Mid-Rise	4 - 7	5	50
24	C3H		High-Rise	8+	12	120
25	PC1	Precast Concrete Tilt-Up Walls		All	1	15
26	PC2L	Precast Concrete Frames with Concrete Shear Walls	Low-Rise	1 - 3	2	20
27	PC2M		Mid-Rise	4 - 7	5	50
28	PC2H		High-Rise	8+	12	120
29	RM1L	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	Low-Rise	1-3	2	20
30	RM2M		Mid-Rise	4+	5	50
31	RM2L	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms	Low-Rise	1 - 3	2	20
32	RM2M		Mid-Rise	4 - 7	5	50
33	RM2H		High-Rise	8+	12	120
34	URML	Unreinforced Masonry Bearing Walls	Low-Rise	1 - 2	1	15
35	URMM		Mid-Rise	3+	3	35
36	MH	Mobile Homes		All	1	10

Building Occupancy Class to Structure Type Mapping

Region: West Coast

Height: Low-rise

Age: Post-1970

Table 3A.4: Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, Low Rise, Post-1970, West Coast* (after ATC-13, 1985)

No.	Specific Occup. Class	Model Building Type															
		1	2	3	6	9	10	13	16	19	22	25	26	29	31	34	36
		W1	W2	S1L	S2L	S3	S4L	S5L	C1L	C2L	C3L	PC1	PC2L	RM1L	RM2L	URML	MH
1	RES1	For State-Specific "Res1" Distribution, Refer to Table 3A.19															
2	RES2																100
3	RES3	73				2	3			6	1		1	9			5
4	RES4	53		3		2	3		4	13				20	2		
5	RES5	33		3	3		6		5	24				23	3		
6	RES6	70								5		5		20			
7	COM1		26	9	1	2	1		6	10	1	15	5	21	3		
8	COM2		8	4	1	3	4		2	12		41	3	19	3		
9	COM3		13	3	2	2	3		3	13		20	5	34	2		
10	COM4		35	3	2	1	3		4	15		8	3	24	2		
11	COM5		35	3	2	1	3		4	15		8	3	24	2		
12	COM6		31	6	1	1	7		4	13		7		28	2		
13	COM7		47	16			5		4	6		2		20			
14	COM8		4	23	8	1	3		2	15		4	1	32	7		
15	COM9		5	27	20					12		4		27	5		
16	COM10			8	8		6		3	49		3	13	7	3		
17	IND1		11	19	28	3	2		1	9		11	3	11	1		1
18	IND2		3	13	9	6	3			10		41	3	12			
19	IND3		2	15	10	5	3			12		28	7	18			
20	IND4		1	26	18	5	4		1	11	1	12	5	15	1		
21	IND5		1	12	8	2	3			10		38	7	17	1		1
22	IND6		30	4	6	11				8		16	6	14			5
23	AGR1	40		8	11	8				3		11	1	15	1		2
24	REL1	23		12	3	1	6			26		1	3	22	3		
25	GOV1		8	15	4	3	7		2	32			4	16	9		
26	GOV2	40		3	7		23			10			7	3	7		
27	EDU1	24		9	6	1	5		3	16	3	4	3	21	5		
28	EDU2	5		10	10		5			20		5		40	5		

* Refer to Table 3C.1 for states' classifications.

Building Occupancy Class to Structure Type Mapping

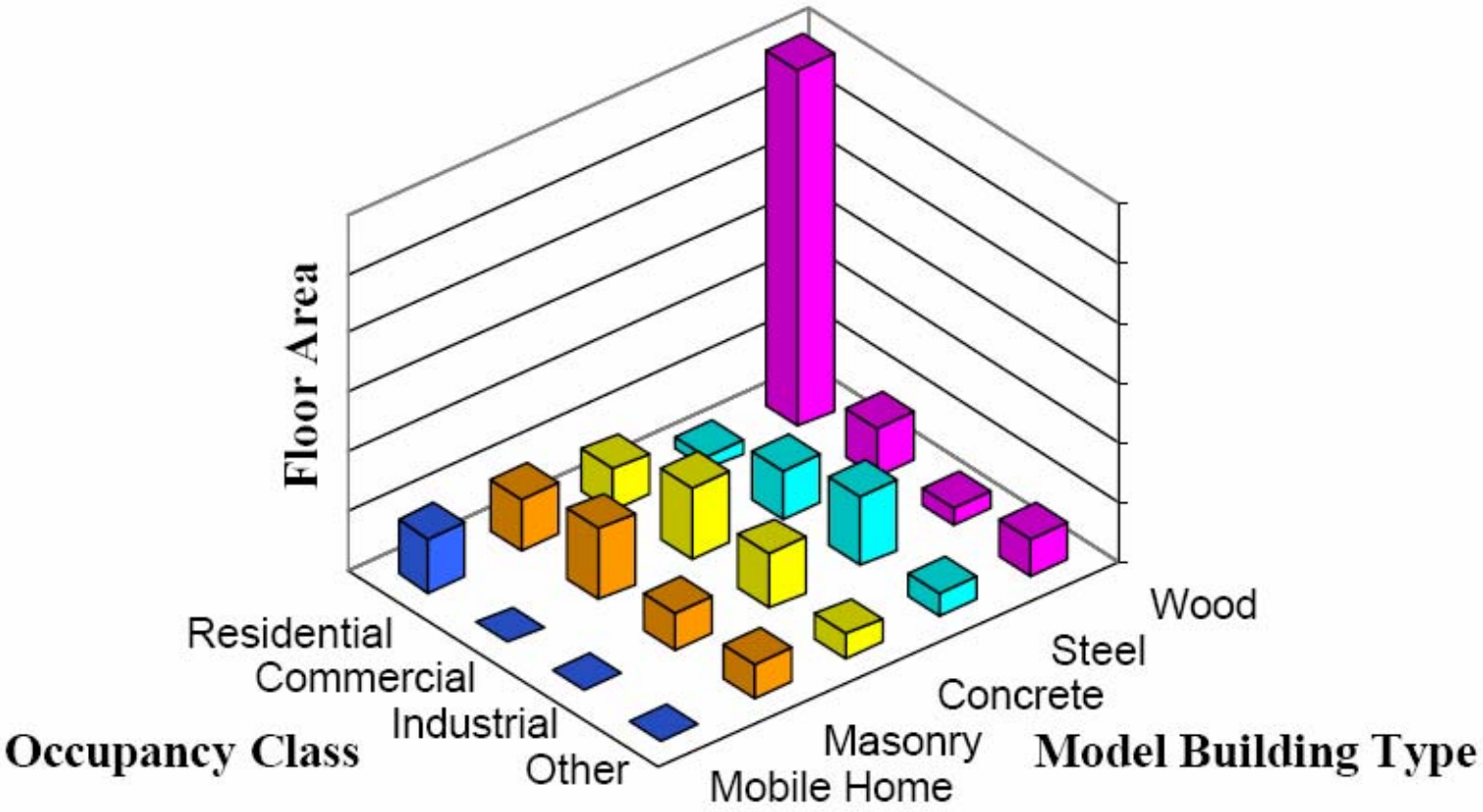


Figure 2.2. Example Inventory Relationship of Model Building Type and Occupancy Class

Individual Building/Structure (HAZUS)

- Advance Engineering Building Module (AEBM)

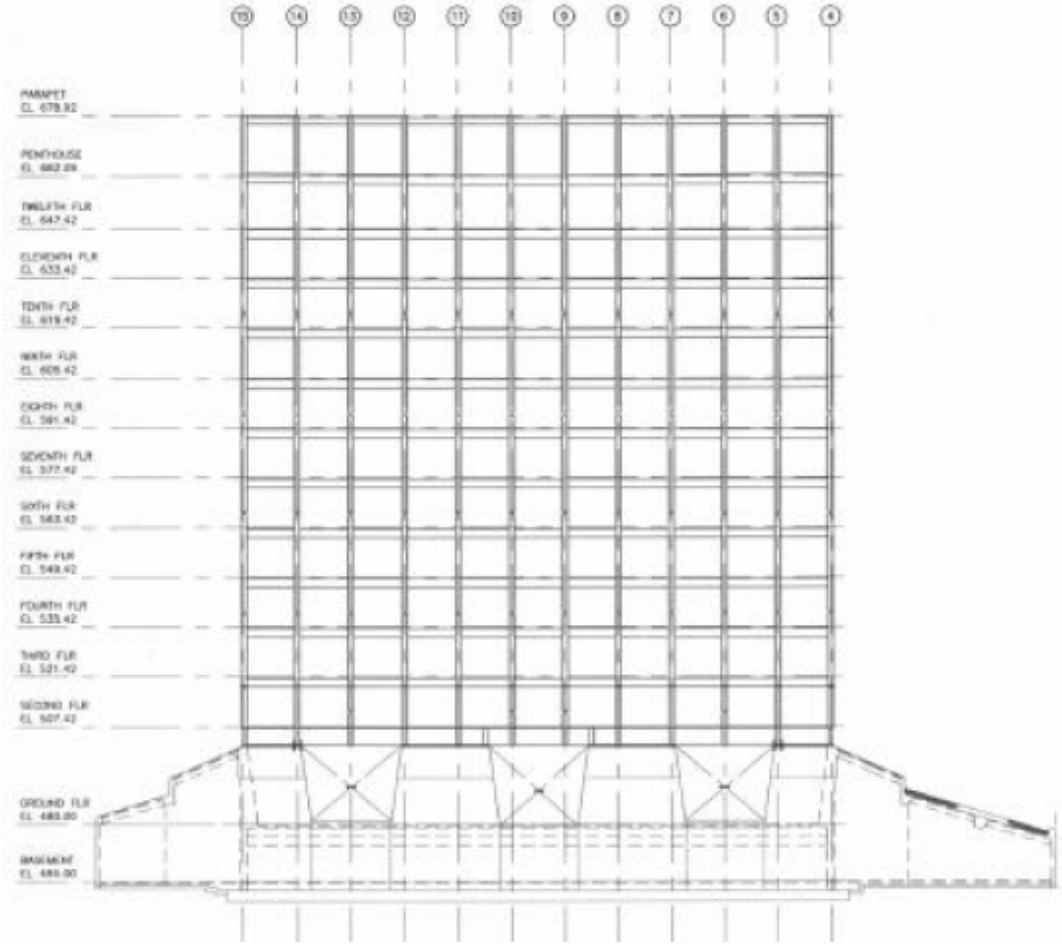


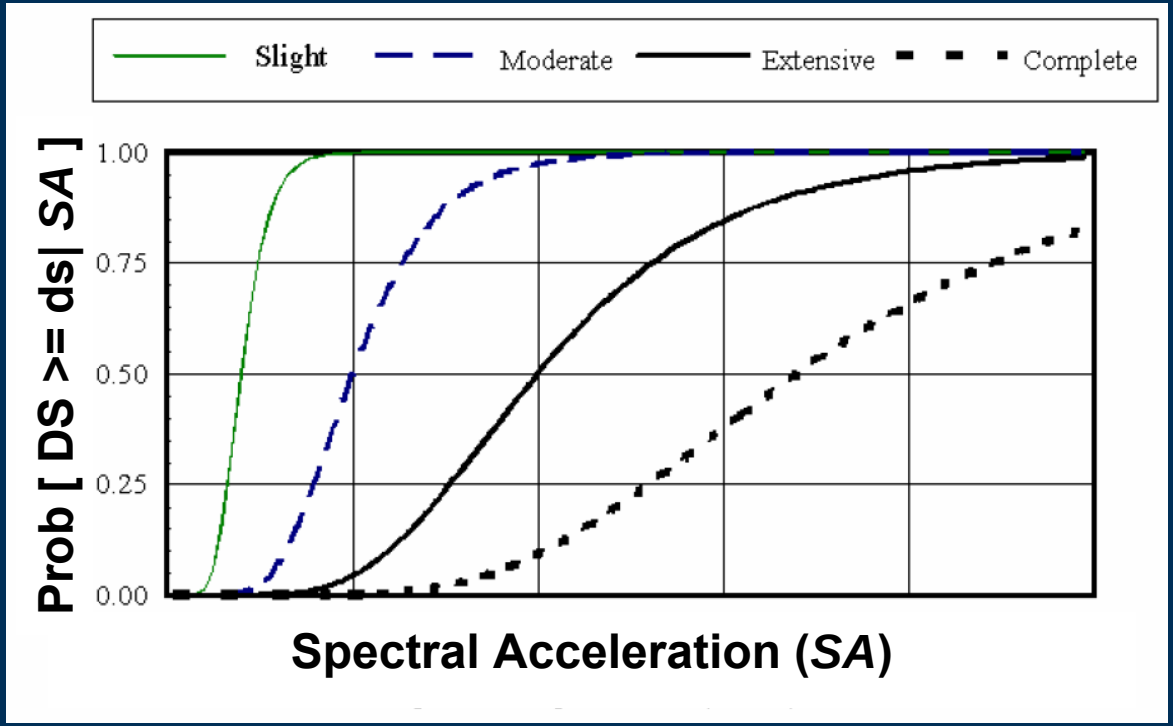
Figure 8.3. Elevation View at Perimeter of the DPW Building [Chen et al., 2001]

Outline of Material

- **How is seismic risk different than seismic hazard, and how is it computed?**
- **Components of seismic risk** (with HAZUS examples)
  - **Hazard**
  - **Exposure/Inventory**
  - **Fragility/Vulnerability**
- **Examples of seismic risk analysis results**

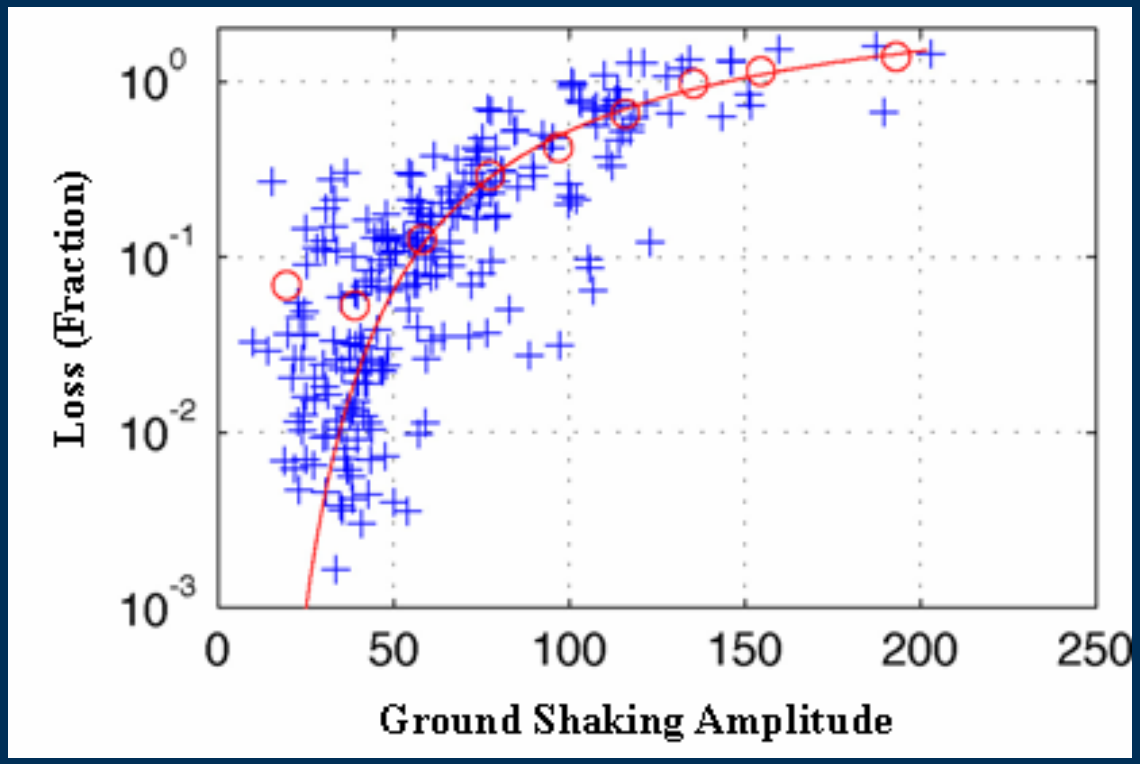
Fragility / Vulnerability

- Conditional probability of exceeding a specified amount of damage (or loss) as a function of the ground motion level, e.g., …



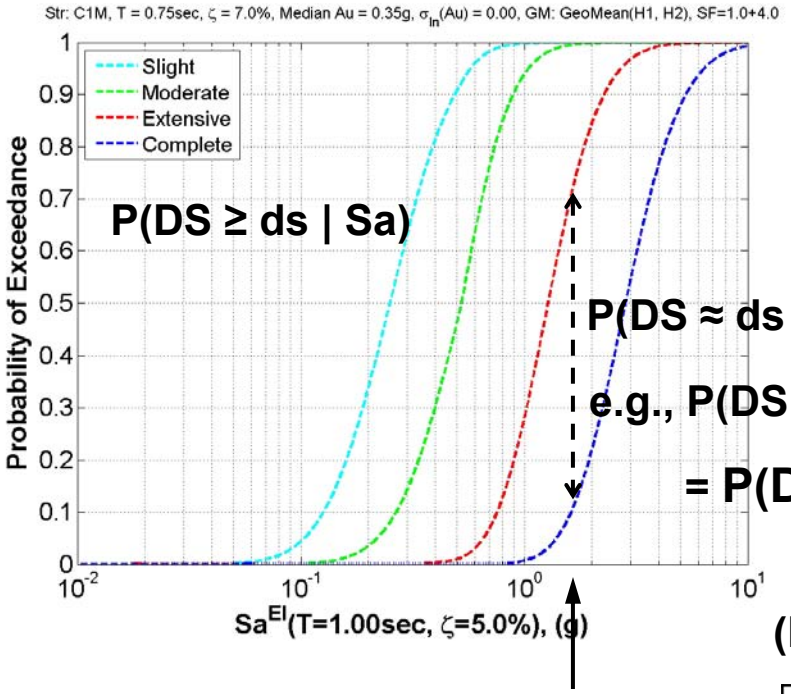
Vulnerability / Fragility

- Expected amount of loss as a function of the ground motion level, e.g., …



Fragility / Vulnerability

Fragility Curve



P(DS ≥ ds | Sa)

