

From PBEE to Resilience: Research Challenges

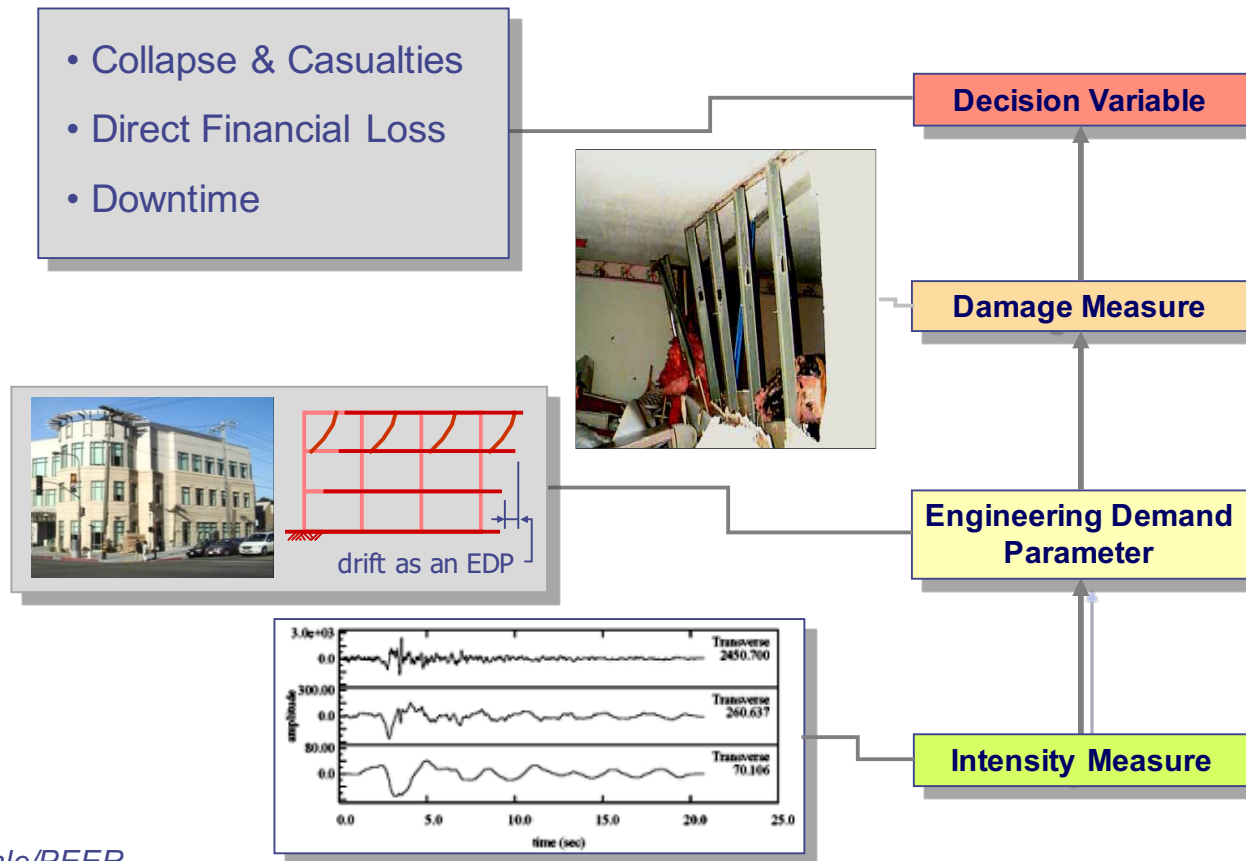


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J. A. Blume Professor
Stanford University

How PBEE can enable Resilience

- **Assessing performance (3D's)**
 - buildings, bridges, other facilities
 - geographically distributed systems
 - communities – assembly of facilities & systems
- **Implications of performance on recovery**
 - safe to occupy (shelter-in-place)
 - interdependencies
- **Developing solutions**
 - quantify critical vulnerabilities (e.g., non-ductile concrete buildings, soft-story buildings, infrastructure systems)
 - tools for economical evaluation and retrofit (e.g., FEMA P-807 soft-story retrofit)
 - benefit-cost analysis to support public policies
 - enable and facilitate design innovations

PBEE Framework - Facilities



Moehle/PEER

MAF of:

- collapse
- loss > \$
- downtime > t

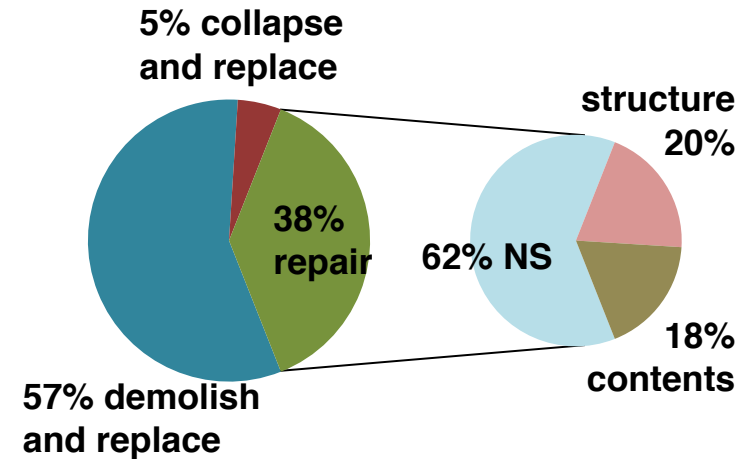
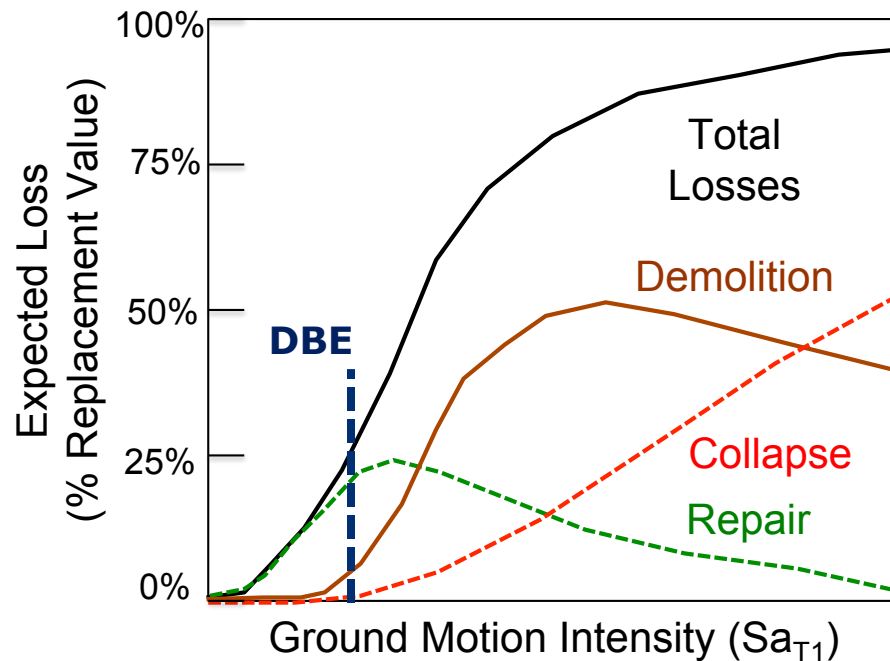
$$v(DV) = \iiint G\langle DV | DM \rangle | dG\langle DM | EDP \rangle | dG\langle EDP | IM \rangle | d\lambda(IM)$$

Impact

Performance (Loss) Models and Simulation

Hazard

PBEE Benchmarking Codes



Expected Risk Metrics

Risk of Collapse: 1% in 50 years
Expected Annual Loss: 1% of Value

- Assessment of Loss
- Implications on Recovery
- Benchmarking - Building Codes, Existing Inventory

Vector of Resilience Metrics ?

