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

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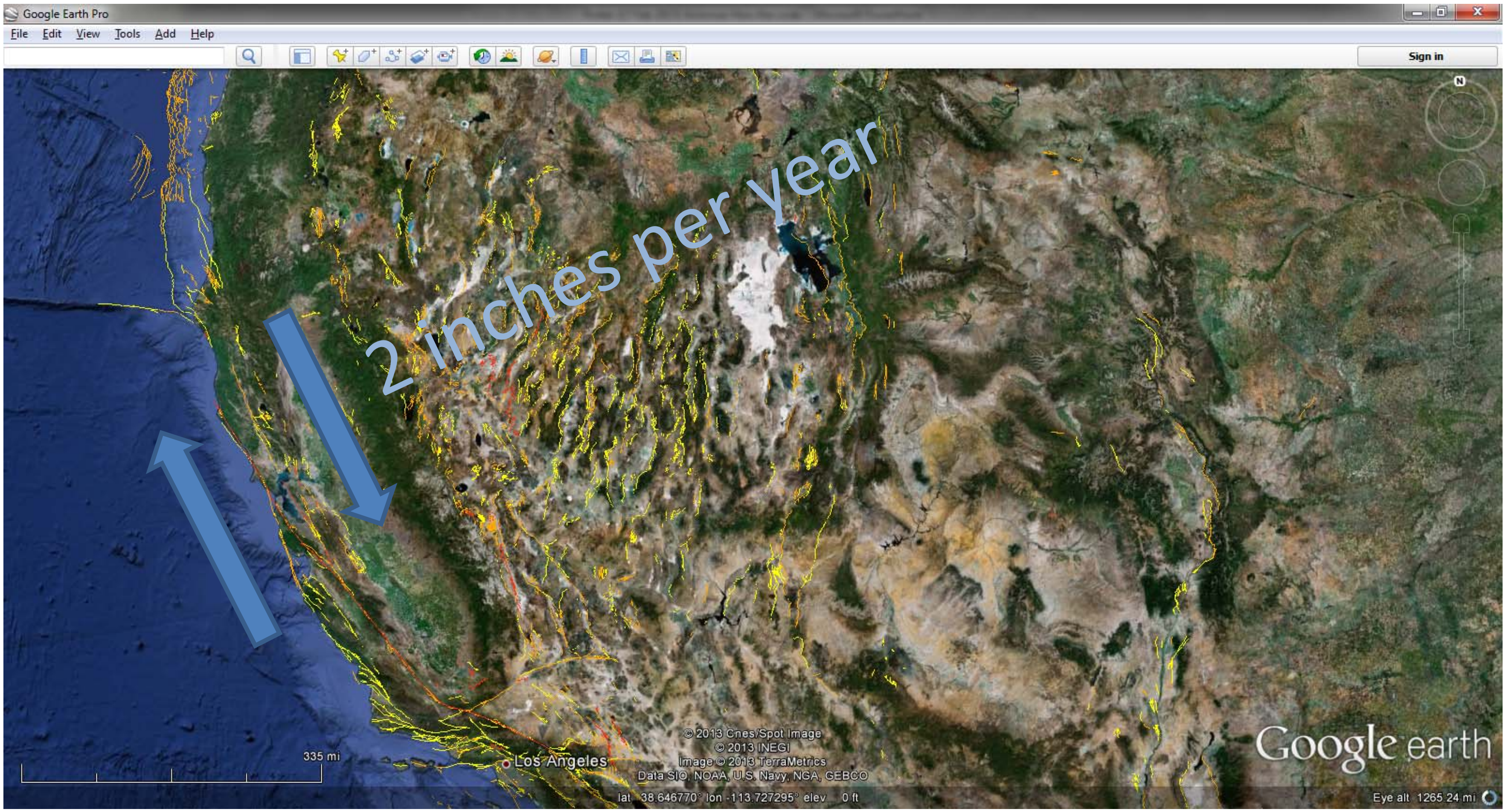
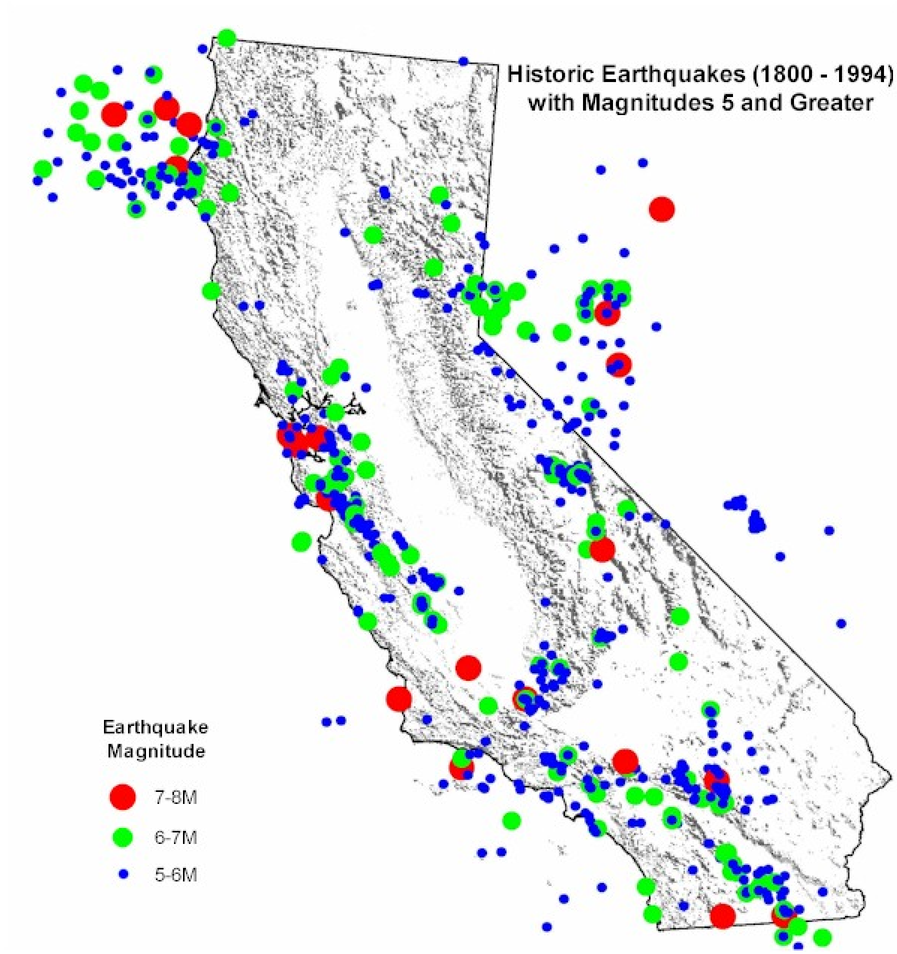
CU SESM Seminar
1 Mar 2013

