Basic Principles of Earthquake Loss Estimation - PML and Beyond
Multi-Site Seismic Risk

Patricia Grossi, PhD, CE
Agenda

- ‘Open Source’ vs ‘Proprietary’ Earthquake Loss Estimation tools (aka Catastrophe Models)
  - Users
  - Key methodological assumptions
  - Utilization of models

- Uncertainty in earthquake loss estimates
  - Classifications and sources of uncertainty
  - An example - Earthquake Risk in Charleston, South Carolina
Catastrophe Modeling Development

Scientific Studies of Natural Hazards

Information Technology and Geographic Information Systems

Catastrophe Modeling

Proprietary
- AIR Worldwide
- EQECAT
- RMS, Inc.

Open Source
- HAZUS
Catastrophe Modeling Framework

Four step process

- Hazard – scenario event or set of stochastic events
- Inventory – properties at risk
- Vulnerability – damage states/curves
- Loss – direct or indirect; loss allocation
‘Open Source’ Modeling
HAZUS: ‘Open Source’ Model

- Intended for public use (free distribution)
- Uses non-proprietary data and methodologies
- Targeted toward emergency managers and planners (federal, state, local and private entities) for:
  - Mitigation and preparedness activities
  - Response planning and response operations
  - Catastrophic disaster response planning scenarios
Use of HAZUS: Nisqually Earthquake

- Creation of damage estimates following the February 28, 2001 event for assistance in response and recovery efforts.

### Outputs from the HAZUS Model

#### Estimated Economic Loss ($ Billions)

<table>
<thead>
<tr>
<th>Description</th>
<th>Residential</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Structural Damage</td>
<td>$0.35 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building Nonstructural &amp; Contents</td>
<td>$1.2 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure (inferred from building damage)</td>
<td>$70 M (20%) of Building Losses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$1.6 B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Estimated Building Damage (Thousands of Buildings)

<table>
<thead>
<tr>
<th>Description</th>
<th>Minor</th>
<th>Major</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Persons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor</td>
<td>20-35</td>
<td>&lt;1</td>
<td>20-40</td>
</tr>
<tr>
<td>Major</td>
<td>1-4</td>
<td>(0.2)</td>
<td>1-2</td>
</tr>
<tr>
<td>Total</td>
<td>21-39</td>
<td></td>
<td>21-42</td>
</tr>
</tbody>
</table>

#### Estimated Casualties

<table>
<thead>
<tr>
<th>Severity Level</th>
<th>Description</th>
<th># of Persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity Level 2</td>
<td>Medical Attention</td>
<td>100-200 (403)</td>
</tr>
<tr>
<td>Severity Level 3</td>
<td>Life-Threatening</td>
<td>&lt;30 (4)</td>
</tr>
<tr>
<td>Severity Level 4</td>
<td>Fatalities</td>
<td>&lt;30 (1)</td>
</tr>
</tbody>
</table>

#### Estimated Shelter Needs

<table>
<thead>
<tr>
<th>Duration</th>
<th>Households</th>
<th>Persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term</td>
<td>1000-2000</td>
<td>(125)</td>
</tr>
<tr>
<td>Long-term</td>
<td>2500-7500</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3500-9500</td>
<td></td>
</tr>
</tbody>
</table>

- Projected residential and non-residential/commercial losses, based on insurance claims: $1.5 Billion
- FEMA IA and EBA assistance: $109 Million
- Documented numbers, as of 6/26/01, shown in (Boldface)

**Disclaimer:** The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and observed economic and social losses following a specific earthquake. These results can be improved by using advanced mapping, geotechnical and observed ground motion data.
Use of HAZUS: Disaster Mitigation Act

- The Disaster Mitigation Act of 2000
  - Amended the Stafford Act
  - Recognized the importance of planning to reduce future disaster loss

- Requirements:
  - State and local mitigation plans with hazard and risk assessment as an element of the plan
  - FEMA is promoting use of HAZUS to support states and locals in developing the risk assessment portion of their mitigation plan
Use of HAZUS: Annualized Loss Estimates

- HAZUS99 Estimated Annualized Earthquake Losses for the United States (FEMA 366)
HAZUS Framework