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDING AND INFRASTRUCTURE										
INFRASTRUCTURE CLUSTER FACILITIES	Event Occurs	Phase 1 Hours			Phase 2 Days		Phase 3 Months			
		4	24	72	30	60	4	36	36+	
CRITICAL RESPONSE FACILITIES AND SUPPORT SYSTEMS										
Hospitals									X	
Police and fire stations			X							
Emergency operations center	X									
Related utilities						X				
Roads and ports for emergency				X						
CalTrain for emergency traffic				X	X					
Airport for emergency traffic				X						
EMERGENCY HOUSING AND SUPPORT SYSTEMS										
90% residence shelter-in-place									X	
Emergency Responder Housing			X							
Public shelters										
90% Related utilities										
90% roads, port facilities, and public transit										
90% Muni and BART capacity										
HOUSING AND NEIGHBORHOOD INFRASTRUCTURE										
Essential city service facilities										
Schools										
Medical provider offices										
90% neighborhood retail services										
95% of all utilities										
90% roads and highways										
90% transit										
90% railroads										
Airport for commercial traffic					X					
95% transit										
COMMUNITY RECOVERY										
All residences repaired, replaced or relocated										
95% neighborhood retail businesses open										
50% offices and workplaces open										X
Non-emergency city service facilities										
All businesses open										X
100% utilities										X
100% highway and roads										X
100% transit										X

INFRASTRUCTURE CLUSTER FACILITIES

CRITICAL RESPONSE FACILITIES AND SUPPORT SYSTEMS

Hospitals

Police and fire stations

Emergency operations center

Related utilities

Roads and ports for emergency

CalTrain for emergency traffic

Airport for emergency traffic

EMERGENCY HOUSING AND SUPPORT SYSTEMS

Source: SPUR Urbanist, February 2018

Source: SPUR Urbanist, February 2009

The Resilient City

www.spur.org

Issue 494 News at SPUR p3 Transportation & Rebuilding p4 Urban Field Notes p26 Member profile p29

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SPUR

Urbanist

Published monthly by San Francisco

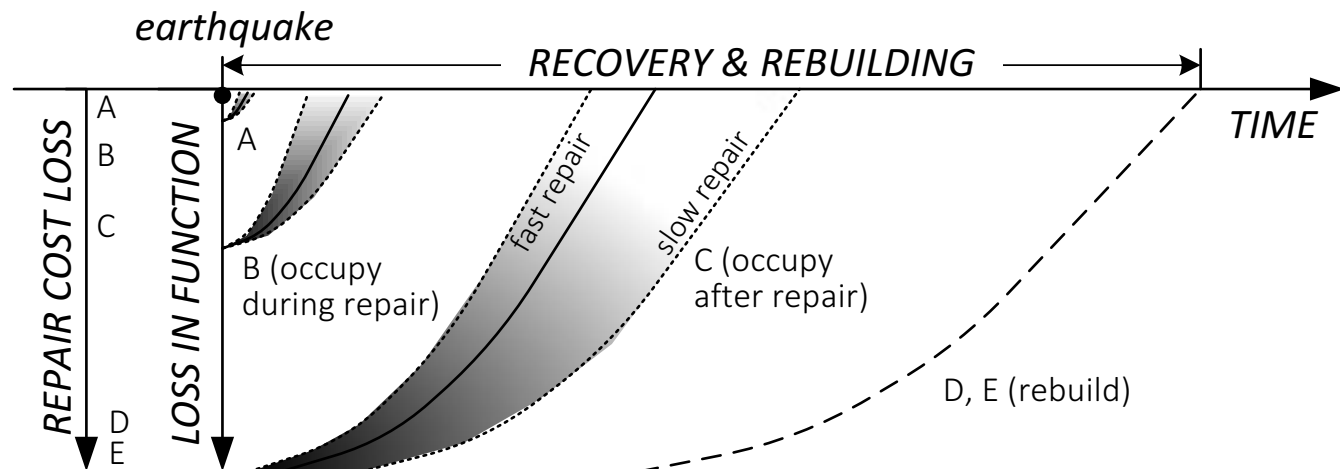
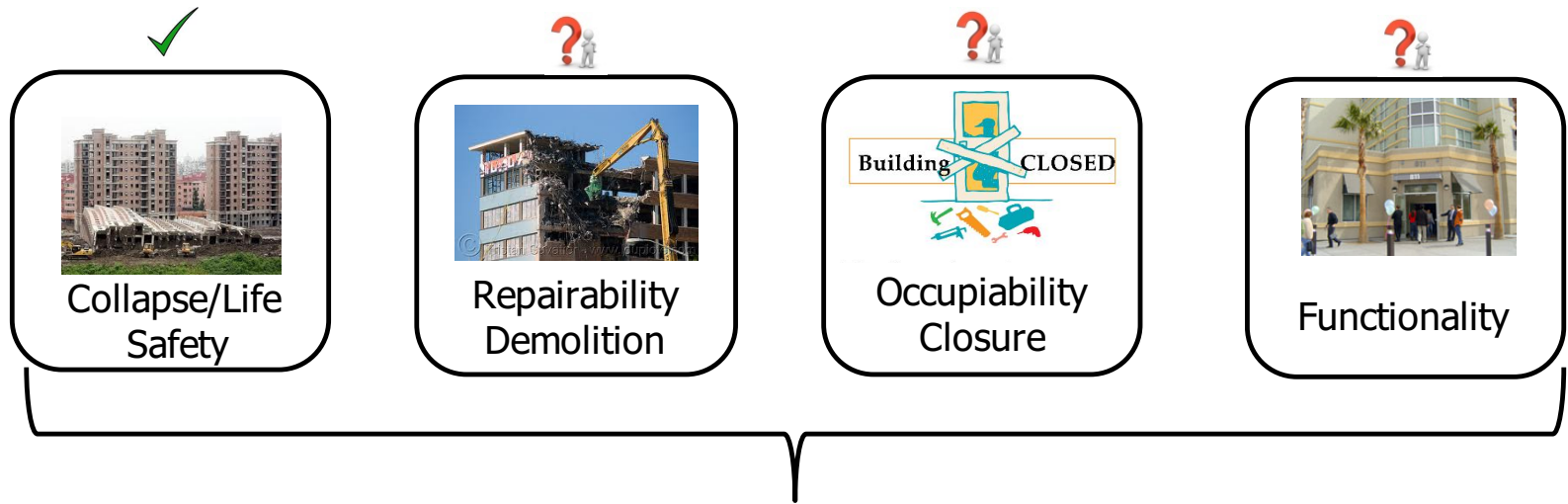
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Emergency operations center	X								
Related utilities						X			
Roads and ports for emergency				X					
CalTrain for emergency traffic				X	X				
Airport for emergency traffic				X					
EMERGENCY HOUSING AND SUPPORT SYSTEMS									

DISASTER

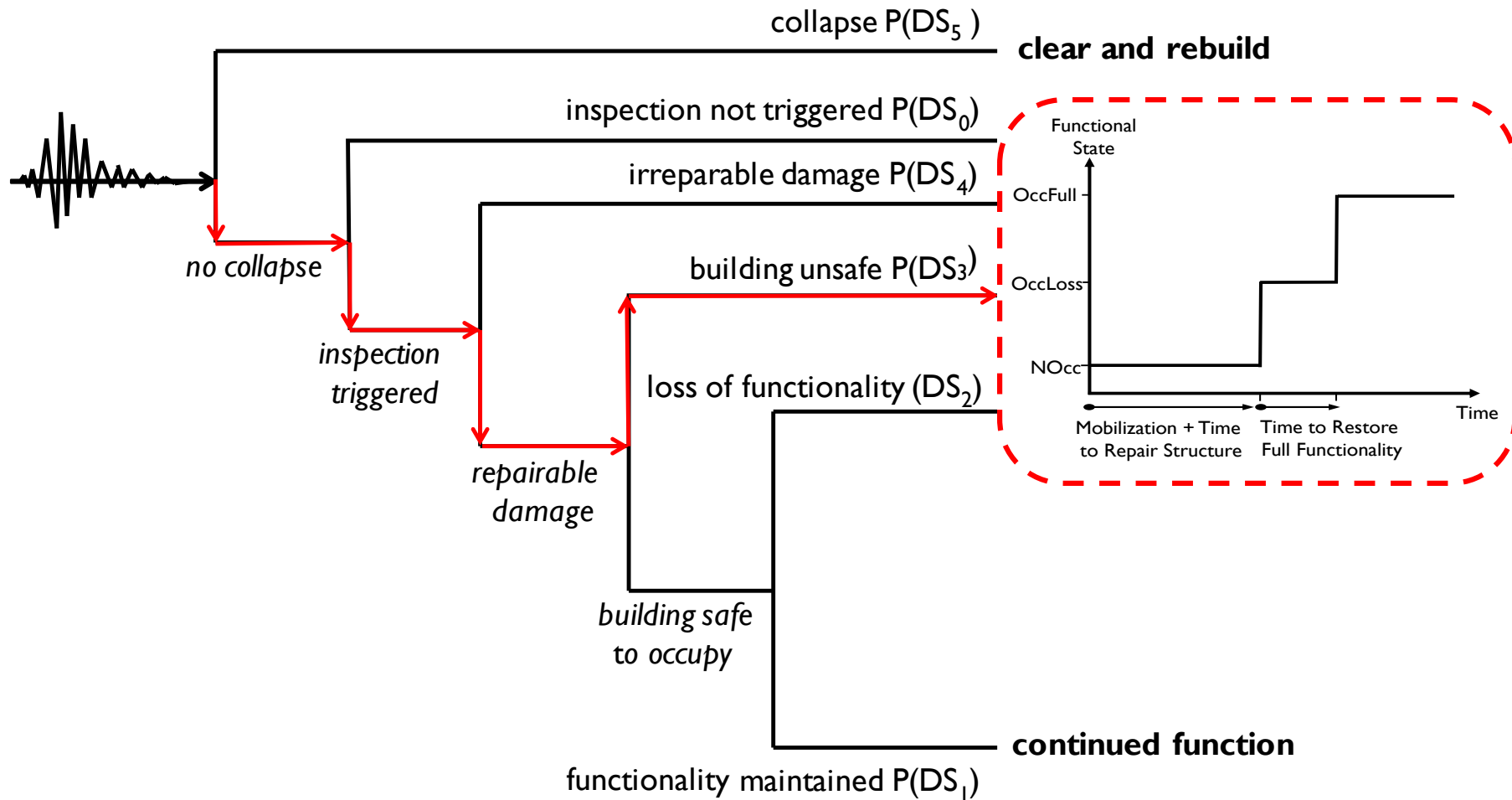
REBUILDING OUR BRIDGES, ROADWAYS AND TRANSIT LINES