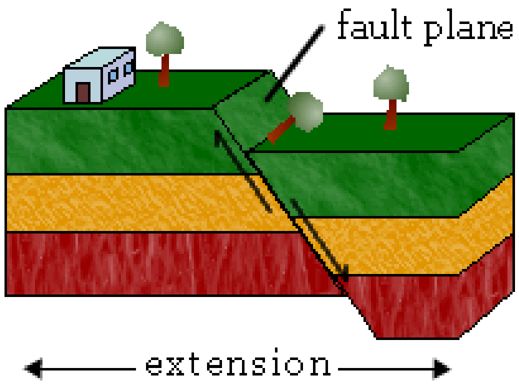
# California earthquakes



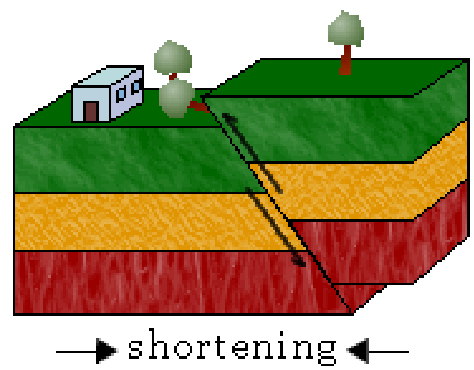
# California seismicity 1800-1994



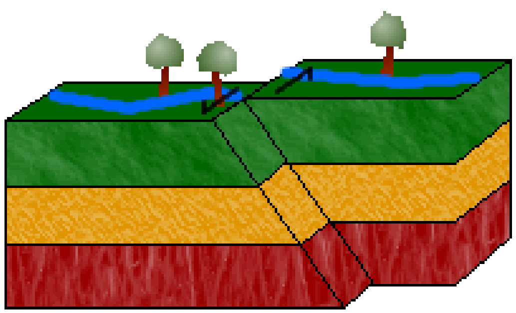
# What happens in an earthquake



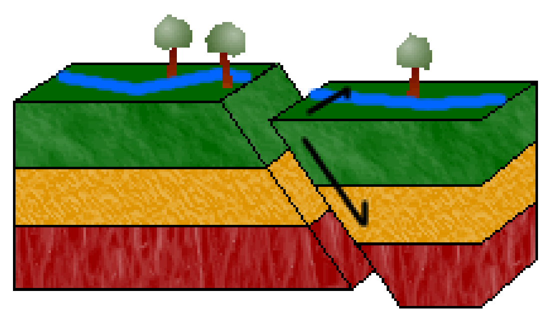

Normal fault




Reverse fault

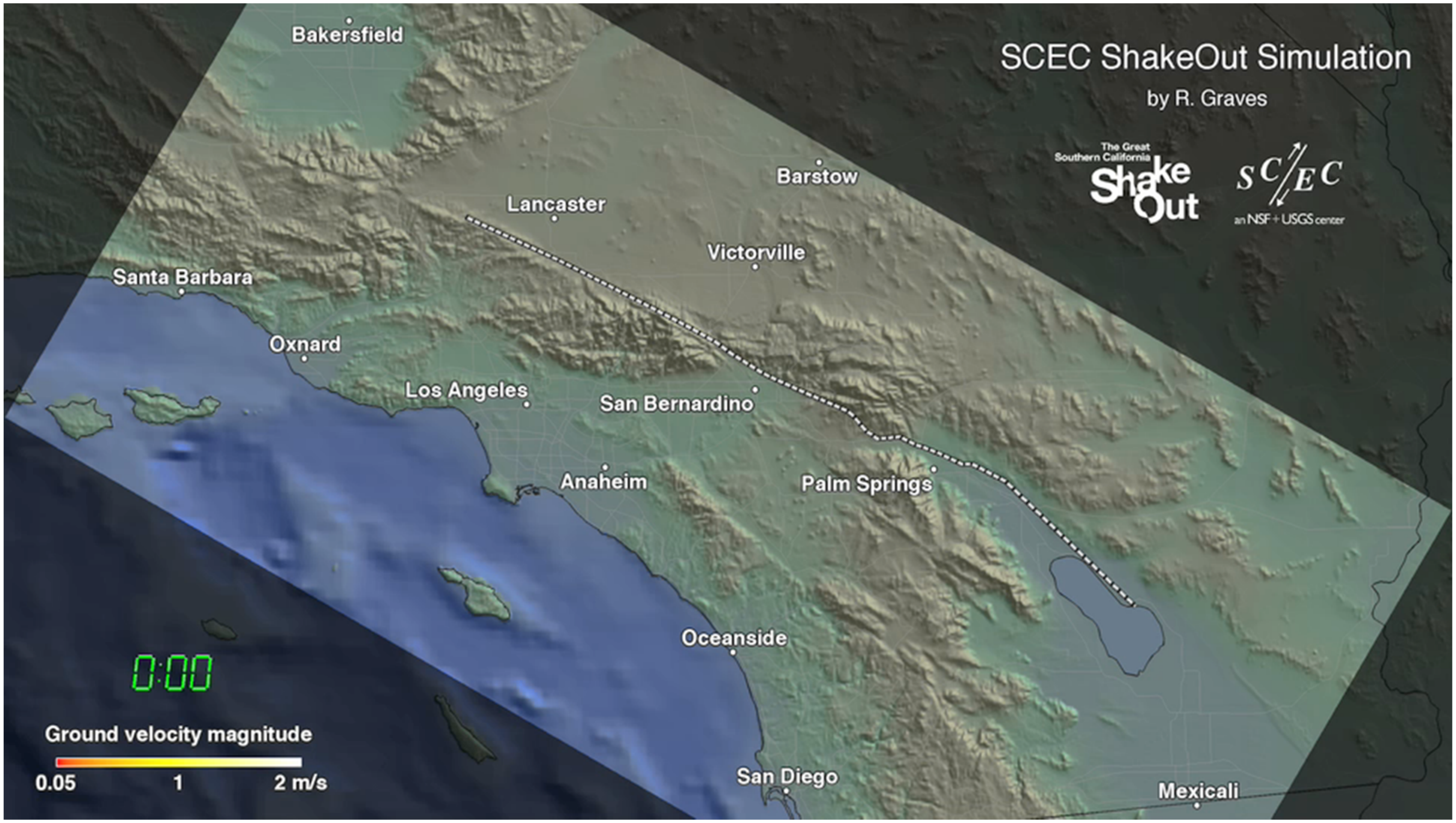


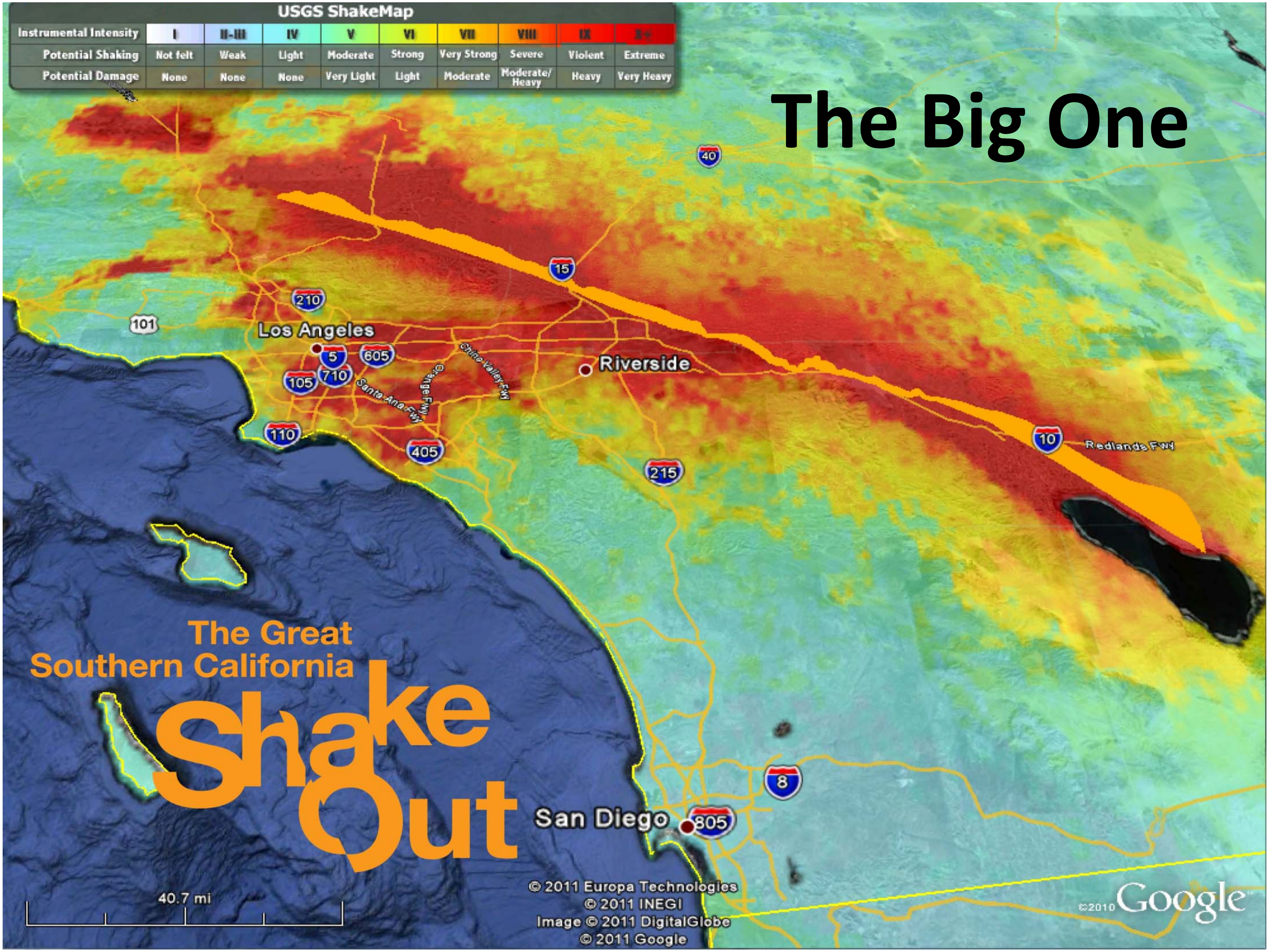
Strike-slip fault



Oblique fault

# Fault rupture





USGS ShakeMap
Instrumental Intensity I II-III IV V VI VII VIII IX X+
Potential Shaking Not felt Weak Light Moderate Strong Very Strong Severe Violent Extreme
Potential Damage None None None Very Light Light Moderate Moderate/Heavy Heavy Very Heavy
The Big One
Los Angeles
Riverside
San Diego
Redlands Fwy
Santa Ana Fwy
Orange Fwy
Chino Valley Fwy
The Great Southern California ShakeOut
40.7 mi
© 2011 Europa Technologies
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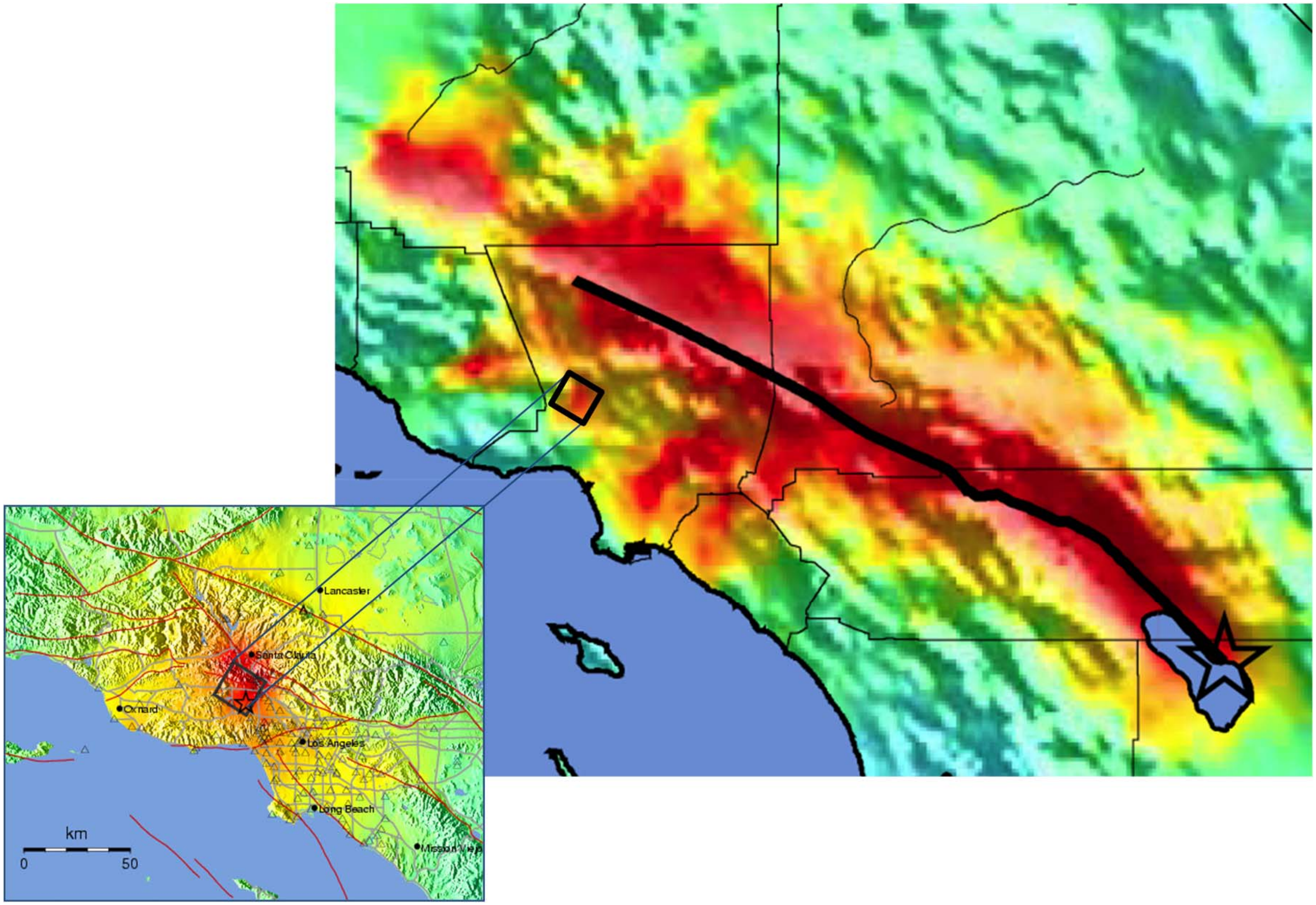
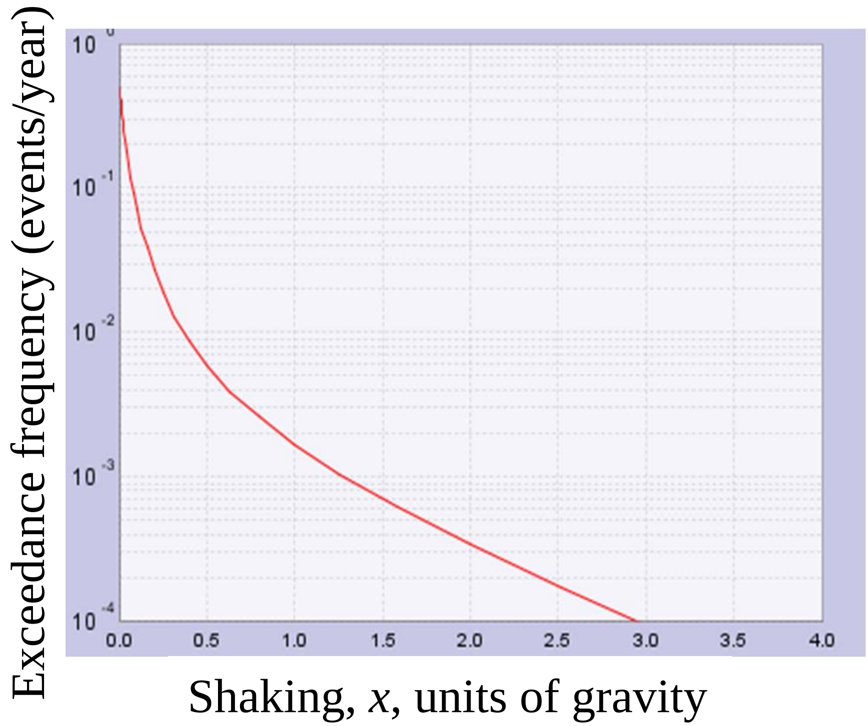
# M6.7 Northridge was not the big one



