Safe Enough? How Building Codes Protect Our Lives but Not Our Cities

Keith Porter, PE, PhD
Associate Research Professor, CU Boulder

CU SESM Seminar
1 Mar 2013
California earthquakes

2 inches per year
California seismicity 1800-1994
What happens in an earthquake

- Normal fault
- Reverse fault
- Strike-slip fault
- Oblique fault
Fault rupture
The Big One
M6.7 Northridge was not the big one
Probabilistic seismic hazard analysis

- Map faults locations
- Treat background sources
- Estimate how frequently each source produces various size earthquakes
- Calculate shaking at each of many points for each possible earthquake
- For each point, calculate the frequency with which various levels of shaking are exceeded

Hazard curve

Exceedance frequency (events/year)

Shaking, $x$, units of gravity
Design each building for shaking with fixed exceedance probability
Or for fixed annual probability of collapse

Seismic hazard

Seismic fragility

Exceedance frequency (events/year)

Shaking, $x$, units of gravity

Failure probability

Demand, $x$
Code performance objectives

• “The probability of collapse due to [2500-year] ground motions ... is limited to 10%, on average.... The probability of collapse for individual archetypes is limited to 20%....”

• “Collapse includes both partial and global instability of the seismic-force-resisting system, but does not include local failure of components not governed by global seismic performance factors, such as localized out-of-plane failure of wall anchorage and potential life-threatening failure of nonstructural systems.”
Risk-targeted design

ASCE 7-10: “The probabilistic [design] accelerations shall be taken as the ... acceleration that is expected to achieve a 1 percent probability of collapse within a 50-year period.”
## Comparable risk

<table>
<thead>
<tr>
<th>Peril</th>
<th>Deaths/100,000 pop/yr</th>
<th>Where, when</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart disease</td>
<td>258</td>
<td>US, 2000</td>
</tr>
<tr>
<td>Very poor building (earthquake)</td>
<td>67</td>
<td>24/7 occupancy</td>
</tr>
<tr>
<td>All accidents</td>
<td>36</td>
<td>US, 2000</td>
</tr>
<tr>
<td>Auto accidents</td>
<td>11</td>
<td>CA, 2001</td>
</tr>
<tr>
<td>Poor building (earthquake)</td>
<td>7</td>
<td>24/7 occupancy</td>
</tr>
<tr>
<td>Gas-industry job</td>
<td>4</td>
<td>US, 1995-2000</td>
</tr>
<tr>
<td>Handguns</td>
<td>3</td>
<td>US, 2004</td>
</tr>
<tr>
<td>Acceptable building (earthquake)</td>
<td>0.7</td>
<td>24/7 occupancy</td>
</tr>
<tr>
<td>New building (earthquake)</td>
<td>0.2</td>
<td>24/7 occupancy</td>
</tr>
<tr>
<td>CA earthquakes last ~50 yr</td>
<td>0.02</td>
<td>CA, 1952-2002</td>
</tr>
</tbody>
</table>
We’ve never chosen “safe enough”

• Objectives calibrated to prior “implicit” goals but not deliberately chosen, objectives. E.g.,
  – 1980: “The new probability-based load criterion should lead to designs which are essentially the same [level of safety]... as those obtained using current acceptable practice.” (ANS 577)
  – IBC 2008 aims to be “consistent with the expected performance expressed in the Commentary of the 2003 NEHRP Provisions, namely that ‘if a structure experiences a level of ground motion 1.5 times the design level [i.e., if it experiences the 2500-year ground motion level], the structure should have a likelihood of collapse... [of] 10%.’”
What the code sees
What society sees
What happens in MCE shaking?

Let’s just rely on FEMA P-695 & history

• FEMA P-695: 10% collapse rate in code-compliant stock
  Even if a “notational” value, reasonable for current stock
• Red tags without collapse
  – Northridge 2,290 red tags in LA County; 200 soft story WF & 15 hillside houses “collapsed or came close;” unknown number of URM & RC collapses, maybe low 10s?
  – SF Marina in 1989: 40-50 red tags & 4 collapses
    Say 10 non-collapse red tags per collapse
• Yellow tags
  – Northridge LA County: 9,445 yellow tags, 2,290 red
    Say 4 yellow tags per red tag
What happens in MCE shaking?

