US Earthquake Model Update- Drivers and Impact

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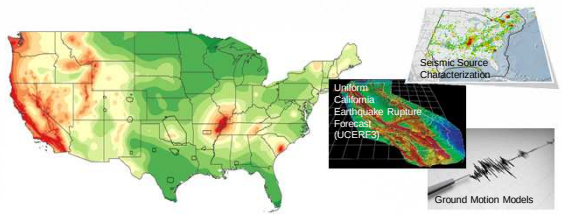
AIR WORLDWIDE

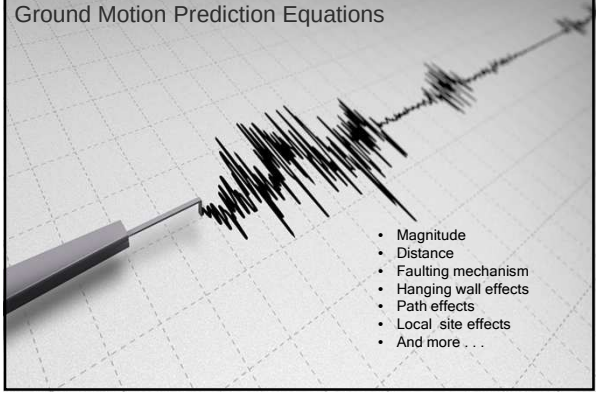
Earthquake Modeling Framework Consists of Several Components

Latest Advancements in Seismic Hazard Studies in United States

- 2014 U.S. Geological Survey National Seismic Hazard Maps
- 2016 USGS One-Year Seismic Hazard Forecast



More Data and Refined Physical Models Are Used to Construct Ground Motion Prediction Equations

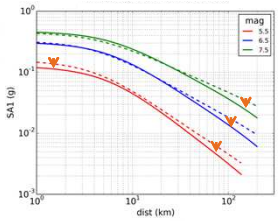


- Magnitude
- Distance
- Faulting mechanism
- Hanging wall effects
- Path effects
- Local site effects
- And more . . .

Active Western U.S. Next Generation of Attenuation Equations

— 2014 Weighted Average GMPE

.... 2008 Weighted Average GMPE

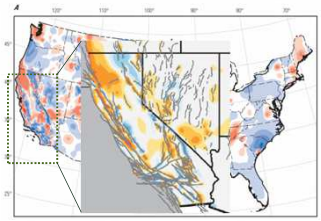


- Lower median ground motion for small magnitudes
- Faster decay with distance

Seismic Hazard in California is Impacted by Several Sources

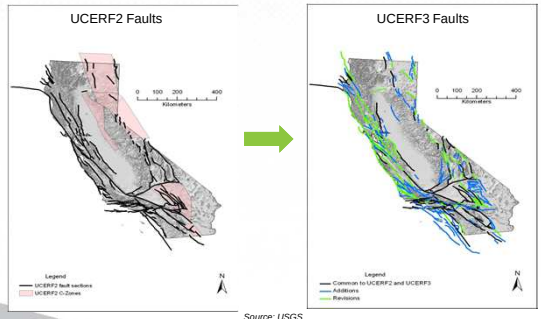
- Fault Models (Uniform California Earthquake Rupture Forecast)
- Cascadia subduction zone

Difference in USGS Hazard Maps (2014 – 2008)



UCERF3 Takes a New Physically-Based Approach to Construct Rupture Probabilities

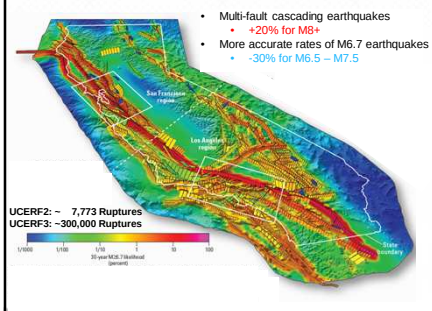
Uniform California Earthquake Rupture Forecast (UCERF)



Source: USGS

Inclusion of Multi-Fault Ruptures in California Increases Rates of Large Magnitude Events

