OPPORTUNITIES AND CHALLENGES IN HIGH FIDELITY SIMULATION FOR PLANNING DISASTER RECOVERY

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Stanford University

with contributions and acknowledgements to many

PEER

SimCenter NHERI
Center for Computational Modeling and Simulation

PEER Annual Meeting

January 16-17, 2020

The John A. Blume Earthquake Engineering Center

Evolution of PBEE Concept

Individual Buildings:
- Evaluation
- Retrofit

e.g., FEMA 273/356

→ "Performance Objectives"

Building Ratings:
- Probable Maximum Loss
- Other

e.g., ST-RISK

→ Percentage or Dollars

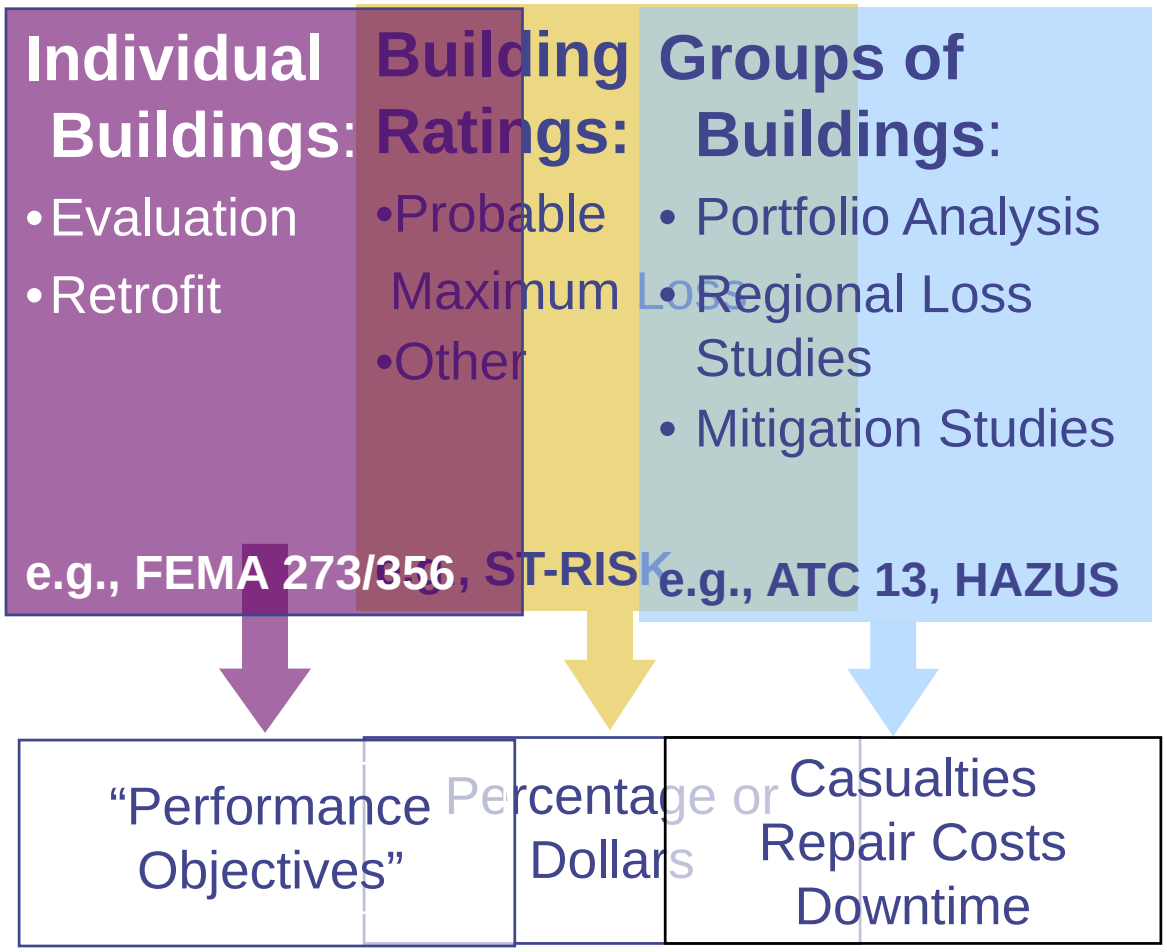
Groups of Buildings:
- Portfolio Analysis
- Regional Loss Studies
- Mitigation Studies