<table>
<thead>
<tr>
<th></th>
<th>Ratio</th>
<th>Fraction of stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collapse</td>
<td>10% of stock</td>
<td>10%</td>
</tr>
<tr>
<td>Red &amp; not collapsed</td>
<td>10 red tags per collapse</td>
<td>Most of the rest</td>
</tr>
<tr>
<td>Yellow</td>
<td>4 yellow tags per red tag</td>
<td>Most of the rest</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>Virtually all</td>
</tr>
</tbody>
</table>

Reflects code-compliant buildings; older buildings would be worse
But the Big One ≠ MCE shaking

- $\text{MCE}_G = 2\%/50 \text{ yr site shaking}$
- Varies by site
- Includes inter- and intra-event uncertainty
- Below-mean shaking at point X accompanies above-mean shaking at Y

→ “Big One” shaking is generally less than MCE
(Big One PGA)/(design-level PGA) ≈ 0.5-1.0 across much of greater LA area
(Big One $S_S$)/(design-level $S_S$) $\approx$ 0.5-1.0 across much of greater LA area

ShakeOut $Sa(0.3 \text{ sec, 5\%})$  

ASCE 7-10 MCE$_R$ $S_S$, B soil ($Fa\approx1.0$)
\( \frac{\text{Big One } S_1}{\text{design-level } S_1} \approx 0.5-1.0 \) across much of the SFBA

M7.9 San Andreas Sa(1.0 sec,5%)  
MCE\(_R\) \( S_1 \), B soil \( (F_v \approx 1.3) \)
Damage at $\frac{1}{2}$ MCE (the Big One)

- $P(\text{coll} \mid S_s=1.5g) = 0.1 \approx \Phi(\ln(1.5/\theta)/\beta)$
- $\theta \approx 1.5 \cdot \exp(1.28 \cdot 0.6) = 3.2$
- $P(\text{coll} \mid S_s=0.75s) \approx 0.01$
- For ref: $\text{MCE}_R$ provides $\sim 1\%$ collapse probability in 50 years
What happens in the Big One

<table>
<thead>
<tr>
<th></th>
<th>Ratio</th>
<th>Fraction of stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collapse</td>
<td>1% of stock</td>
<td>1%</td>
</tr>
<tr>
<td>Red</td>
<td>10 red tags per collapse</td>
<td>10%</td>
</tr>
<tr>
<td>Yellow</td>
<td>4 yellow tags per red tag</td>
<td>40%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>50%</strong></td>
</tr>
</tbody>
</table>

(Again, assumes 100% code-compliant stock)
We don’t have a code-compliant stock

CA highrise ages (Emporis 2007)

LA & Long Beach dwellings (American Housing Survey 2013)
Can SoCal survive a 300-year earthquake?
Implications for a not-very-rare earthquake

• 2012 Los Angeles vacancy rates
  – Residential: 2-5%
  – Commercial: 11%
  – Industrial: 5%

• ShakeOut (300-year earthquake): 1800 deaths in 20 million affected population (20 deaths/100,000 people), but perhaps 25-50% of households and businesses move away.

• Does “society” know that’s what it is getting?
So we may have a serious problem
How we got here; 4 assumptions

1. Greater seismic resilience of the building stock is difficult to achieve
2. The public would be unwilling to pay increased initial construction costs for improved seismic performance
3. The public is incapable of participating in the process of setting community seismic performance goals
4. Current seismic provisions encode the proper performance measures and goals
Assumption 1: greater seismic resilience of the building stock is difficult to achieve
Broad Center for the Biological Sciences
CUREE-Caltech Woodframe Project

Small house: 1200 sf, 2 bdrm, 1 ba

Large house: 2,400 sf, 3 bdrm, 2½ba

Townhouse: 2,000 sf, 3+2

Apartment building: 10 850-sf units

Animations by Doron Serban (CUREE)
Retrofit benefit-cost ratio can reach 8

*Brace cripple walls of CUREE-Caltech small house, not every small house
Retrofit benefit-cost ratio can reach 8

* Add wood shearwalls on apartment building*

BCR: up to 7 i.e., *this* apartment building, not *every* one

Cost: $11,000
Assumption 2: public unwilling to pay increased initial costs for better seismic performance

A longish digression
San Francisco Community Action Plan for Seismic Safety

“The CAPSS project of the San Francisco Department of Building Inspection (DBI) was created to provide ... a plan ... to reduce earthquake risks in existing, privately-owned buildings, ... and also to develop ... guidelines that will expedite recovery....”