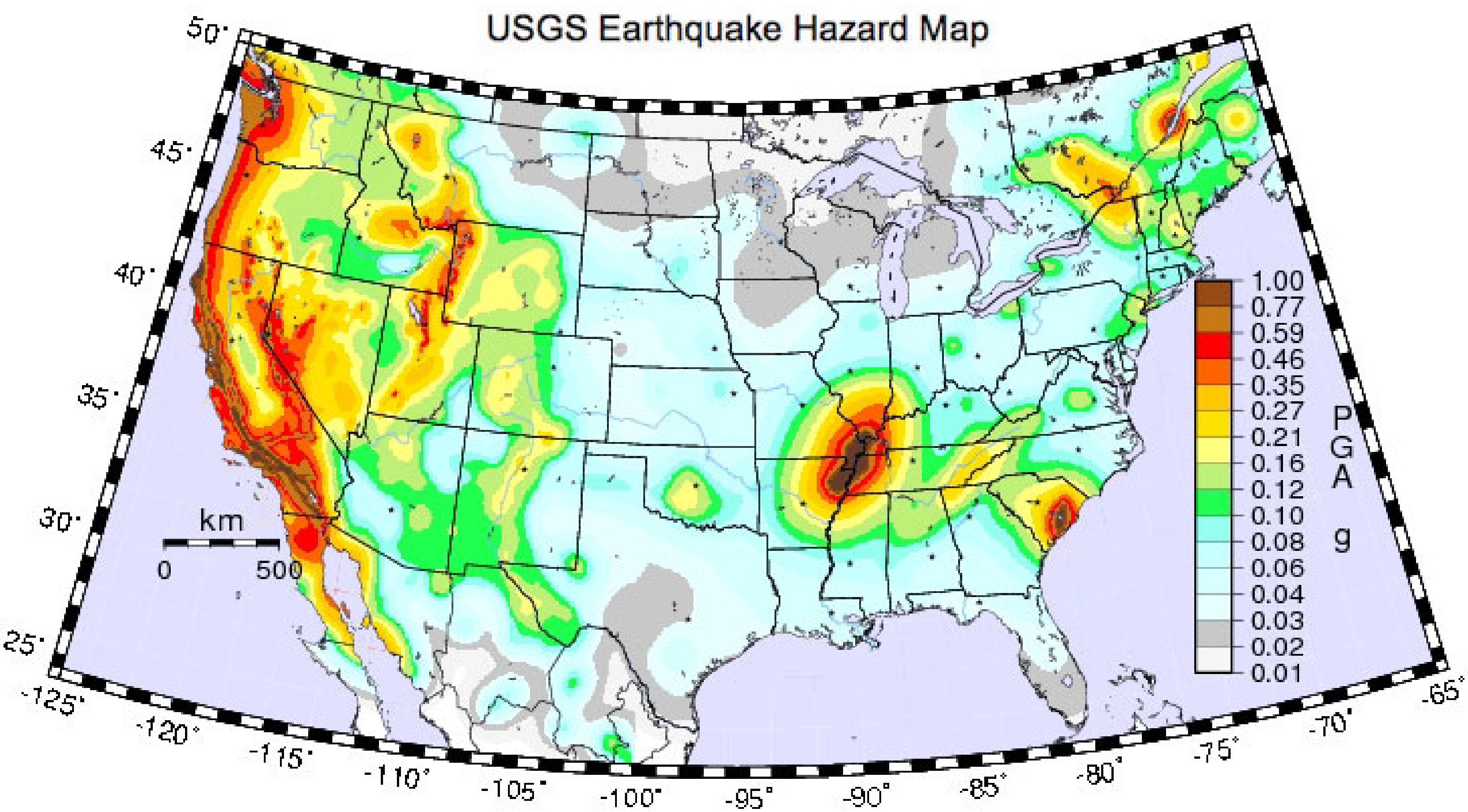
# Probabilistic seismic hazard analysis

- 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

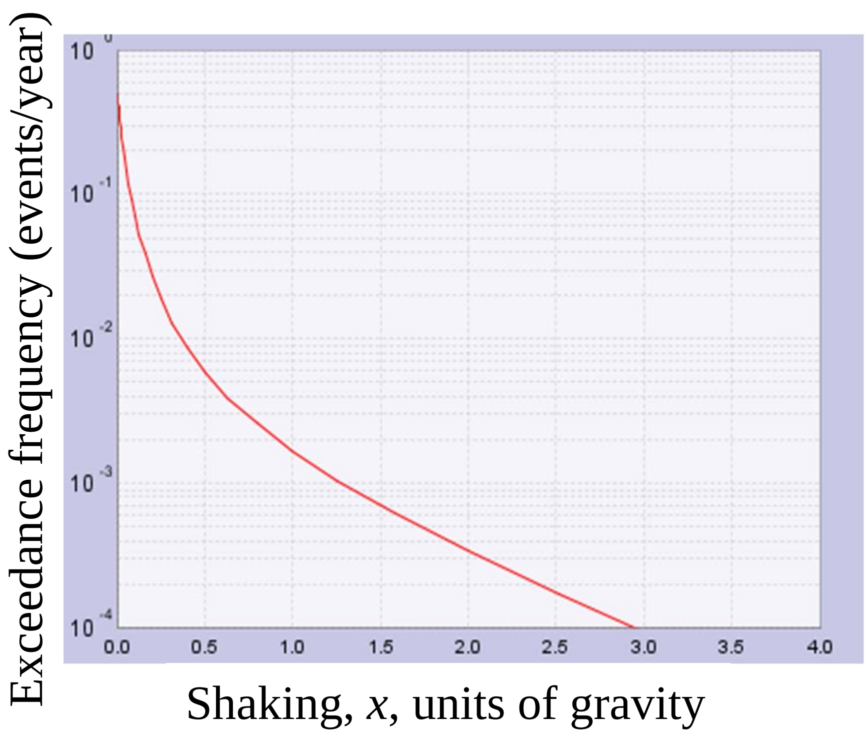


# Design each building for shaking with fixed exceedance probability

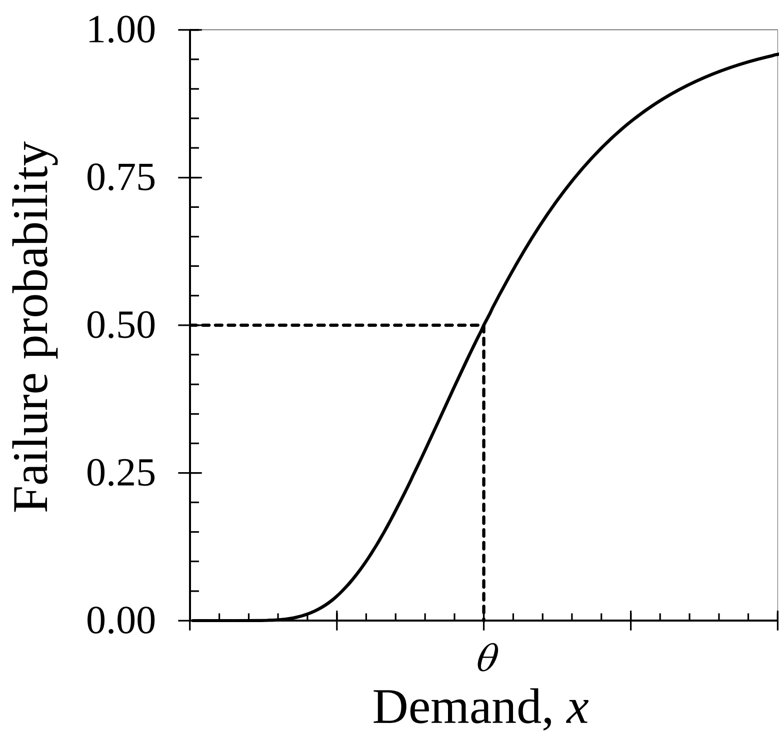


# Or for fixed annual probability of collapse

**Seismic hazard**




**Seismic fragility**

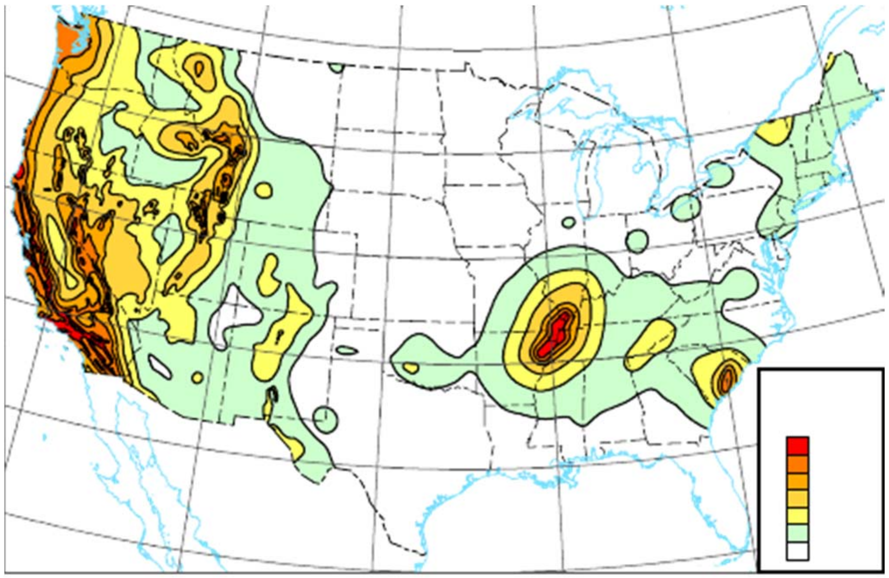


# Code performance objectives

- “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

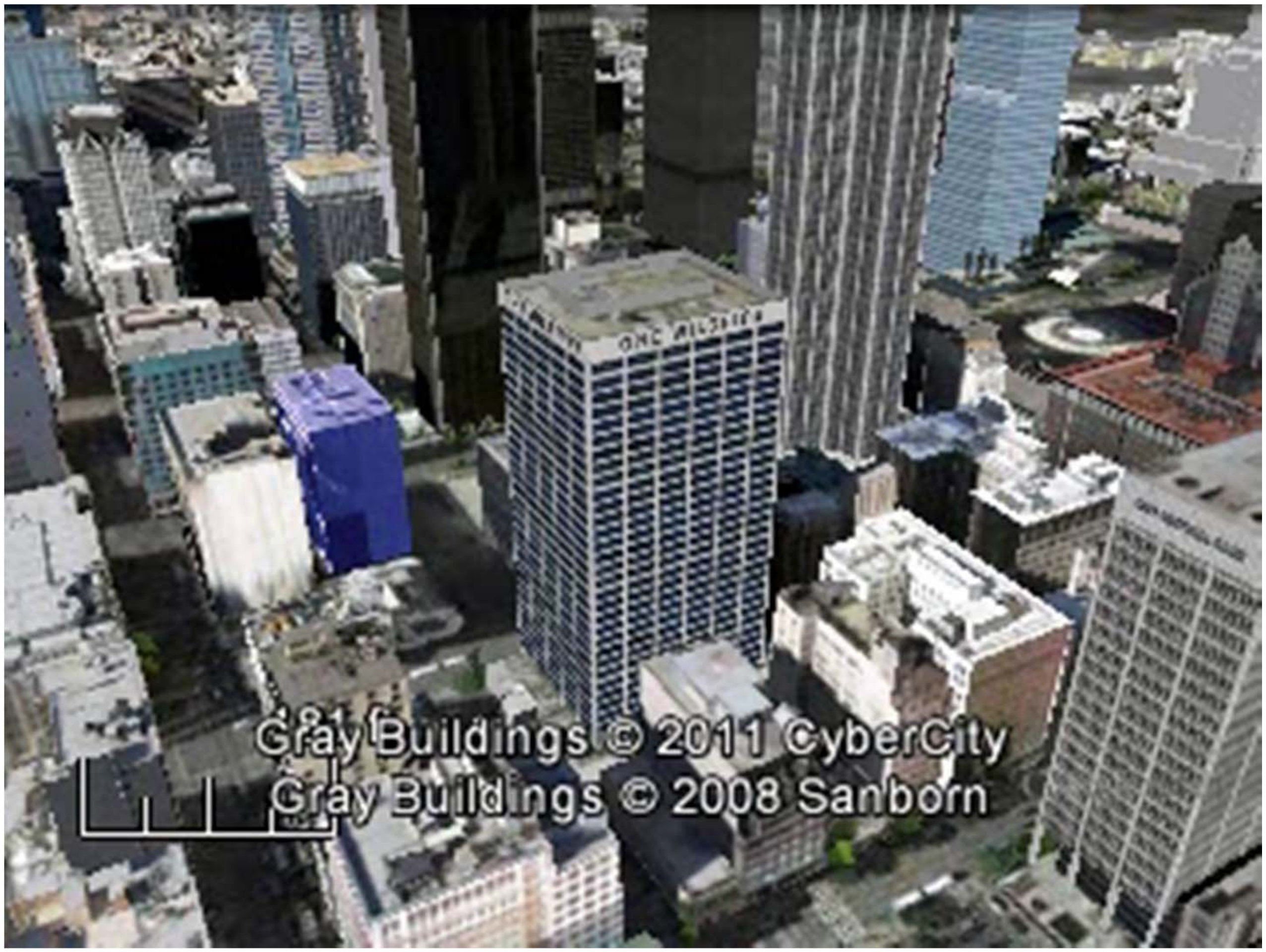
| Peril | Deaths/100,000 pop/yr | Where, when |
|---|---|---|
| Heart disease | 258 | US, 2000 |
| Very poor building (earthquake) | 67 | 24/7 occupancy |
| All accidents | 36 | US, 2000 |
| Auto accidents | 11 | CA, 2001 |
| Poor building (earthquake) | 7 | 24/7 occupancy |
| Gas-industry job | 4 | US, 1995-2000 |
| Handguns | 3 | US, 2004 |
| Acceptable building (earthquake) | 0.7 | 24/7 occupancy |
| New building (earthquake) | 0.2 | 24/7 occupancy |
| CA earthquakes last ~50 yr | 0.02 | CA, 1952-2002 |

# 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?

| | Ratio | Fraction of stock |
|---|---|---|
| Collapse | 10% of stock | 10% |
| Red & not collapsed | 10 red tags per collapse | Most of the rest |
| Yellow | 4 yellow tags per red tag | Most of the rest |
| Total | | Virtually all |