P(DS ≈ ds | Sa)

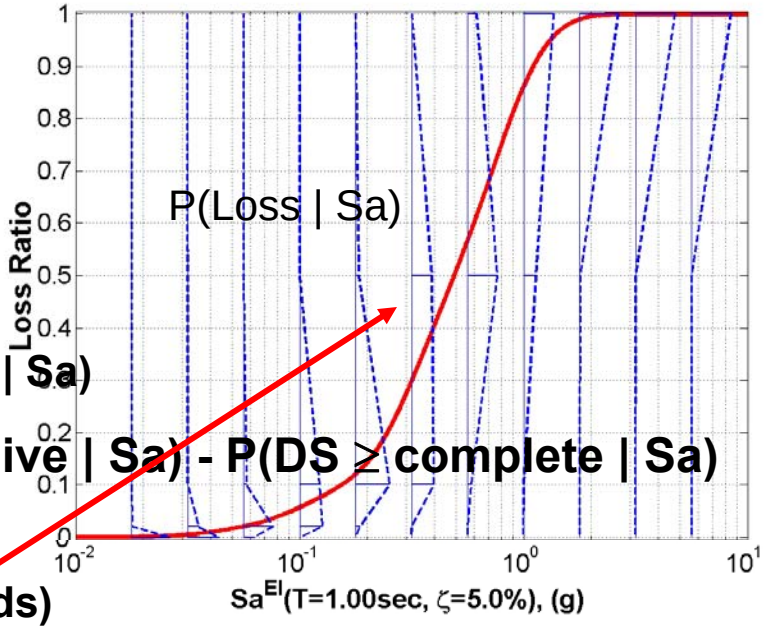
e.g., P(DS ≈ extensive | Sa)

= P(DS ≥ extensive | Sa) - P(DS ≥ complete | Sa)

(Loss | DS ≈ ds)

Spectral acceleration, PGA, MMI,
Inelastic spectral displacement, or,
Inter-story drift ratio, …

Vulnerability Curve



Damage State	Loss Ratio
Slight	2%
Moderate	10%
Extensive	50%
Complete	100%

$$E[Loss \mid Sa] = \sum_{ds} (Loss \mid DS \approx ds) \times P[DS \approx ds \mid Sa]$$

Building Fragility Curves (HAZUS)

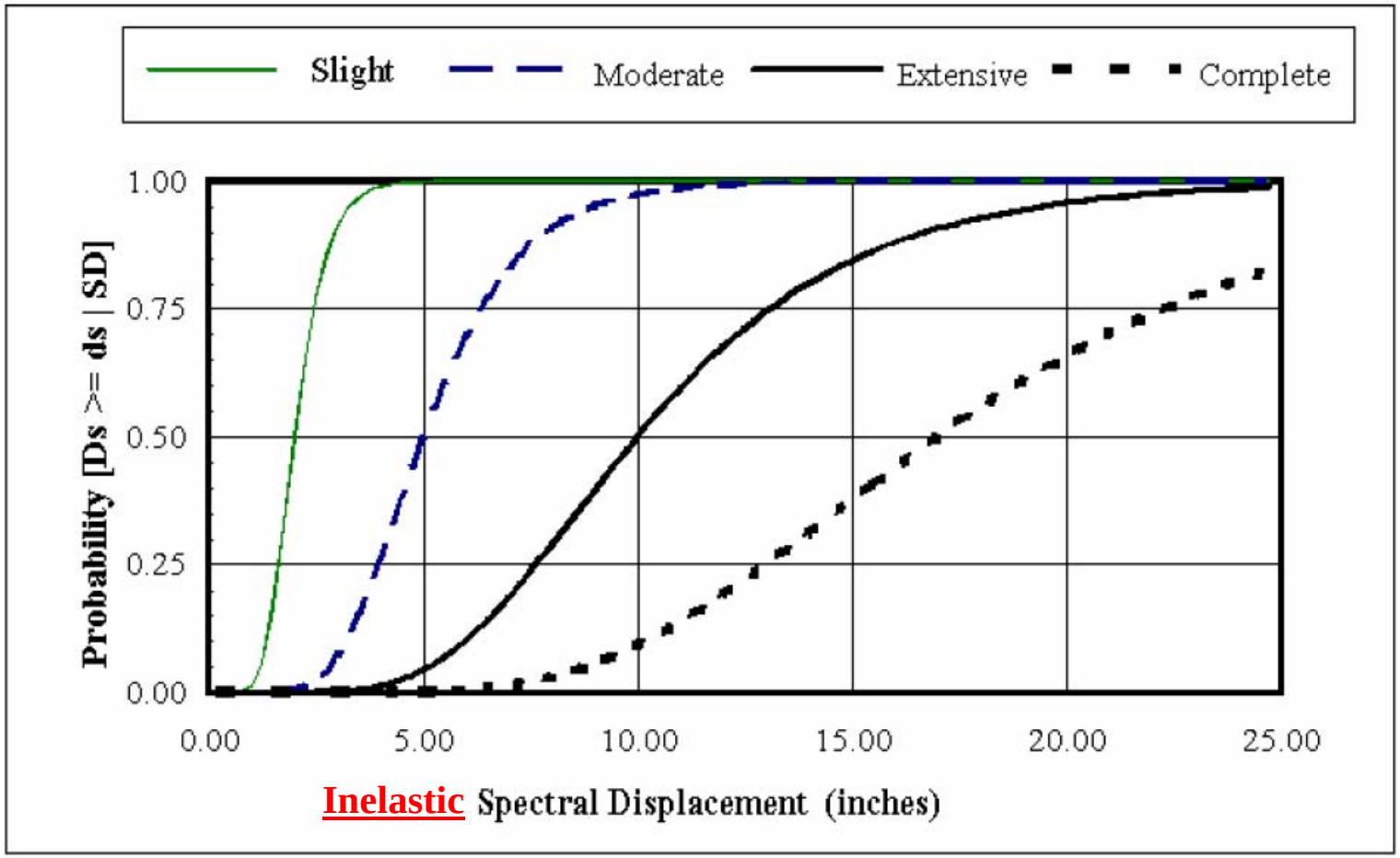
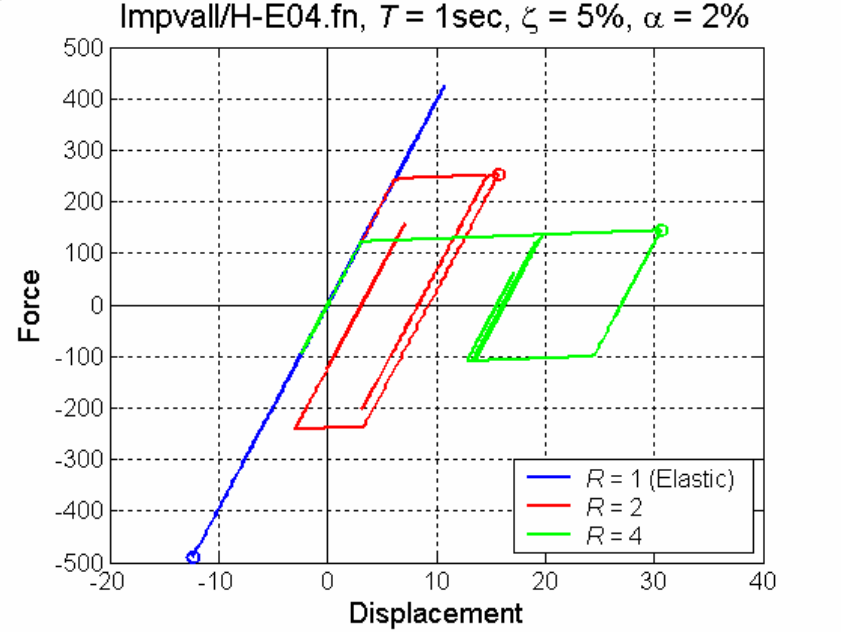


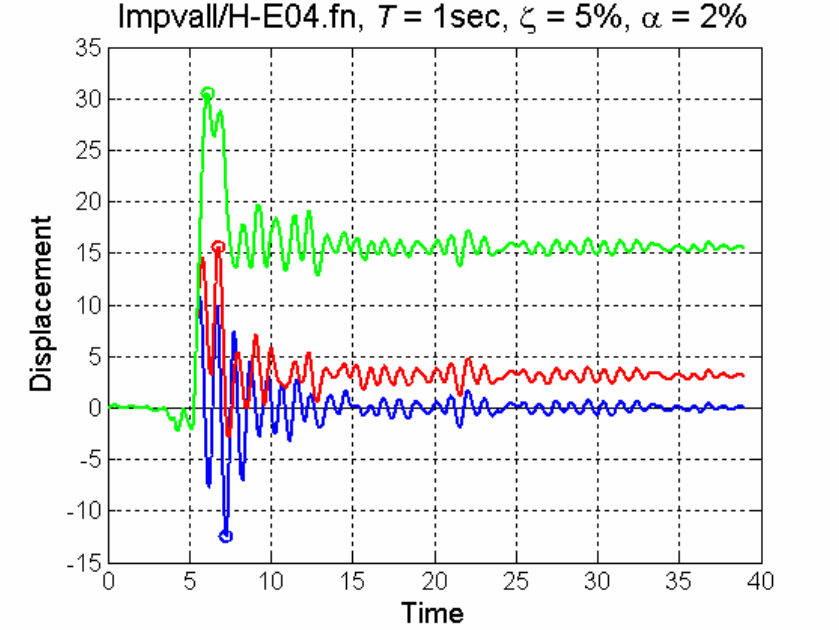
Figure 5.1 Example Fragility Curves for Slight, Moderate, Extensive and Complete Damage.

Sidebar – Inelastic Spectral Displacement

$$S_a(T,\zeta) \equiv \text{peak acceleration of elastic oscillator} \approx \frac{S_d(T,\zeta)}{(T/2\pi)^2}$$

$$S_d(T,\zeta,R,\alpha) \equiv \text{peak displacement of inelastic oscillator}$$





Capacity Spectrum Method (HAZUS)

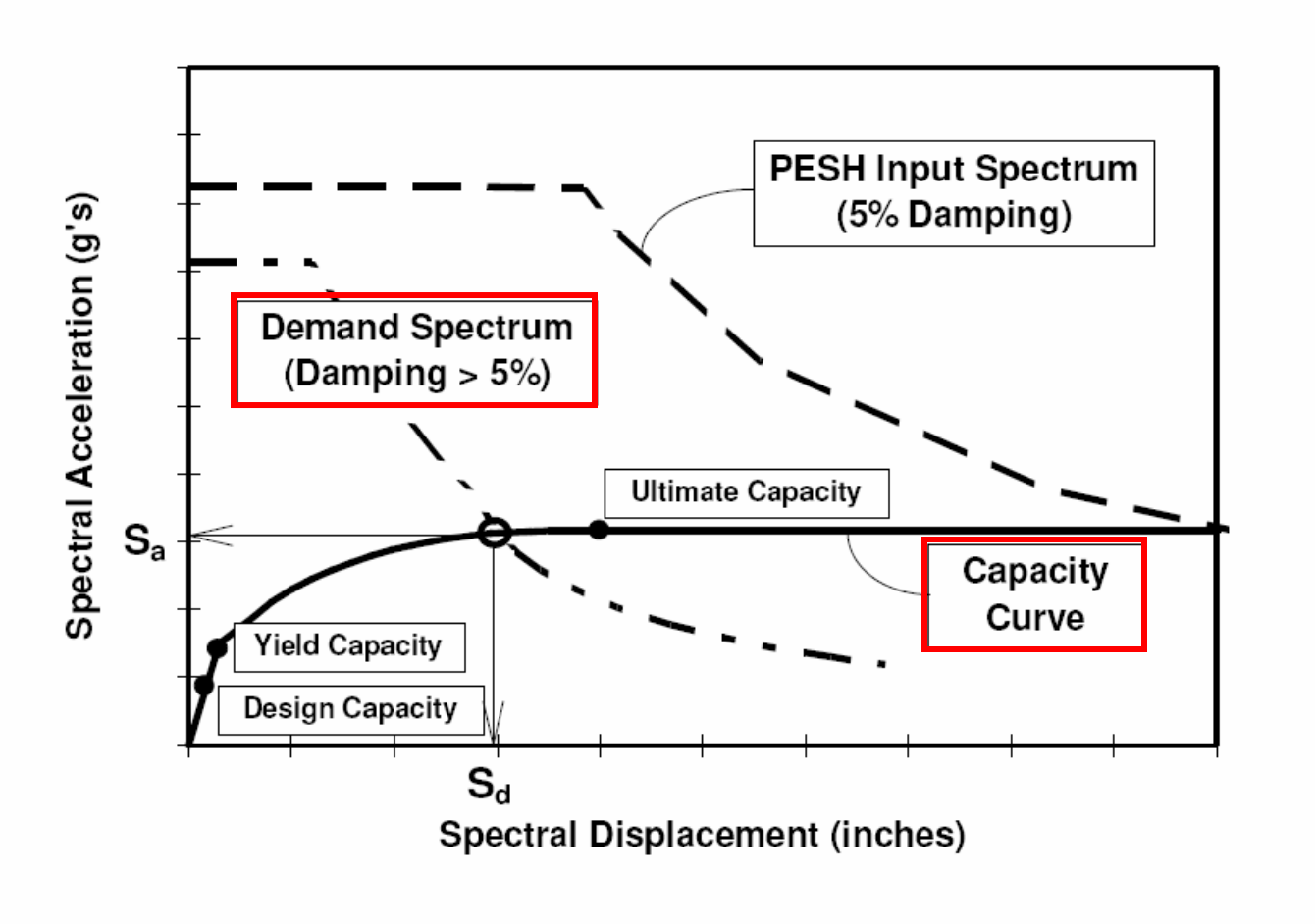
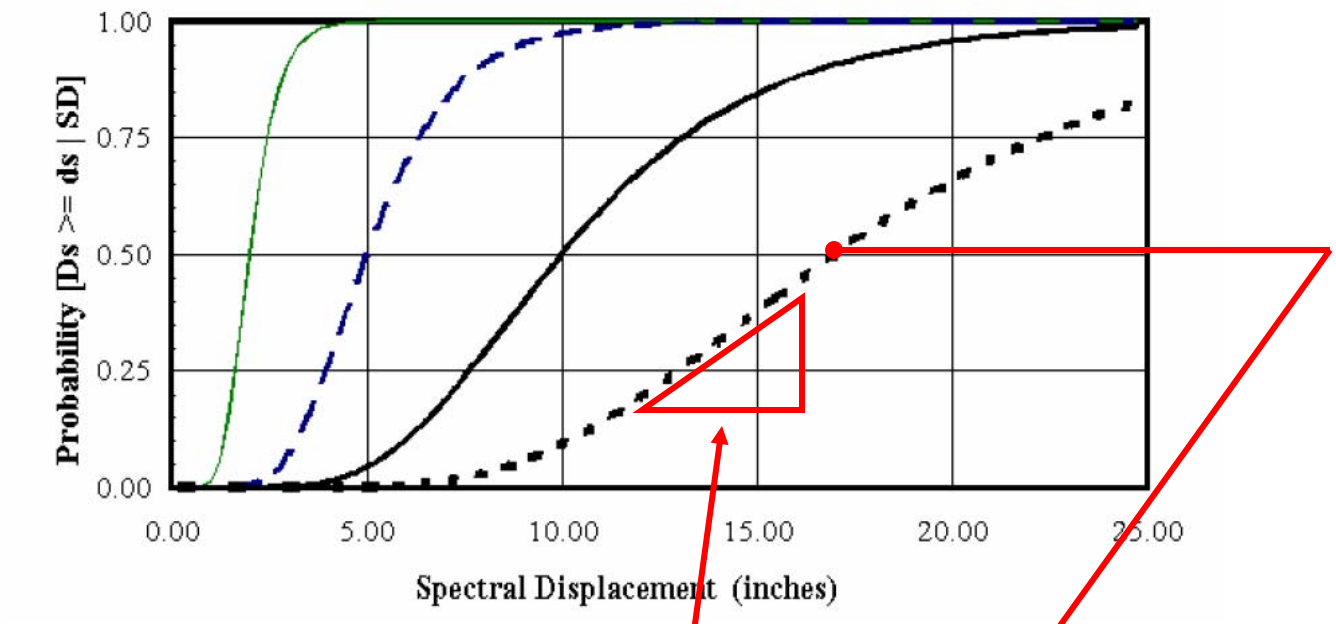


Figure 5.2 Example Building Capacity Curve and Demand Spectrum.

Building Fragility Curves (HAZUS)

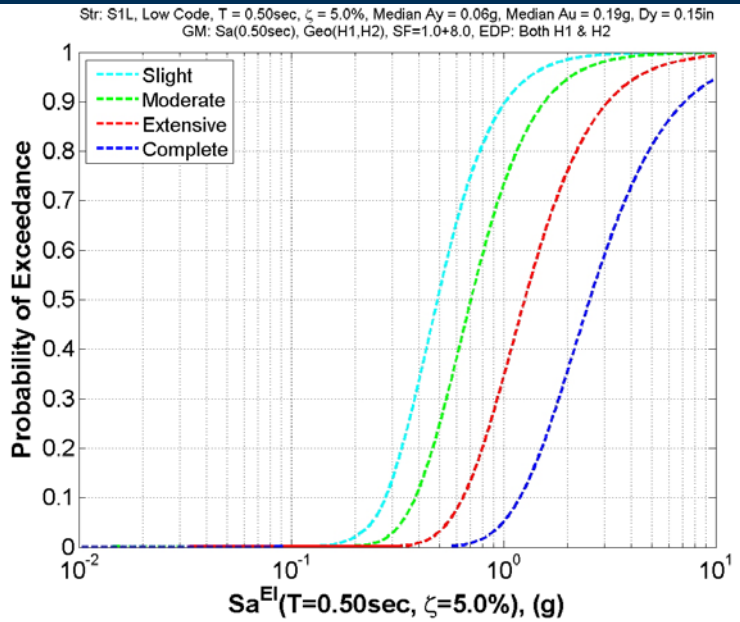


$$P[DS \mid S_d] = \Phi\left[\frac{1}{\beta_{T,ds}} \ln\left(\frac{S_d}{\overline{S}_{d,ds}}\right)\right]$$

$$\beta_{T,ds} \rightarrow \beta_{ds} = \sqrt{(CONV(\beta_C, \beta_D))^2 + (\beta_{T,ds})^2}$$

Capacity Curve uncertainty = β_C **β_D = Demand Spectrum Uncertainty**

Revamping HAZUS Fragilities (USGS)



- Revamped HAZUS fragilities are:

  1) Based on nonlinear dynamic structural analysis rather than Capacity Spectrum Method.

