Basic Principles of Earthquake Loss Estimation – PML and Beyond

Northern California Chapter

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

William Graf, Patricia Grossi, Stephanie King

Wednesday April 19, 2006

100th Anniversary Earthquake Conference Tutorial

Introduction

- Today's speakers
- Who is in the audience?
- What is Earthquake Loss Estimation?
- Seismic risk milestones
- Topics covered in session
- Session schedule (2 1/2 hours)

Today's Speakers

- William Graf, MS, CE
  - Manager, Earthquake Risk, URS Corporation
  - William_Graf@URSCorp.com; 213-996-2381
- Patricia Grossi, PhD, CE
  - Manager, Earthquake Modeling, Risk Management Solutions
  - Patricia.Grossi@rms.com; 510-505-3237
- Stephanie King, PhD, CE
  - Director of Risk Analysis, Weidlinger Associates
  - sking@wai.com; 650-230-0295

Audience Breakdown

- Engineers (civil / structural)
- Insurance / mortgage banking / risk analysts
- Property owners / managers
- Emergency managers
- Government officials / public policy
- Earth scientists / seismologists
- Educators
- Contractors
- Building inspectors
- Architects

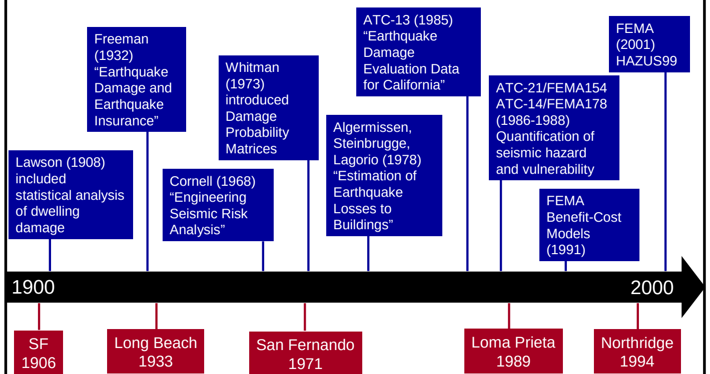
Earthquake Loss Estimation

- Quantifying seismic risk under uncertainty
  - Hazard * Vulnerability * Exposure
- Primary losses
  - Damage, Business Interruption, Casualties
- Secondary losses
  - Unemployment, Clean-up, Relocation, Time Delays, Financing Repairs, Property Values, and others

Earthquake Loss Estimation

- Quantified Risk = Decision Support
  - Identifying and ranking high risk assets
  - Evaluating risk management alternatives
    - Accept (rational basis for risk tolerance)
    - Transfer (insurance)
    - Reduce (mitigation, contingency and response planning, portfolio modification)
  - Sample applications
    - Insurance and lending (single-site and portfolio)
    - Engineering design (new and retrofit)
    - Emergency response
    - Evaluation of public policy

Seismic Risk Milestones



Session Topics

- Single-Site Seismic Risk
  - Hazard and vulnerability assessment
  - Terminology and standards
  - Software tools
  - Uncertainty
- Multi-Site Seismic Risk
  - Regional loss estimation
  - Catastrophe modeling
  - Insurance portfolio analysis
  - Uncertainty

Session Schedule

- 2:00-2:20 Introduction (King)
- 2:20-3:30 Single-Site Seismic Risk (Graf)
- 3:30-3:50 Break
- 3:50-5:00 Multi-Site Seismic Risk (Grossi)
- 5:00-5:25 Q&A Discussion (All)
- 5:25-5:30 Session Wrap-up (King)

Single-Site Seismic Risk

- William Graf, MS, CE
  - Manager, Earthquake Risk, URS Corporation
  - 26 years experience
  - Registered Civil Engineer in California
  - Contributing author, American Lifelines Alliance guidelines for risk assessment for lifeline systems
  - Specialized in seismic risk assessment for high-value buildings and building portfolios, and retrofit options
  - Adapted vulnerability relationships for buildings in South Carolina as a part of a statewide HAZUS earthquake study [EERI Spectra, November, 2005].
  - Develops earthquake risk software for use by engineers, lenders and insurers

Multi-Site Seismic Risk

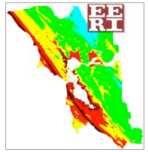
- Patricia Grossi, PhD, CE
  - Manager, Earthquake Modeling, Risk Management Solutions
  - Registered Civil Engineer in California
  - 10 years experience in risk management and catastrophe modeling
  - EERI's Graduate Fellow in Earthquake Hazard Reduction (2000)
  - Published book on 'Catastrophe Modeling: A New Approach to Managing Risk' (2005)

Session Wrap-Up

- Summary of material covered
  - Overview of earthquake loss estimation
  - Hazard and vulnerability modeling
  - Terminology, standards, software tools
  - Uncertainties, limitations, critical issues
  - Discussion of single- and multi-site analysis
  - Engineering and financial applications
- References and sources of information

REDUCING OUR RISK BY THE 100TH ANNIVERSARY OF THE 1906 EARTHQUAKE

QUAKE '06



A Campaign by the
Earthquake Engineering Research Institute
Northern California Chapter

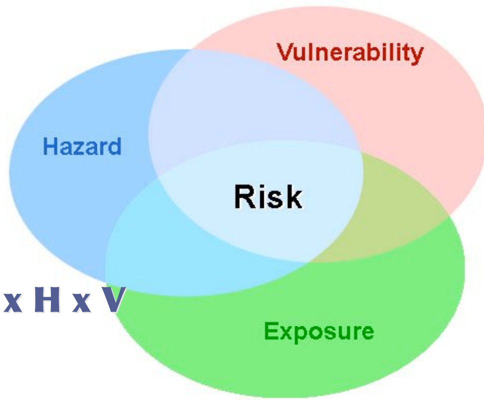
Basic Principles of Earthquake Loss Estimation - PML and Beyond