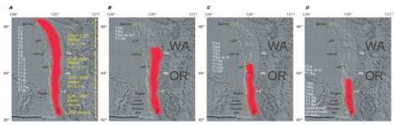
- Multi-fault cascading earthquakes
  - +20% for M8+
- More accurate rates of M6.7 earthquakes
  - -30% for M6.5 – M7.5



UCERF2: ~ 7,773 Ruptures
UCERF3: ~300,000 Ruptures

USGS Present a New Understanding of the Cascadia Subduction Zone

- Updated magnitude, recurrence, and geometry of large earthquakes
- Inclusion of partial ruptures on the southern portion of the subduction zone



M8.6 – 9.3
526 years

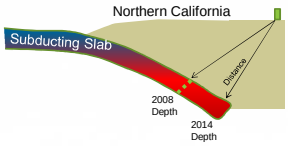
M8.4 – 9.1
2,500 years

M8.3 – 8.9
1,111 years

M8.1 – 8.8
1,000 years

USGS Present a New Understanding of the Cascadia Subduction Zone

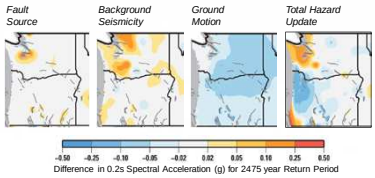
- Increase in down-dip area on the southern portion of the subduction zone in Oregon and N. California



Impact of Pacific Northwest Hazard Update

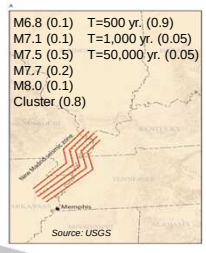
- Inclusions of Tacoma and Seattle Faults
- Increases to background seismicity rates and maximum magnitudes
- Decreases in GMPEs (on base rock)

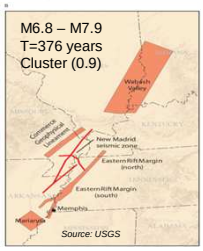
Difference in USGS Hazard Maps (2014 vs. 2008)



New Madrid Geometry, Magnitudes, and Return Periods Are Updated

- Incorporation of more complex New Madrid model
- Addition of rare large magnitude earthquake zones
- Increase in background seismicity
- Decreases in GMPEs (on base rock)

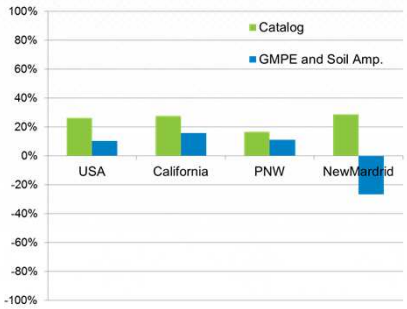




Overall Impact of Hazard Update

Change in AAL:

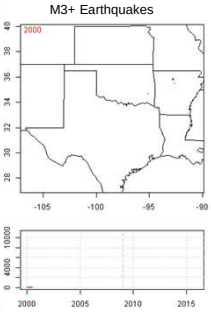
- Constant exposure*
- Constant vulnerability
- Varying shake hazard components



* Exposure distributed at zip code centroids

Rate of Seismicity Has Increased in Central U.S.

M3+ Earthquakes

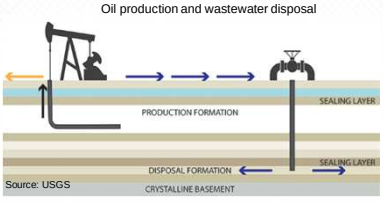


2011 Prague Earthquake

- M5.8 Pawnee, Oklahoma 2016
- M5.7 Prague, Oklahoma 2011 (earthquake sequence)
- M5.3 Trinidad, Colorado 2011
- M4.8 Timpson, Texas 2012
- M 4.7 Guy-Greenbrier, Arkansas 2011
- M4.5-5.0 in Arkansas, Colorado, Kansas, Oklahoma, and Texas

What is Induced Seismicity?