  2) Independent of ground motion variability, which is taken care of in hazard computation.

  3) Fully probabilistic with variability in ground motion and building response properly accounted for.

Revamping HAZUS Fragilities (USGS)

- Revamped HAZUS fragilities are (continued):

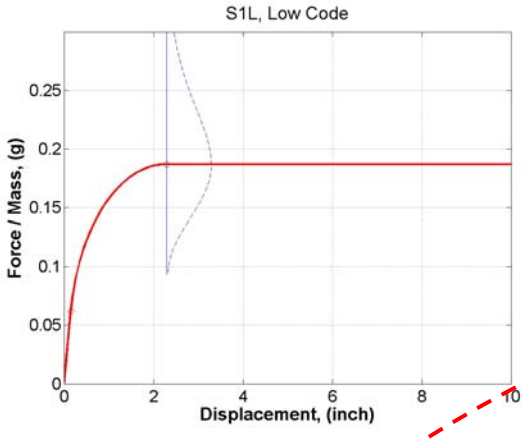
  4) In terms of ground motion parameters for which hazard is typically computed, e.g., S_a(0.3s).

  5) Available for a large number of structures (all HAZUS building types and code levels).

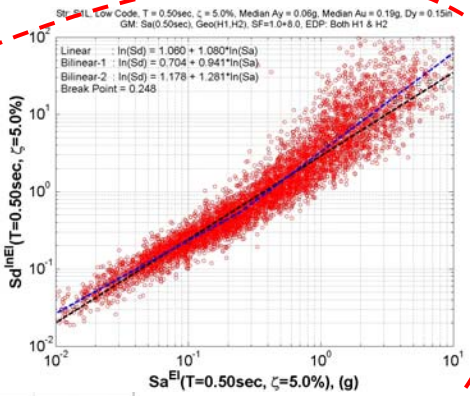
  6) Can be easily combined with seismic hazard information to …

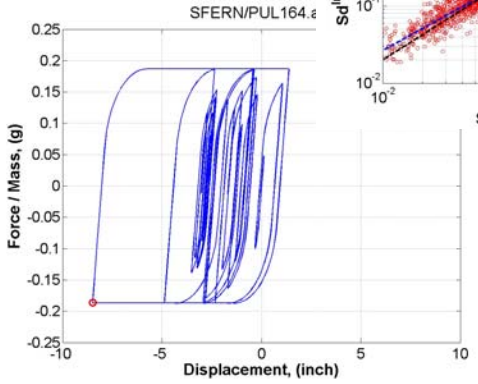
     - Evaluate seismic risk, e.g. seismic risk maps.
     - Estimate losses from a scenario event, e.g. seismic damage maps.
     - Evaluate building design/mitigation options, e.g. SBC vs IBC design.

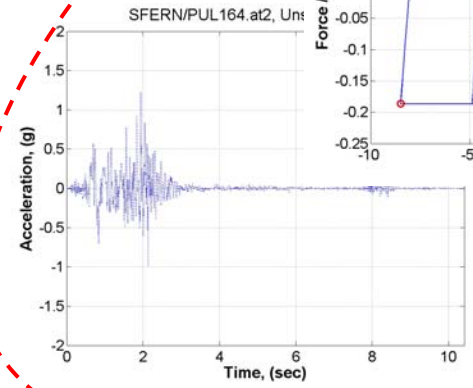
Revamping HAZUS Fragilities (USGS)



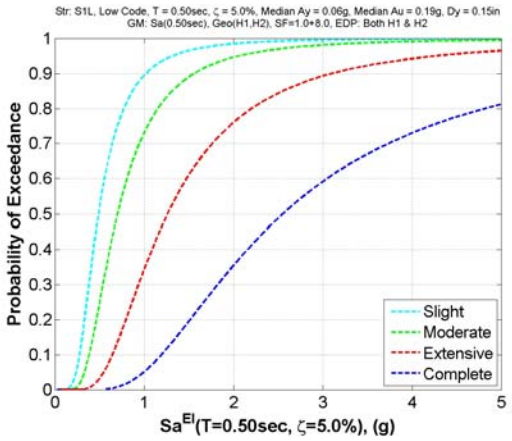
Capacity Curve







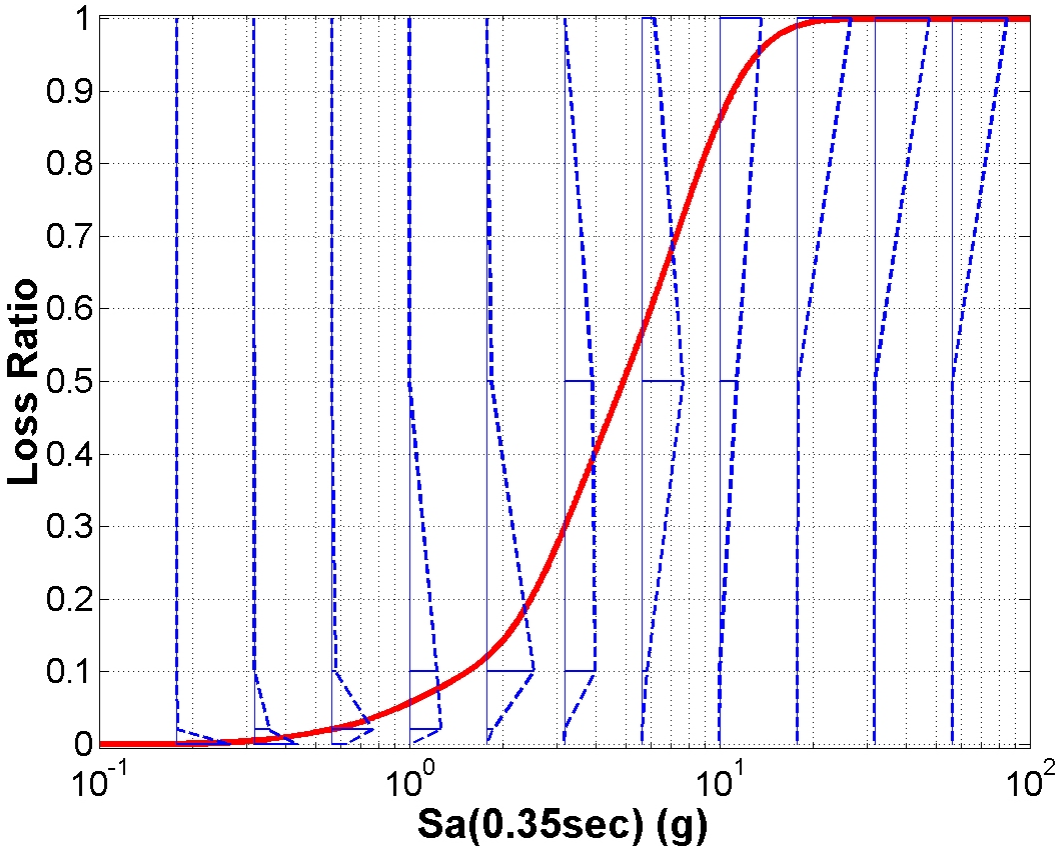
Time History Analysis



Fragility Curve in terms of **Elastic Spectral Acceleration**

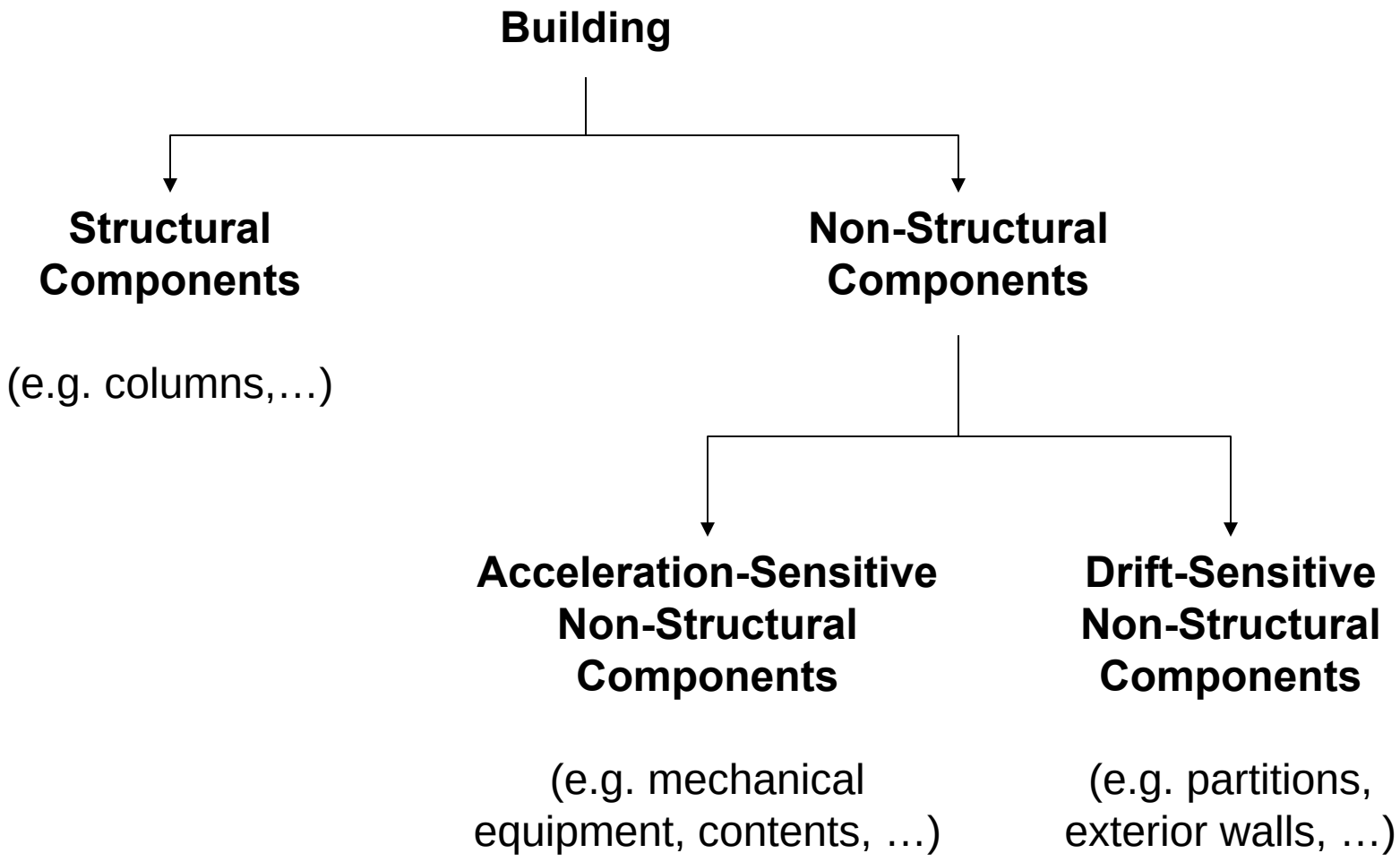
Revamping HAZUS Fragilities (USGS)

- Result: Vulnerability curve.



- Can also easily relate Loss to a vector of two (or more) GM parameters (e.g., S_a's at two different periods).

Building Components (HAZUS)



Individual Building/Structure (HAZUS)

- Advance Engineering Building Module (AEBM)
  - Building-specific fragility/vulnerability curves
  - Extension of HAZUS methodology
  - More accurate than generic model building types
  - For structural/seismic engineers
  - Makes evaluation of retrofit possible

Outline of Material

- **How is seismic risk different than seismic hazard, and how is it computed?**
- **Components of seismic risk** (with HAZUS examples)
  - **Hazard**
  - **Exposure/Inventory**
  - **Fragility/Vulnerability**
- **Examples of seismic risk analysis results**

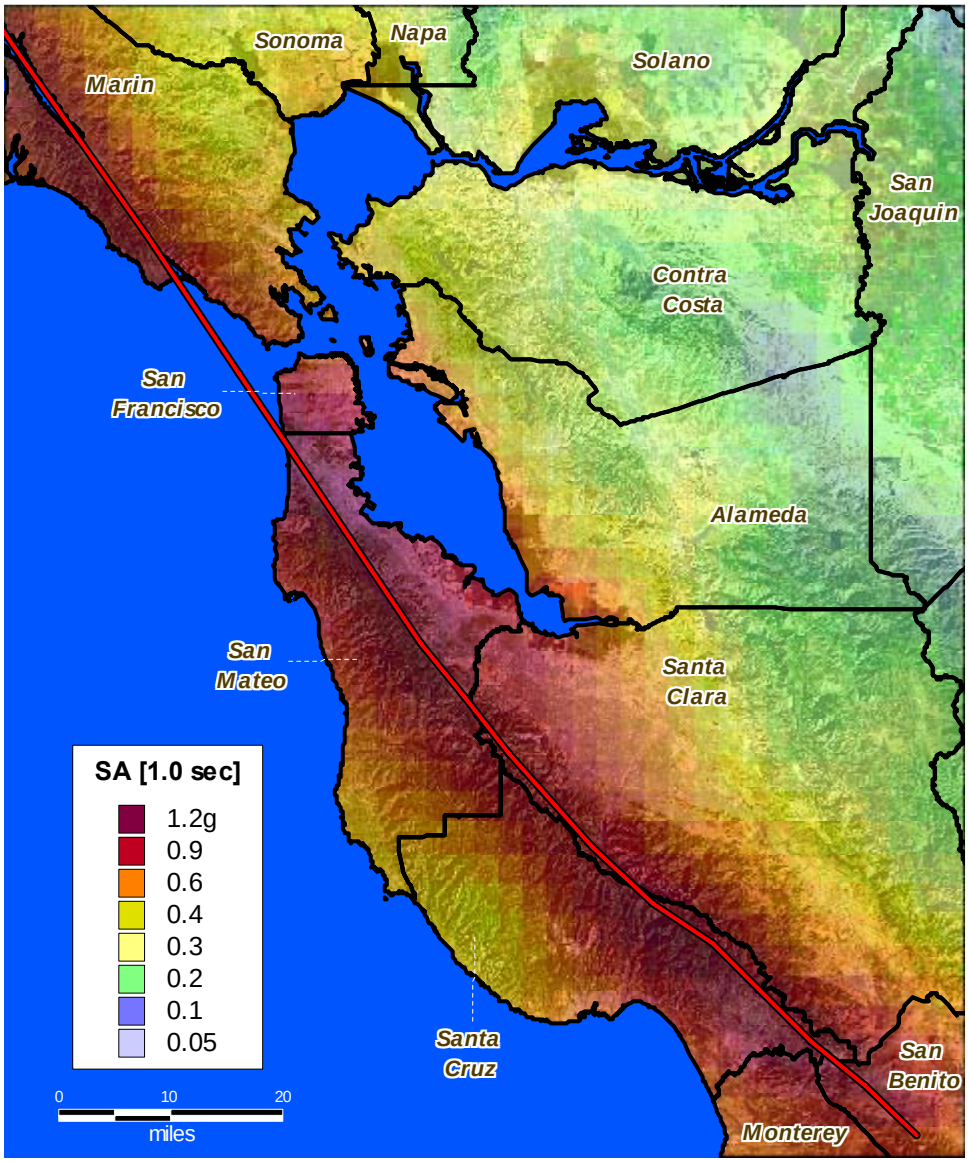
Examples of seismic risk analysis results

- Deterministic Scenarios (HAZUS)
  - HAZUS Example: Repeat of 1906 San Francisco Earthquake
  - M7.9 on San Andreas Fault
  - http://www.fema.gov/plan/prevent/hazus/dl_sfeqlosses.shtm
  - E[Loss | Earthquake]

- Probabilistic Scenarios (USGS)
  - Seismic Damage Maps, P[Loss | Earthquake]
  - Seismic Risk Maps, P[Loss] / year