- Single-Site Seismic Risk

Seismic Risk Terminology

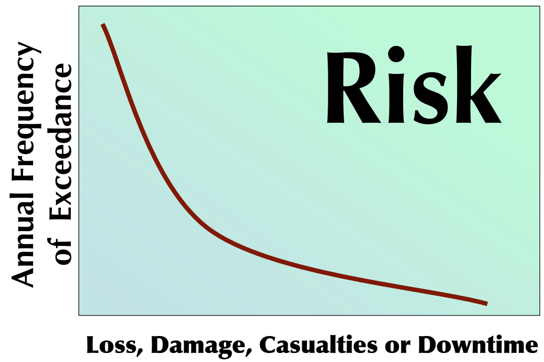
- **Earthquake Hazards:** ground shaking, soil liquefaction, surface fault rupture, slope instabilities, tsunami, seiche, etc.
- **Seismic Vulnerability:** fragility or damageability, the relationship between hazard and damage, loss or disruption
- **Risk:** the relationship between loss severity and frequency
- **Exposure:** the buildings, contents, people and processes at risk

Risk



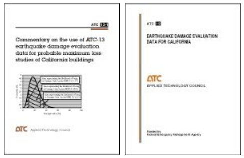
R = E x H x V

Risk occurs at the intersection of exposure, hazard and vulnerability



Risk has at least two dimensions:
- **severity and frequency, or**
- **mean and variance**

Seismic Risk Standards



Damage Relationships:

ATC-13, ATC 13-1
NIBS – HAZUS
K.V. Steinbrugge, J.H. Wiggins, Thiel & Zsutty

Seismic Risk Terminology: ASTM E 2026-99
Rapid Visual Screening: FEMA 154
Vulnerability of Buildings: ASCE 31-03 (FEMA 310)
Vulnerability of Contents: FEMA 74
Rehabilitation of Buildings: FEMA 356

Qualifications for Seismic Risk

Needed: Engineering Judgment

Minimum: C.E. or S.E. + lots of experience

Seismic Risk Assessment, Individual Buildings
Expertise in Seismology + Geology + Structural Engineering and Statistics

Seismic Risk Assessment, Building Portfolios
Expertise in Seismology + Geology + Structural Engineering + Actuarial Science + Systems Analysis

Seismic Risk Tools

ATC 13-1

HAZUS-MH MR1 National Institute of BUILDING SCIENCES

FEMA Benefit/Cost Tools

Proprietary Tools

Multi-Site tools for insurance – RMS, AIR, ABS, URS

For Engineers

– **ST-Risk (Risk Engineering and Degenkolb)**
– **SiteRisk (URS)**

ASTM E 2026 – 99

Standard Guide for the Estimation of Building Damageability in Earthquakes

Probable Loss - a direct relationship between probability and earthquake damage, considering both the hazard and damage function uncertainties.

Scenario Loss - estimates damage for a defined quake scenario:

- Scenario Expected Loss (mean estimate)
- Scenario Upper Loss (90% estimate)

'PML' defined in ATC 13-1: "…probable maximum loss studies"
PML50 and PML90 equivalent to SEL and SUL for earthquake hazards with a 475-year return period

ASTM E 2026 – 99 Levels of Investigation

Standard Guide for the Estimation of Building Damageability in Earthquakes

Higher levels of investigation are required where higher hazards exist, and/or where higher certainty is required in the result.

Assessment	Level 0 (Screening)	Level 1	Level 2	Level 3
Building Stability	Visual observation or drawing review or age and code-based	Detailed visual inspection	Engineering Review (limited/manual calculations)	Engineering review (computer modeling)
Site Stability	Assess site area, using eneral data from maps or geotechnical report	Assess site-specific hazards using maps or geotechnical report	Assess site-specific hazards and building impacts using maps or geotechnical report	Detailed (new) studies of site hazards and building impacts
Damageability	Use BS 0 investigation results and tables for basic building type. Excludes site failures.	Use BS 1 investigation results and tables or software for basic building type. Excludes site failures.	Use BS 2 investigation results and estimate damage specific to each building. Consider site failures.	Use BS 3 investigation results and estimate damage specific to each building. Consider site failures, SSI, etc.

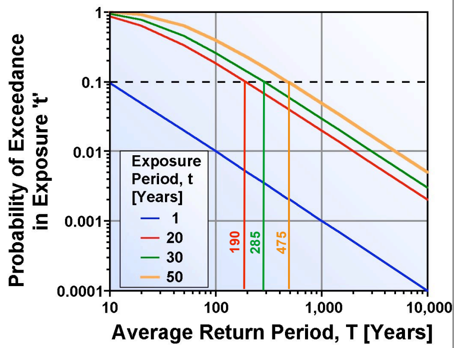
Return Period vs. Exposure Period and Probability of Exceedance

$$P = 1 - e^{\frac{-t}{T}}$$

t = exposure period (years)

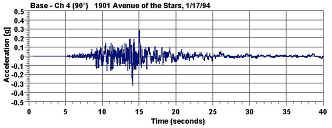
P = probability of exceedance in exposure period, t

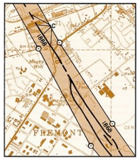
T = average return period

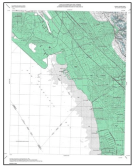


Seismic Hazards –

- Ground shaking
- Surface fault rupture
- Soil liquefaction and soil failures
- Slope instability
- Tsunami