Reflects code-compliant buildings; older buildings would be worse

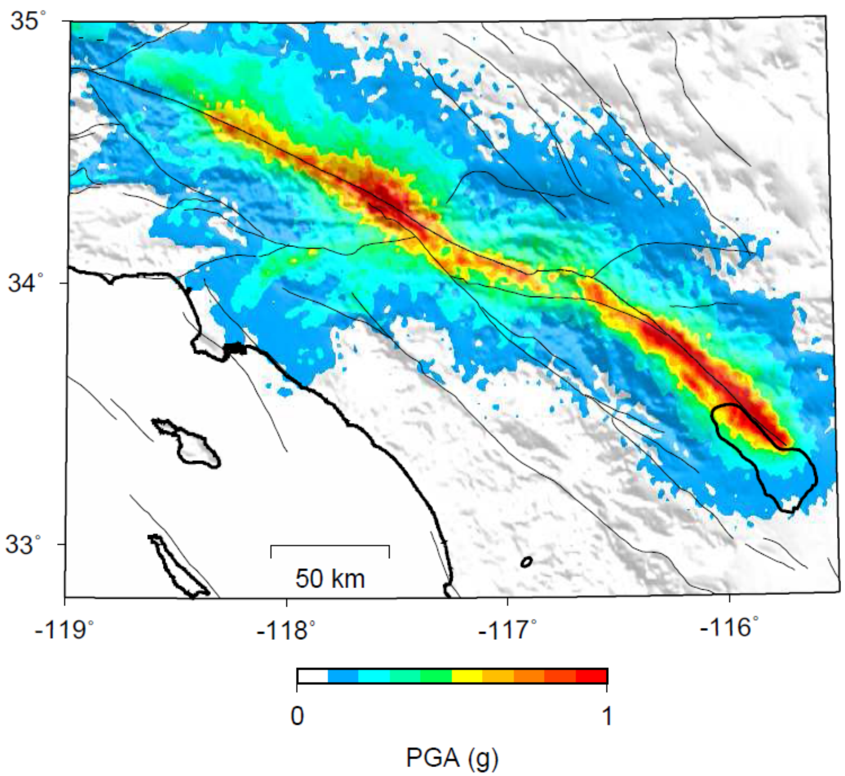
# But the Big One ≠ MCE shaking

- $MCE_G$ = 2%/50 yr site shaking
- Varies by site
- Includes inter- and intra-event uncertainty
- Below-mean shaking at point X accompanies above-mean shaking at Y

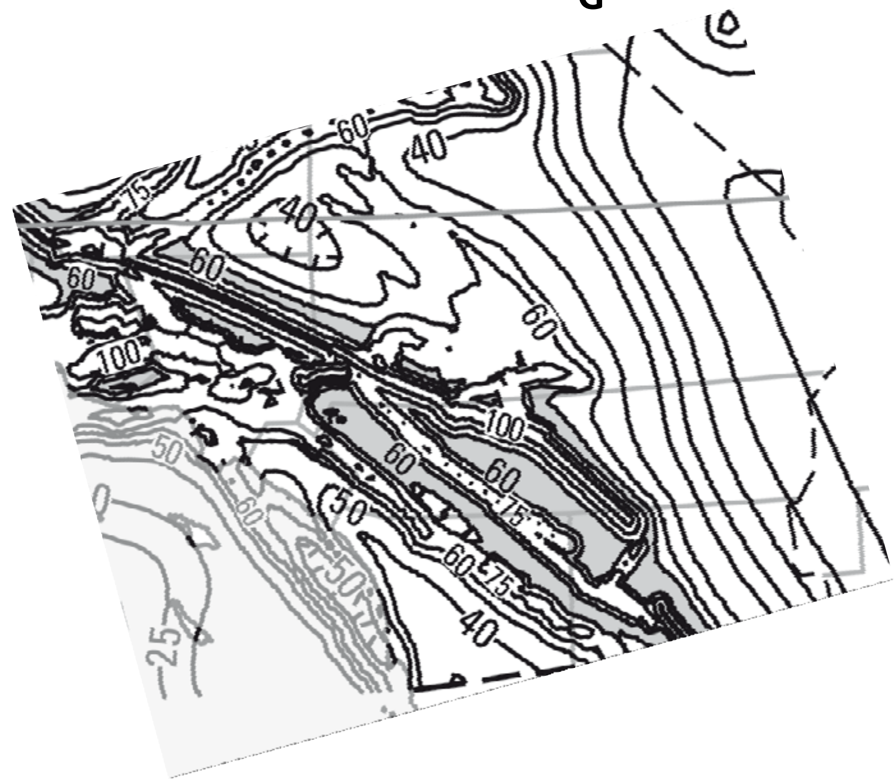
→ "Big One" shaking is generally less than MCE

# (Big One PGA)/(design-level PGA)≈0.5-1.0 across much of greater LA area

**ShakeOut PGA**

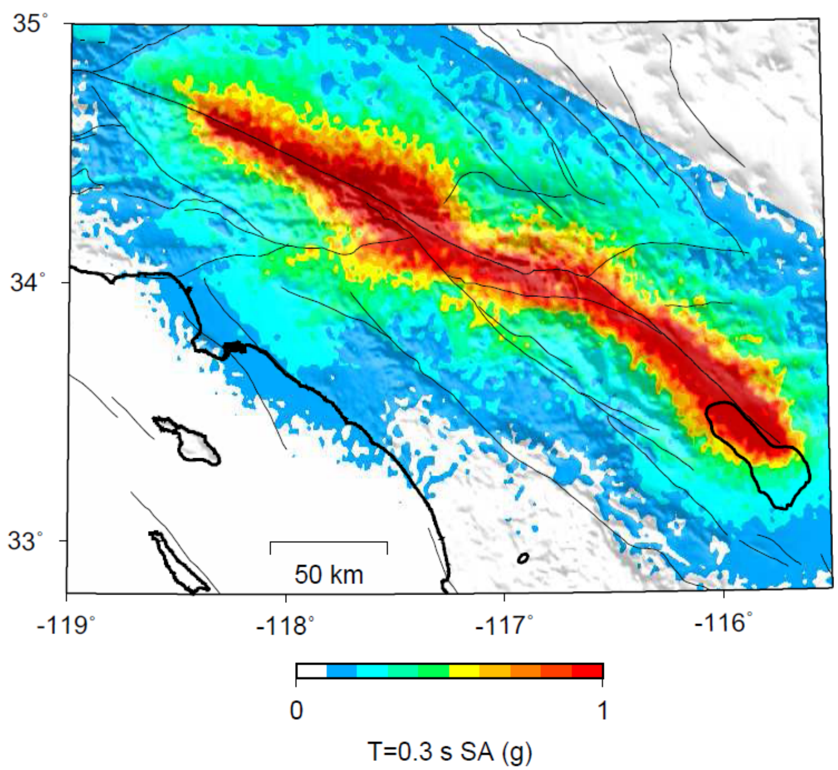



**ASCE 7-10 $MCE_G$ PGA**

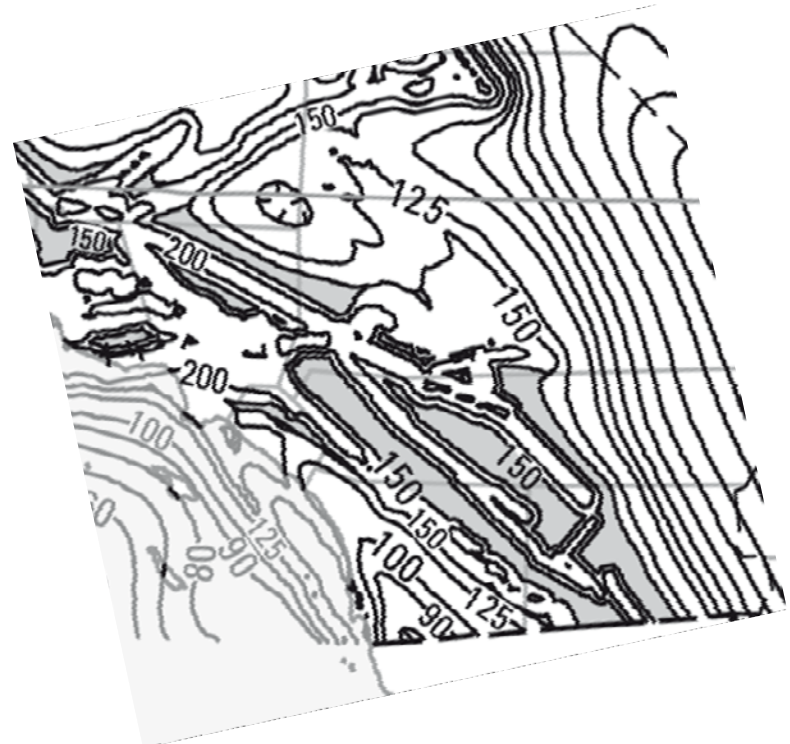


# $(\text{Big One } S_S)/(\text{design-level } S_S) \approx 0.5\text{-}1.0$ across much of greater LA area

**ShakeOut Sa(0.3 sec, 5%)**

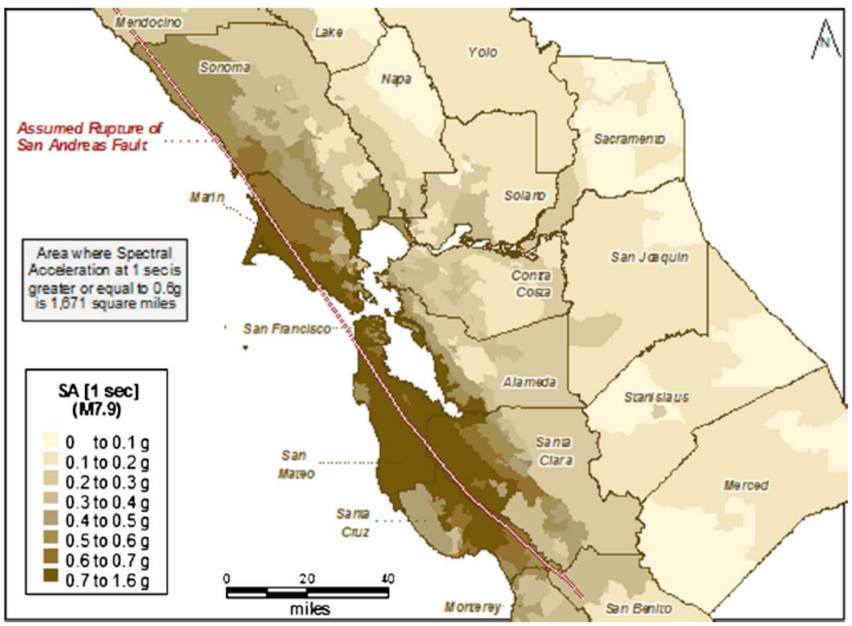



**ASCE 7-10 $MCE_R$ $S_S$, B soil (Fa≈1.0)**

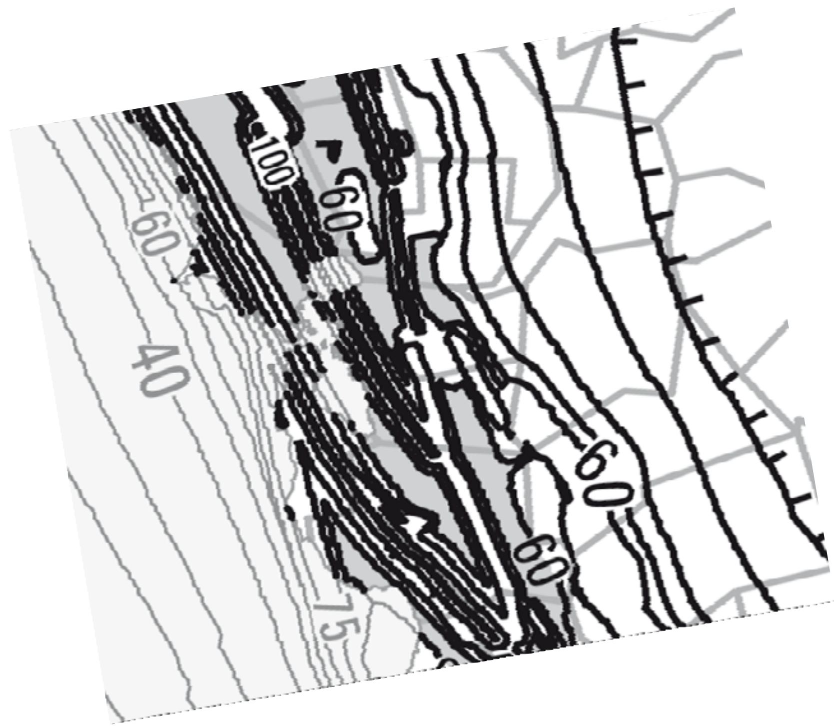


# (Big One $S_1$)/(design-level $S_1$) ≈ 0.5-1.0 across much of the SFBA

**M7.9 San Andreas Sa(1.0 sec,5%)**




**$MCE_R$ $S_1$, B soil ($F_v$ ≈ 1.3)**



# Damage at ½ MCE (the Big One)

- $P(coll|S_S{=}1.5g) = 0.1 \approx \Phi(\ln(1.5/\theta)/\beta)$
- $\theta \approx 1.5 \cdot \exp(1.28 \cdot 0.6) = 3.2$
- $P(coll|S_S{=}0.75s) \approx 0.01$
- For ref: $MCE_R$ provides ~1% collapse probability in 50 years