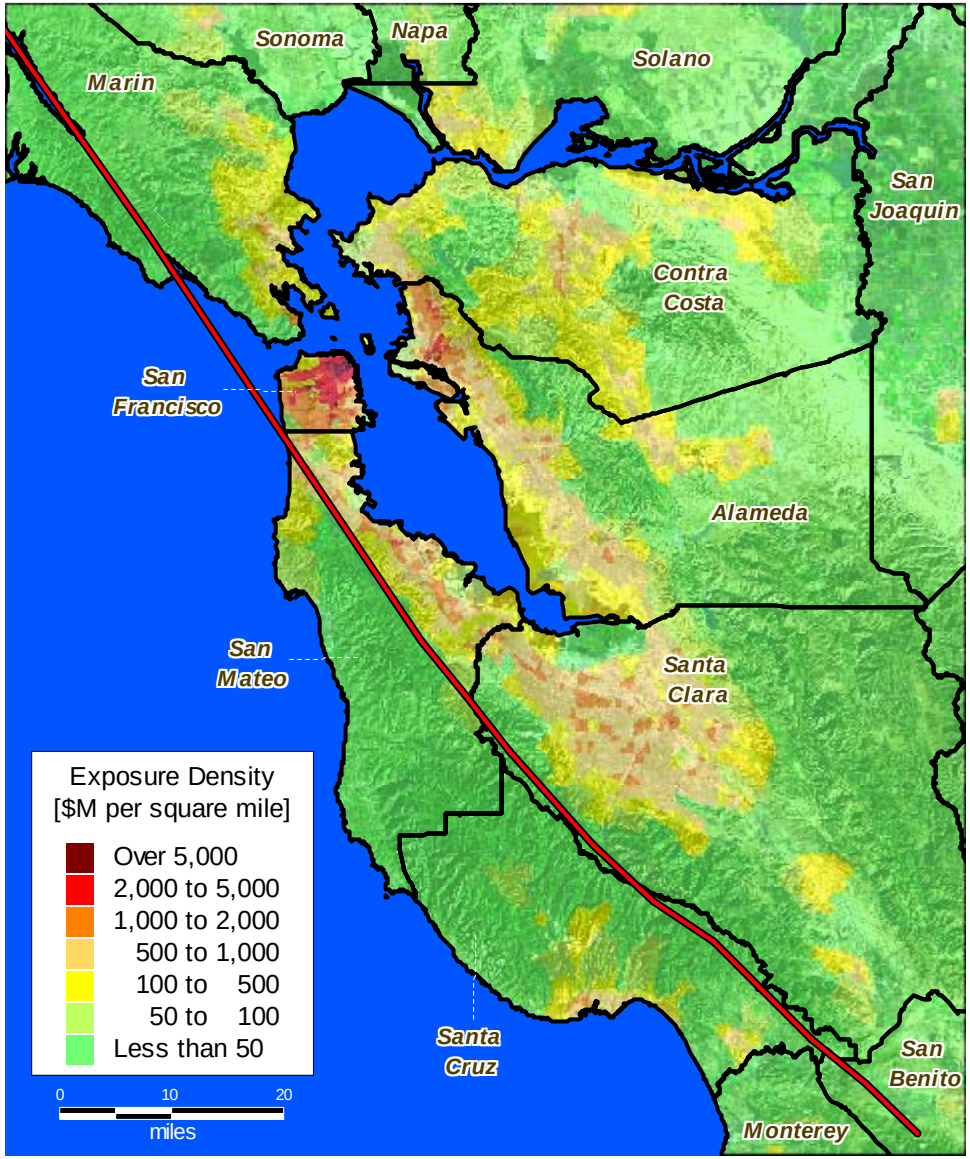
SF Eq. Example: Overview of Shaking (HAZUS)

- All counties will be affected
- San Francisco, San Mateo, and Santa Clara counties with highest risk (combination of strong shaking and dense / vulnerable assets)



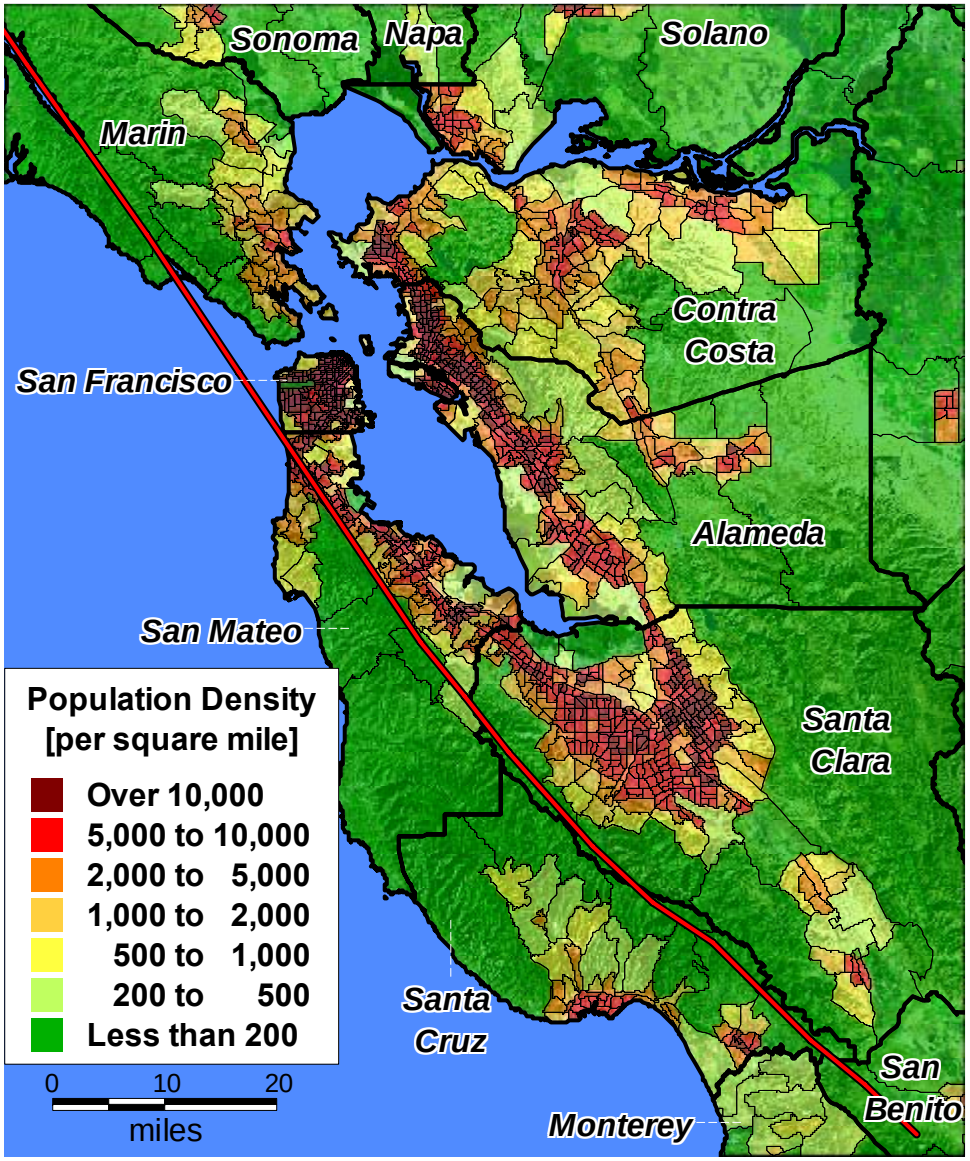
SF Eq. Example: Overview of Assets at Risk (HAZUS)

- 1.1 trillion dollars of building exposure
- 780 Billion dollars of residential exposure
- 204 Billion dollars of commercial exposure
- 43 billion dollars of industrial exposure



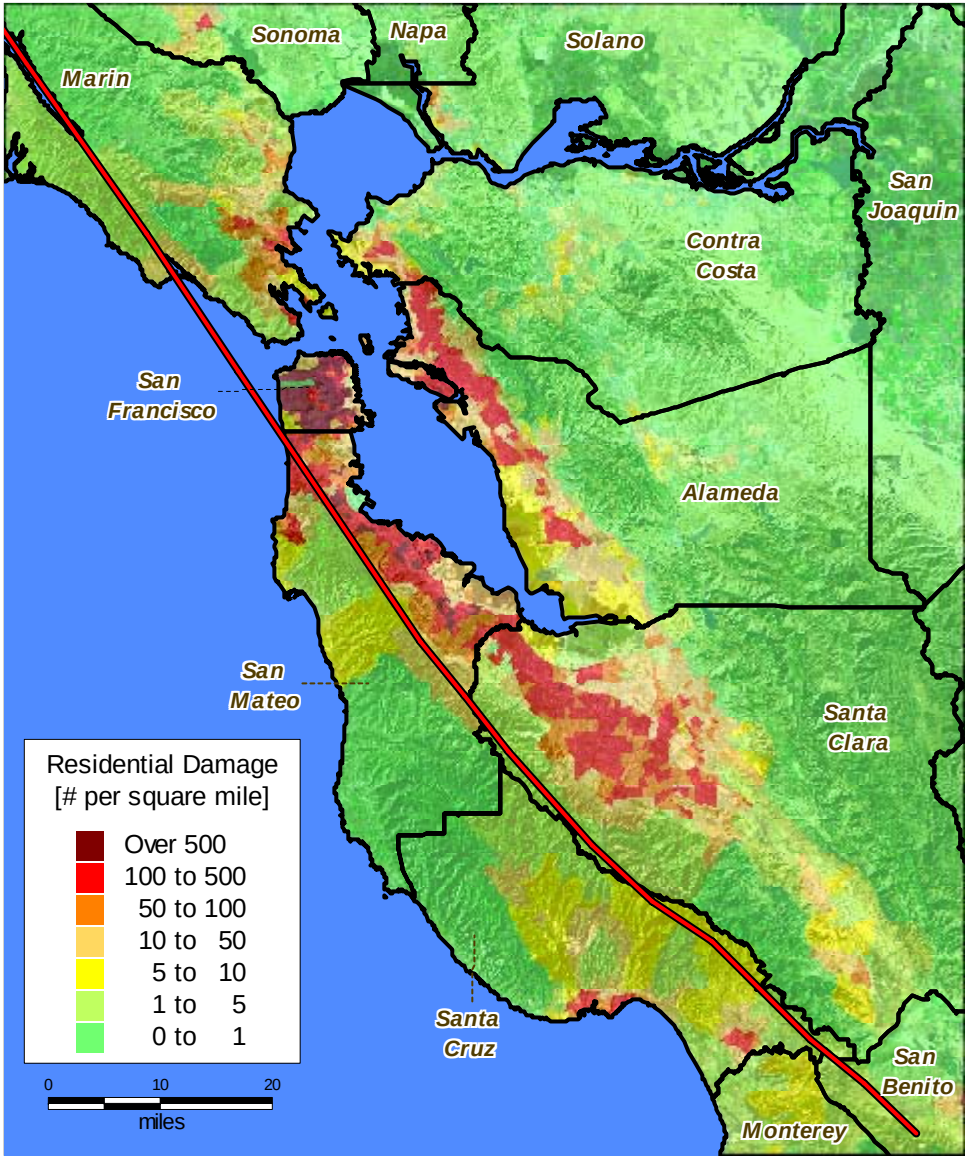
SF Eq. Example: Population at Risk (HAZUS)

- 10.5 million people
- 3.7 million households
- About 0.6 million households with annual income less than 20K
- About 1.2 million people over 65 years old



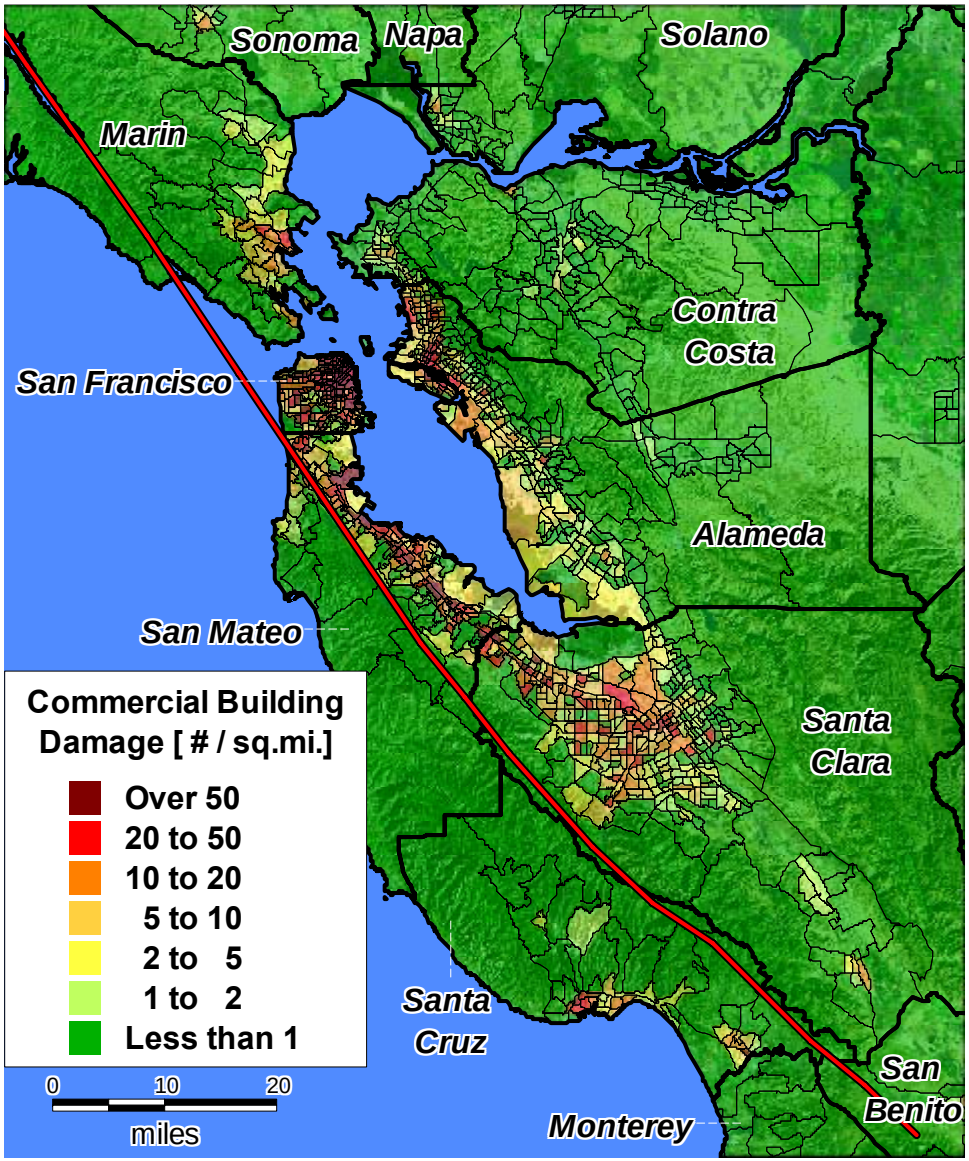
SF Eq. Example: Residential Damage (HAZUS)

- Over 3 million residences
- Over 100,000 residences potentially destroyed



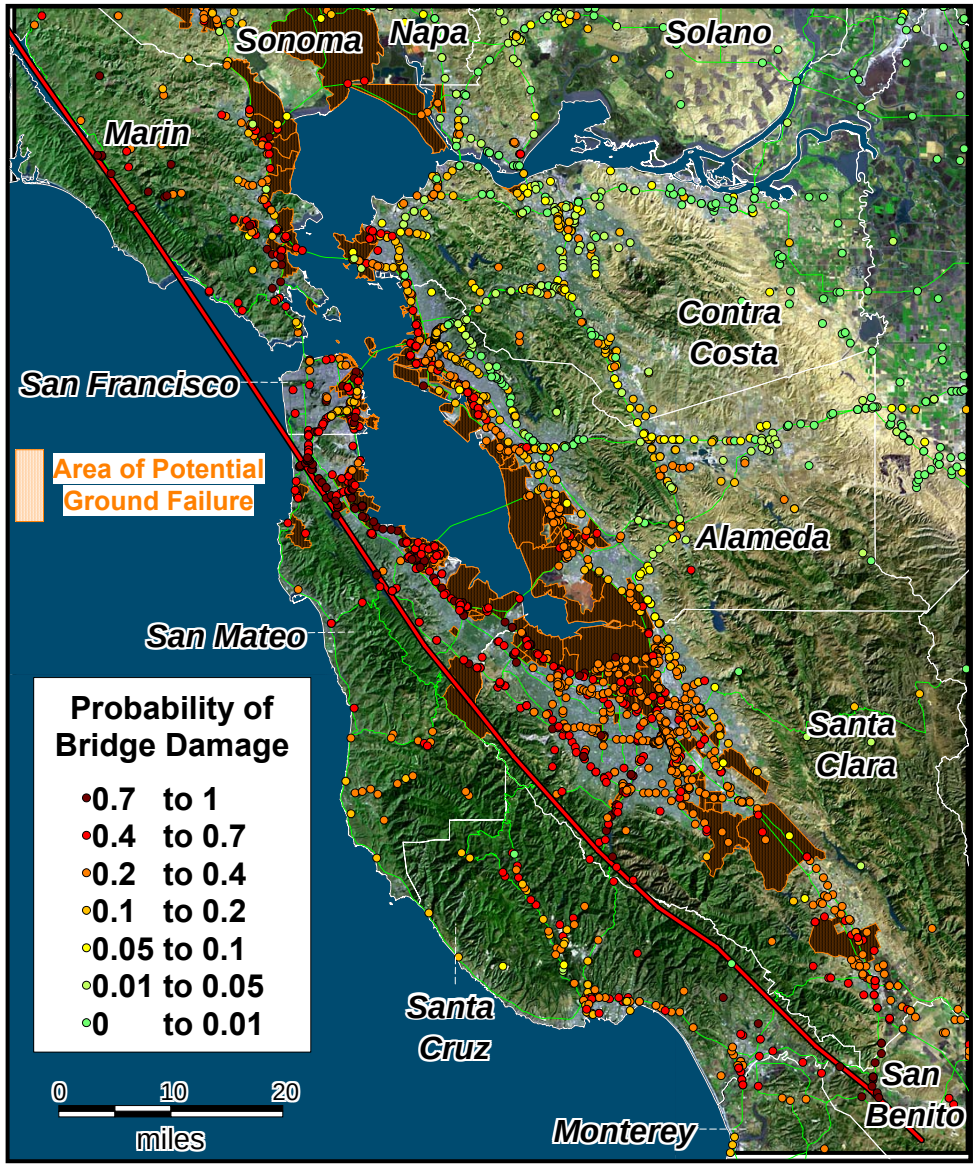
SF Eq. Example: Commercial Damage (HAZUS)

- About 70,000 commercial facilities
- Over 10,000 facilities with at least extensive damage



