1. How will a code-compliant building stock perform in a large earthquake?
2. What does the public expect and prefer?
3. How to inform local government decisions?
Topic 1: How will a code-compliant building stock perform in a large earthquake?
“... 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’....”
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 as of summer 2014
### The code seems to meet its objective

<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>0.1</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>

*Assumes 0.6% collapse probability/50 years rather than 1.0%
What about resilience?
Let’s call these buildings “impaired”
How many buildings are impaired for each collapse?

1989 Loma Prieta & 1994 Northridge
  1 collapse
  + 13 red
  + 13 \cdot 3.8 \text{ yellow}
  = 63 \text{ impaired per collapse}
(3x more with “moderate damage” – Comerio 2006)

Napa 2014 had 57 impaired per collapse
What happens in the Big One?
USGS HayWired scenario
$M_w 7.05$ Hayward Fault earthquake

Probability of Hayward Fault $M 7.05 = 0.5\%$/year
M 7.05 Hayward Fault assuming all-new buildings

10,000 buildings collapse
100,000 red-tagged
400,000 yellow-tagged
How many people & businesses?

\( M_w 7.05 \) Hayward Fault scenario
1.5 million people
150,000 businesses

\( M_w 7.8 \) So San Andreas scenario
1.6 million people
160,000 businesses
What if the goal were resilience?

Ordinary buildings in earthquakes will:

“Avoid serious injury and life loss due to structural collapse, substantial damage to nonstructural components and systems, and release of hazardous materials, and be largely habitable or functional.”
50% stronger might cost 1% more

NIST GCR 14-917-26: I = 1.6 relative to 1999 SBC in Memphis TN

<table>
<thead>
<tr>
<th>Building</th>
<th>IBC/Local code</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N-S</td>
<td>E-W</td>
</tr>
<tr>
<td>Apartment</td>
<td>1.36</td>
<td>1.46</td>
</tr>
<tr>
<td>Office</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>Retail</td>
<td>1.92</td>
<td>1.94</td>
</tr>
<tr>
<td>Warehouse</td>
<td>1.88</td>
<td>1.88</td>
</tr>
<tr>
<td>Hospital</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>School</td>
<td>1.49</td>
<td>1.49</td>
</tr>
</tbody>
</table>

If designed 50% stronger, buildings might cost 0.5-1.5% more incl. land, except special cases requiring different foundation, lateral system, etc.

-- oral commun. 2015., D. Bonneville, E. Reis, R. Mayes, J. Harris
We do this all the time

\( I_e = 1.5 \) here costs less than \( I_e = 1.0 \) here

\( 1.0 \ I_e \) in west SF = \( 1.5 \) in east SF = \( 1.5 \) in Seattle = \( 2.0 \) in Sacramento = \( 2.0 \) in San Diego
Implication

50% stronger buildings might cost 1% more

We can afford this

We do it all the time without noticing
Benefits of stronger buildings

$I = 1.0$

$I = 1.5$
### Stronger buildings in HayWired

<table>
<thead>
<tr>
<th>Condition</th>
<th>Buildings affected</th>
<th>I = 1.0</th>
<th>I = 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collapsed</td>
<td>8,000</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>Red tagged</td>
<td>102,000</td>
<td>27,000</td>
<td></td>
</tr>
<tr>
<td>Yellow tags</td>
<td>390,000</td>
<td>100,000</td>
<td></td>
</tr>
<tr>
<td>Total impaired buildings</td>
<td>500,000</td>
<td>130,000</td>
<td></td>
</tr>
<tr>
<td>Affected people</td>
<td>1,500,000</td>
<td>390,000</td>
<td></td>
</tr>
<tr>
<td>Affected businesses</td>
<td>150,000</td>
<td>39,000</td>
<td></td>
</tr>
<tr>
<td>% of 2,050,000 buildings in 9 SF Bay counties</td>
<td>24%</td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>
Topic 2: What does the public expect or prefer?
How much does the public know? What do owners want?

*Lucy Jones, oral 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.

*Lucy Jones, written comm., 20 Nov 2015:*
“[T]he board of the Building Owners and Managers Association of Greater Los Angeles ... would accept an unspecified greater construction cost to achieve better seismic performance, if it was mandated. They ... would like to see it mandated because they don't want to have their building be a financial loss after the earthquake. [The higher cost] would just be the cost of business in Los Angeles....”
Public might prefer more...

2/5/2013, SF Mayor’s Office: “Today [the Mayor & others] introduced legislation mandating the seismic retrofit of the City’s large wood-frame soft-story residential buildings.”

“Moore’s new ... homes would be built to withstand winds up to 135 miles per hour rather than the accepted standard building requirements of 90 miles per hour.”
A population survey by MMC & USGS

In a formal, scholarly survey, we ask:
1. Respondent’s role (elected official, etc.)
2. What respondent thinks the code objective is
3. What it should ensure
4. Tradeoffs between cost and higher performance
5. Income, education, age...
Surveyed 814 CA & Central US adults

413 Californians
- Completed, 413, 55%
- Incomplete, 278, 37%
- Disqualified, 62, 8%

401 in St Louis and Memphis
- Completed, 401, 53%
- Incomplete, 309, 41%
- Disqualified, 43, 6%
What should it ensure?

What should the building code provide? That is, if someone builds a new building in your community and it meets building-code requirements for seismic safety, which one of these would you most prefer the code to ensure? In some of the responses below we use the term "the Big One," by which we mean an earthquake that might be considered a once-in-a-lifetime event.
What is occupiability worth?

Suppose that in the Big One..., up to 1 out of 5 buildings ... would collapse or require major repairs, taking a year or more to repair before they could be reoccupied. Suppose that you could change the code so that it would reduce that fraction to 1 in 100 or less, but at the cost of higher initial construction costs. What additional cost do you think building buyers should be willing to pay to achieve that end?
Implication

Public expects & is willing to pay for IO design
Topic 3: informing city-council decisions
Life-safety design produces safe buildings and economic catastrophe
Citizens want resilient buildings
*(Need surveys in Seattle, Utah, SC...)*

People expect resilience
- Life safe 22%
- Occupiable 41%
- Functional 18%
- Do not know 17%
- Other 2%

They are willing to pay for it
- $0/sf 12%
- $1/sf 20%
- $3/sf 31%
- $10/sf 20%
- Do not know 17%
Optional code adoption language?

ASCE 7 Table 1.5-2 is modified so that all buildings shall be designed with seismic importance factor $I_e$ of 1.50

<table>
<thead>
<tr>
<th>Risk Category from Table 1.5-1</th>
<th>Snow Importance Factor, $I_s$</th>
<th>Ice Importance Factor—Thickness, $I_i$</th>
<th>Ice Importance Factor—Wind, $I_w$</th>
<th>Seismic Importance Factor, $I_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.80</td>
<td>0.80</td>
<td>1.00</td>
<td>1.50</td>
</tr>
<tr>
<td>II</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.50</td>
</tr>
<tr>
<td>III</td>
<td>1.10</td>
<td>1.25</td>
<td>1.00</td>
<td>1.50</td>
</tr>
<tr>
<td>IV</td>
<td>1.20</td>
<td>1.25</td>
<td>1.00</td>
<td>1.50</td>
</tr>
</tbody>
</table>
An MMC/CFIRE product?
Thanks

Keith.porter@colorado.edu

626-233-9758