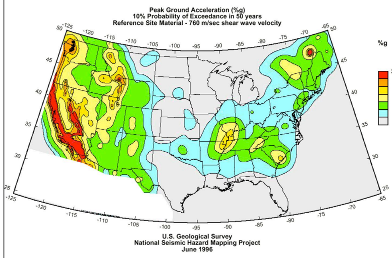


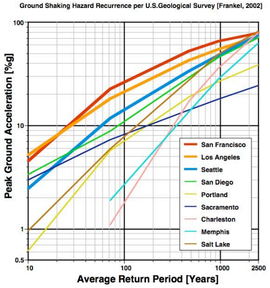


Seismic Hazards – Ground shaking

Hazard-recurrence: Use this where loss is related to a single ground motion parameter, with no magnitude dependence

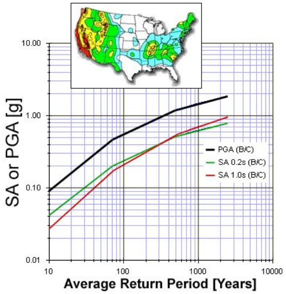
Good Source: USGS National Seismic Hazard Mapping Project [2002]

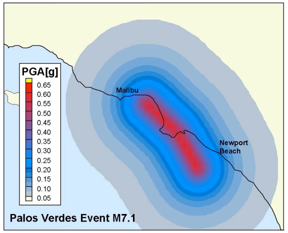




Seismic Hazards – Ground shaking

USGS National Seismic Hazard Mapping Project 2002





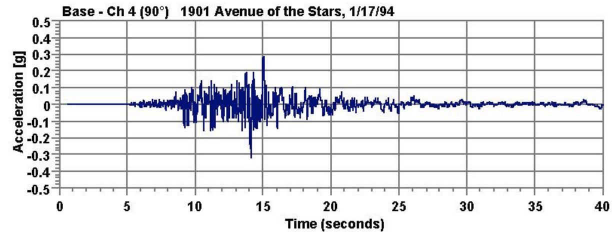
Hazard-recurrence (single-site, single ground motion parameter)

Where losses are magnitude dependent, multi-site, or multi-period, use an **event set**

Seismic Hazards – Ground shaking

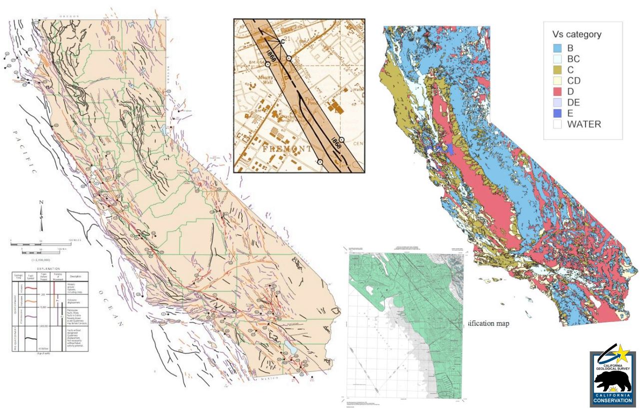
Damage from ground motions: which parameter works best?

- Peak ground acceleration
- Peak ground velocity
- Spectral acceleration @ fundamental structural period
- Modified Mercalli Intensity
- Arias Intensity



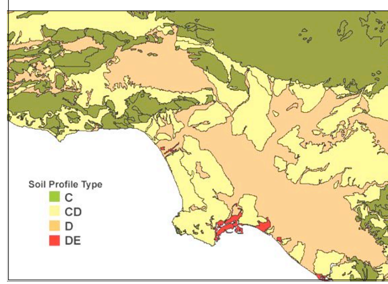
Seismic Hazards – Local Hazards

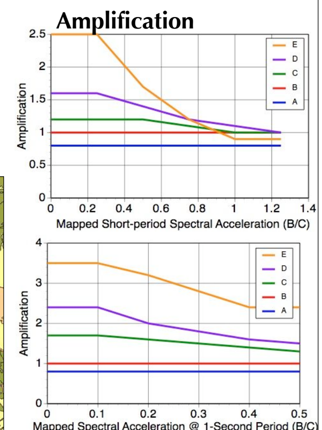
Liquefaction,surface faulting, landslide, Site Class