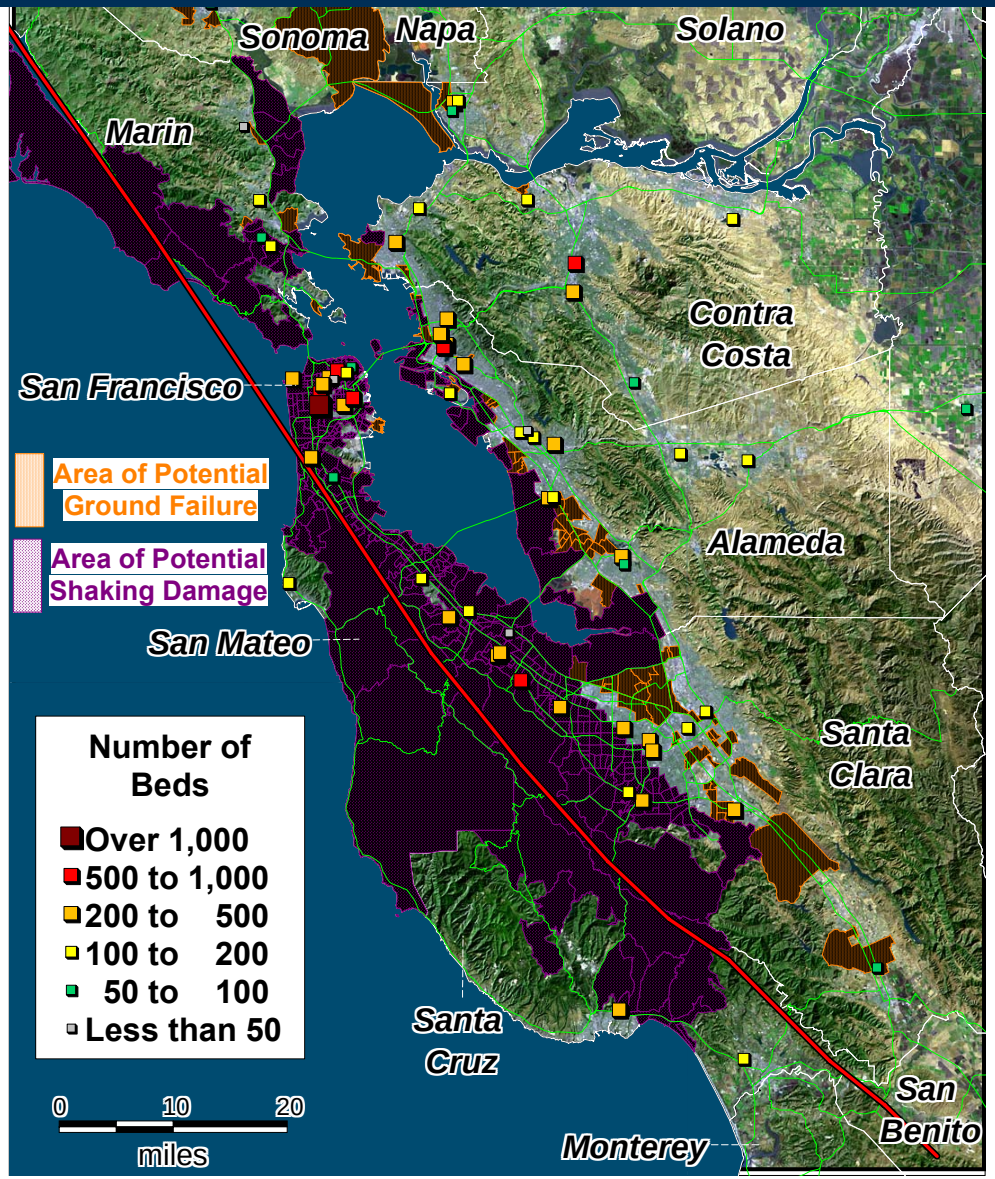
SF Eq. Example: Damage to Bridges (HAZUS)

- About 6900 bridges in 19-county area
- Over 1,300 bridges may require repairs
- Map shows damage to multi-span bridges



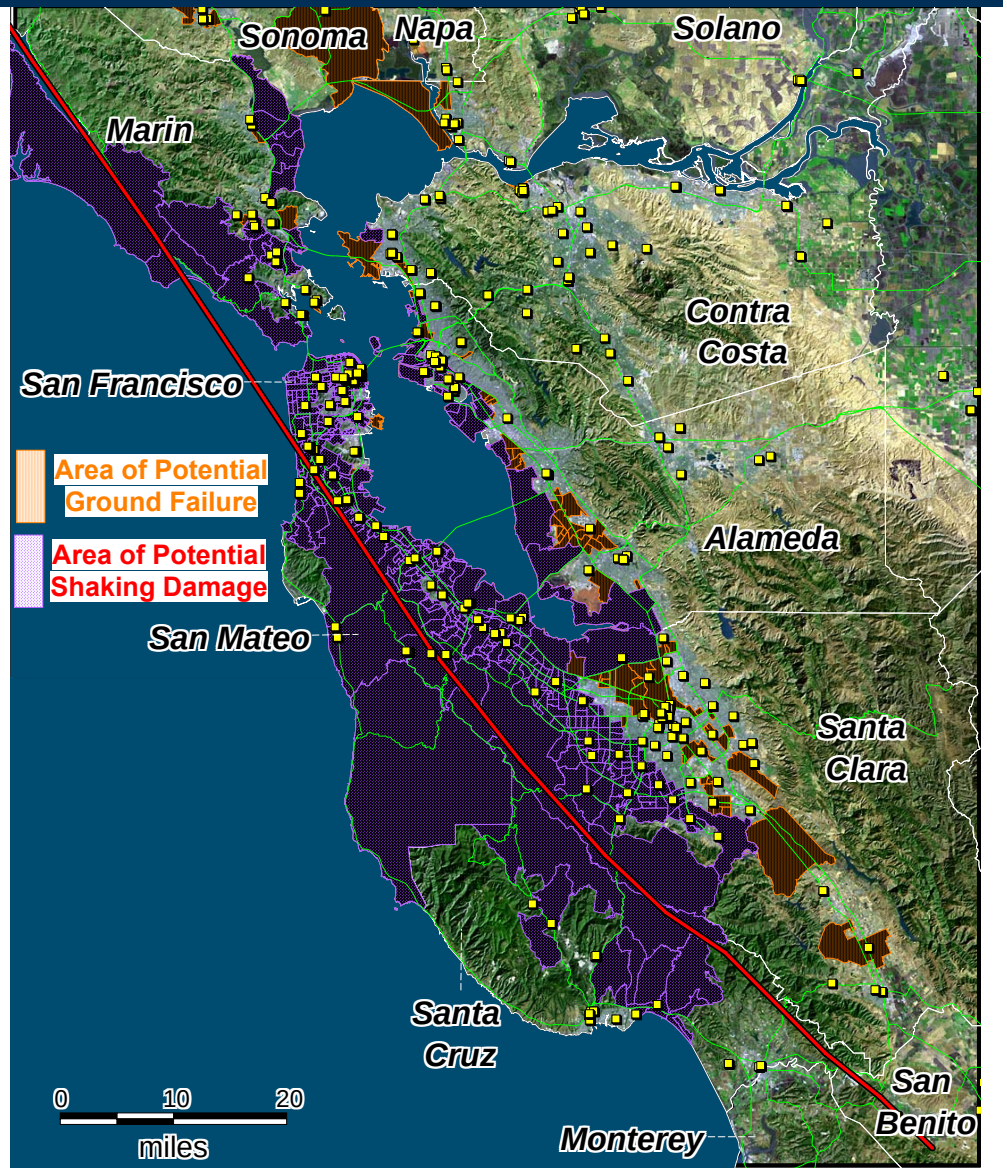
SF Eq. Example: Performance of Hospitals (HAZUS)

- About 120 hospitals (excluding clinics)
- About 30 to 50 hospitals may suffer minor to major damage



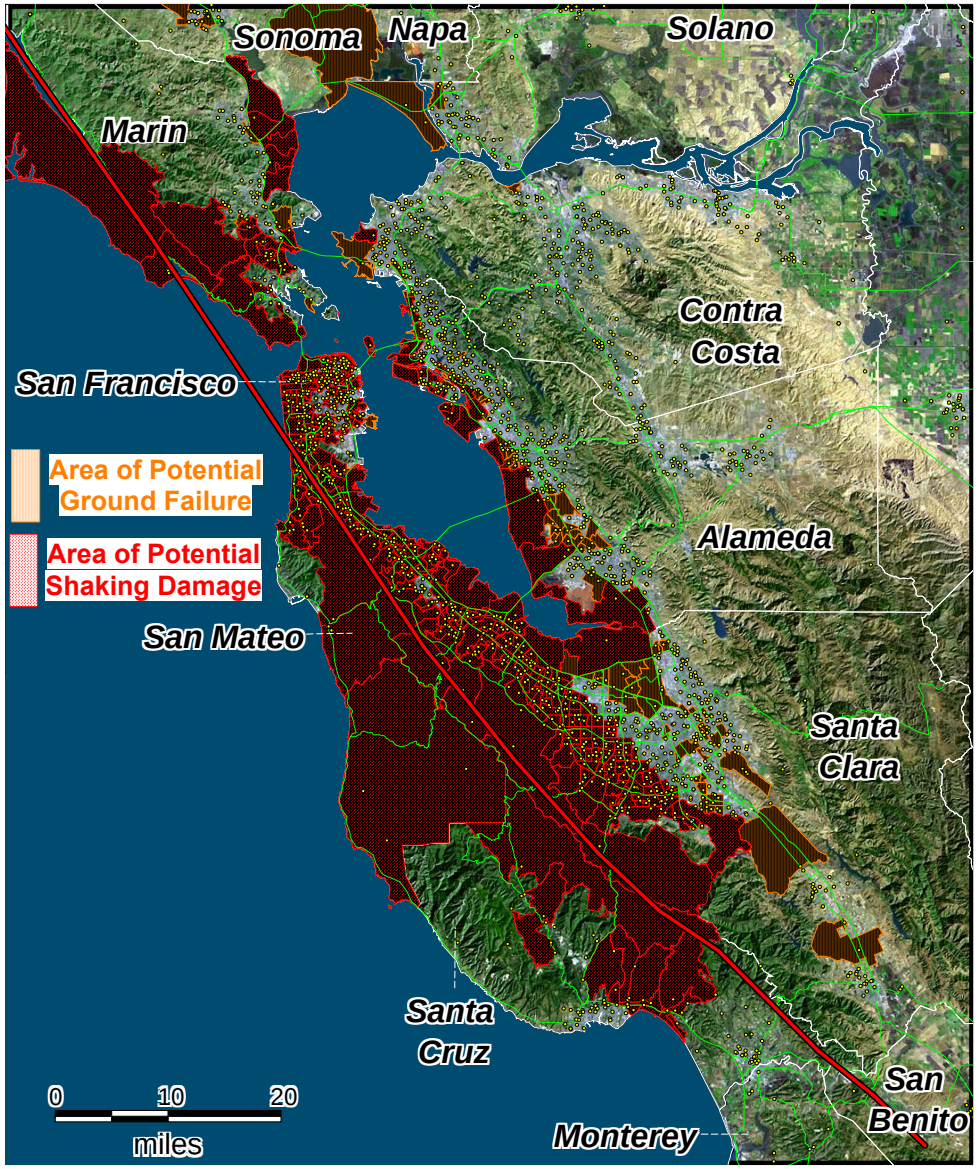
SF Eq. Example: Emergency Response Facilities

- 35 fire stations may be seriously affected
- 50 police stations may be seriously affected
- 2 EOC's potentially with significant damage



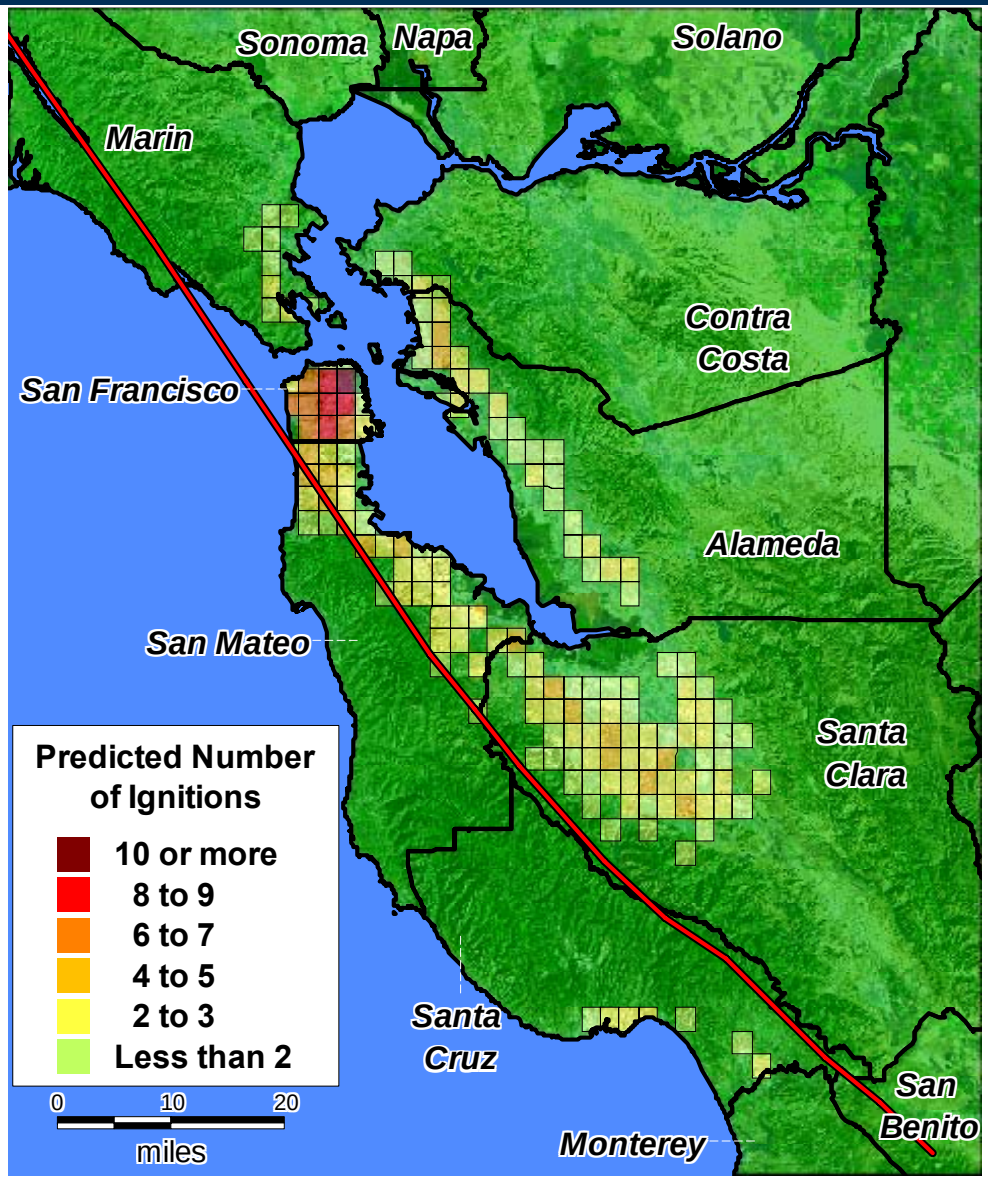
SF Eq. Example: School Performance (HAZUS)

- About 4,000 schools in 19-county area
- About 400 schools may be closed
- Schools shown in yellow dots



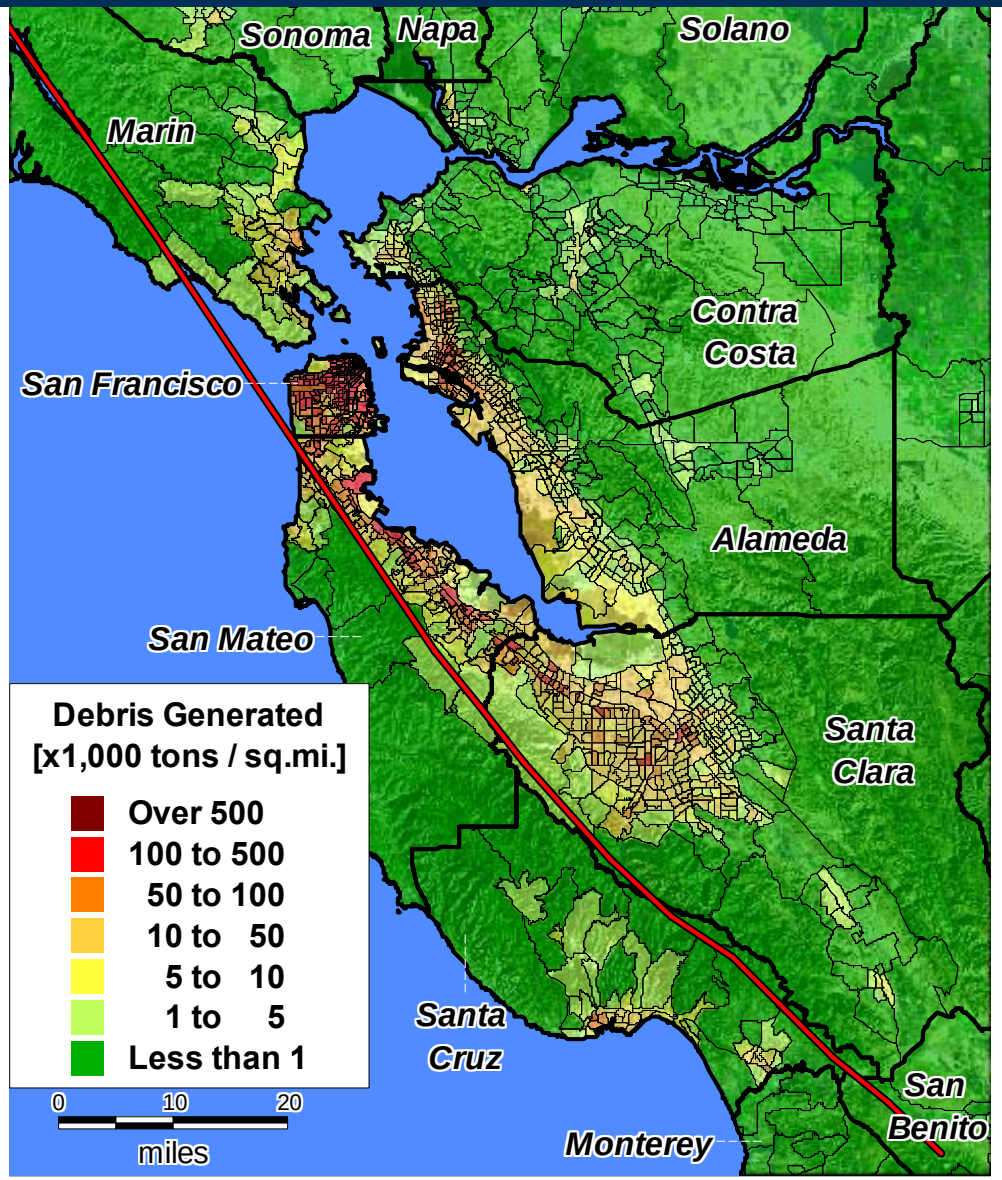
SF Eq. Example: Fire Ignitions and Consequences