PBEE to Resilience

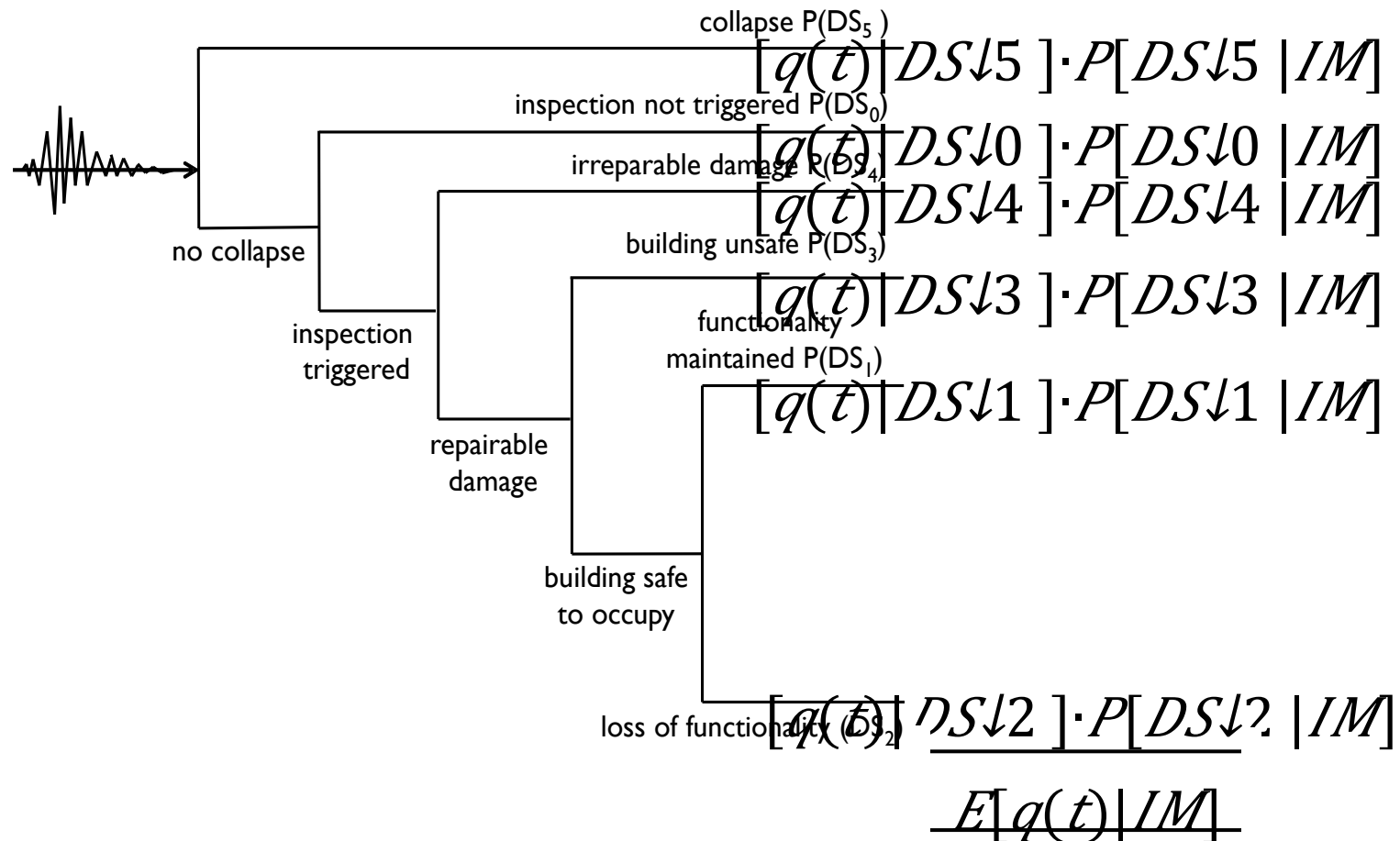
Resilience – recovery and restoration of functionality