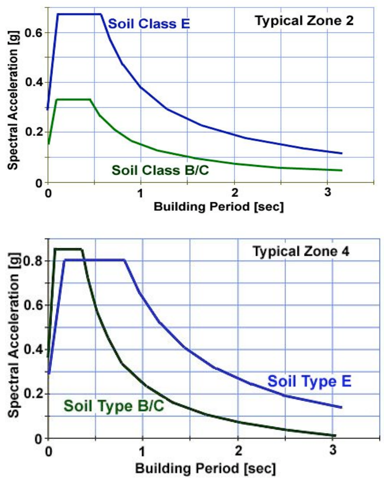
Adjustment for Site Conditions

Fa, Fv factors in SEI/ASCE 31-03 and FEMA 356



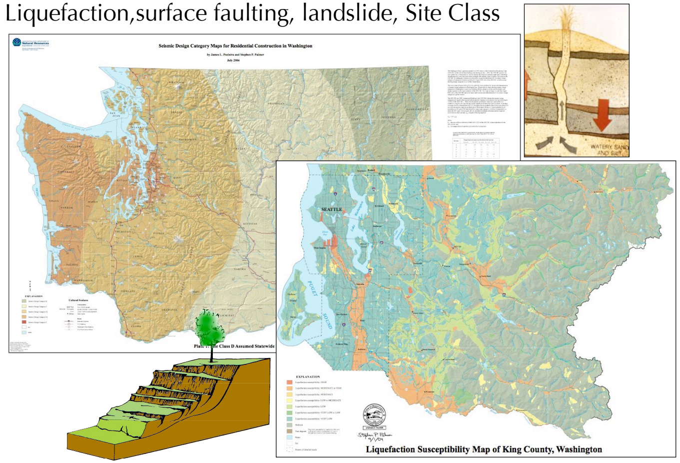


Soil Factors are amplitude-dependent



Seismic Hazards – Local Hazards

Liquefaction,surface faulting, landslide, Site Class

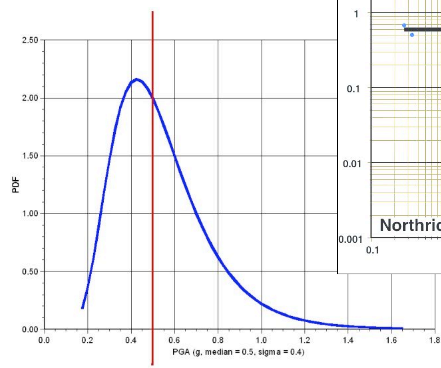


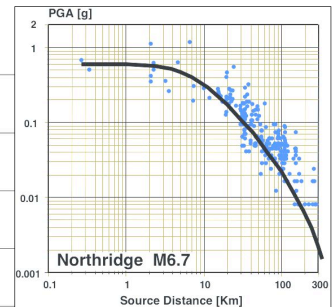
Local Hazards per HAZUS

Table 10.2 PESH Module Outputs - Ground Deformation

Component	Description of Output	Measure
Liquefaction	**HAZUS** determines the probability of and expected level of permanent ground deformations for liquefaction susceptible sites during the deterministic, probabilistic, or user-defined event.	a) PGD Contour Maps b) Location-Specific PGD
Landsliding	**HAZUS** determines the probability of and expected level of permanent ground deformations for landsliding susceptible sites during the deterministic, probabilistic, or user-defined event.	a) PGD Contour Maps b) Location-Specific PGD
Surface Fault Rupture	**HAZUS** determines the probability of and expected level of permanent ground deformations for surface fault rupture susceptible sites during the deterministic, probabilistic, or user-defined event.	a) PGD Contour Maps b) Location-Specific PGD

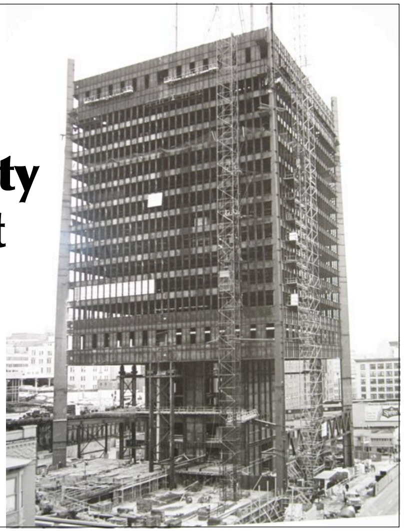
Uncertainty in Seismic Hazards





Large uncertainty

Structural Vulnerability Assessment



Structural Vulnerability Assessment

Resources -- see Bibliography

Structural Evaluation

ASCE 31-03 (previously FEMA 310 FEMA 178)
Building Codes (IBC, UBC, etc.)

Relationship?

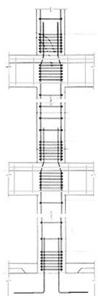
Damage Relationships

ATC 13 "Earthquake Damage Evaluation Data for California"
Steinbrugge, K.V. ***various publications***
Theil & Zsutty, EERI Spectra, 1987
Wesson et al., EERI Spectra, 2004
Porter et al, CUREE
HAZUS MH

Structural Evaluation

"Wish List" for Documents for Seismic Studies

Structural drawings (originals, mods, retrofits)
Architectural drawings
Geotechnical report ('soils report')
Construction photos
Earthquake damage reports
Accelerometer recordings
Computer models (ETABS, SAP, …)



Also, access to Engineer-of-Record, Constructor

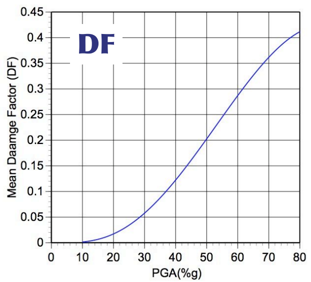
Damage Relationships

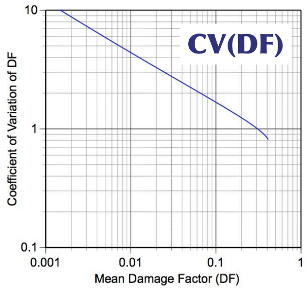
Courtesy USGS

Damage Relationships

Two parts to the damage relationship:

1) Damage versus ground motion
2) Variability of damage





Damage to wood frame dwellings in Northridge [Wesson, 2004]

Damage Relationships

Two parts to the damage relationship:

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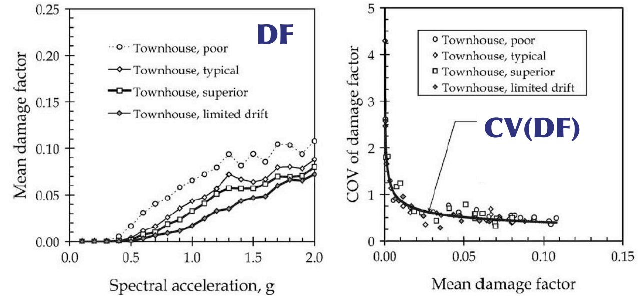
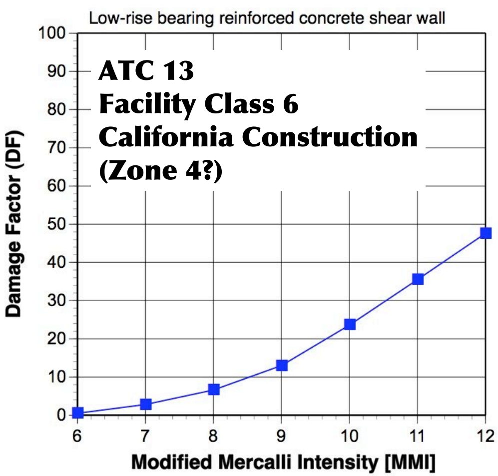