- 500 to 600 Fires
- About 100 in San Francisco
- San Francisco, San Mateo, Santa Clara, Alameda, and Marin Counties at highest risk



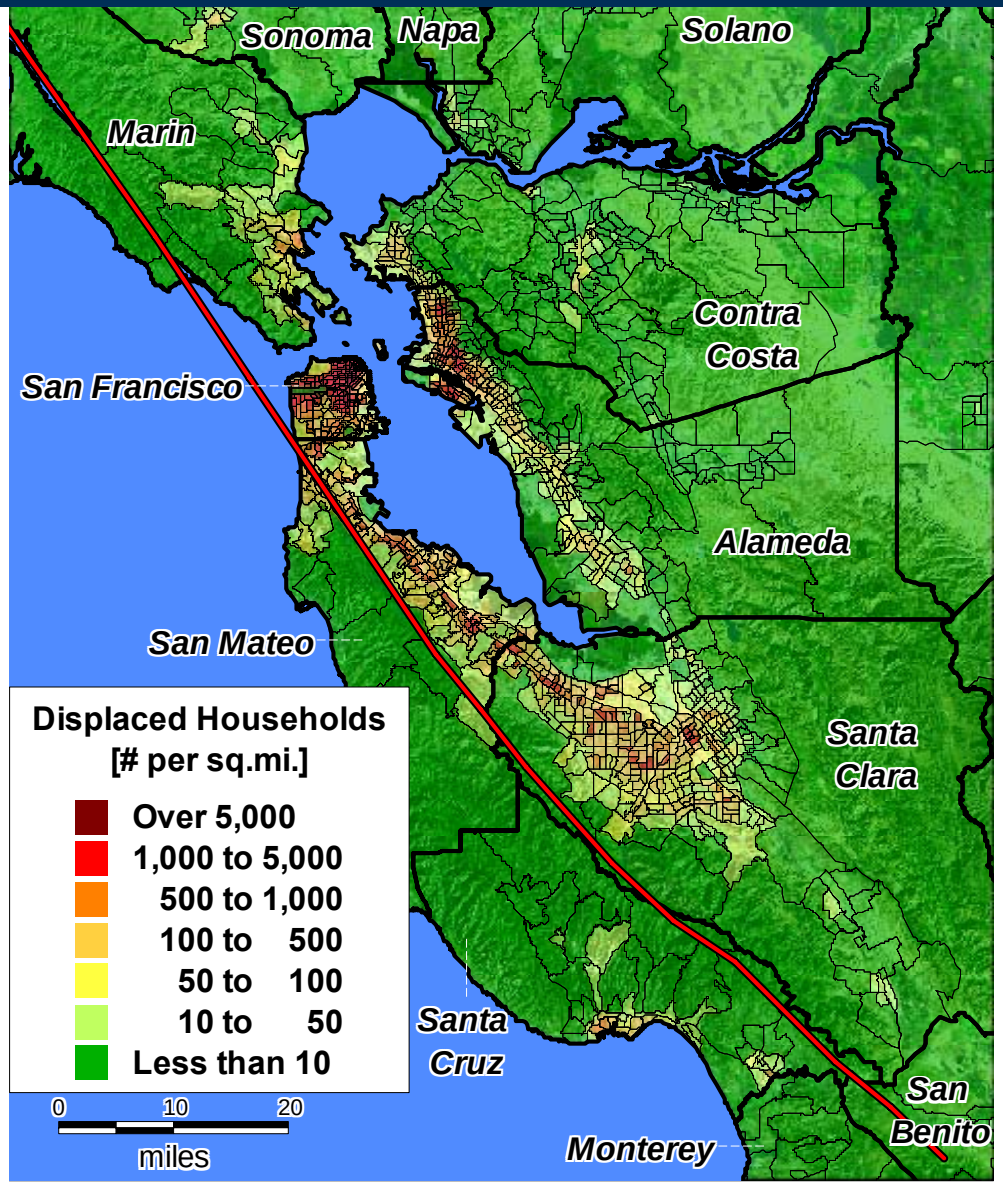
SF Eq. Example: Debris Generated (HAZUS)

- 25 to 40 Million tons of debris generated



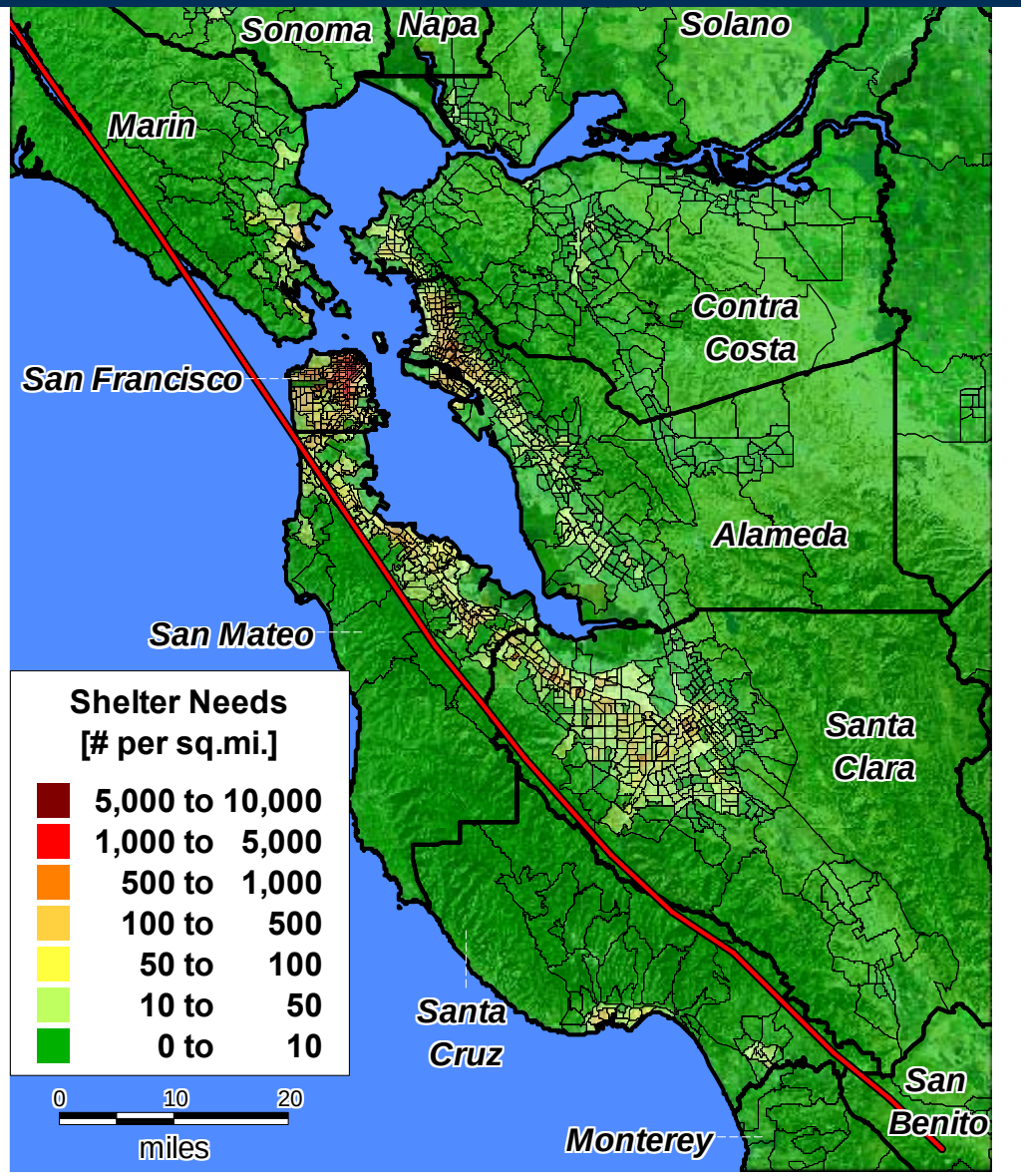
SF Eq. Example: Displaced Households (HAZUS)

- 200,000 to 300,000 displaced households



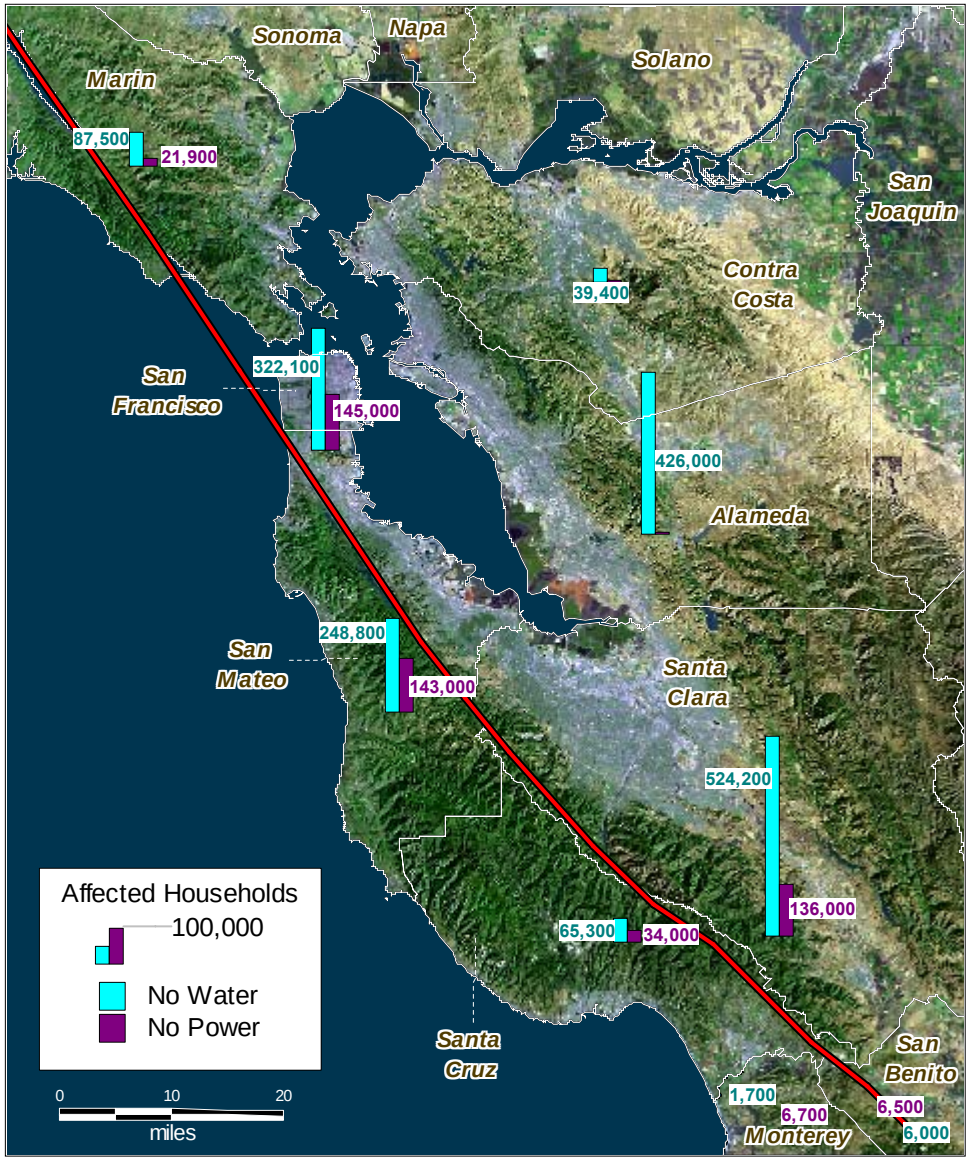
SF Eq. Example: Shelter Demand (HAZUS)

- 60,000 to 120,000 persons requiring short-term shelter



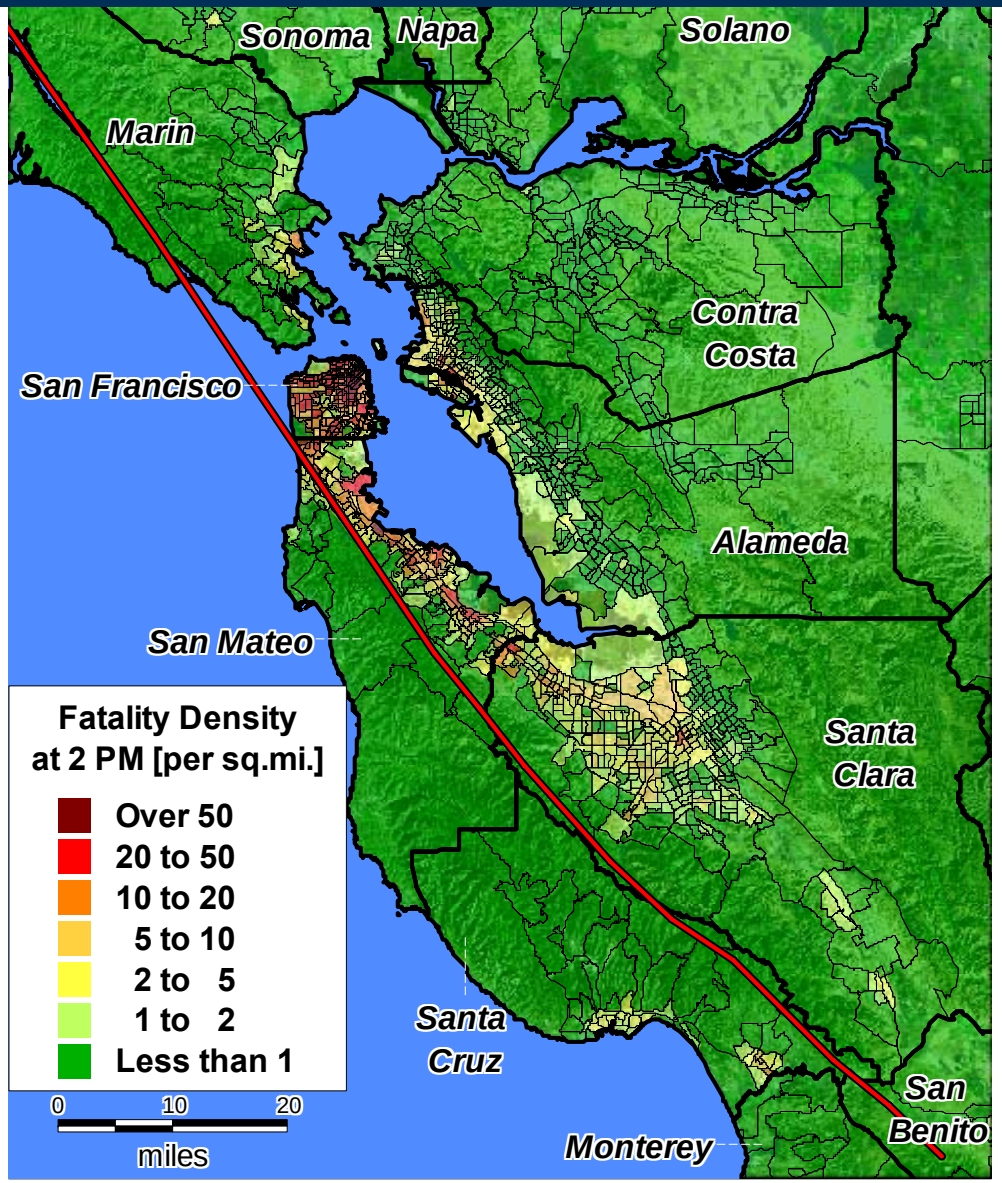
SF Eq. Example: Utility Disruption (HAZUS)

- Total Households in 19 counties = 3.66 Million
- Households without power (1 day after EQ) = 0.5 Million
- Households without water (1 day after EQ) = Over 1 Million



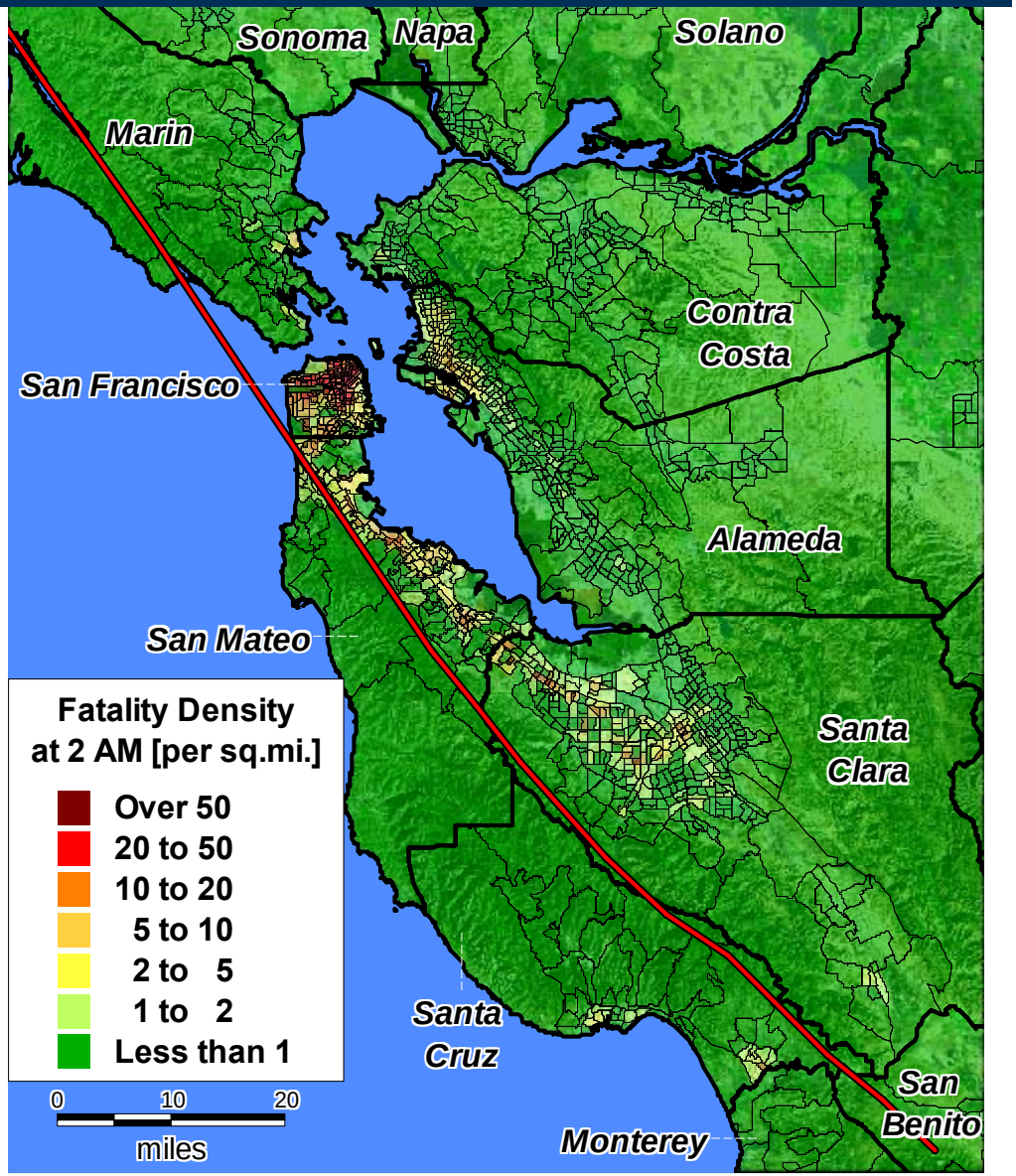
SF Eq. Example: Daytime Casualties (HAZUS)