PBEE Framework for Recovery

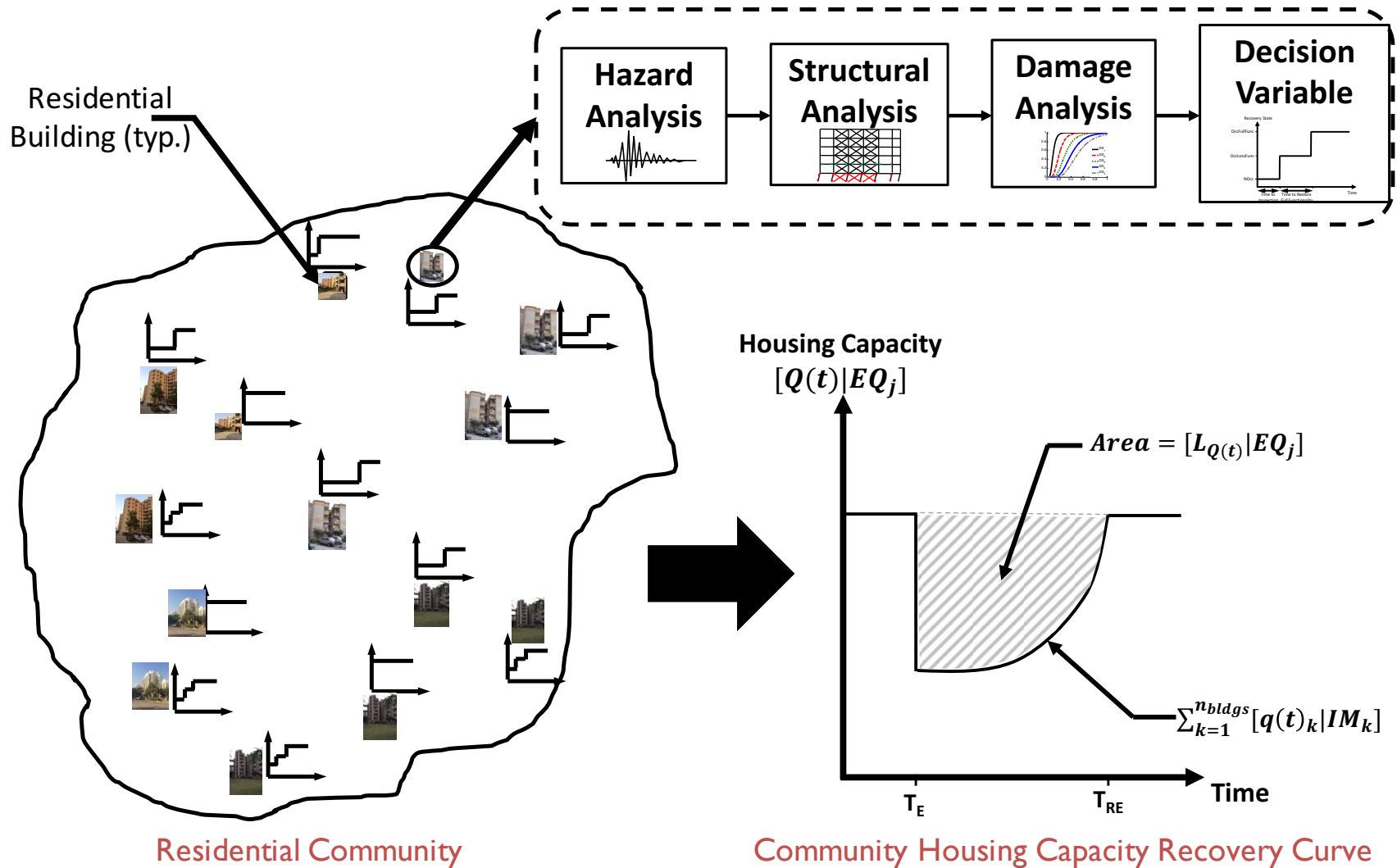


PBEE Framework for Recovery

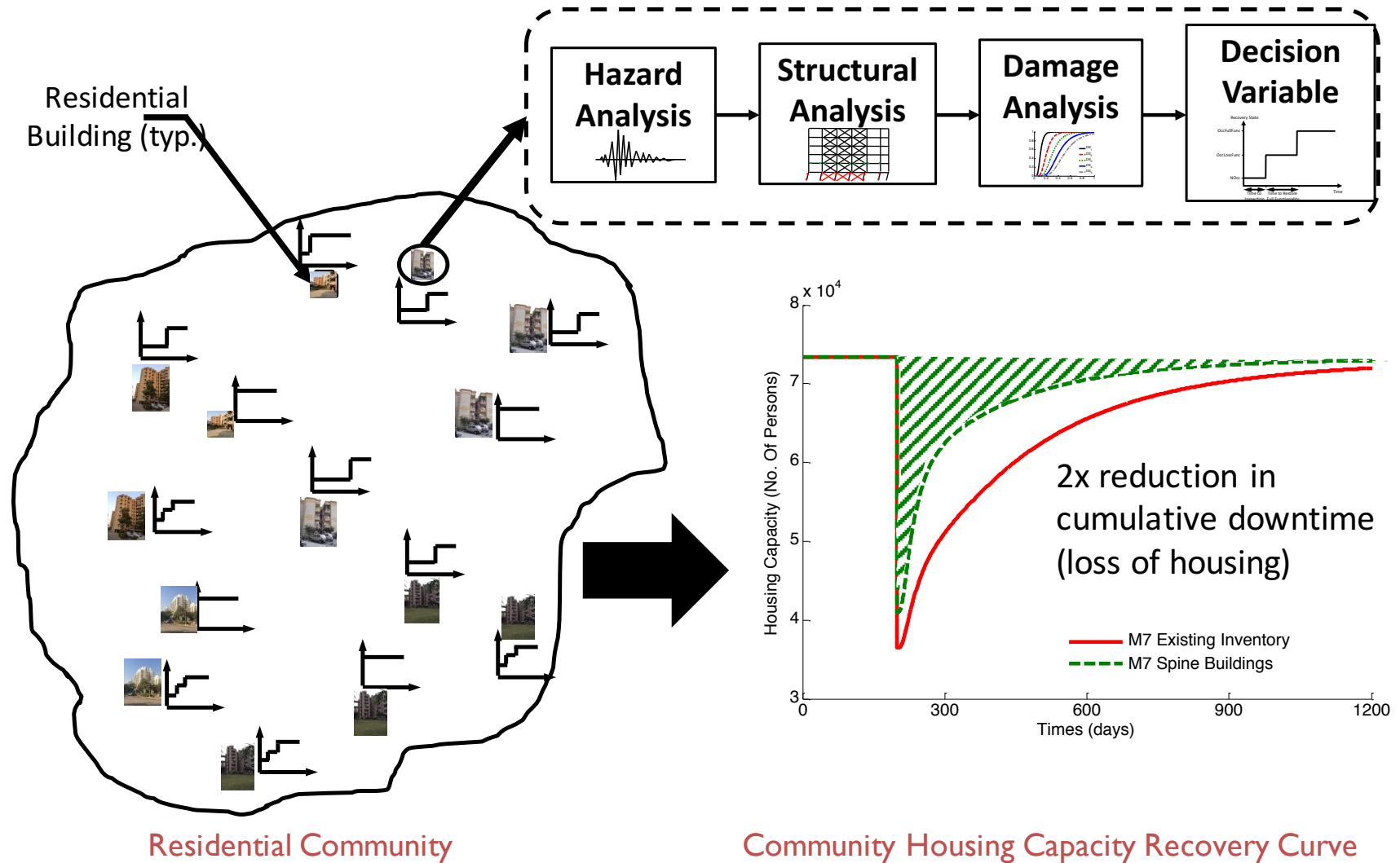


$$E[q(t)|IM] = \sum_{i=1}^n [q(t)|DS \downarrow i] \cdot P[DS \downarrow i | IM]$$

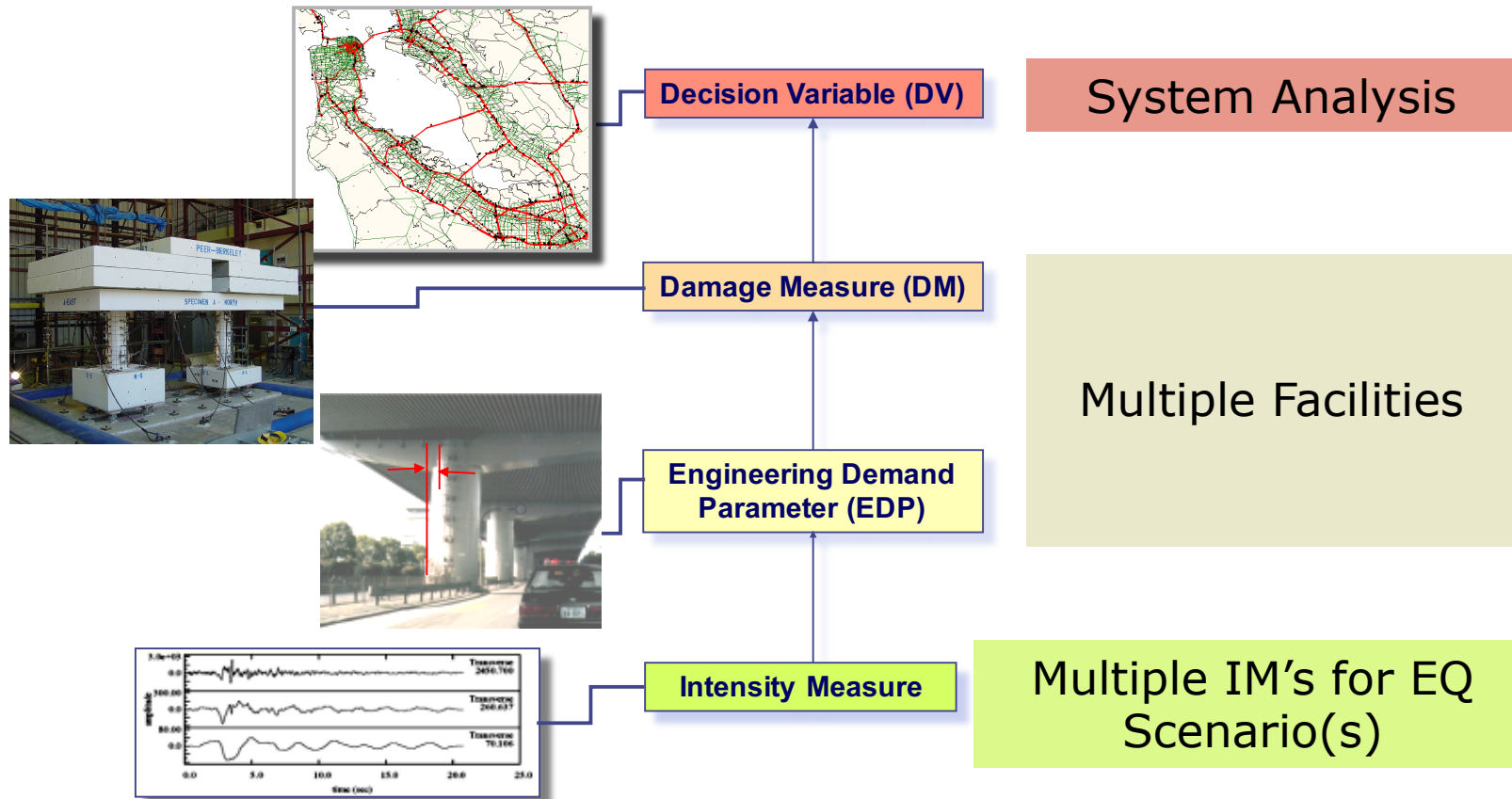
PBEE Framework for Recovery



PBEE Framework for Recovery



PBEE Framework - Systems



MAF of:

- fatalities
- loss > \$
- **traffic delay > t**

$$v(DV) = \iiint G\langle DV | DM \rangle | dG\langle DM | EDP \rangle | dG\langle EDP | IM \rangle | d\lambda(IM)$$