HAZUS INPUT

Earthquake Epicenter Location and Magnitude

+ Earth Attenuation Model

INVENTORIES

Soil Maps + Building Inventory Maps + Demographic Maps

= HAZUS OUTPUT

Ground Shaking Maps

Direct and Indirect Economic Losses and Damage Estimates

Casualties and Shelter Demand Estimates
Levels of Analysis using HAZUS

- **Level 1**: ‘Default’ assumptions (e.g. soil class D – stiff soils)
- **Level 2**: Better inventory and/or hazard maps (e.g. tax assessor’s data, detailed soil classification map)
- **Level 3**: ‘State of the Art’ (e.g. use of the Advanced Engineering Building Module – AEBM)
‘Proprietary’ Modeling
Insurance and Catastrophe Risk

- Insurance is founded on the principle of risk diversification
  - When the magnitude of a potential loss is considered too great to bear, risk is transferred to an insurer (in exchange for a premium) to be pooled with other uncorrelated risks
  - Insurance is discretionary – insurer can choose what to insure and (in unregulated markets) at what price

- Key challenge to the insurance industry is risk correlation = Catastrophe Risk
  - Insurers buy insurance from reinsurers to protect themselves against catastrophic (CAT) losses
Catastrophe models are used within and across each organization of the pyramid.
The Commercial Imperatives around Cat Modeling (1)

- Industry standards
  - Insurance regulators and rating agencies approving capital adequacy
  - Actuarial Standards of Practice (ASOP 38: Using Models Outside the Actuary’s Area of Expertise)
  - Risk analyses for new cat bond offerings

- Catastrophe response
  - Guaranteed provision of loss information post-event (e.g., hurricane stochastic track, damage assessment, etc.)

- Corporate responsibility for quality of the model
The Commercial Imperatives around Cat Modeling (2)

- Claims data from competing insurance companies
  - Proprietary issues: non-disclosure agreements play a role in the business
  - Provides high resolution exposure and loss information
  - Aids calibration of vulnerability functions and identification of improved vulnerability differentiation
  - Identifies and quantifies additional sources of loss
  - Advances understanding of loss uncertainty and correlation of spatial losses
Stochastic Event Set

- A set of discrete events covering all possible combinations of
  - Type
  - Location
  - Size
  - Recurrence
Characterizing Seismic Sources: Types

Crustal Sources
- Faults
- Background Seismicity: Smaller events on unidentified faults

Subduction Sources
- Interface
- Intraslab
Characterizing Seismic Sources: Event Sizes

- The upper bounds for events on a given structure are estimated from fault dimensions (area or length)

- Characteristic Magnitude
  - The largest expected event on a fault based on fault dimensions

- Maximum Magnitude
  - Largest credible earthquake taking into account uncertainty in characteristic magnitude

- Typically the maximum magnitude will be 0.2 to 0.5 greater than the characteristic event, but is attributed very little rate

Wells and Coppersmith, 1994
Magnitude – Rupture Area Relationship
Characterizing Seismic Sources: Recurrence

- Exponential (Gutenberg-Richter) Model
  - Earthquake magnitude has a log-linear relationship with rate of occurrence

- Characteristic Model
  - Only events of a particular characteristic magnitude are expected to occur on a source
  - Shown with magnitude uncertainty

- Combined Model
  - Exponential for small earthquakes, but largest ("characteristic") events have a different rate of occurrence
Inventory: Geocoding Match Levels

- Coordinate
- Street Address
- Postal Code
- City
- County
- CRESTA

Increasing Resolution → Increasing Uncertainty
Inventory: Regional Variations

- Building codes, code enforcement and construction practices vary from country to country as well as within a country.
- Vulnerability models reflect these variations and is linked to where the location is geocoded.
### Inventory: Earthquake Vulnerability Classifications

Vulnerability damage curves developed for every possible combination to assure all aspects of the structure are incorporated.