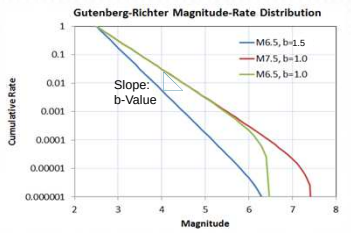
Oil production and wastewater disposal



Source: USGS

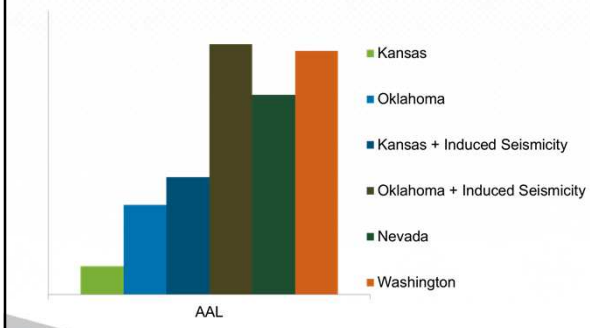
- Presence of a fault
- Stresses acting on the fault favorable to fault slip
- Pathway for the pressure increase from the injection to interact with the fault (permeability)

There Are Great Uncertainties in Modeling Induced Seismicity



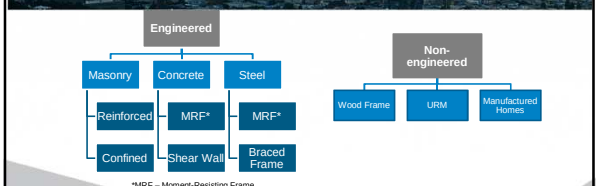
- Blended view based on:
  - 2016 USGS induced seismicity model
  - AIR-View to account for additional uncertainties
- Catalog can be switched On/Off

Incorporation of Induced Seismicity Increases the Risk in Oklahoma and Kansas

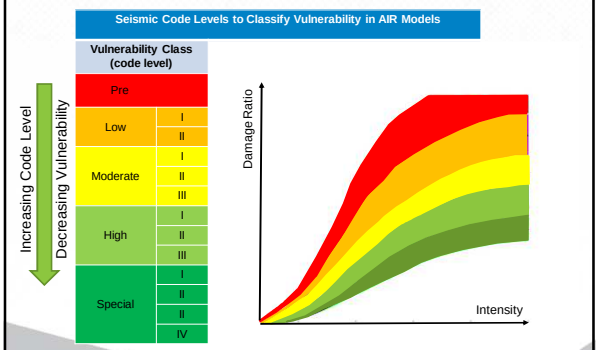


Vulnerability Modeling

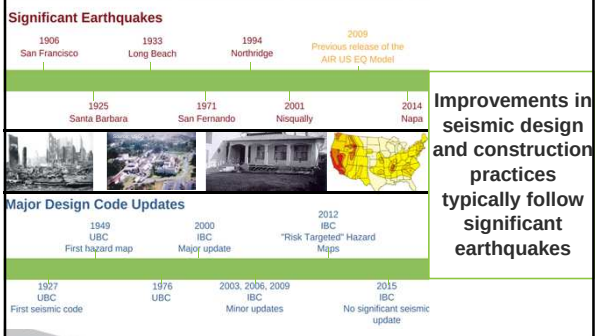
Diversity in Building Stock Requires Efficient Approaches In Vulnerability Assessment



Stringency of Seismic Design Codes Provides an Implicit Measure for Vulnerability Assessment



A Comprehensive Review of Building Code Evolution Helps to Understand the Spatial and Temporal Variation of Vulnerability



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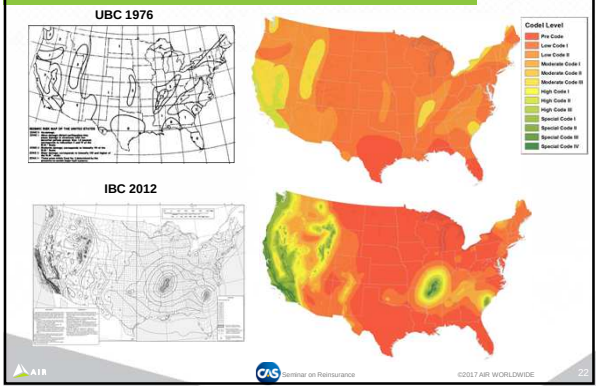