Impact

Performance (Loss) Models and Simulation

Hazard

Geographically Distributed GM's

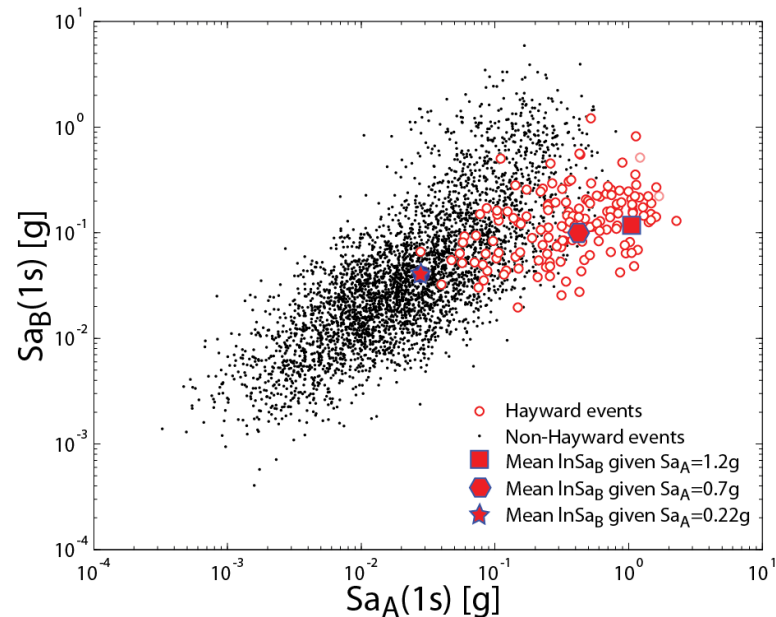
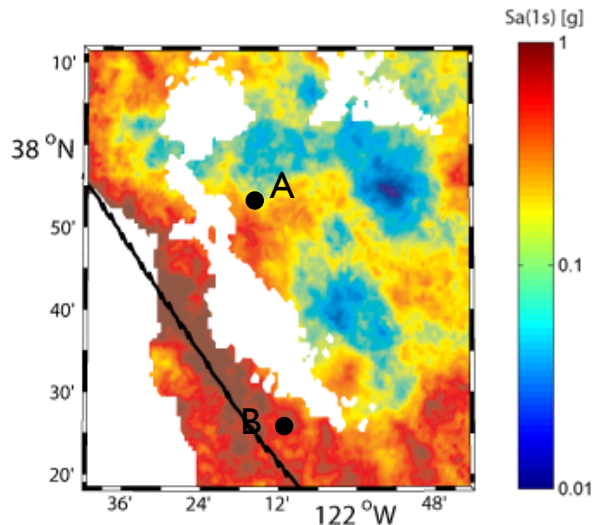
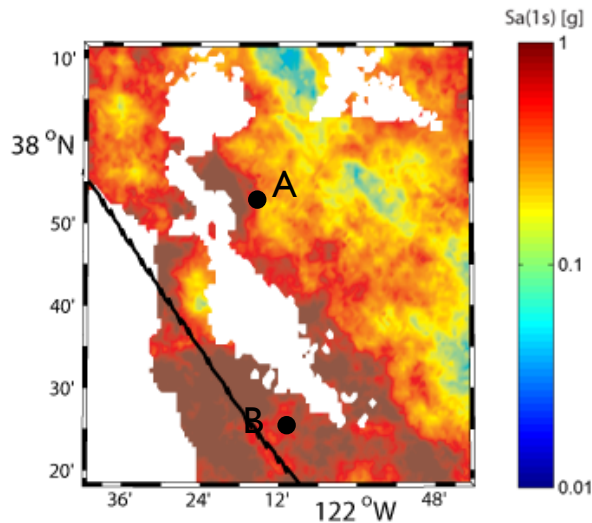
Variability & Correlations in Sa

$$\ln Sa_{1j} = \overline{\ln Sa(M_j, R_{1j}, V_{s30,1}, T, \dots)} + \underbrace{\sigma_{1j} \varepsilon_{1j}}_{\text{Intra-event (site i)}} + \underbrace{\tau_j \eta_j}_{\text{Inter-event}}$$

Mean Sa: M, V_{s30}

Intra-event (site i)

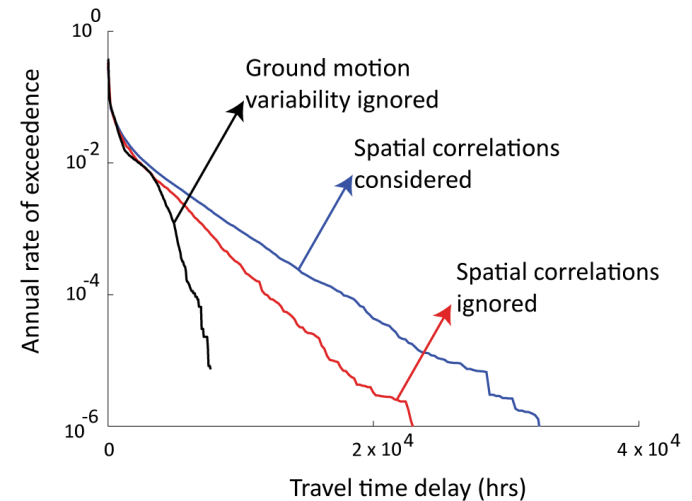
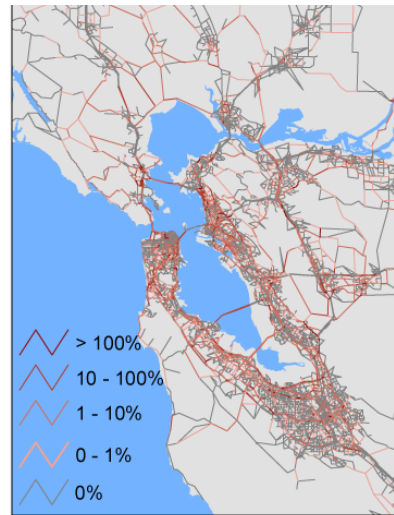
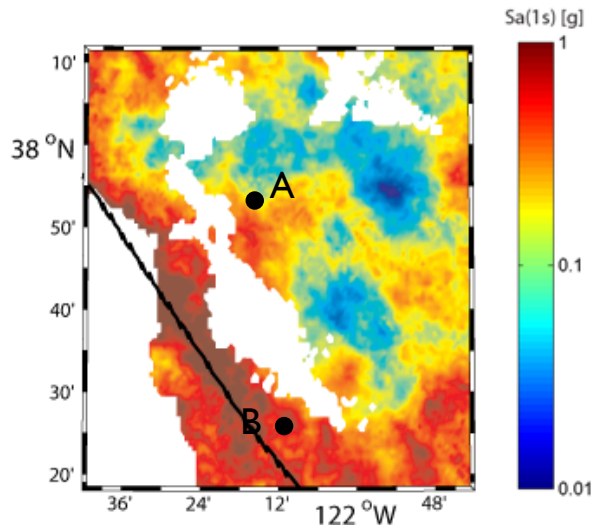
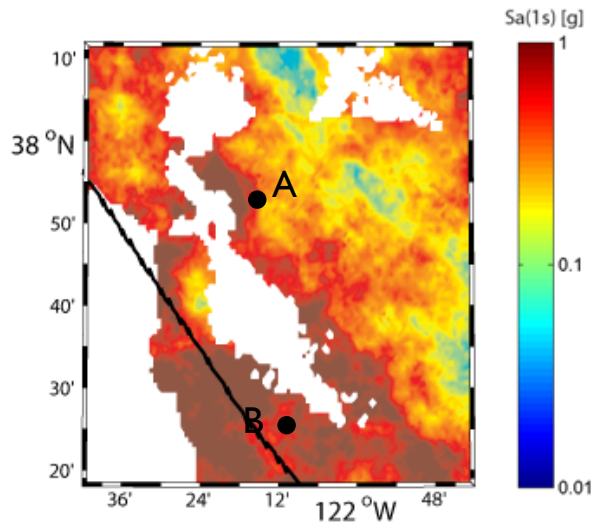
Inter-event