- Injuries = 13,000
- Deaths = 3,400



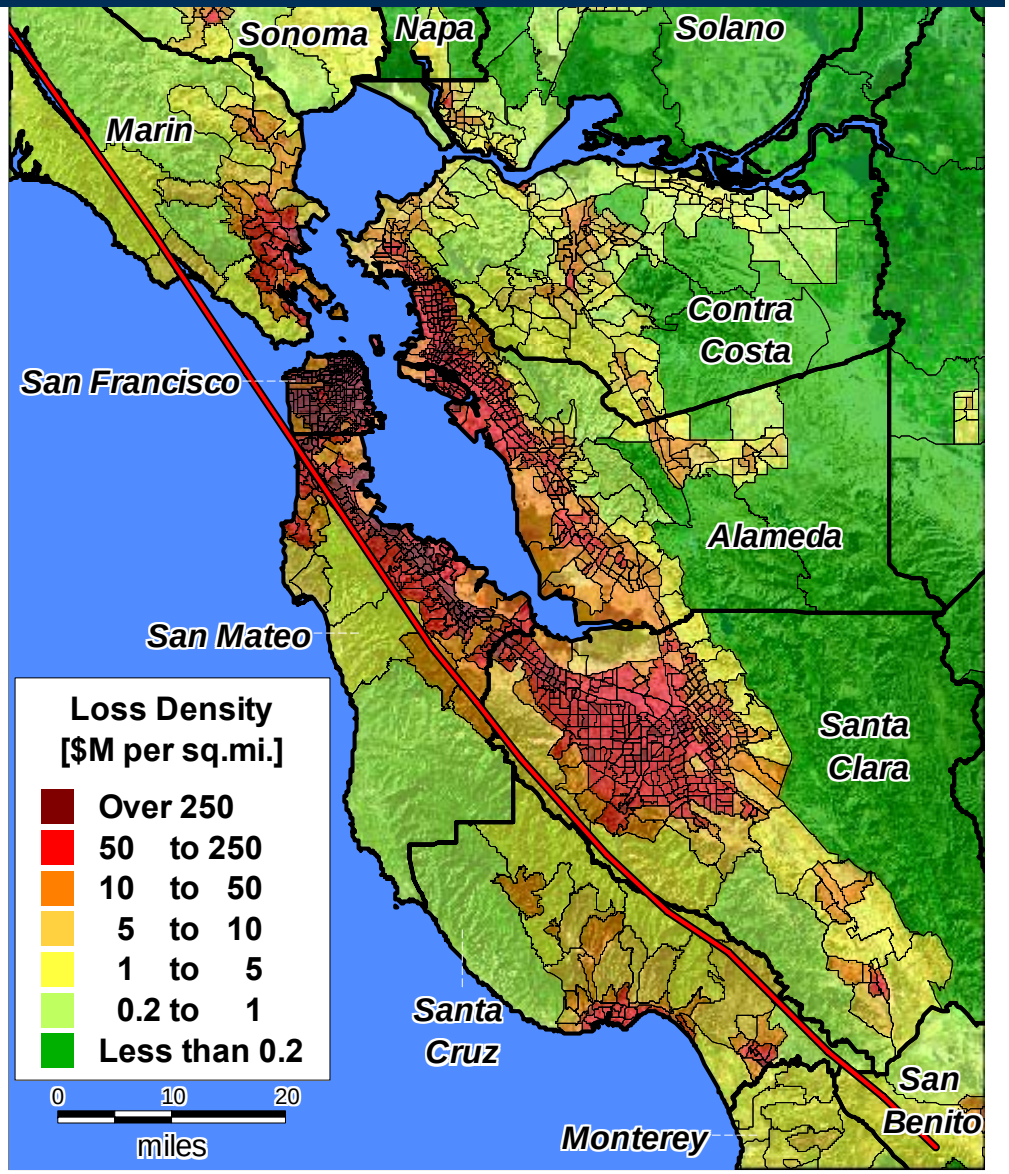
SF Eq. Example: Nighttime Casualties (HAZUS)

- Injuries = 8,000
- Deaths = 1,800



SF Eq. Example: Economic Impact (HAZUS)

- Over 120 Billion Dollars of Building Losses
- All direct and indirect losses will be in excess of 150 Billion dollars

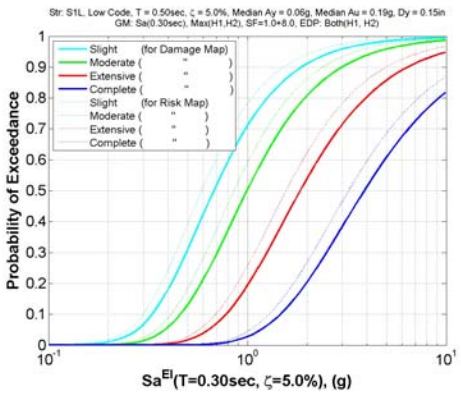


Building Damage Maps (USGS)

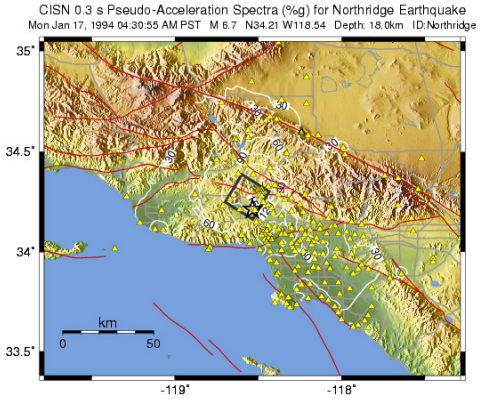
- Building damage maps show the ***probabilities*** of different *structural damage states* (or losses) for each of the 36 *building types* in HAZUS designed to 4 different *code levels*

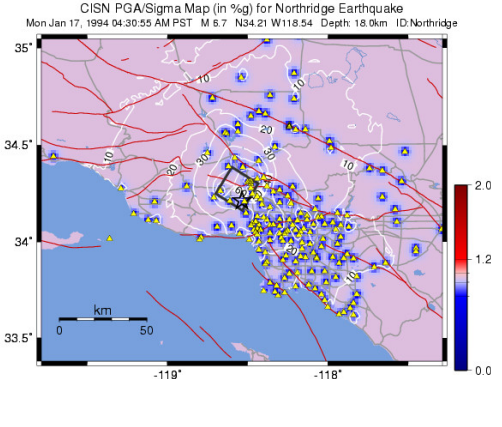
$$P[DS > ds] = \int_{sa} P[DS > ds \mid SA = sa]\ f_{SA}(sa)\ \mathrm{d}sa$$

Fragility Curve



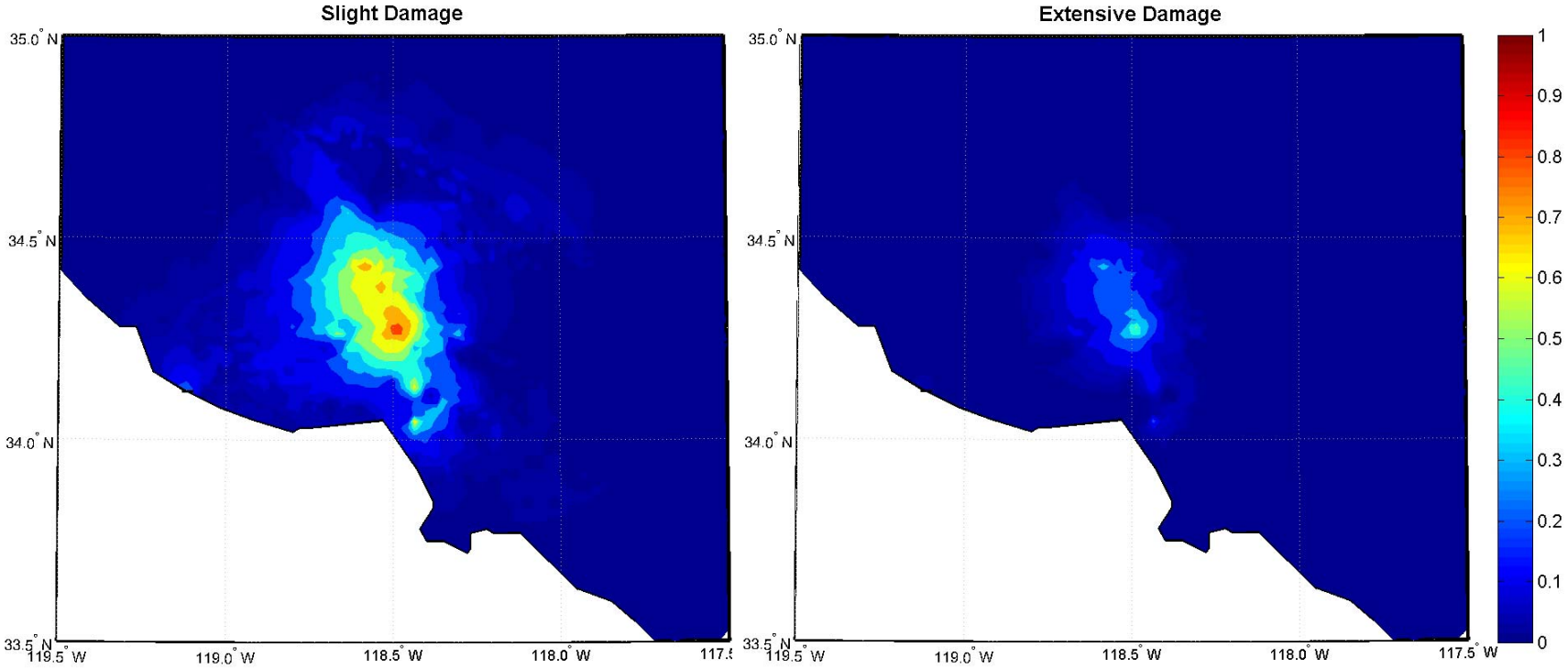
Seismic "Hazard"





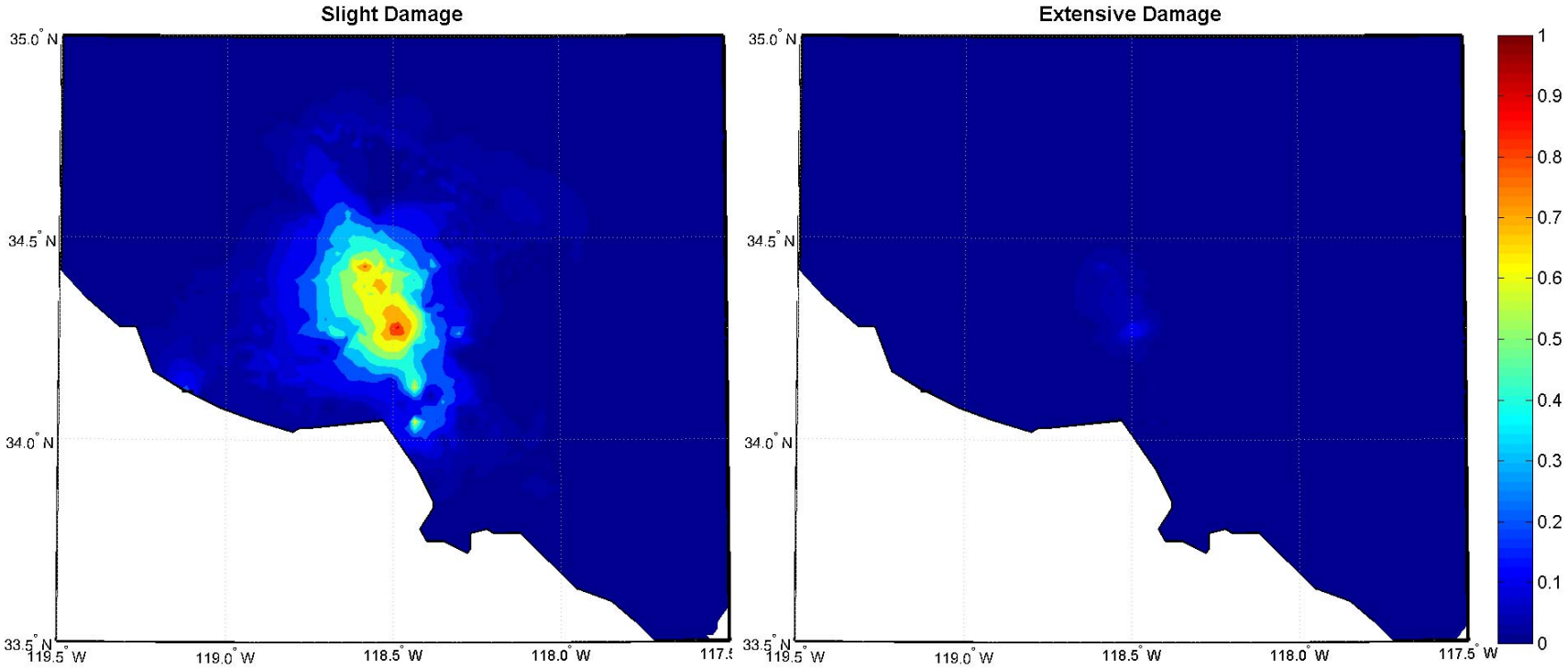
Example Building Damage Maps: Northridge Eq.

Low Rise Steel Moment Frame Building, Low Code



Example Building Damage Maps (USGS)

Light Frame Wood Building, Low Code

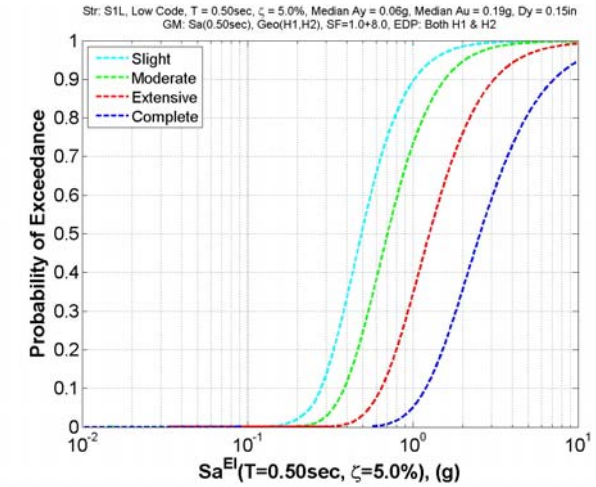


Building Risk Maps (USGS)

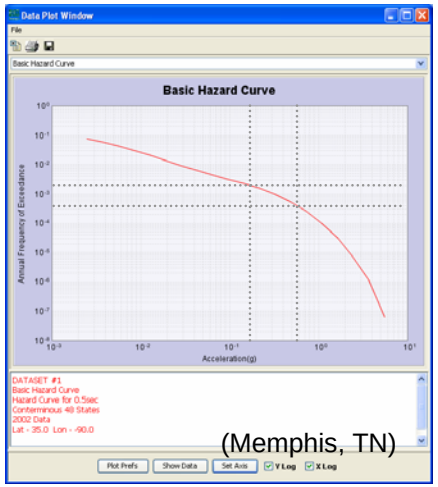
- Building risk maps show the ***mean annual frequencies (MAFs, λ) of exceeding*** different *structural damage states* (or losses) for each of the 36 *building types* in HAZUS designed to 4 different *code levels*

$$\lambda[DS > ds] = \int_{sa} P[DS > ds \mid SA = sa] \; | \mathrm{d}\lambda[SA > sa] |$$