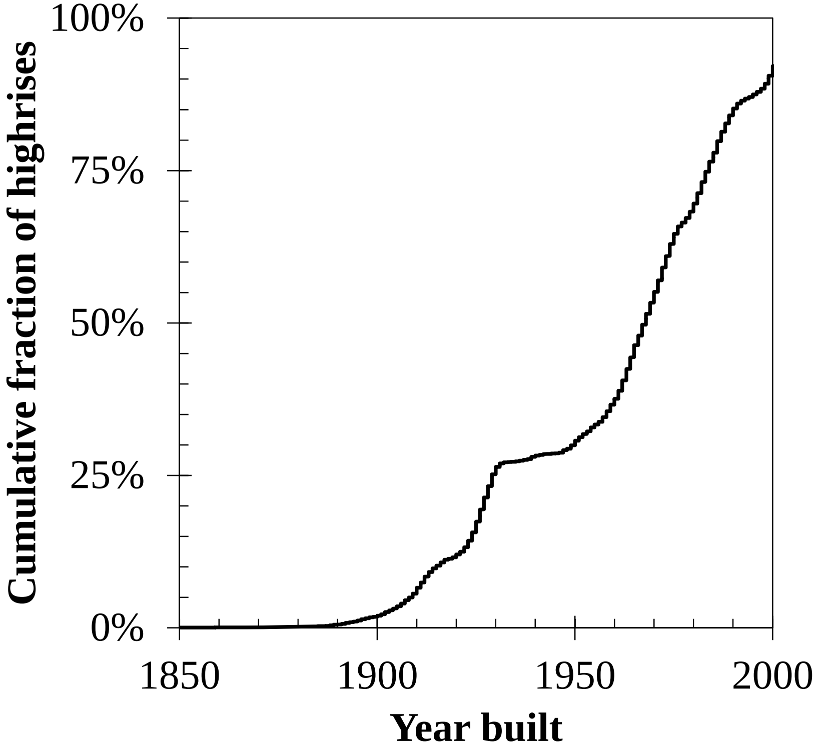
# What happens in the Big One

| | Ratio | Fraction of stock |
|---|---|---|
| Collapse | 1% of stock | 1% |
| Red | 10 red tags per collapse | 10% |
| Yellow | 4 yellow tags per red tag | 40% |
| Total | | 50% |

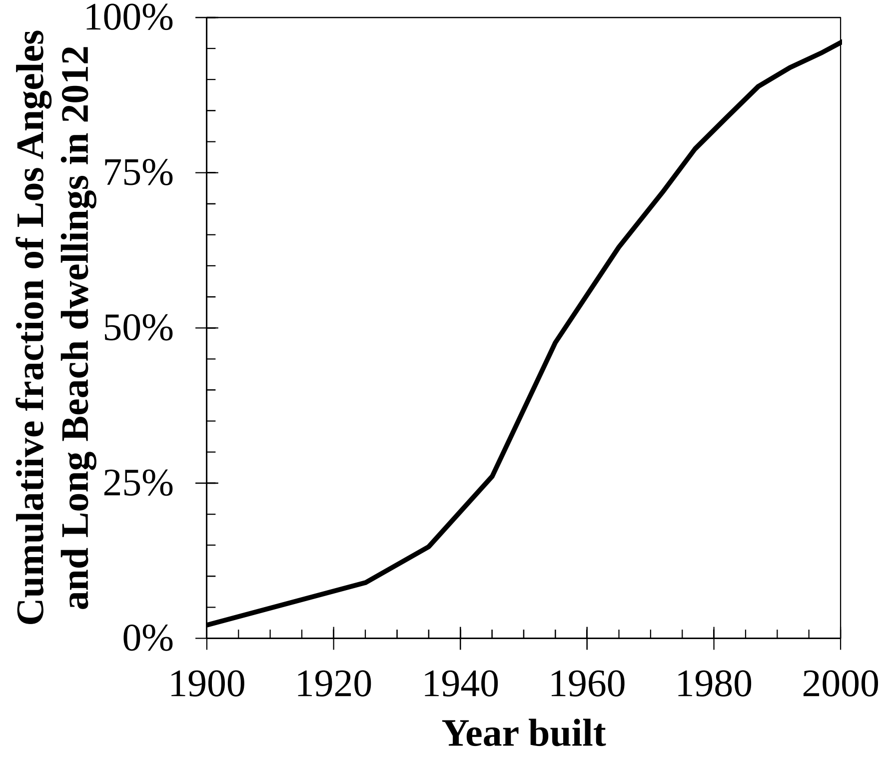
(Again, assumes 100% code-compliant stock)

# We don't have a code-compliant stock

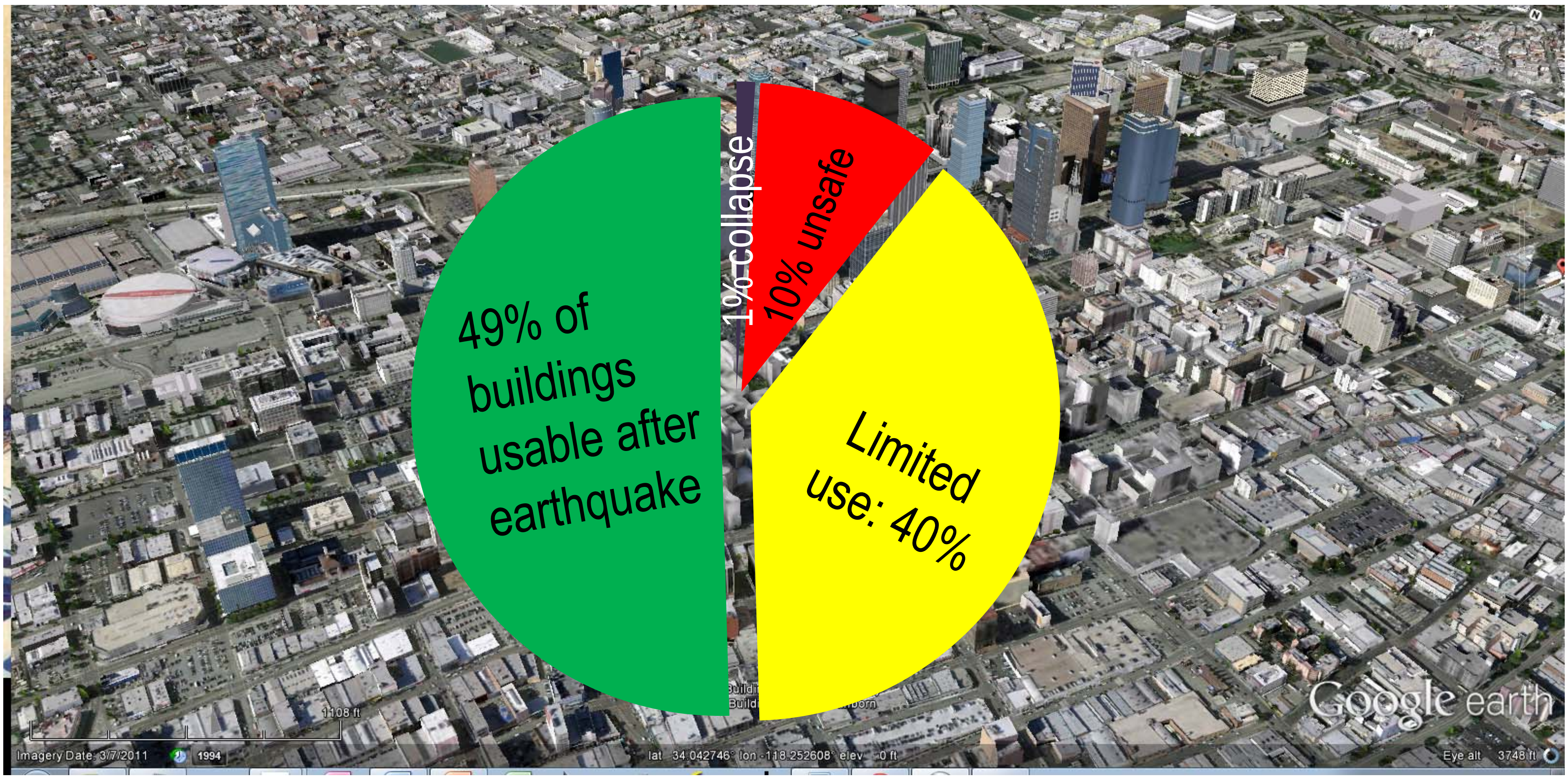
**CA highrise ages (Emporis 2007)**




**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

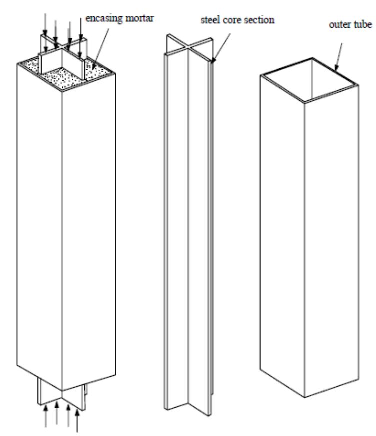
1. Greater seismic resilience of the building stock is difficult to achieve
2. The public would be unwilling to pay increased initial construction costs for improved seismic performance
3. The public is incapable of participating in the process of setting community seismic performance goals
4. Current 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