Subperils

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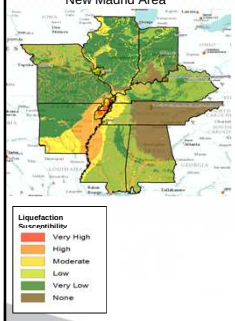
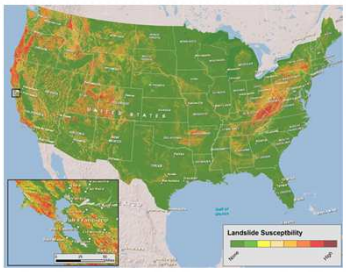
Recent Major Events Around the World Have Demonstrated the Importance of Earthquake Sub-Perils

Liquefaction and Earthquake-Triggered Landslides Can Cause Significant Damage to Property and Infrastructure

Liquefaction Susceptibility in New Madrid Area



Landslide Susceptibility



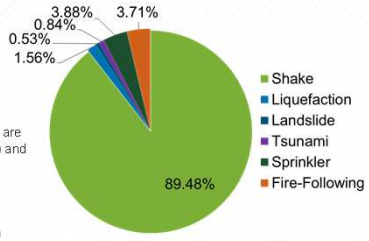
The Three Western States Are Exposed to High Tsunami Hazard from the Subduction Zone and Local Earthquakes

- More than 2,300 km coastline is exposed to tsunami
- Large exposure concentration at ports and coastal areas
- AIR model includes a probabilistic tsunami module
  - Uses bathymetry data, ground motion parameters (slip rate, magnitude,…)
  - Uses high-resolution grids
  - Incorporates astronomical tides
  - Considers levees

Tsunami damage in Kodiak, Alaska. Photo: US Navy, March 30, 1964

Contribution of Sub-Perils to Average Annual Losses in the U.S.

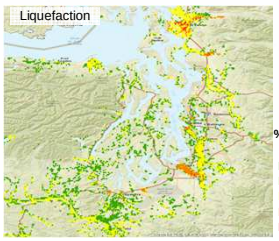
- Dominant peril with regard to earthquake damage is shake
- Next most prevalent sub-perils are fire following earthquake (FFE) and sprinkler leakage followed by liquefaction
- Tsunami sub-peril becomes significant for large events with longer return periods



Contribution of Sub-Perils Can Be Much Higher For Individual Events and at the Location Level

Simulation of the recurrence of the 1700 M9.0 Cascadia Earthquake

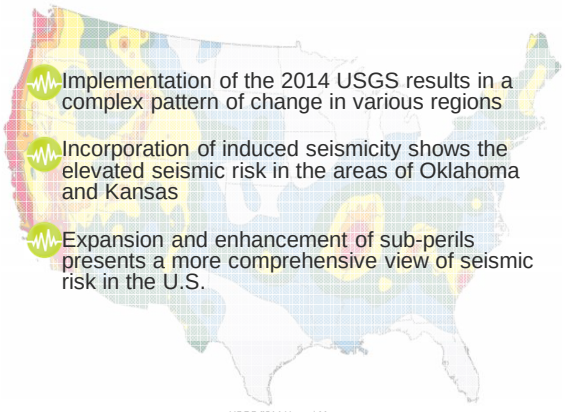
Tsunami



Liquefaction

% of Total Loss

- <=0.05
- 0.06 - 0.10
- 0.11 - 0.30
- 0.31 - 0.50
- 0.51 - 1.00



- Implementation of the 2014 USGS results in a complex pattern of change in various regions
- Incorporation of induced seismicity shows the elevated seismic risk in the areas of Oklahoma and Kansas
- Expansion and enhancement of sub-perils presents a more comprehensive view of seismic risk in the U.S.

USGS 2014 Hazard Map