Fragility Curve



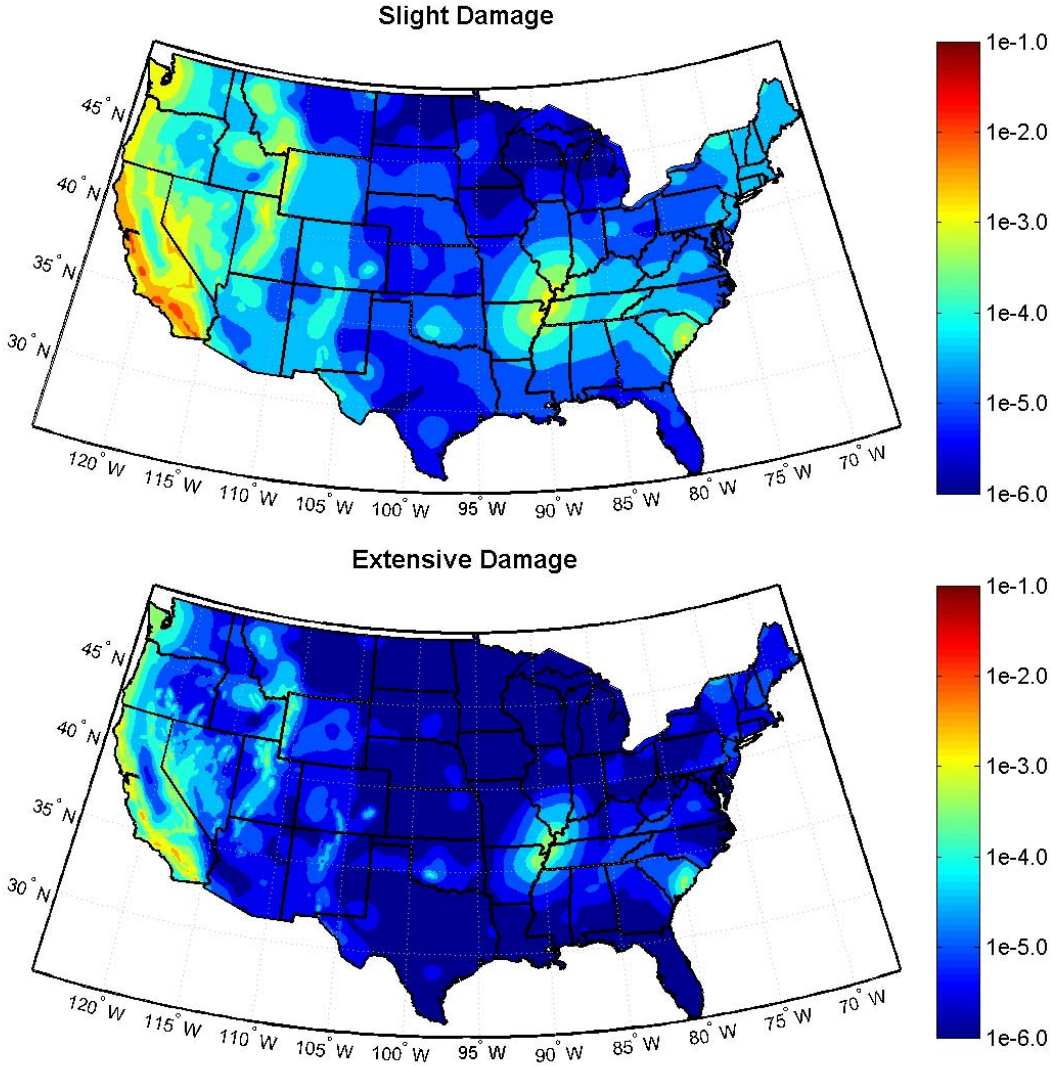
Hazard Curve



(Memphis, TN)

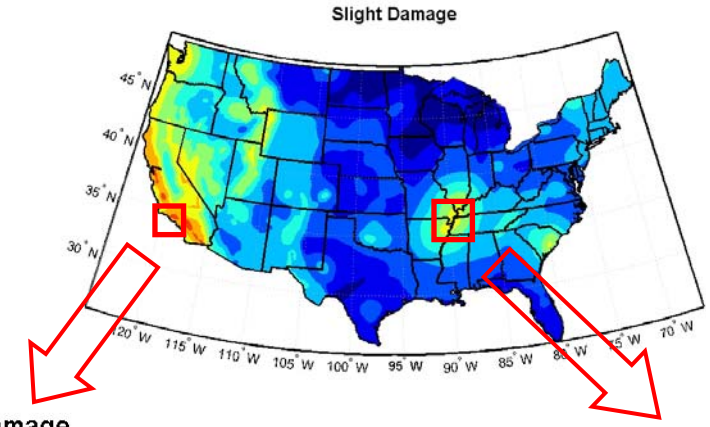
Example Building Risk Maps (USGS)

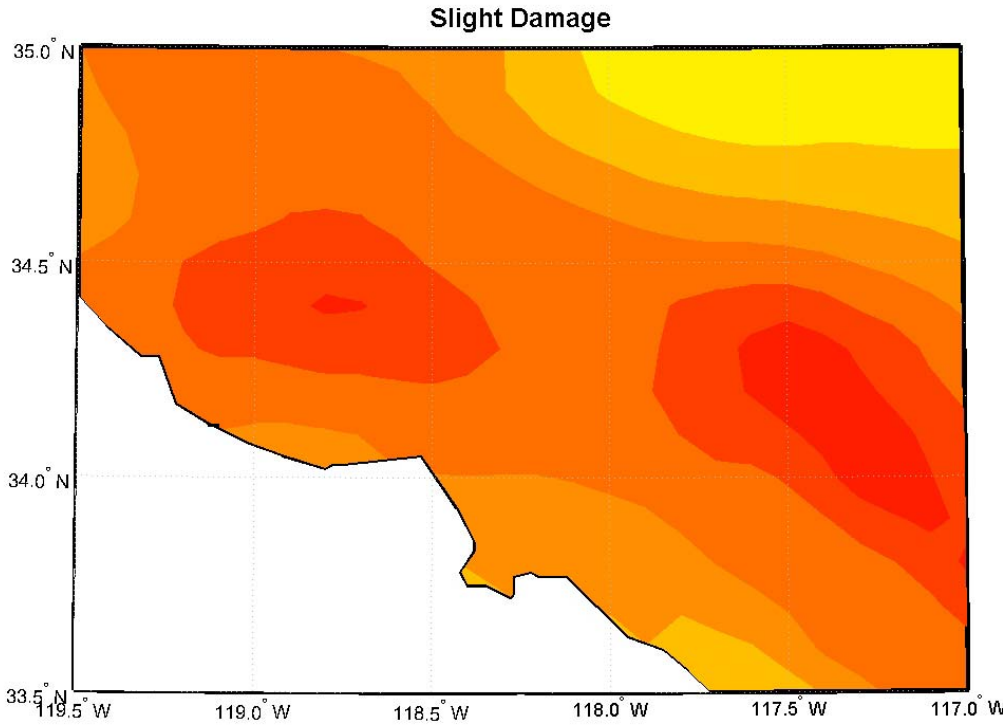
Low Rise Steel Moment Frame Building, Low Code

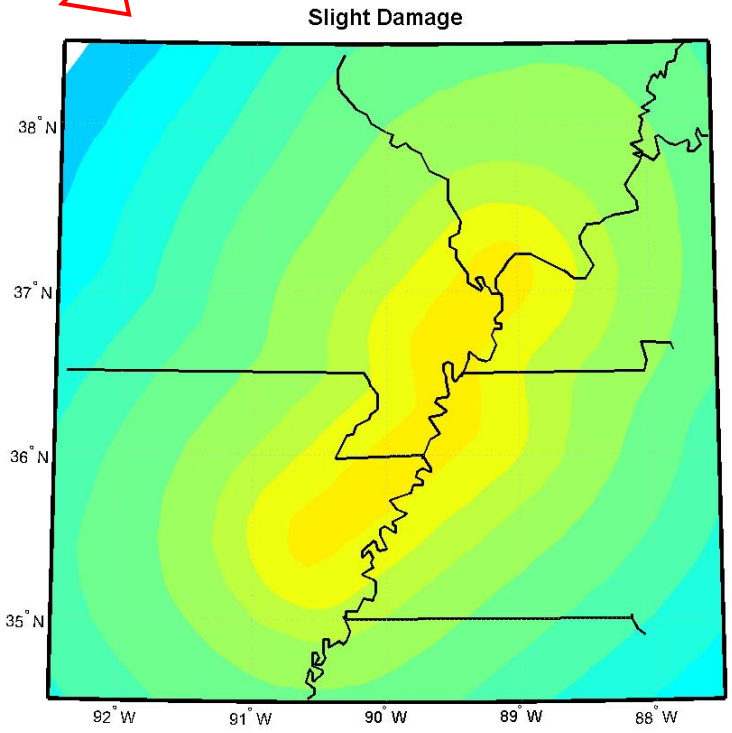


Example Building Risk Maps (USGS)

Slight Damage

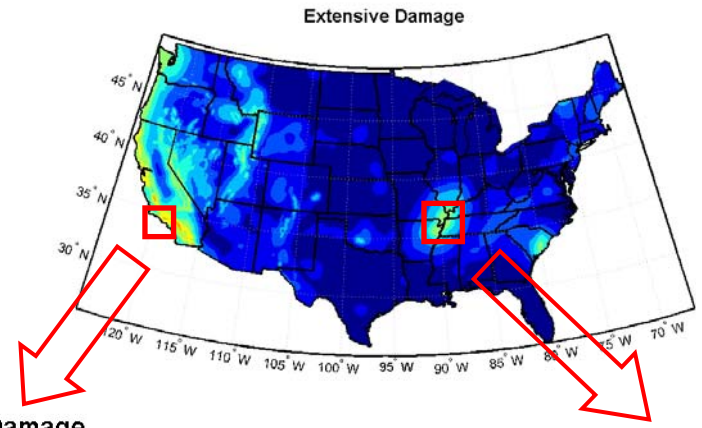


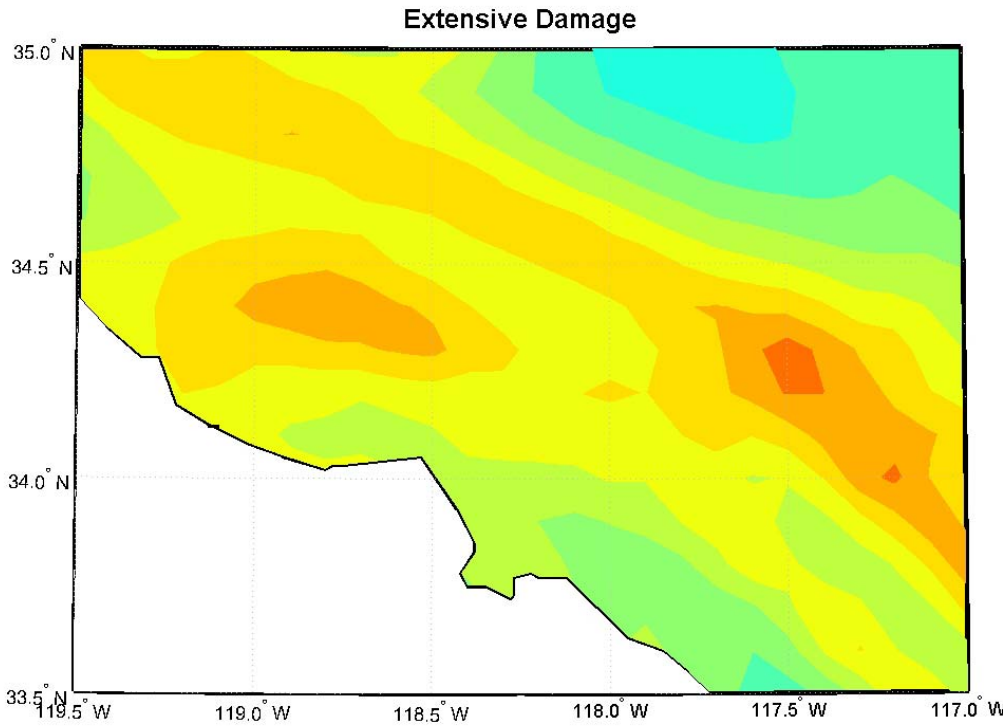


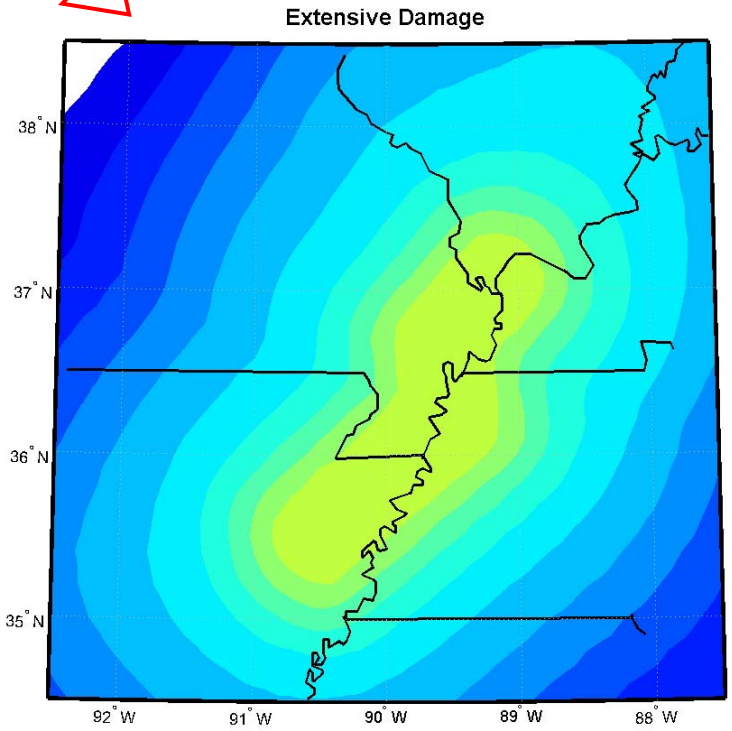


Example Building Risk Maps (USGS)

Extensive Damage





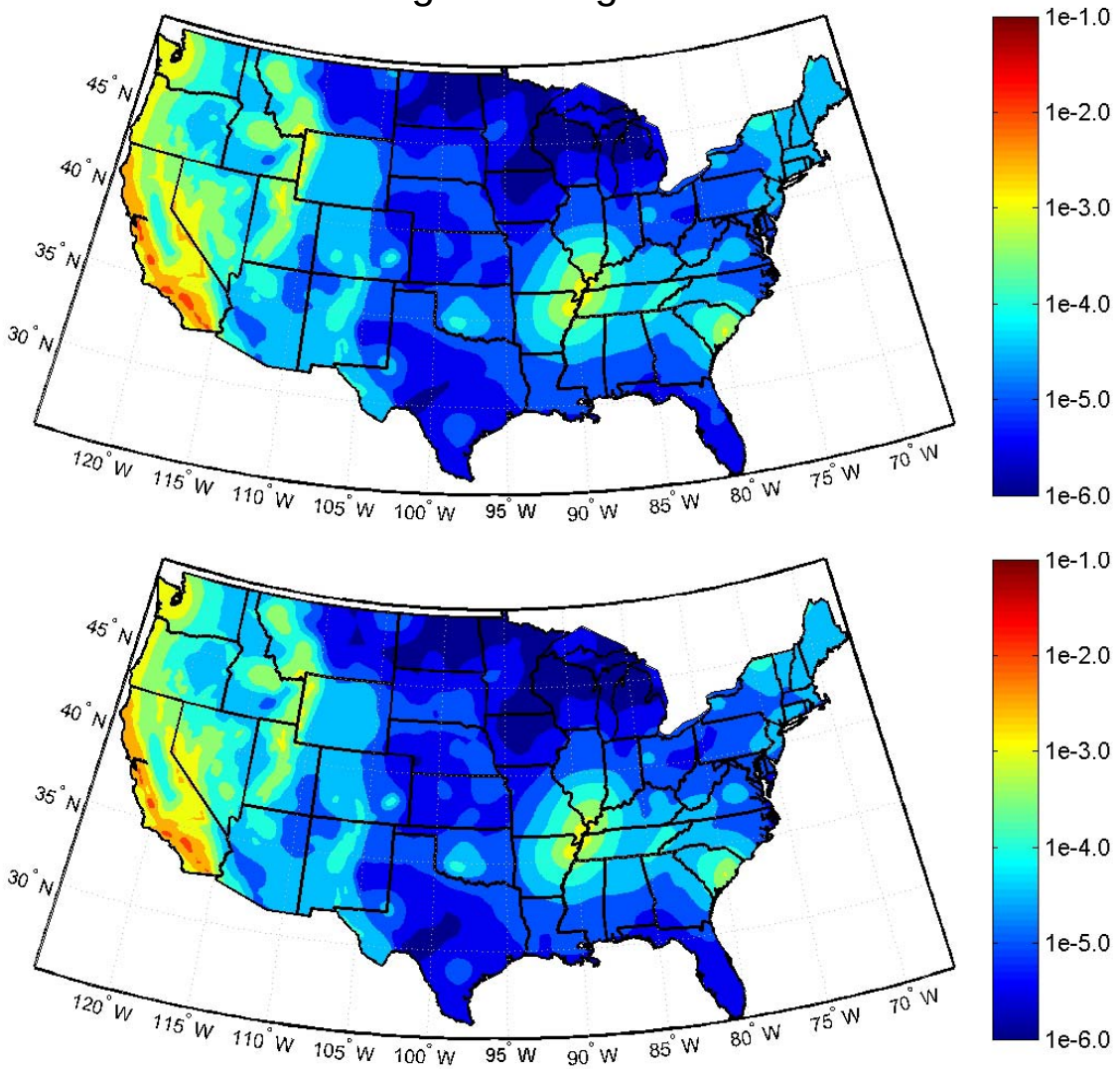


Example Building Risk Maps (USGS)

Low-Code

High-Code

Slight Damage



Summary of Risk/Loss Analyses

- For an individual structure and location:

$$\lambda[Loss > l] = \int_0^\infty P[Loss > l \mid SA = a] \left| \frac{d\lambda_{SA}(a)}{da} \right| da$$

$$E[Loss] / \text{ year} \approx \int_0^\infty E[Loss \mid SA = a] \left| \frac{d\lambda_{SA}(a)}{da} \right| da$$

- For a region as a whole:

$$E[\sum_{i=1:n} Loss_i] / \text{ year} = \sum_{i=1:n} E[Loss_i] / \text{ year}$$

$$\lambda[(\sum_{i=1:n} Loss_i) > l] = \text{complicated!}$$

Outline of Material

- **How is seismic risk different than seismic hazard, and how is it computed?**
- **Components of seismic risk** (with HAZUS examples)
  - **Hazard**
  - **Exposure/Inventory**
  - **Fragility/Vulnerability**
- **Examples of seismic risk analysis results**