Damage to wood frame dwellings [Porter, CUREE-CalTech, 2002]

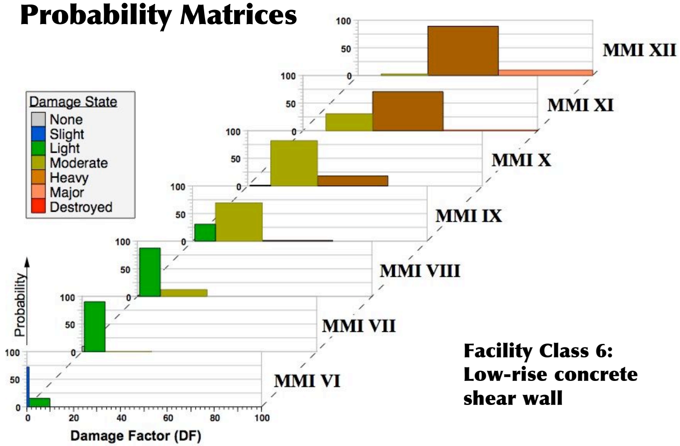


ATC 13 Damage Probability Matrices

Damage State	Damage Factor Range (%)	Central Damage Factor (%)
1 – None	0	0
2 – Slight	0 – 1	0.5
3 – Light	1 – 10	5
4 – Moderate	10 – 30	20
5 – Heavy	30 – 60	45
6 – Major	60 – 100	80
7 – Destroyed	100	100

Facility Class 6: Low-rise concrete shear wall

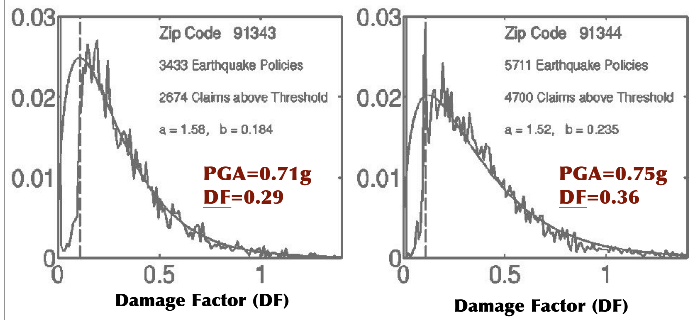
ATC 13 Damage Probability Matrices



Facility Class 6: Low-rise concrete shear wall

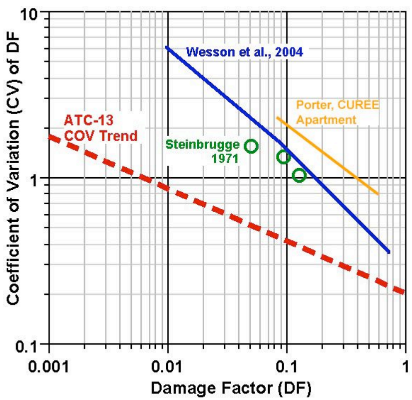
Variability of Building Damage

Damage Histograms from Wesson, 2004, Northridge Damage to Dwellings And Gamma function fits



These are **"fat"** distributions -- high uncertainty.

Variability of Building Damage



Fit DF, CV to: Beta, Lognormal or Gamma distribution

Levels of Investigation

Typical Levels of Investigation

Level 0 – Desktop

Level 1 – Site Visit (visual survey, exteriors + interiors, nondestructive examination of readily available areas)

Level 2 – Site Visit + review of design documents

Level 3 – Detailed Engineering Review (computer mode, material testing)

Compare: ASTM levels; ASCE 31-03 Tiers

Levels of Investigation

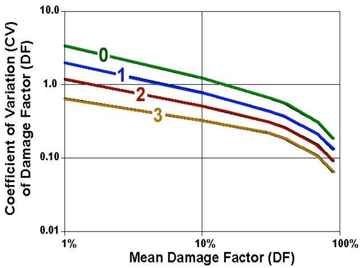
Level 0 – Desktop

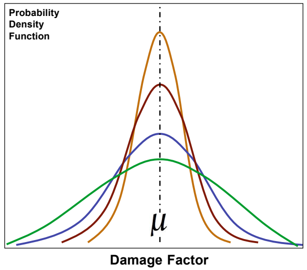
Level 1 – Site Visit

Level 2 – Site Visit + review of design documents

Level 3 – Detailed Engineering Review

How do we relate 'Level of Investigation' and uncertainty in the risk model?

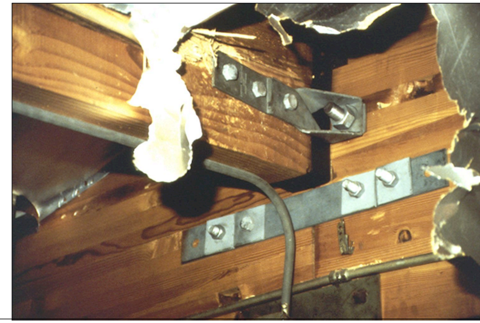




Major Challenges

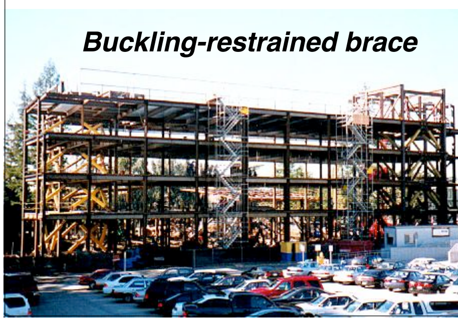
Modifying seismic vulnerability to reflect seismic retrofit.