Here: one aspect of CAPSS focusing on soft-story dwellings
The problem: 4,400 wood framed buildings in San Francisco susceptible to soft-story-induced damage during earthquakes
The problem:

45,000 dwelling units
89,000 residents
90% rental units
7% of housing
8% of population
2100 businesses
84% with 5 or fewer employees
CAPSS Public Advisory Committee volunteers

- Neighborhood groups
- Landlords
- Tenants
- Affordable housing advocates
- Architects, engineers
- Seismologists
- Historic preservation interests
Public Advisory Committee concerns

- Population that lives, works, owns buildings
- Concentration of buildings in neighborhoods
- Contribution to neighborhood character
- Effects of a few scenario earthquakes
- Financial impact on neighborhood
- How to fund repair
- How to fund retrofit
CAPSS scenario earthquakes

Scenario Earthquakes considered in study:
- Hayward fault; magnitude 6.9 (rupture length: 36 km)
- San Andreas fault; magnitude 6.5 (rupture length: 18 km)
- San Andreas fault; magnitude 7.2 (rupture length: 60 km)
- San Andreas fault; magnitude 7.9 (rupture length: 198 km)

ATC, 2009: Here Today, Here Tomorrow
CAPSS soft story model buildings

ATC, 2009: Here Today, Here Tomorrow
4 design levels & performance goals

- As-is
- Retrofit 1 - safe but not repairable – address obvious lack of shear walls
- Retrofit 2 – safe and usable after repair – provide systematic bracing in ground story
- Retrofit 3 – safe and usable during repair – increased stiffness to reduce drift-related damage

Photos: Anderson Niswander Construction
M 7.2 San Andreas event, no retrofit

A possible outcome:

- 600 buildings collapsed
- 1200 additional buildings red tagged
- 36,000 residents displaced long-term
- 800 businesses displaced long-term

*ATC, 2009: Here Today, Here Tomorrow*
M 7.2 San Andreas event, no retrofit

- **Impact on residents** – displaced long term from jobs, schools, support services – low income or elderly
- **Impacts on housing** – 50% not usable after 4 years
- **Impacts on owners** – lack of repair resources
- **Impacts on businesses** – small business failures
- **Impacts on neighborhoods** – loss of residents, buildings and character, shift to lower income residences, inability to support housing repair
Same M7.2 event with retrofit

<table>
<thead>
<tr>
<th></th>
<th>Per Building</th>
<th>Per Residential Unit</th>
<th>Per Square Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
<td>Average</td>
</tr>
<tr>
<td>Retrofit Scheme 1</td>
<td>$65,000</td>
<td>$49,000 to $79,000</td>
<td>$9,000 to $13,000</td>
</tr>
<tr>
<td>Retrofit Scheme 2*</td>
<td>$105,000</td>
<td>$59,000 to $132,000</td>
<td>$15,000 to $20,000</td>
</tr>
<tr>
<td>Retrofit Scheme 3*</td>
<td>$93,000</td>
<td>$58,000 to $114,000</td>
<td>$13,000 to $19,000</td>
</tr>
</tbody>
</table>

ATC, 2009: Here Today, Here Tomorrow
Retrofit means more people can stay in their homes

Shelter in place

Figure 16. Approximate distribution of damage tags before and after three retrofit schemes in a scenario magnitude 7.2 earthquake on the San Andreas Fault. The number of tags in each category could vary as shown in Table 2.
Same M7.2 event with retrofit

As-is

Retrofit 3

Wood Frame Buildings with 3+ Stories and 5+ Residential Units with Significant Ground Floor Openings - San Andreas M7.2 "As-Is"

Wood Frame Buildings with 3+ Stories and 5+ Residential Units with Significant Ground Floor Openings - San Andreas M7.2 Retrofit 3

ATC, 2009: Here Today, Here Tomorrow
Retrofit has other benefits

A possible soft-story outcome (M7.2 scenario):

- 14,600 buildings collapsed
- 110,120 additional buildings red tagged
- 5,300,36,000 residents displaced long-term
- 120,800 businesses displaced long-term
Public Advisory Committee key recommendations