Geographically Distributed GM's

Variability & Correlations in Sa

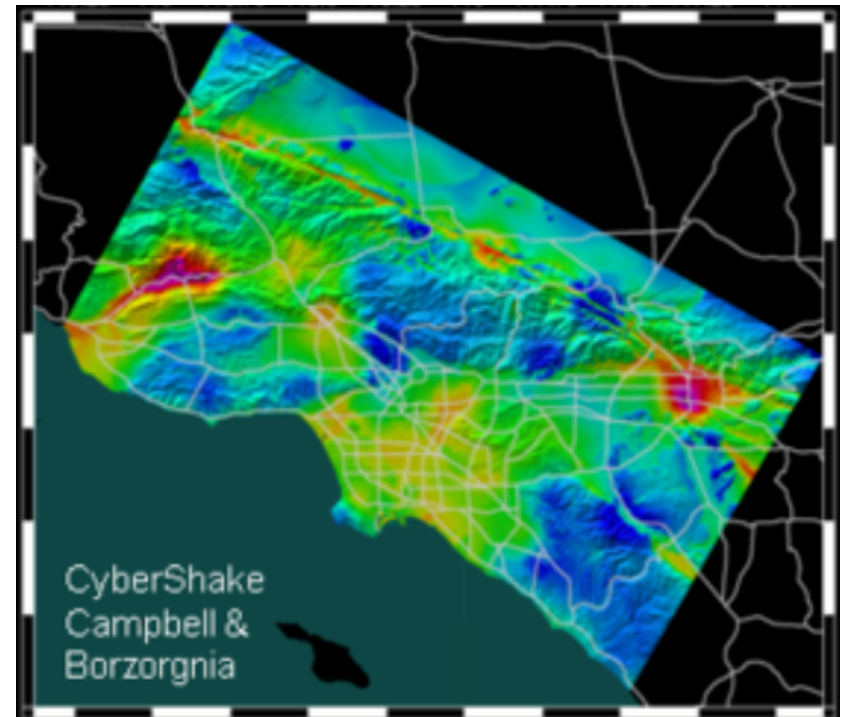
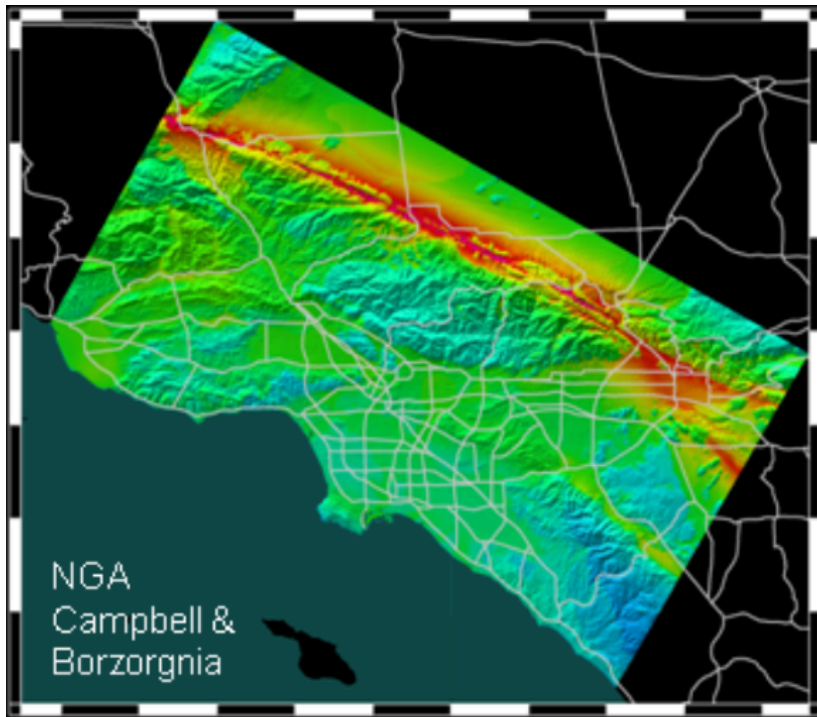
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Transportation Travel Time Delays (MAF)

Role of Earthquake Simulations

Comparison: Conventional GMPE versus
Simulated CyberShake Hazard Models for LA

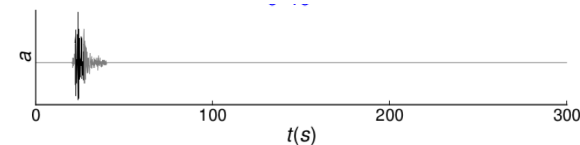
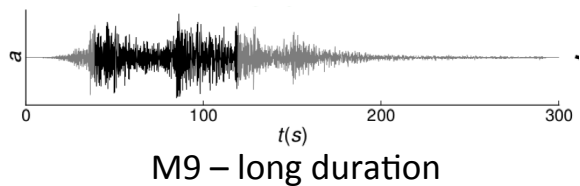
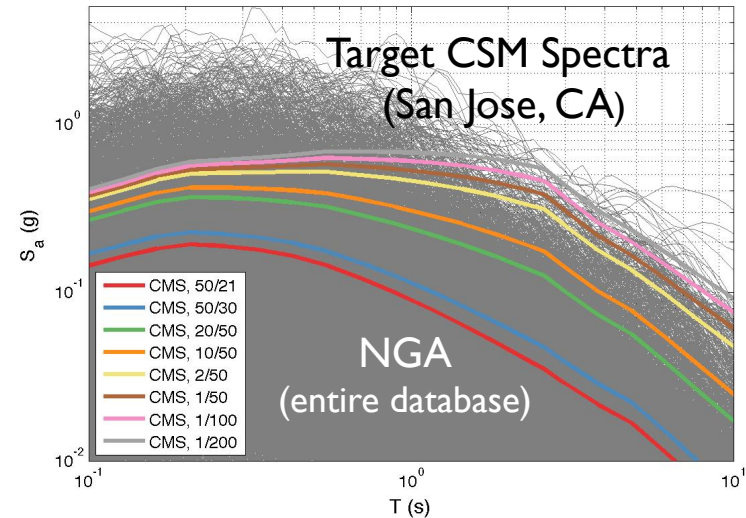


Role of Earthquake Simulations

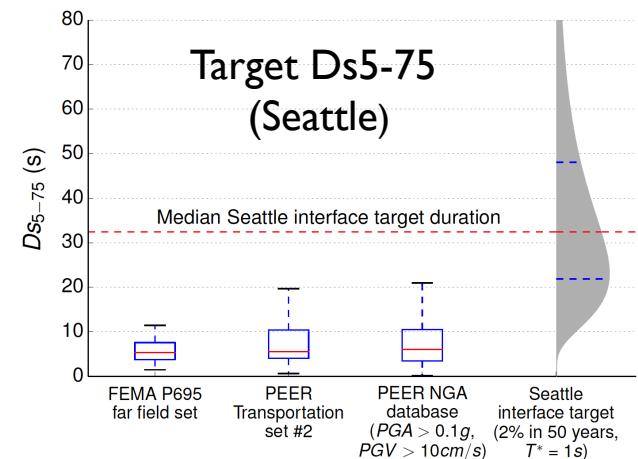
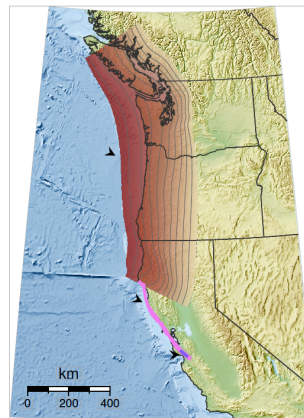
PEER NGA-2 Database

20,000 GM records ... still not enough.

- high intensity (high M, low R)
- long duration
- near-fault pulse
- basin effects
- variability: e.g., *inter- and intra-earthquake correlations*