How do changes in strength, ductility, period, and damping, and increased regularity and redundancy, affect damage?



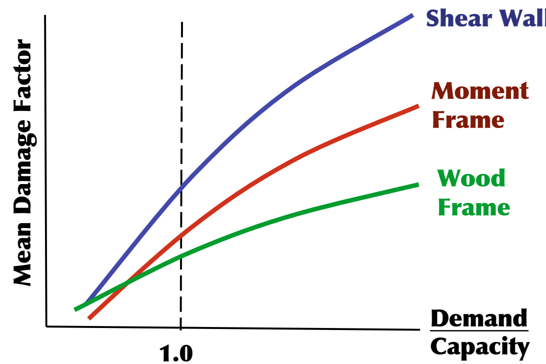
Major Challenges

Seismic vulnerability relationships for <u>new</u> systems.

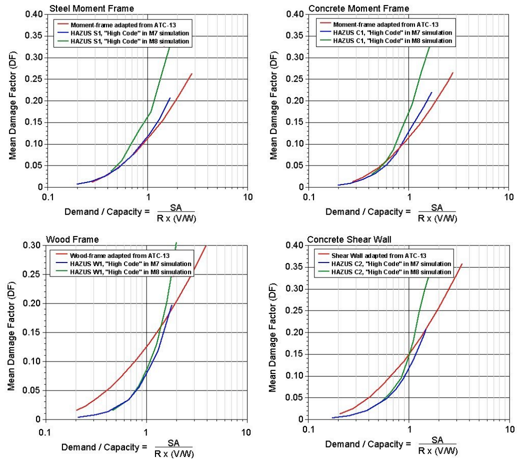


Major Challenges

Relating Damage to 'Code' Factors



The Future? Damage vs. Demand-to-Capacity



Casualties

Relationships for injuries and fatalities

Note high variance!

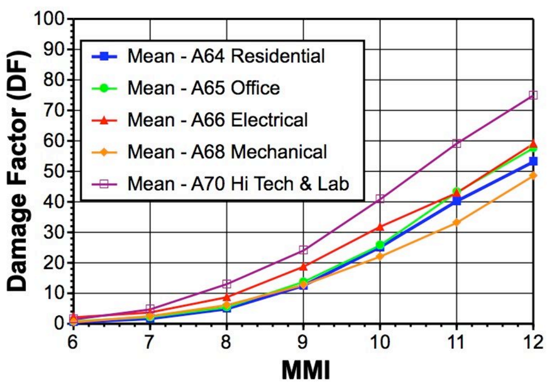
Table 1. ATC-13 injury and death rates.

	Damage State	Range	Minor Injuries	Serious Injuries	Dead
1	None	0	0	0	0
2	Slight	0-1	3/100,000	1/250,000	1/1,000,000
3	Light	1-10	3/10,000	1/25,000	1/100,000
4	Moderate	10-30	3/1,000	1/2,500	1/10,000
5	Heavy	30-60	3/100	1/250	1/1,000
6	Major	60-100	3/10	1/25	1/100
7	Destroyed	100	2/5	2/5	1/5

*For light steel and wood frame construction, multiply all numerators by 0.1

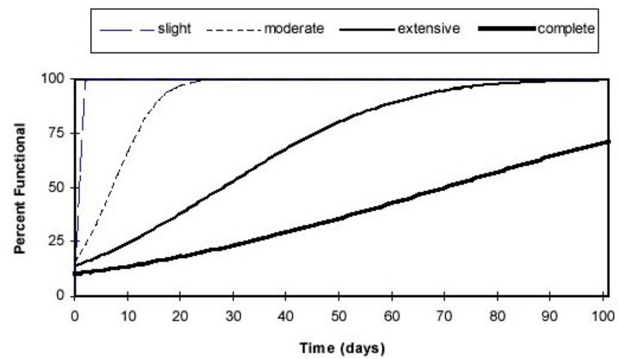
Contents Damage

ATC 13 damage relationships for equipment and contents



Downtime Relationships

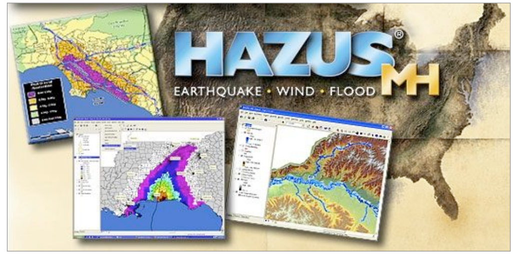
Dependent upon building damage state + Social Function Class (occupancy)



Risk Assessment

HAZUS-MH MR1

Advanced Engineering Building Module



- Scenario-based
- Building- and site-specific

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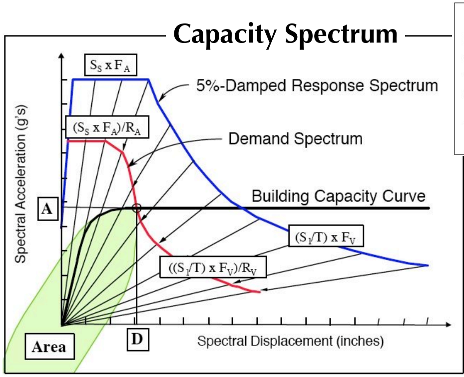
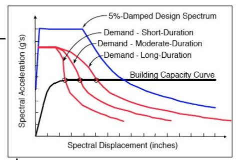
HAZUS-MH MR1