<table>
<thead>
<tr>
<th>Construction Class</th>
<th>Other Primary Characteristics</th>
<th>Secondary Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Frame</td>
<td>Occupancy</td>
<td>Soft Story</td>
</tr>
<tr>
<td>Unreinforced Masonry</td>
<td>Year Built</td>
<td>Foundation Bolting</td>
</tr>
<tr>
<td>Reinforced Masonry</td>
<td>Number of Stories</td>
<td>Torsion</td>
</tr>
<tr>
<td>Steel-Braced Frame</td>
<td></td>
<td>Opening Resistance</td>
</tr>
<tr>
<td>Concrete Shear wall</td>
<td></td>
<td>Cladding Type</td>
</tr>
<tr>
<td>etc.</td>
<td></td>
<td>etc.</td>
</tr>
</tbody>
</table>
Damage Assessment Methodologies

- PGA
- Frequency
- Amplitude

PGA $\rightarrow$ MMI $\rightarrow$ Modified MMI (site effects) $\rightarrow$ Damage Ratio

Ground Motion $\rightarrow$ Spectral Acceleration $\rightarrow$ Structural Response $\rightarrow$ Damage Assessment

- Rock Spectra
- Soil Spectra

Spectral Acceleration $\rightarrow$ Period (Height) $\rightarrow$ Damage Ratio

Spectral Acceleration $\rightarrow$ Damage Assessment
Damage Estimation Flowchart
Loss Distributions

- **Event loss distributions**
  - Combine coverages (building, contents, time element) to arrive at a site loss distribution for each event
  - Combine sites to yield a policy loss distribution for each event
  - Combine policies to produce a portfolio loss distribution for each event

- **Annual loss distributions**
  - Combine all event loss distributions to arrive at an annualized probability distribution
## Loss Allocation Example

<table>
<thead>
<tr>
<th>Event (E&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>Annual probability of occurrence (p&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>Loss (L&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>Exceedance probability (EP(L&lt;sub&gt;i&lt;/sub&gt;))</th>
<th>E[L] = (p&lt;sub&gt;i&lt;/sub&gt; * L&lt;sub&gt;i&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.002</td>
<td>25,000,000</td>
<td>0.0020</td>
<td>50000</td>
</tr>
<tr>
<td>2</td>
<td>0.005</td>
<td>15,000,000</td>
<td>0.0070</td>
<td>75000</td>
</tr>
<tr>
<td>3</td>
<td>0.010</td>
<td>10,000,000</td>
<td>0.0169</td>
<td>100000</td>
</tr>
<tr>
<td>4</td>
<td>0.020</td>
<td>5,000,000</td>
<td>0.0366</td>
<td>100000</td>
</tr>
<tr>
<td>5</td>
<td>0.030</td>
<td>3,000,000</td>
<td>0.0655</td>
<td>90000</td>
</tr>
<tr>
<td>6</td>
<td>0.040</td>
<td>2,000,000</td>
<td>0.1029</td>
<td>80000</td>
</tr>
<tr>
<td>7</td>
<td>0.050</td>
<td>1,000,000</td>
<td>0.1477</td>
<td>50000</td>
</tr>
<tr>
<td>8</td>
<td>0.050</td>
<td>800,000</td>
<td>0.1903</td>
<td>40000</td>
</tr>
<tr>
<td>9</td>
<td>0.050</td>
<td>700,000</td>
<td>0.2308</td>
<td>35000</td>
</tr>
<tr>
<td>10</td>
<td>0.070</td>
<td>500,000</td>
<td>0.2847</td>
<td>35000</td>
</tr>
<tr>
<td>11</td>
<td>0.090</td>
<td>500,000</td>
<td>0.3490</td>
<td>45000</td>
</tr>
<tr>
<td>12</td>
<td>0.100</td>
<td>300,000</td>
<td>0.4141</td>
<td>30000</td>
</tr>
<tr>
<td>13</td>
<td>0.100</td>
<td>200,000</td>
<td>0.4727</td>
<td>20000</td>
</tr>
<tr>
<td>14</td>
<td>0.100</td>
<td>100,000</td>
<td>0.5255</td>
<td>10000</td>
</tr>
</tbody>
</table>

Average Annual Loss (AAL) = $760,000
Loss Allocation: L1

- Total Loss
- Loss borne by L1 (Homeowners)
Loss Allocation: L2

- Total Loss
- Loss borne by L2 (Insurer)
Loss Allocation: L3

![Graph showing the relationship between loss and exceedance probability with two lines representing Total Loss and Loss borne by L3 (Reinsurer).]
Loss Allocation

The graph illustrates the loss allocation with the following lines:

- **Total Loss**
- **Loss borne by L1 (Homeowners)**
- **Loss borne by L2 (Insurer)**
- **Loss borne by L3 (Reinsurer)**

The x-axis represents the loss, ranging from $0$ to $50,000,000$, and the y-axis represents the exceedance probability, ranging from $0\%$ to $6\%$.
Uses of Catastrophe Models

**Portfolio Analysis**
- Portfolio analysis of risk contribution before and after proportional retrocessions
- Portfolio strategies on both global or individual cedant relationships
- Ranking of treaties and cedants by risk-to-premium ratios

**Enterprise Risk**
- Manage risk and capital on an enterprise-wide basis
- Understand multi-line risk
- Maximize efficient use of capital
- Reinsurance optimization

**Securitization**
- Analytical support for those wishing to transfer risk via the capital markets
- Evaluation of cost effectiveness of securitization
Portfolio Management and the EP Curve

- Insurer’s 250 year loss target is $100M, but modeled losses exceed this.
- How can the EP be shifted?

Policy changes
Diversification
Risk transfer
Uncertainty
Classifications of Uncertainty

- Aleatory uncertainty: inherent randomness – cannot be reduced by the collection of additional data

- Epistemic uncertainty: uncertainty due to lack of information – can be reduced by the collection of additional data

- Catastrophe modelers do not necessarily distinguish between these two types of uncertainty; instead, they concentrate on not ignoring or double counting uncertainties and clearly documenting the process in which they quantify uncertainty
Sources of Uncertainty

- Aleatory uncertainty captured in probability distributions
  - Earthquake recurrence
  - Vulnerability/damage curves

- Epistemic uncertainty
  - Availability of seismological data (e.g. attenuation models) or geotechnical data
  - Lack of accurate data on structure’s characteristics, property valuation
  - Deficiency of information on repair costs and business interruption costs
Vulnerability Uncertainty

- Which intensity measure correlates best with building damage?
  - Modified Mercalli Intensity
  - Peak ground acceleration/velocity/displacement
  - Spectral response, etc.

- How to account for secondary hazards?
  - Fire following
  - Liquefaction, landslides
  - Water damage from sprinkler leakage
Vulnerability Uncertainty

- Sensitivity of AAL to Magnitude, Distance, Height, and Soil

Spectral Response – Magnitude 8.0

- AAL High Rise / Low Rise
- Soil B
- Soil D

Distance from San Andreas Fault
3 and 25-story steel structure

MMI – Magnitude 8.0

- Tall / Low Rise - Soil B
- Tall / Low Rise - Soil D

Distance (km)
Uncertainty Example

- Competing catastrophe models will generate different EP curves for the same portfolio of structures
- Experienced users expect a range of possible EP curves

Charleston, South Carolina Example

<table>
<thead>
<tr>
<th>Component</th>
<th>Assumption</th>
<th>Defined by individual model?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>Seismic sources, recurrence, soils</td>
<td>YES</td>
</tr>
<tr>
<td>Inventory</td>
<td>134 census tracts from HAZUS</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>‘default’ database</td>
<td></td>
</tr>
<tr>
<td>Vulnerability</td>
<td>Damage curves</td>
<td>YES</td>
</tr>
<tr>
<td>Loss</td>
<td>Repair costs (‘ground up’ loss)</td>
<td>YES</td>
</tr>
</tbody>
</table>
Composite Model Curves

- $P(L > $1 billion) = 0.65\%$
- 1-in-154 year event

**Legend:**
- Blue line: Upper Bound (95th percentile)
- Dashed black line: Equally-Weighted Mean
- Pink line: Lower Bound (5th percentile)
Uncertainty Example – Use of HAZUS

Initialize $j = 1$

Scenario Builder
Hazard Component
(EQ Event $j$: Source, Magnitude, Recurrence, Propagation)

Inventory Component
(HAZUS97 database of structures)

HAZUS

Vulnerability Component

Loss Component

Yes

$j < N$

No

HAZUS-EP

$j = j + 1$
HAZUS EP Curve

\[ P(L > \$1 \text{ billion}) = 0.48\% \]

1-in-208 year event
“Ultimately, models are tools, and modeling is a collaborative venture between those who build them and those who use them...”