+10%

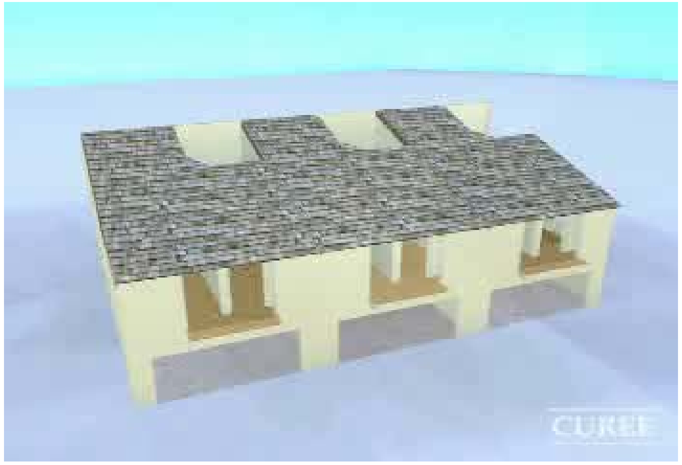
+2%



# CUREE-Caltech Woodframe Project


Small house: 1200 sf, 2 bdrm, 1 ba


Large house: 2,400 sf, 3 bdrm, 2½ba

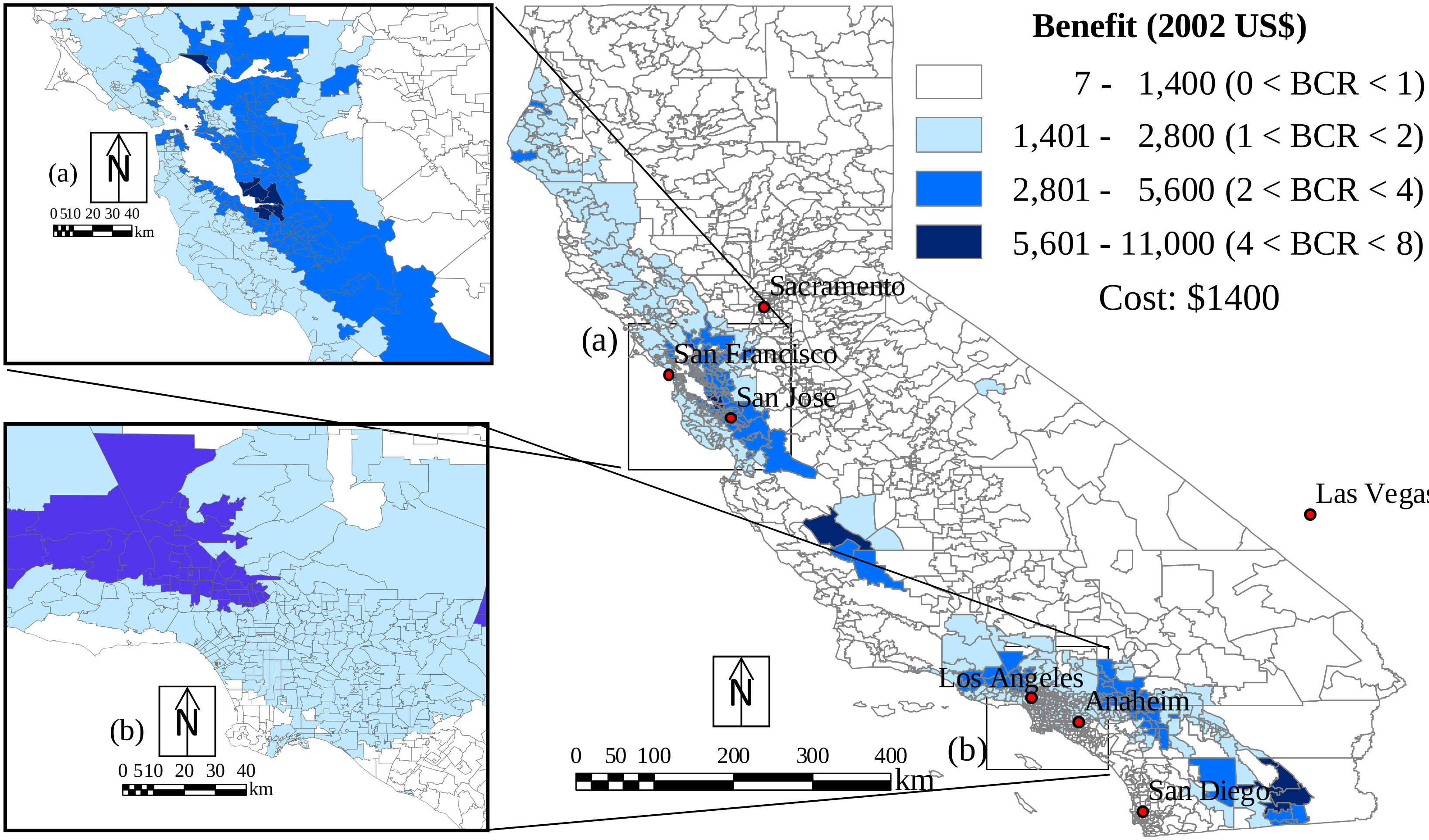



Townhouse: 2,000 sf, 3+2


Apartment building : 10 850-sf units

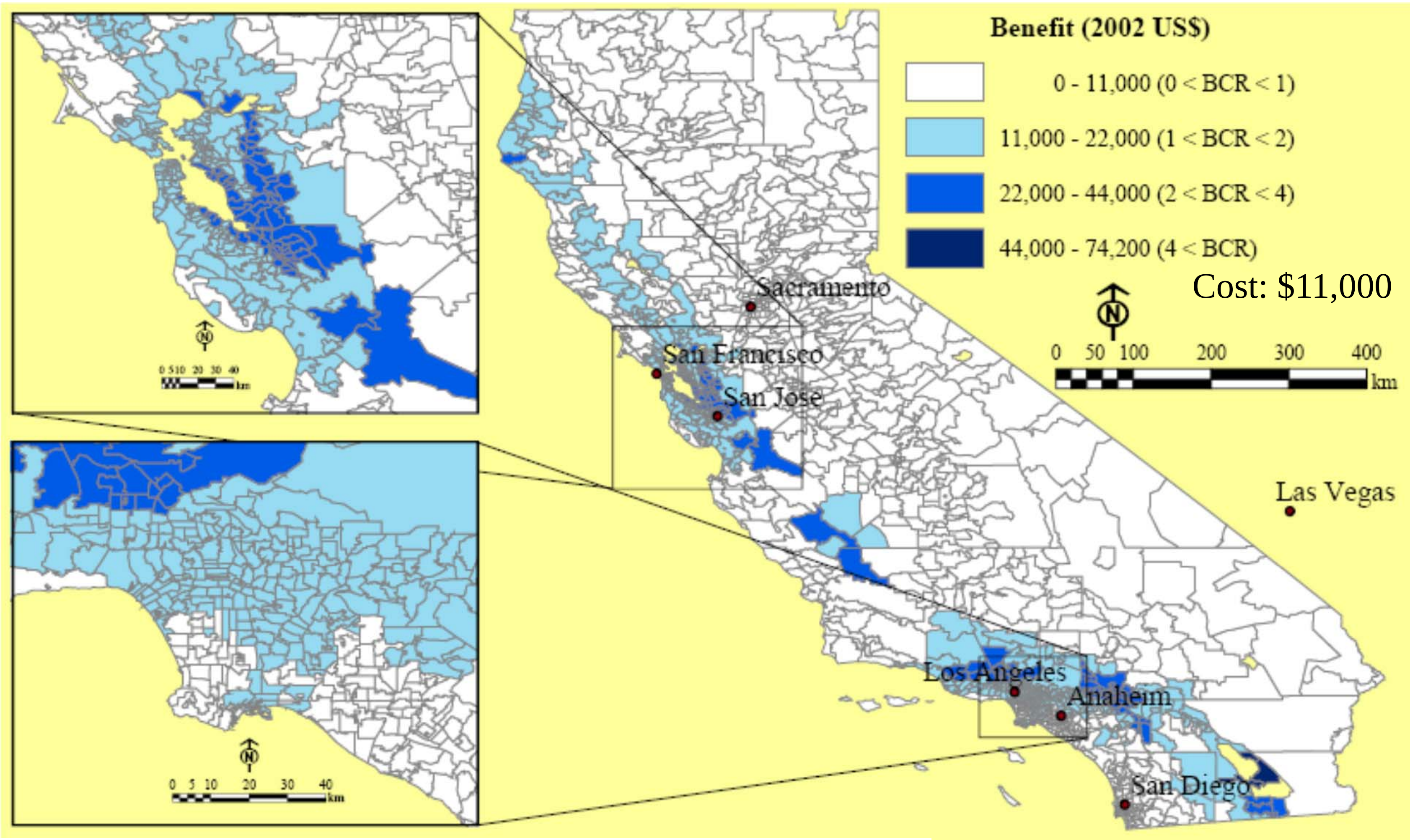
*Animations by Doron Serban (CUREE)*

# 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

# 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

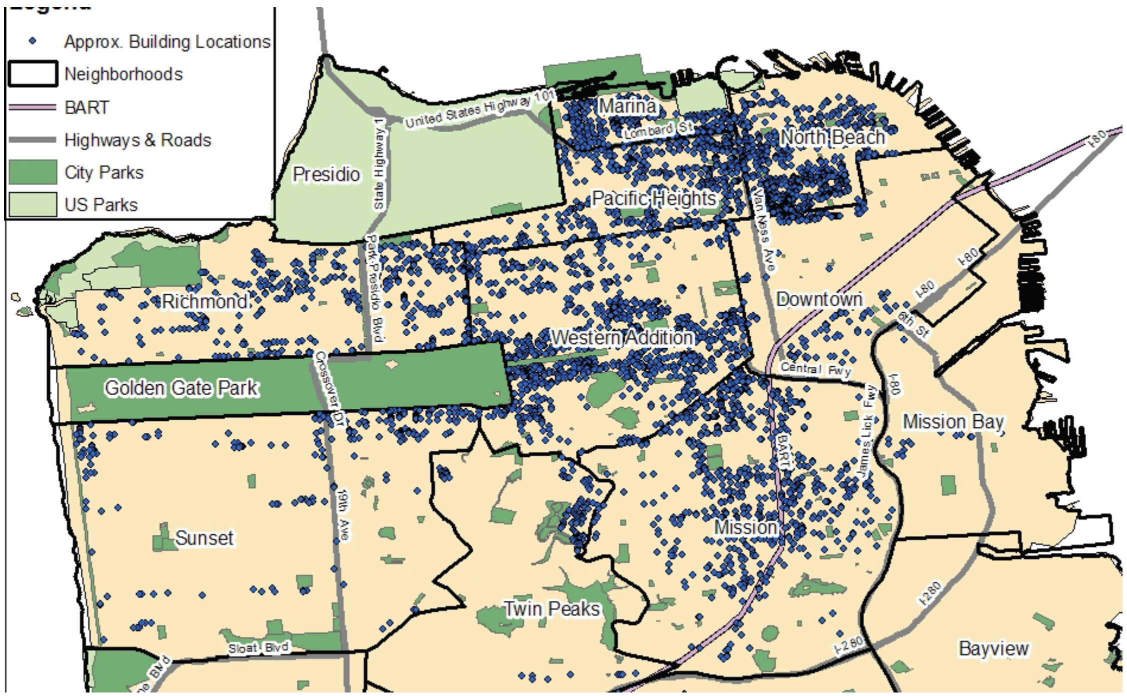
90% rental units

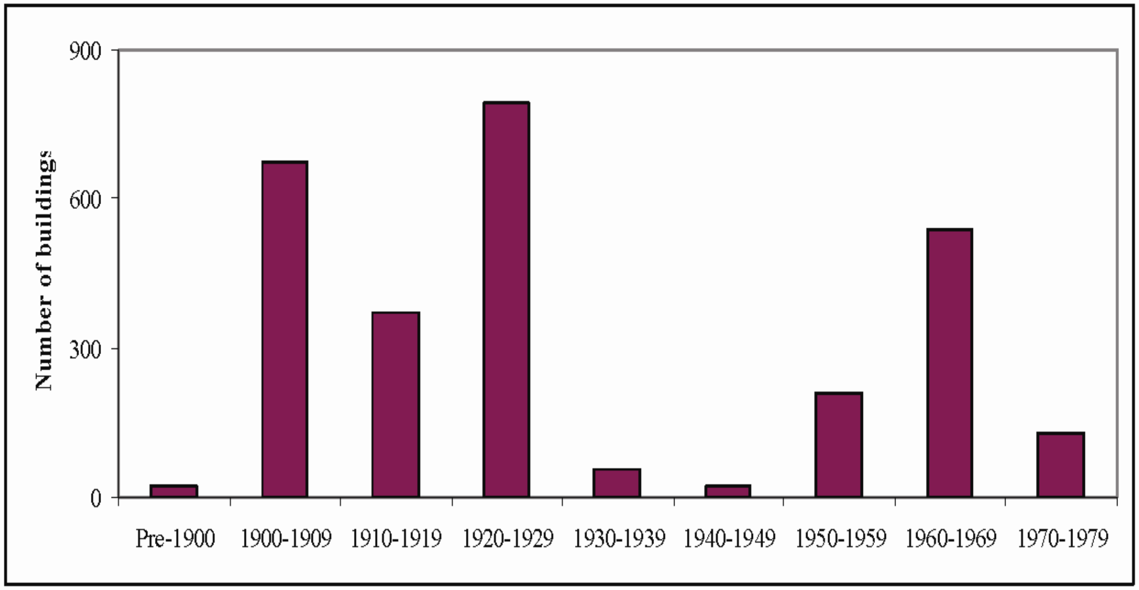
7% of housing

8% of population

2100 businesses

84% with 5 or fewer employees



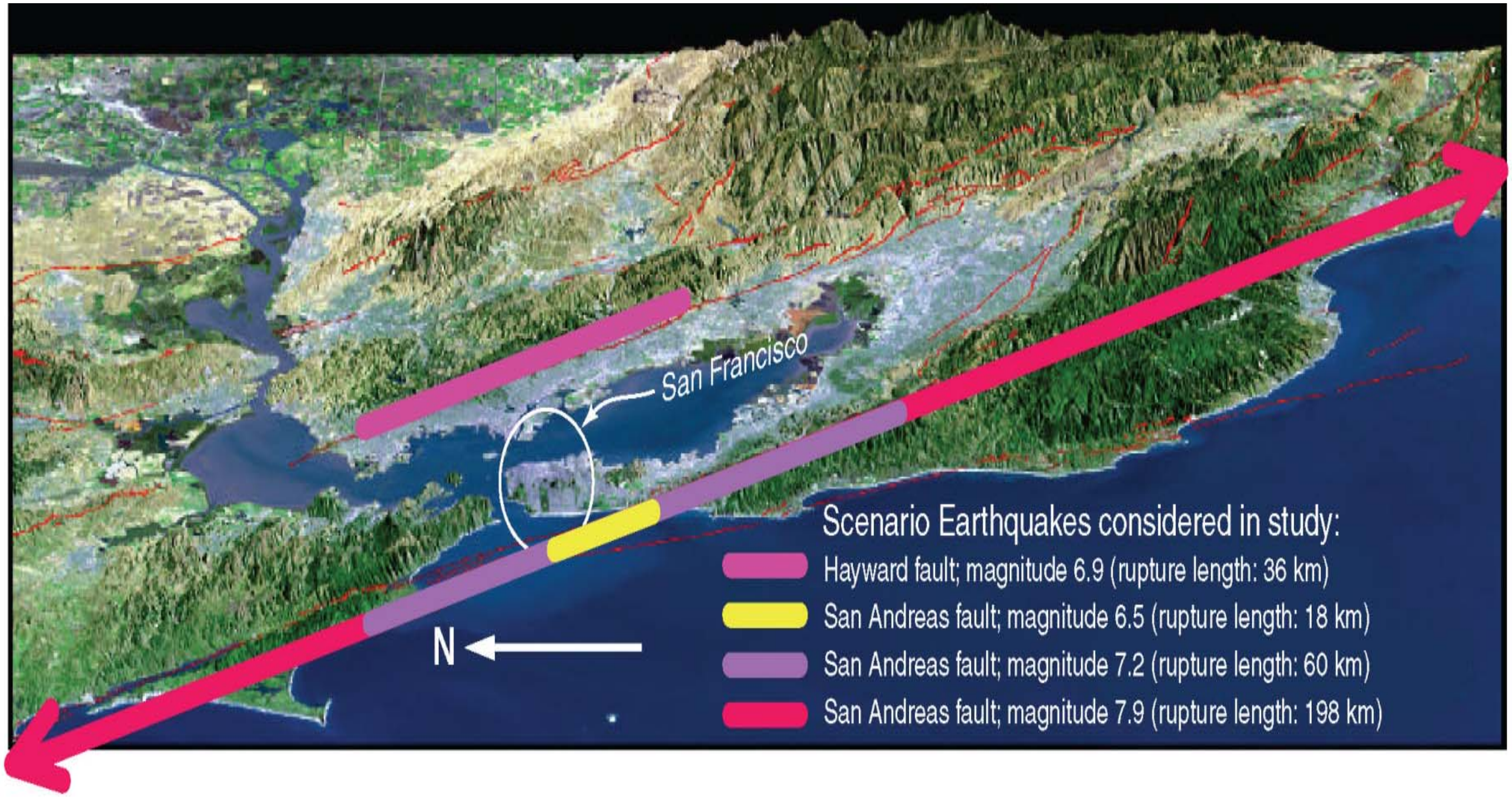
# CAPSS Public Advisory Committee volunteers

- Neighborhood groups
- Landlords
- Tenants
- Affordable housing advocates
- Architects, engineers
- Seismologists
- Historic preservation interests

# Public Advisory Committee concerns

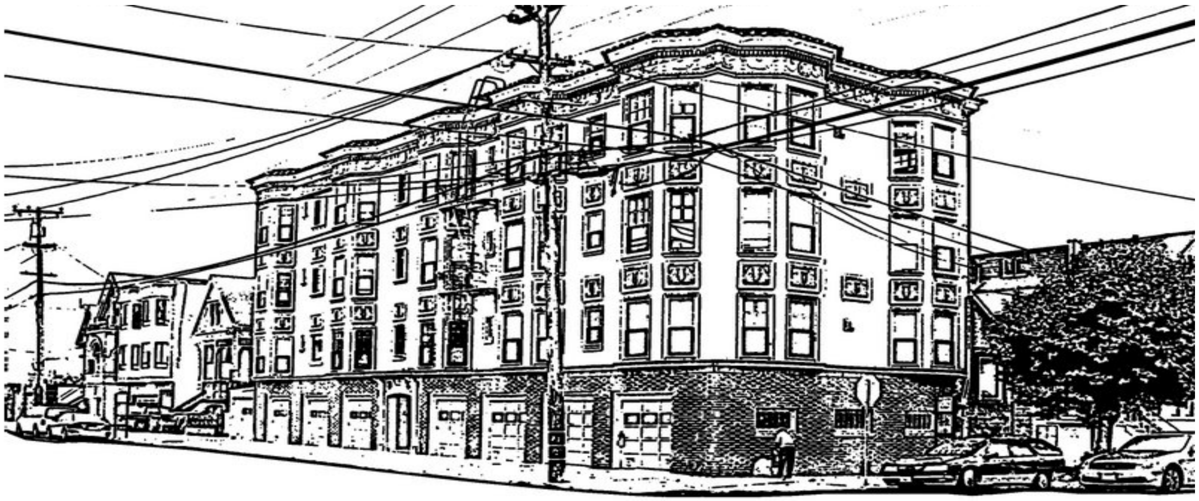
- Population that lives, works, owns buildings
- Concentration of buildings in neighborhoods
- Contribution to neighborhood character