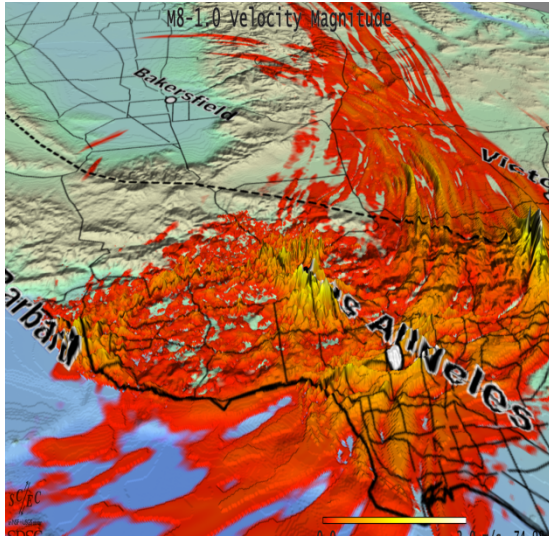


M7 – typical of recorded GM's



Regional Resilience Simulations

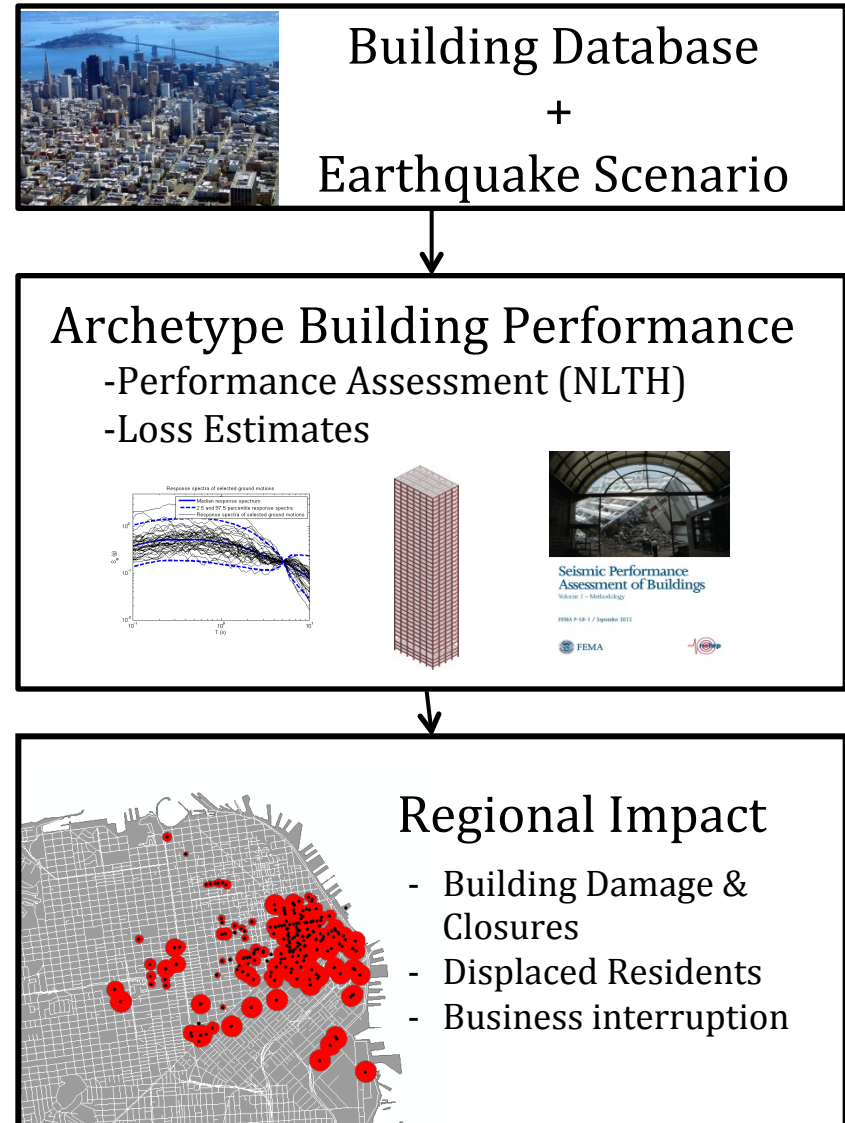
Simulated Earthquake Scenarios



SCEC M8 earthquake on the southern San Andreas Fault

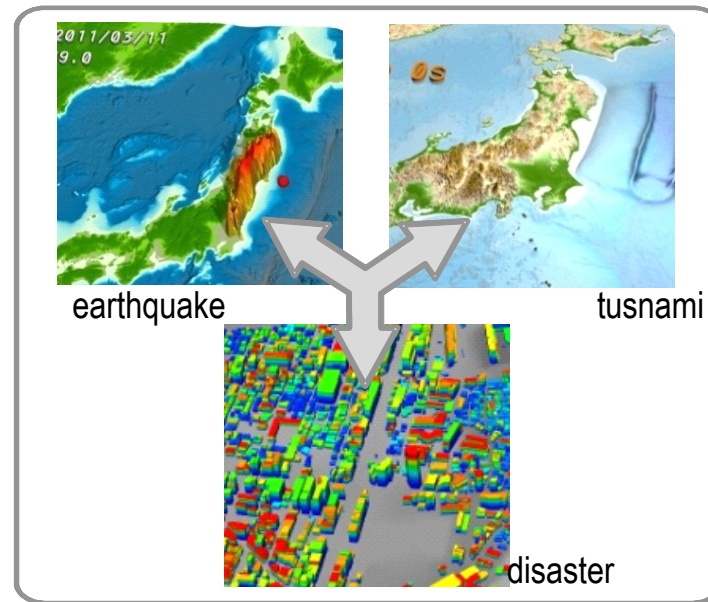
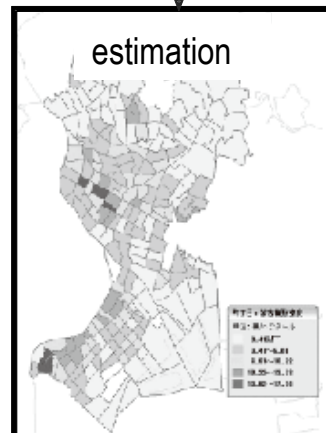
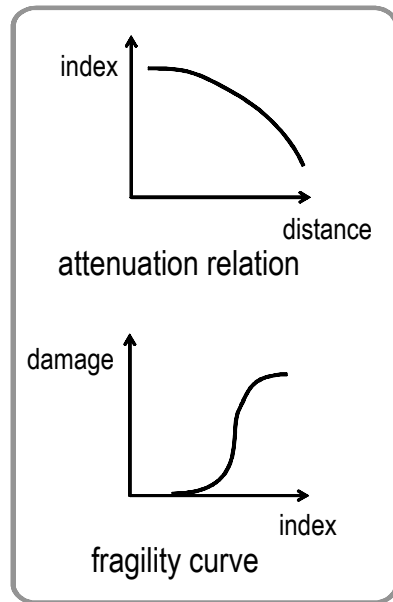
Utilization of simulated ground motions to assess performance

- long duration motions
- high energy at long periods
- near-fault directivity and pulse effects

