Safe Enough? How the Building Code Protects Our Lives but Not Our Cities

MMC Mitigation Seminar Series
April 23, 2014
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Principal, SPA Risk LLC, Denver CO
63% of the US population lives in regions of moderate to high seismicity
Many possible “big ones”
1994 Northridge M6.7 was not big
Design each building for $\frac{2}{3} \text{MCE}_R$.
NEHRP Provisions Objective

Ordinary buildings in earthquakes will:

“Avoid serious injury and life loss due to structural collapse, failure of nonstructural components or systems, and release of hazardous materials... And reduce structural and nonstructural repair costs where practicable to do so.”

-- 2015 in-progress draft
ASCE 7 performance objective

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.”
FEMA P-695 performance objective

FEMA P-695, Sec 7.1.2 Acceptable Probability of Collapse:

“... It is suggested that the probability of collapse due to MCE ground motions ... be limited to 10%.... A limit of twice that value, or 20%, is suggested ... for evaluating the acceptability of potential ‘outliers’....”
The code *does* protect our lives

<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>194</td>
<td>US, 2010</td>
</tr>
<tr>
<td>All accidents</td>
<td>39</td>
<td>US, 2010</td>
</tr>
<tr>
<td>Occupational fatality, roofers</td>
<td>32</td>
<td>US, 2011</td>
</tr>
<tr>
<td>Auto accidents</td>
<td>11</td>
<td>US, 2009</td>
</tr>
<tr>
<td>Handguns</td>
<td>10</td>
<td>US, 2010</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>0.007</td>
<td>CA, 1964-2014</td>
</tr>
</tbody>
</table>
We’ve never chosen “safe enough”

“We feel strongly that the new probability-based load criterion should lead to designs which are essentially the same ... as those obtained using current acceptable practice.”
(ANS SP 577 pg 61)
What the code sees
What society sees
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, not collapsed</td>
<td>10 red tags per collapse in Northridge &amp; SF Marina</td>
<td>Most of the rest</td>
</tr>
<tr>
<td>Yellow</td>
<td>4 yellow tags per red tag in Northridge</td>
<td>Most of the rest</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>Virtually all</td>
</tr>
</tbody>
</table>

1. Buildings optimized to just meet ASCE 7-10 objective. Real buildings would have some margin and do somewhat better.
2. Assumes new buildings have same ratios as existing, and constant ratios apply at all levels of shaking.
Big-one shaking in LA area

ShakeOut $\text{Sa}(0.3 \text{ sec, 5\%})$  ASCE 7-10 $S_s$, B soil ($F_a\approx 1.0$)

“Demand-to-design ratio” (DDR): the ratio of these
Collapse probability varies with shaking

Collapse prob. at $DDR = 0.5$ is 0.7-1.6%
Example: $DDR = 0.5$

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<th>Fraction of stock</th>
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</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></td>
<td><strong>Total impairment rate:</strong></td>
<td><strong>50%</strong></td>
</tr>
</tbody>
</table>

(100% code-compliant stock)
What code sees

1% collapse

What society sees

“Impairment rate”

49% of buildings usable after earthquake

Limited use: 40%

10% unsafe
M 7.0 Hayward Fault (~200-yr event)  
$DDR \geq 0.5$ over $3,000 \text{ km}^2$  
Avg impairment rate 50% over $8,400 \text{ km}^2$
ShakeOut (~150-year event)  
DDR ≥ 0.5 over 7,000 km² of this map  
Avg impairment rate 50% over 15,000 km²
Impairment rate in tangible terms

8,400 km\(^2 \cdot 411 \text{ people/km}^2\)
≈ 3.5 million people
≈ 350,000 businesses

15,000 km\(^2 \cdot 203 \text{ people/km}^2\)
≈ 3.0 million people
≈ 300,000 businesses
In a not-very-rare earthquake

• 2012 SF Bay Area vacancy rates
  – Single family dwellings: 1.1%
  – Residential rental units: 3.5%
  – San Francisco offices: 9%
• ½ households and businesses in 8,400 km² leave
• ... with a code-compliant building stock

Does “society” know that’s what it is getting?
Do they know what they’re getting?

Lucy Jones, pers. comm., 19 Nov 2013:
City councils and mayors “absolutely do not know” about the life-safety objective & how damaged a code-compliant building stock will be in the aggregate, and are unsatisfied when they do learn of it.
We may have a serious problem

And it’s not just the existing buildings
How we got here

4 assumptions
Assumption 1: greater seismic resilience of the building stock is difficult to achieve

- Housner (1956) “it would be quite costly to design for lateral forces of this magnitude”
- Housner and Jennings (1982): “It is not economical to design every structure to resist the strongest possible earthquake without damage” and therefore codes “permit yielding and structural damage in the event of very strong shaking.”
Broad Center for Biological Sciences

+10%

+2%
CUREE-Caltech Woodframe Project

Small house: 1200 sf, 2 bdrm, 1 ba

Large house: 2,400 sf, 3 bdrm, 2½ ba

Townhouse: 2,000 sf, 3+2

Apartment building: 10 850-sf units

Animations by Doron Serban (CUREE)
CUREE-Caltech large house

Reitherman and Cobeen (2003)

- Design to conventional objectives: $221,000
- Immediately occupiable: $229,000
- 3% difference (½ a bathroom remodel)
Retrofit benefit-cost ratio can reach 8

*Brace cripple walls of CUREE-Caltech small house, not every small house*
Assumption 2: public unwilling to pay for better seismic performance