- Effects of a few scenario earthquakes
- Financial impact on neighborhood
- How to fund repair
- How to fund retrofit

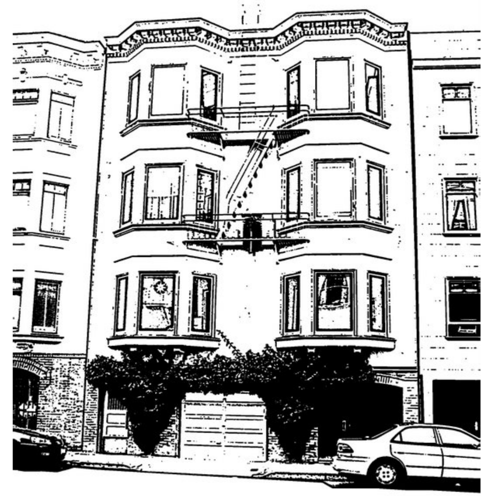
# CAPSS scenario earthquakes

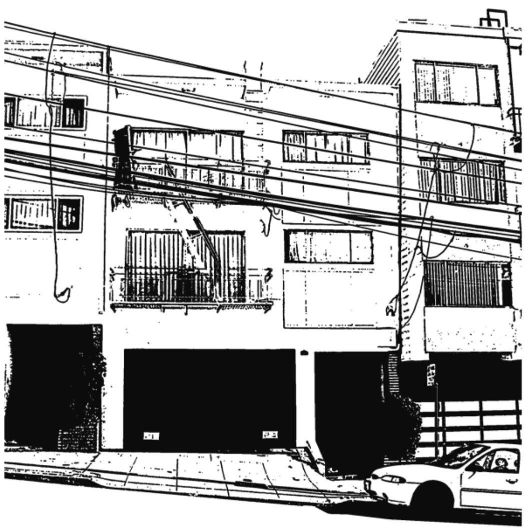



*ATC, 2009: Here Today, Here Tomorrow*

# CAPSS soft story model buildings







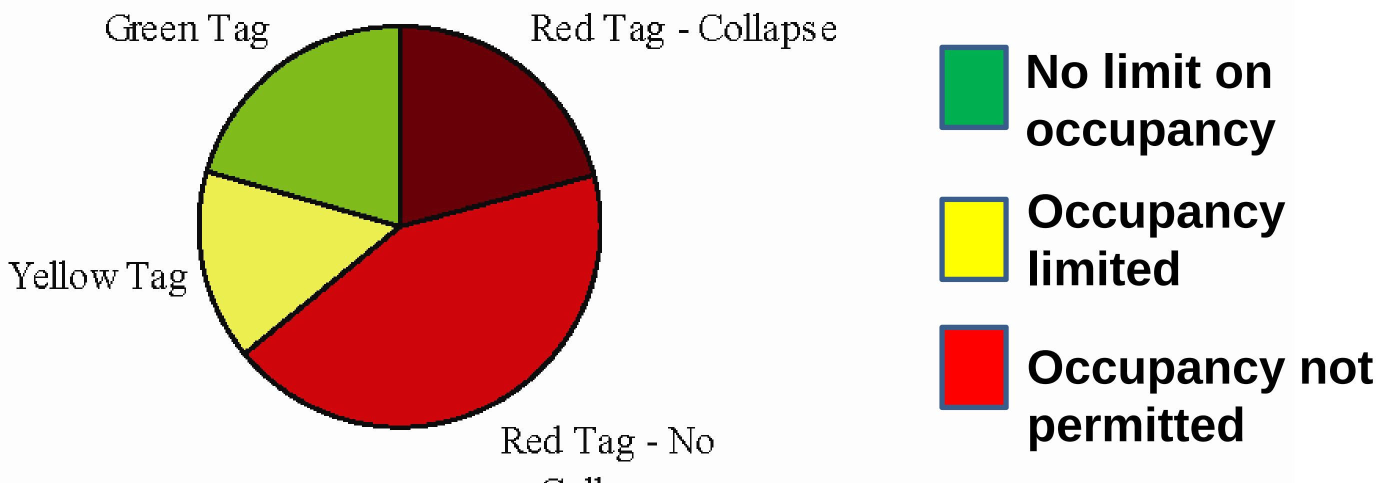
*ATC, 2009: Here Today, Here Tomorrow*

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

| | Per Building | | Per Residential Unit | | Per Square Foot | |
|---|---|---|---|---|---|---|
| | Average | Range | Average | Range | Average | Range |
| Retrofit Scheme 1 | $65,000 | $49,000 to $79,000 | $11,000 | $9,000 to $13,000 | $6.60 | $3.00 to $9.40 |
| Retrofit Scheme 2* | $105,000 | $59,000 to $132,000 | $17,000 | $15,000 to $20,000 | $10.00 | $5.70 to $12.10 |
| Retrofit Scheme 3* | $93,000 | $58,000 to $114,000 | $16,000 | $13,000 to $19,000 | $9.00 | $4.60 to $11.10 |

*ATC, 2009: Here Today, Here Tomorrow*

# Retrofit means more people can stay in their homes

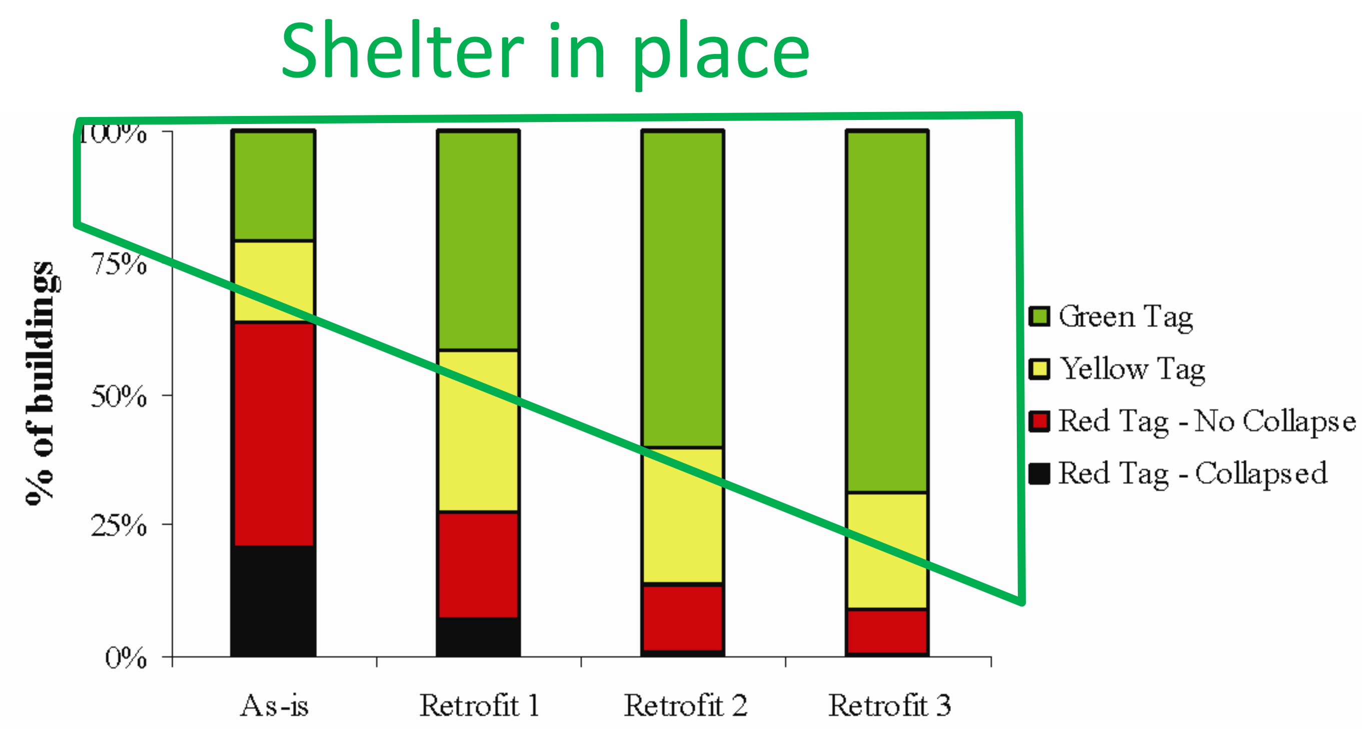
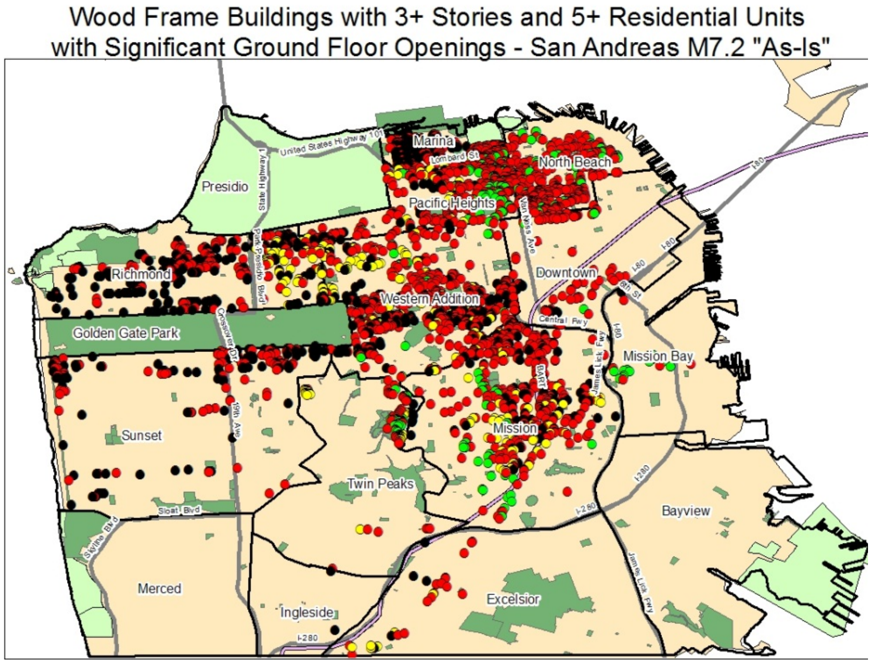