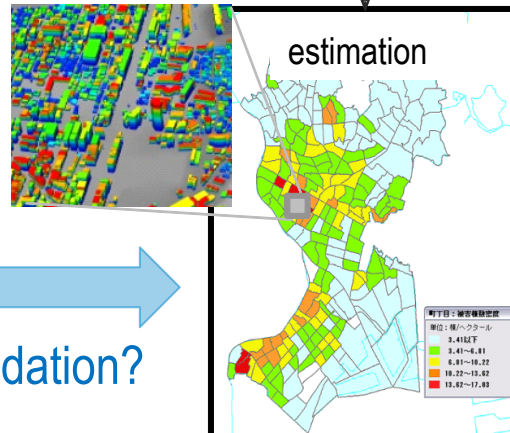


Regional Loss Assessment

CURRENT
empirical

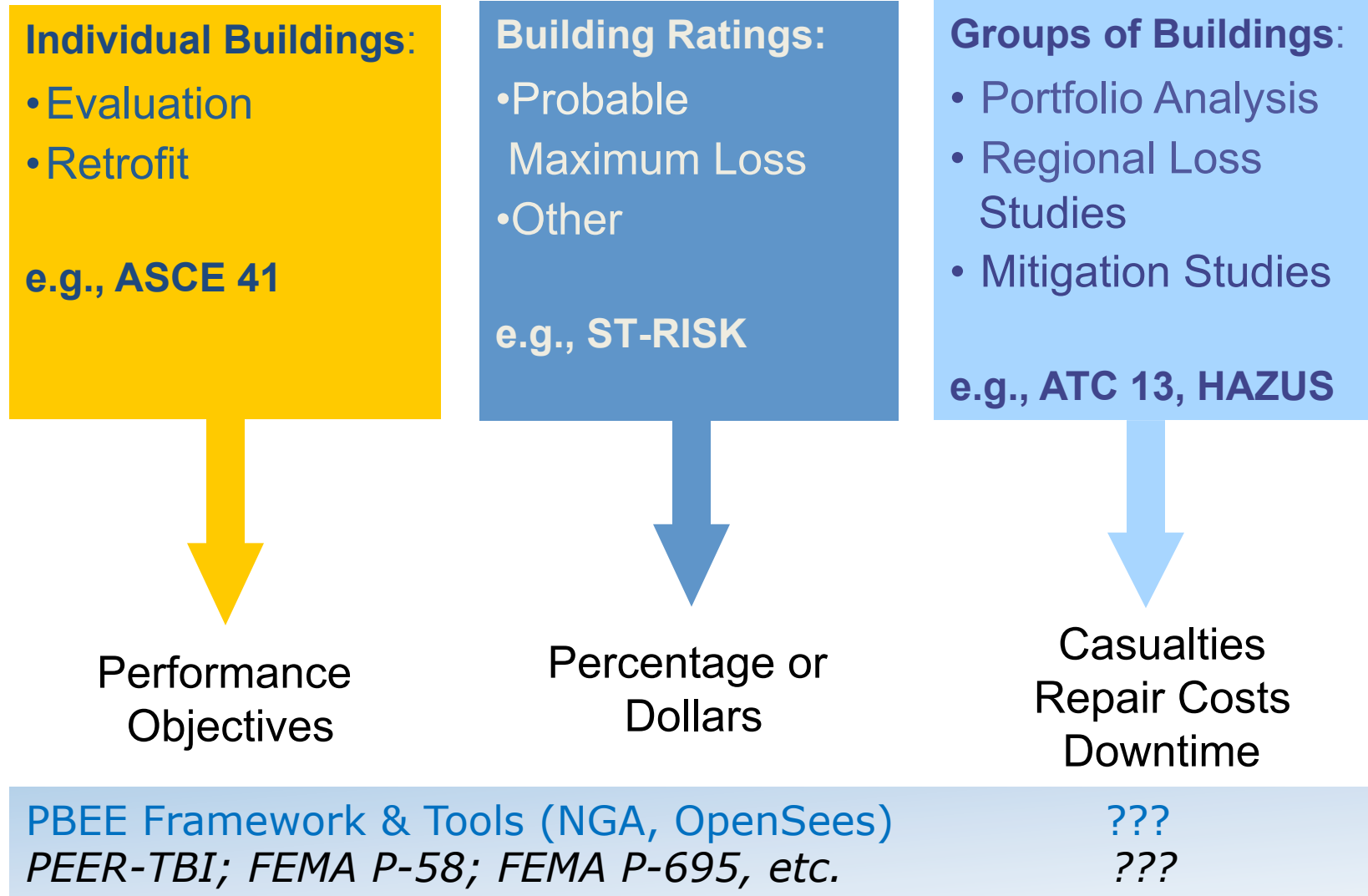


FUTURE
simulation

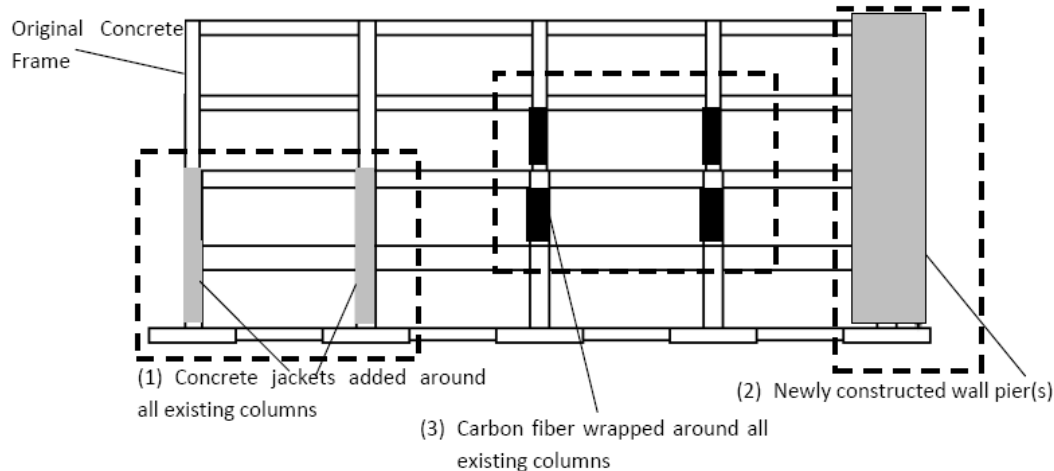


validation?

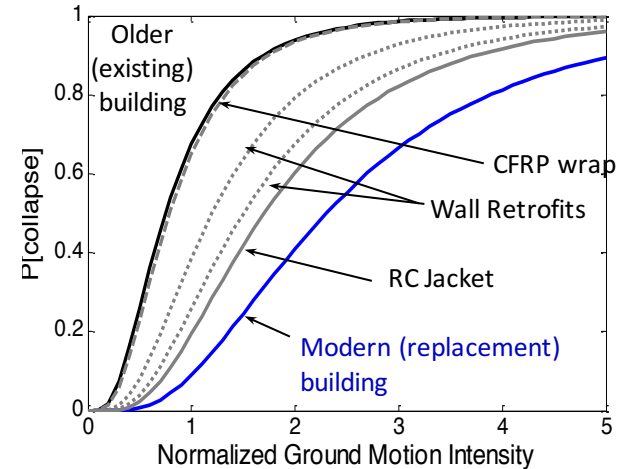
PBEE to Resilience Framework



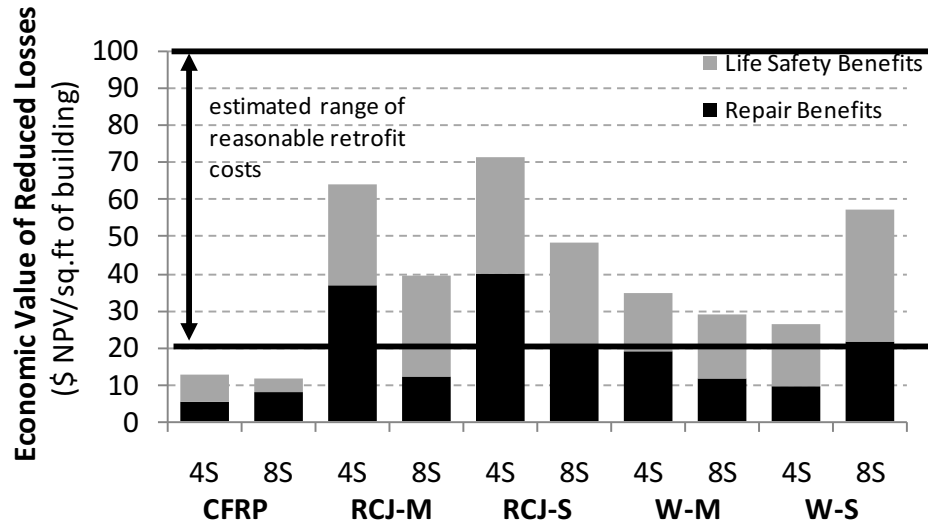
Benefit-Cost of Mitigation Measures



Seismic Retrofit Strategies



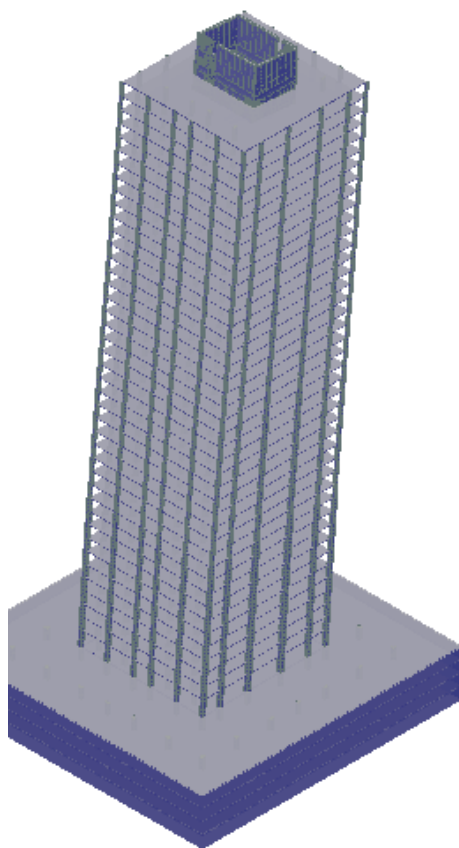
collapse fragilities



ECONOMIC VALUE OF BENEFITS:

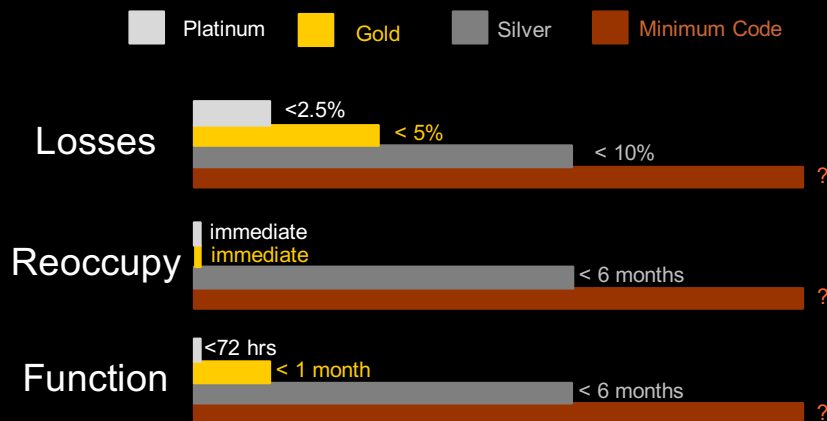
- LIFE SAFETY - assume \$2M per life
- ECONOMIC – repair costs
- DOWNTIME – (NOT INCLUDED)

Resilience of New Buildings?



Modern RC Shear Wall
Residential Building

REDi Rating Targets for "Expected Earthquake" (10% in 50 yr)



Standard (PEER TBI Design)

Direct Losses: ~15% replacement

Reoccupy: ~18 months

Code

Structural Enhancements

Direct Losses: ~10% replacement

Reoccupy: ~8 months

Silver

Non-structural Enhancements

Direct Losses: ~8% replacement

Reoccupy: ~6 months

BOTH Structural & Non-structural

Direct Losses: ~2% replacement

Reoccupy: <1 month

Gold

Final Remarks

- **Extend PBEE framework**
 - disruption and recovery of function
 - time dependent hazards and risk exposure
 - regional assessments of geographically distributed inter-connected systems
- **Innovations to improve resilience**
 - reduce damage and disruption (physical systems)
 - speed recovery (communication and information systems)
- **Facilitate decision making for resilience**
 - benefit-cost information to inform decisions
 - reconcile scenarios versus full probabilistic-based
 - embrace new (disruptive) technologies
- **Identify needs of industry professionals and stakeholders**