• ATC-3-06 (1978) were unable to provide figures on the probable costs to make buildings remain functional after a rare earthquake, but codified the assumption that it is economically infeasible to do so

• Nobody asked the public
4,400 wood framed buildings in SF susceptible to soft-story damage in earthquakes
45,000 dwelling units, 89,000 residents
7% of housing, 8% of population
90% are rental units
2100 businesses, 84% with ≤5 employees
CAPSS Public Advisory Committee

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

- Population that lives, works, owns them
- 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)
4 design levels & performance goals

As-is, or any of 3 retrofits

1 – safe but not repairable
2 – safe & usable after repair
3 – safe & usable during repair

Photos: Anderson Niswander Construction
## Retrofit costs

### Table 3: Direct Construction Costs Estimated for Four Representative Multi-Unit, Wood-Frame Soft-Story Buildings for Each Retrofit Scheme

<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.
Retrofit and the M7.2 earthquake

Higher retrofit $\rightarrow$ more people shelter in place
Retrofit and the M7.2 earthquake

As-is

Retrofit 3
Retrofit and the M7.2 earthquake

Under retrofit 3:

- 14,600 buildings collapsed
- 110,120 non-collapses are red tagged
- 5,300-36,000 residents displaced long-term
- 120,800 businesses displaced long-term
Recommendations of the Public Advisory Committee

• 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 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: public has no role setting seismic performance goals

• Ellingwood et al. (1980): A58 standards committee represents

“those substantially concerned with [the standard’s] scope and provisions.” Committee members include “a broad-spectrum group of ... researchers, ... code groups, industry, professional organizations and trade associations.”

(No owners or tenants.)
Non-engineers can participate in setting community seismic performance goals

Feb 2012 *Urbanist*: SPUR interpreted CAPSS study, addressed:

1. How much SF housing needs to meet shelter-in-place standards?
2. What engineering criteria should be used to determine whether a home has adequate shelter-in-place capacity?
3. What needs to be done to enable residents to shelter in place for days and months after a large earthquake?

San Francisco Planning and Urban Research (SPUR), “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

• 1980-2009: single-building risk of life-threatening damage given rare shaking
• 2010-: single-building long-term collapse risk, formulated to work like 1980-2009
What are proper performance measures?

Slovic et al. (1981): Public risk judgments “only moderately related to the annual death rates, raising the possibility that risk means something different to them.”

1. Dread (fatal to large numbers of people)
2. Unknown-ness (new, involuntary, delayed)
3. Number exposed, rater’s own exposure
Performance metrics noticed in ShakeOut PSAs and public officials’ talks

<table>
<thead>
<tr>
<th>International Building Code</th>
<th>What the public focused on</th>
</tr>
</thead>
<tbody>
<tr>
<td>• An earthquake with ~1/2500 year shaking</td>
<td>• An earthquake that happens once in 150 years</td>
</tr>
<tr>
<td>• 1% collapse probability in 50 years</td>
<td>• Community-level impacts</td>
</tr>
<tr>
<td>• 10% collapse probability given 2/3 x 2500-year shaking</td>
<td>• 1,500 buildings collapsed</td>
</tr>
<tr>
<td></td>
<td>• 300,000 significantly damaged</td>
</tr>
<tr>
<td></td>
<td>• 1,800 killed</td>
</tr>
<tr>
<td></td>
<td>• 53,000 injured</td>
</tr>
<tr>
<td></td>
<td>• 255,000 homeless</td>
</tr>
<tr>
<td></td>
<td>• $213B in damage</td>
</tr>
<tr>
<td></td>
<td>• Many people trapped</td>
</tr>
<tr>
<td></td>
<td>• 1,600 fires started...</td>
</tr>
</tbody>
</table>
Dissonance

10% collapse rate in MCE *may* be tolerable to society...

... when the Big One strikes a remote community

... probably *not* when it strikes a metropolis
A way forward?

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 for gravity loads.
A way forward?

• 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.
A way forward?

• New tools to express catastrophe risk implicit in code objectives
  – New knowledge of what the public is interested in and capable of understanding
  – Physics-based models of “big ones”
  – FEMA P-695

• Can assess scenarios in light of design maps through DDR and impairment rate
A way forward

• Could similarly assess catastrophe risk
  – In Memphis, Salt Lake City, Charleston, ...
  – Under “as-is” and “what-if” code objectives
  – Difference is the benefit of a stricter code

• Let’s assess the cost of greater seismic resilience (the challenge of ATC 3-06)

• Let’s use DDR, impairment maps, costs and benefits in a nationwide conversation about code objectives
Summary and conclusions
Summary

1. Performance goals never deliberately chosen
2. Never any debate, never involved the public
3. We don’t understand public perception of risk, which is different from ours
4. We don’t reflect it in the code
5. Better performance may be very affordable
6. Public is capable of understanding risk, willing to pay for greater resilience
Conclusions

1. Code protects our lives but not our cities
2. Code may not deliver what the public wants
3. We need a societal conversation about costs & benefits of design requirements, reflecting
   – Community level impacts (tags, usability, injuries…)
   – Regionally varying preferences?
   – More-frequent earthquakes?
   – Our obligation to “hold paramount the safety, health and welfare of the public….” in terms the public cares about.
• Code operates on 1 building at a time
• Today’s code produces the building stock of 2064
• We know where we are heading now

Where do we want to be in 2064?
Who will turn the ship?
Thanks

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