*Figure 16. Approximate distribution of damage tags before and after three retrofit schemes in a scenario magnitude 7.2 earthquake on the San Andreas Fault. The number of tags in each category could vary as shown in Table 2.*

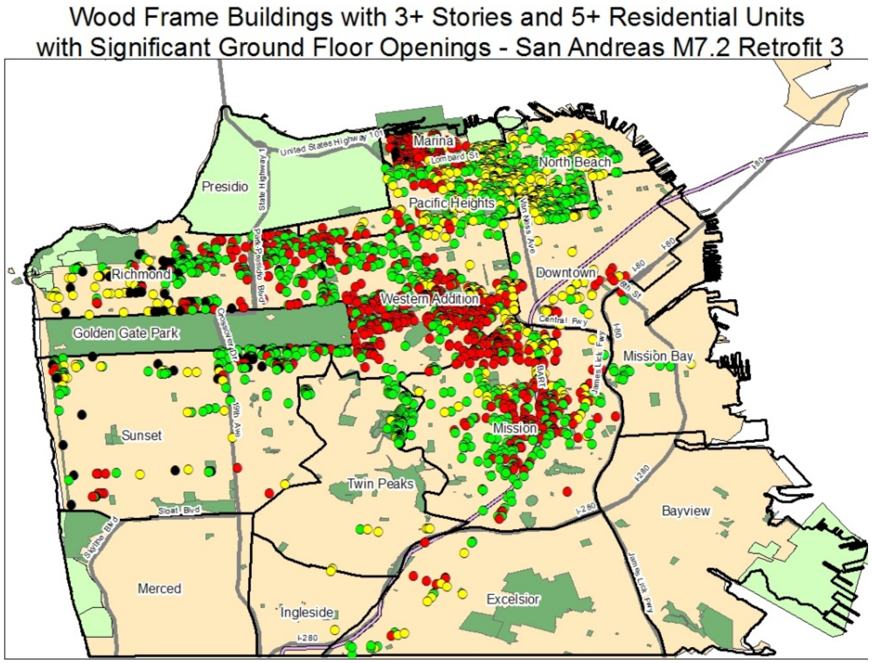
*ATC, 2009: Here Today, Here Tomorrow*

# Same M7.2 event with retrofit

**As-is**




**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** ~~1200~~ **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 *****

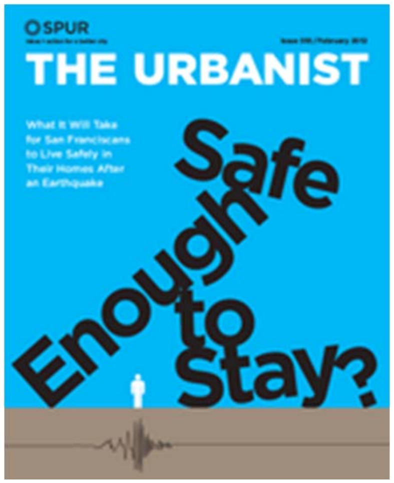
**MAYOR LEE, PRESIDENT CHIU & SUPERVISOR WIENER INTRODUCE LEGISLATION MANDATING SEISMIC SAFETY RETROFIT FOR SOFT-STORY RESIDENTIAL BUILDINGS**

*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*

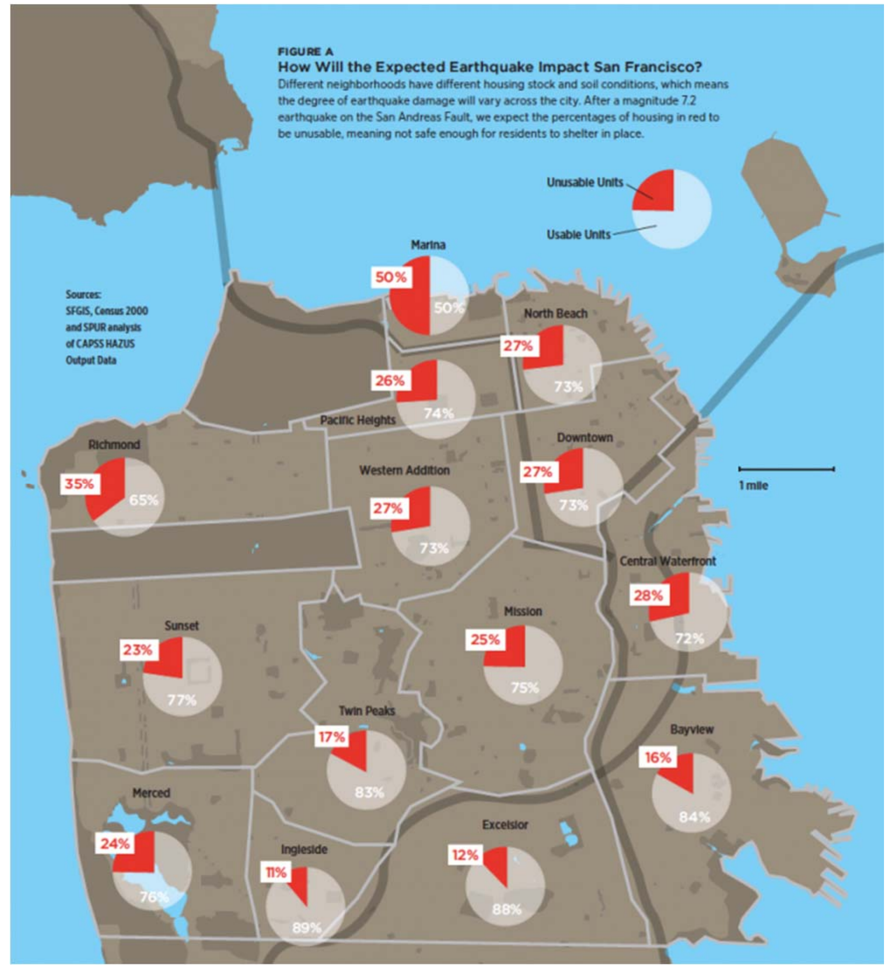
**San Francisco, CA—**Today Mayor Edwin M. Lee, Board President David Chiu and Supervisor Scott Wiener introduced legislation mandating the seismic retrofit of the City's large wood-frame soft-story residential buildings, a historic step forward to ensure San Francisco's resilience and safety. The legislation 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”



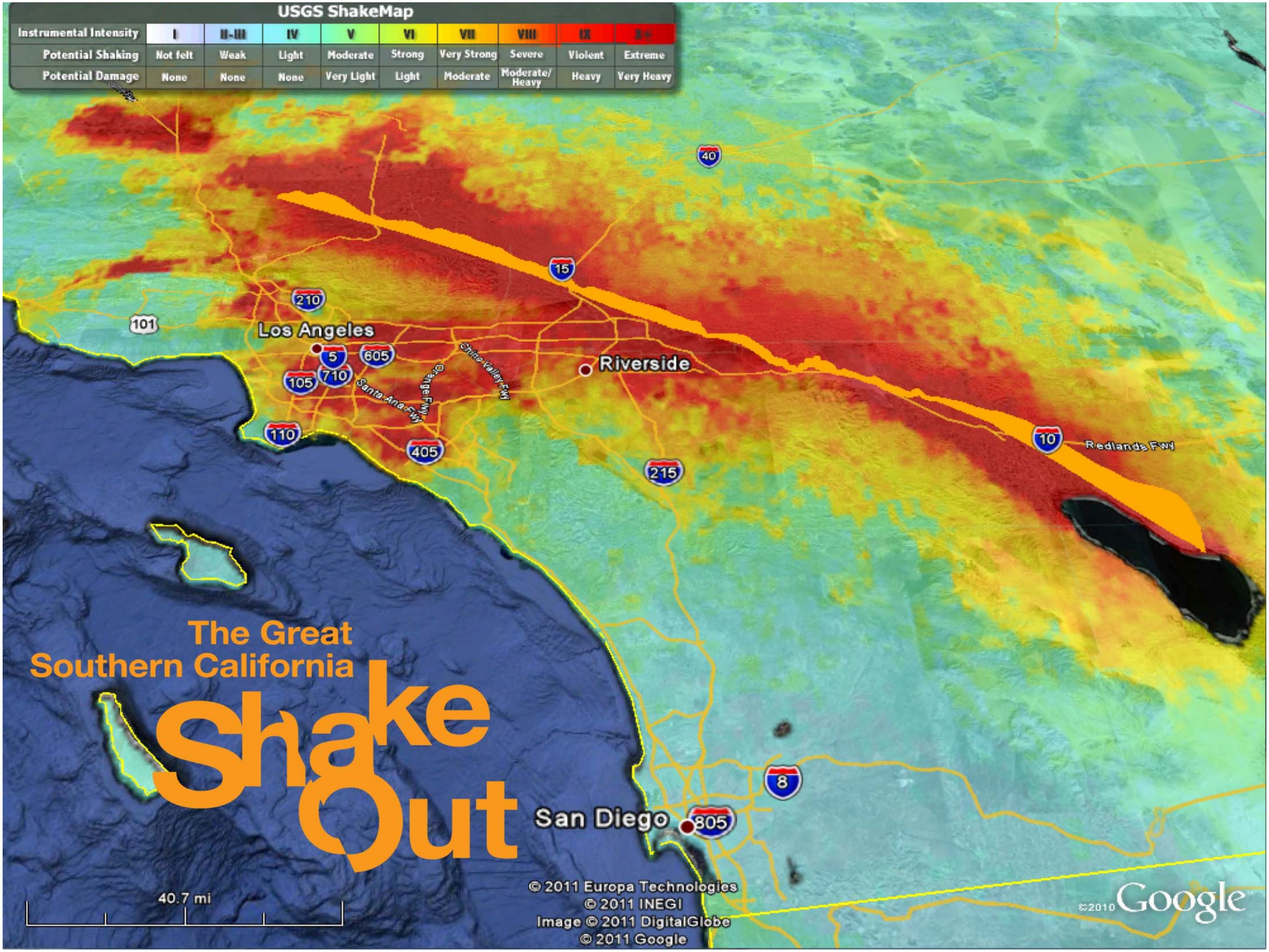
Earthquake Country **Alliance**

*We're all in this together.*

*"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



USGS ShakeMap
Instrumental Intensity
I
II-III
IV
V
VI
VII
VIII
IX
X+
Potential Shaking
Not felt
Weak
Light
Moderate
Strong
Very Strong
Severe
Violent
Extreme
Potential Damage
None
None
None
Very Light
Light
Moderate
Moderate/Heavy
Heavy
Very Heavy
Los Angeles
Riverside
San Diego
Redlands Fwy
Santa Ana Fwy
Orange Fwy
Chino Valley Fwy
The Great Southern California
ShakeOut
40.7 mi
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*Alexopoulos, 2008: Preparedness Now*

# 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

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