Advanced Engineering Building Module





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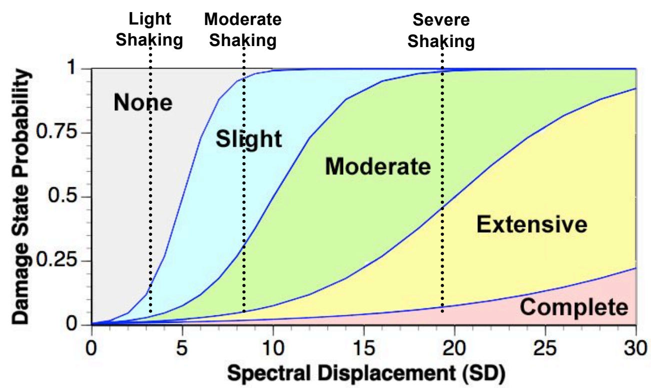
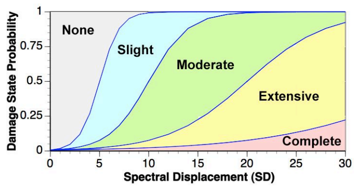
HAZUS Fragility Curves



HAZUS-MH MR1

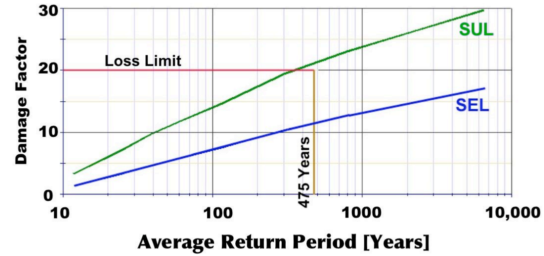
Advanced Engineering Building Module

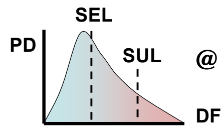
- HAZUS is scenario-based (deterministic or semi-probabilistic) and it can provide expected loss (SEL).
- Uncertainty in damage state is listed, but HAZUS does not provide upper-bound loss (SUL) or Probable Loss (PL)
- High degree of user knowledge and expertise required.



Single-Site Seismic Risks: SEL, SUL

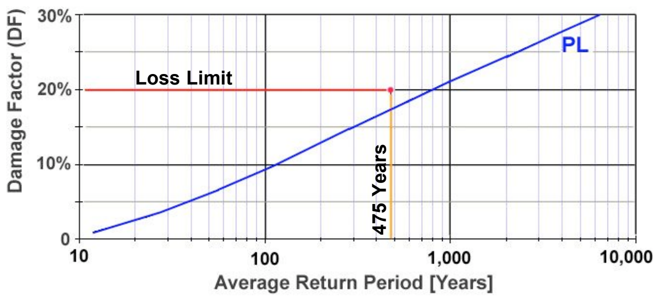
A more complete answer is a loss curve or a distribution





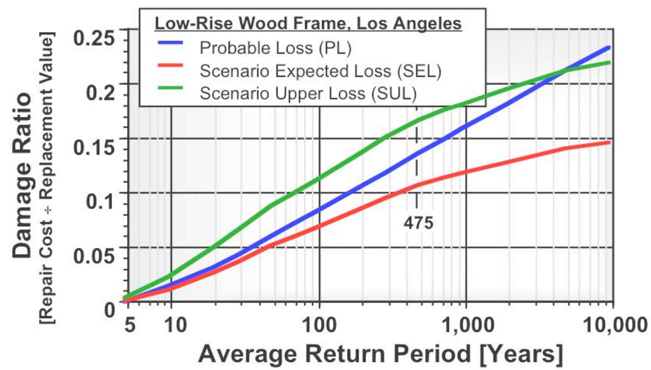
@ 475 year return period

Single-Site Seismic Risks: Probable Loss



Typical Seismic Risk Analysis

Comparing Scenario Losses and Probable Loss



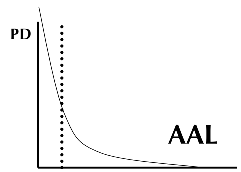
Single-Site Seismic Risks

Average Annual Loss (AAL) or **Expected Annual Loss (EAL)** – *The long-term annual loss rate*

AAL is found by summing the product of each discrete loss state (L_i) x its annual frequency of occurrence (f_i), over all loss states:

$$\mathbf{AAL = \sum L_i \times f_i}$$

…mean and variance

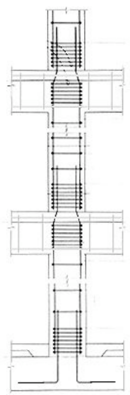


Benefit/Cost Analysis

The reduction in **Average Annual Loss** afforded by retrofit is an annual **benefit**. The present value of the loss reduction benefit can be compared with (present) cost of retrofit, to estimate a **benefit-to-cost ratio**.

Benefit/cost ratios are long-term, time-averaged **"expected values."** But retrofit for any single structure has a high uncertainty: what is the probability that it will experience earthquake hazards high enough to pay back the retrofit?