• Establish a program that requires owners to evaluate, and to retrofit if found deficient

• Buildings should be retrofitted to a standard that will allow most of them to be occupied after a large earthquake

• Incentives to encourage voluntary retrofits

• Working group to develop implementation plan
Some surprises of CAPSS

What one might expect

• Voluntary standards
• Minimum standards
• Conflict between tenants and landlords

What the committee called for

• Mandatory retrofits
• Highest standards
• Consensus between tenants and landlords
• Agreed to share costs
FOR IMMEDIATE RELEASE:
Tuesday, February 5, 2013
Contact: Mayor’s Office of Communications, 415-554-6131

*** PRESS RELEASE ***

MAYOR LEE, PRESIDENT CHIU & SUPERVISOR WIENER INTRODUCE LEGISLATION MANDATING SEISMIC SAFETY RETROFIT FOR SOFT-STORY RESIDENTIAL BUILDINGS

Legislation Requires Seismically Retrofitting Large Woodframe Soft-Story Residential Buildings as Part of Earthquake Safety Implementation Program to Prepare City & Residents for Recovery & Rebuild After Major Earthquake

San Francisco, CA—Today Mayor Edwin M. Lee, Board President David Chiu and Supervisor Scott Wiener introduced legislation mandating the seismic retrofit of the City’s large wood-frame soft-story residential buildings, a historic step forward to ensure San Francisco’s resilience and safety. The legislation is also co-sponsored by Supervisors Norman Yee, Mark Farrell, London Breed and Eric Mar.
Assumption 3: the public is incapable of participating in the process of setting community seismic performance goals
Non-engineers can participate in setting community seismic performance goals.

San Francisco Planning and Urban Research (SPUR), “the citizens' voice for good planning”
“The Bay Area Earthquake Alliance, which is composed of 182 member groups and organizations, coordinates earthquake awareness and preparedness activities throughout the San Francisco Bay Area. The Alliance is a part of the Earthquake Country Alliance, a statewide alliance linking organizations and individuals that provide earthquake information and services.”
Assumption 4: current seismic provisions encode the proper performance measures and goals

How non-engineers perceived the Big One in ShakeOut
Notice the dissonance

International Building Code

• An earthquake with ~1/2500 year shaking
• 1% collapse probability in 50 years
• 10% collapse probability given 2/3 x 2500-year shaking

Preparedness Now Video

• An earthquake that happens once in 150 years
• Community-level impacts
• 1500 buildings collapsed
• 300,000 significantly damaged
• 1800 killed
• 53,000 injured
• 255,000 homeless
• $213B in damage
• Large number of people trapped
• 1600 fires started...
Notice the dissonance

• 10% acceptable collapse probability in MCE may be tolerable from a societal viewpoint...

  ... when the Big One strikes a remote community
  ... maybe *not* when it strikes Los Angeles
A Way Forward
A profession-wide debate?

Authors of the 1st probabilistic seismic design requirements (Ellingwood et al. 1980) were concerned that seismic and wind safety were “relatively low when compared to that for gravity loads,” and called for “a profession-wide debate” over whether wind and seismic loads ought to have similar reliability as that inherent in gravity loads.
A profession-wide debate?

• In 2008 discussion over setting the goal for new design to be 10% collapse probability in 2500-year shaking, one participant was “Shocked that there was literally no debate” over whether the goal was reasonable or the right measure.

• In discussions in BSSC Project ‘07 (reassessment of seismic design procedures), there “May have been a little discussion” about measuring societal impacts, but no formal discussion.
Conclusions

• The code’s performance metric is an accident of history
• We never deliberately chose a performance goal
• We called for but never had a debate about it
• We never involved the public
• The code protects our lives, but represents a catastrophic threat to our cities
Conclusions

• The public is capable of discussing tolerable seismic risk
• The public thinks about earthquake risk in very different terms than do building professionals
• The public is willing to pay for greater seismic resilience
• Better seismic performance may be quite affordable
Conclusions

We need a societal conversation about costs and benefits of design requirements that consider

• A more frequent earthquake
• Community level impacts (higher requirements in a metropolis?)
• Significant damage
• Post-earthquake usability
• Fatalities and nonfatal injuries
• Repair costs, fires, people trapped in elevators...
Thanks

keith@cohen-porter.net
626-233-9758