Benefit/Cost Analysis Example

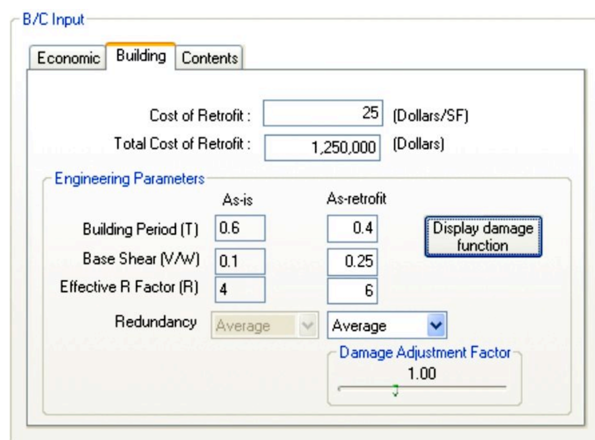


Hypothetical frame

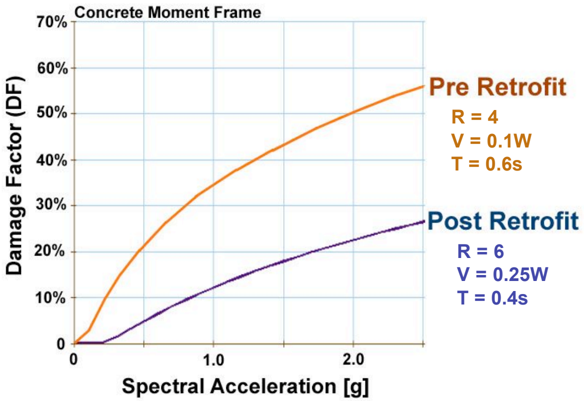
5-Story nonductile concrete frame in San Bernardino, CA

\$25/s.f retrofit to increase the effective "R" from 4 to 6 and the design strength from V=0.1W to V = 0.25W

Benefit/Cost Analysis Example



Benefit/Cost Analysis Example



Benefit/Cost Analysis Example

B/C Results

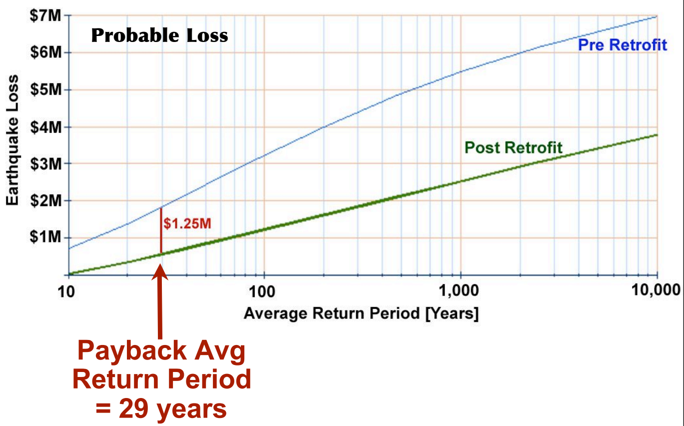
Total Initial Retrofit Cost :	1,300,000	(Dollars)
Annual Maintenance Cost :	0	(Dollars)
AAL 'as-is' :	276,456.6	(Dollars)
AAL 'as-retrofit' :	52,999.4	(Dollars)
Annual Benefit :	223,457.2	(Dollars)
Present Value of Future Benefit :	3,435,085.5	(Dollars)
Benefit/Cost Ratio :	2.64	
Return Period for Retrofit Pay-back :	29	(Years)

Payback Curves

Excludes Life-safety Benefits

	Building	Contents	Time Element
AAL 'as-is'	220,370	12,143	43,942
AAL 'as-retrofit'	43,375	1,881	7,742
AAL Benefit	176,995	10,261	36,200
PV of Future Benefit	2,720,847	157,751	556,486
Retrofit Costs	1,250,000	50,000	0

Benefit/Cost Analysis Example



Benefit/Cost Analysis *Beyond BCA…*

Other benefits of seismic retrofit -- not included in a simple benefit-to-cost calculation:

- **enhanced life-safety** (fewer deaths and injuries)
- **increased resale value** and **marketability** (i.e., salvage value and rentability)
- **extended useful life** for the building
- **fewer customers lost** due to interruption or delay of service
- possible **lower insurance rates**
- **reduced need for insurance**
- reduced demand on emergency resources

Single-Site Seismic Risks

Geographic correlation of risks

→ **Geographic diversification!**
Use multi-site analysis...

Uncertainties in Seismic Risks

Ground Motion uncertainty in the selected ground motion parameter for damage, and uncertainty in annual frequency of occurrence

Building Performance variability (damage or loss, given the ground motion parameter)

Risks from "Special" hazards (fault rupture, liquefaction, landslide, ...) are difficult to model

Glossaries, Websites

GLOSSARIES
Hazards:
http://earthquake.usgs.gov/learning/glossary.php?alpha=All
http://www.seis.utah.edu/qfacts/glossary.shtml
http://www.ess.washington.edu/SEIS/PNSN/INFO_GENERAL/NQT/glossary.html
StructuralEngineering:
http://www.seaonc.org/public/what/glossary.html

WEBSITES:
United States Geological Survey http://earthquake.usgs.gov/
http://earthquake.usgs.gov/research/hazmaps/products_data/48_States/index.php

California Geology http://www.consrv.ca.gov/CGS/
http://www.consrv.ca.gov/CGS/geologic_hazards/regulatory_hazard_zones/index.htm

Utah Geology http://geology.utah.gov/utahgeo/hazards/index.htm
http://www.seis.utah.edu/guide/guide.shtml

Oregon Geology http://www.oregongeology.com/sub/default.htm

Washington Geology http://www.dnr.wa.gov/geology/
http://www.dnr.wa.gov/geology/hazards/hmgp.htm

Seismic Hazards In Canada http://earthquakescanada.nrcan.gc.ca/index_e.php

Global Seismic Hazard Assessment Program http://www.seismo.ethz.ch/GSHAP/index.html

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