e.g., ATC 13, HAZUS

→ Casualties
Repair Costs
Downtime

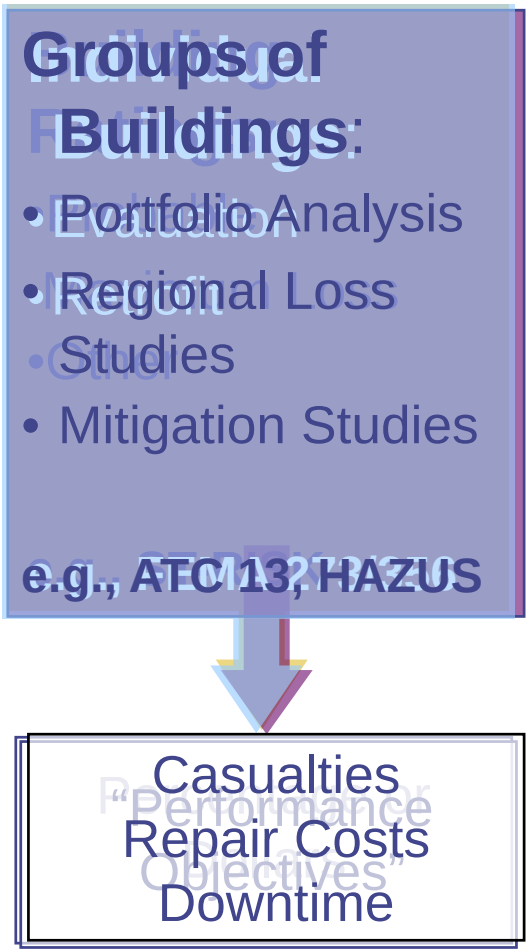
W. Holmes c.2000

Evolution of PBEE Concept



W. Holmes c.2000

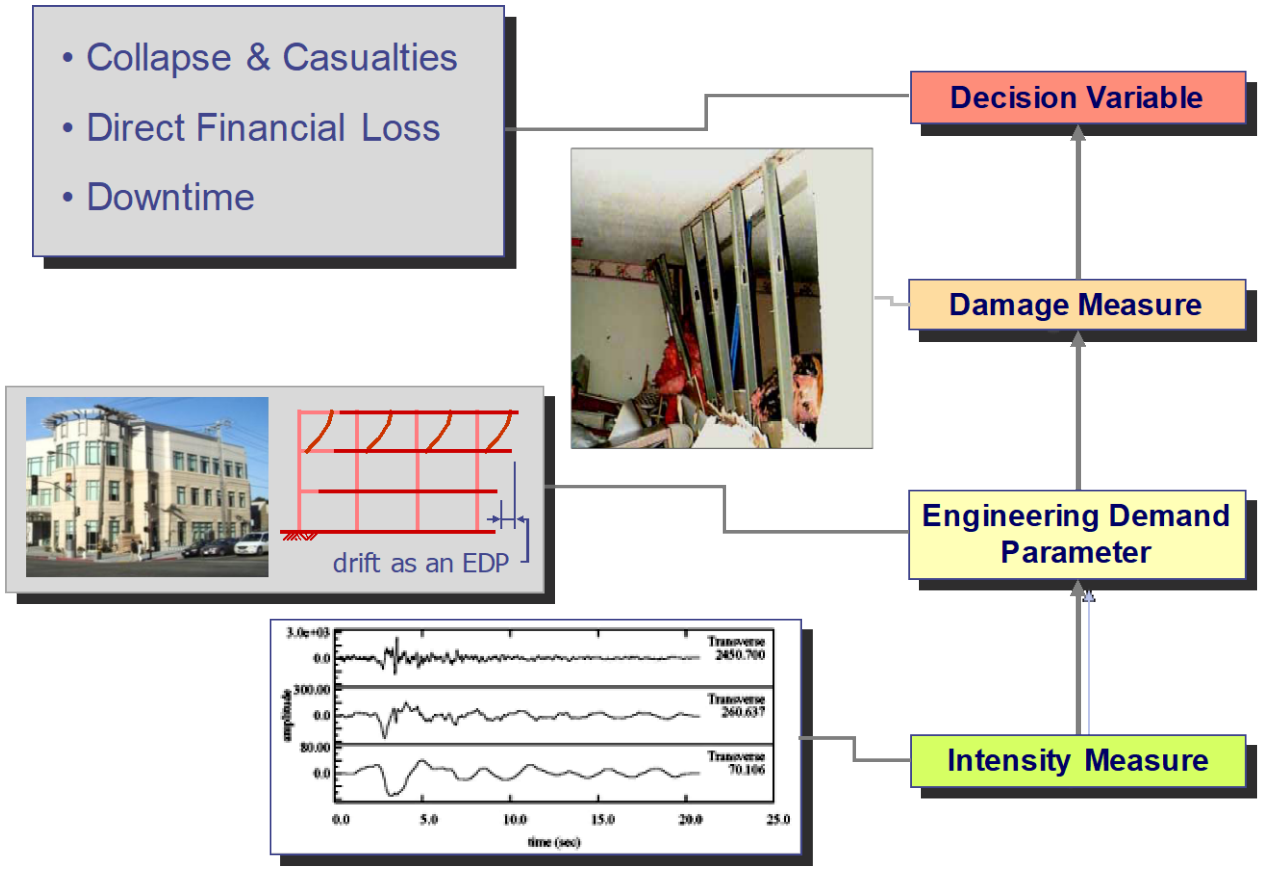
Evolution of PBEE Concept



Unified Performance Framework !

W. Holmes c.2000

Performance-Based Methodology



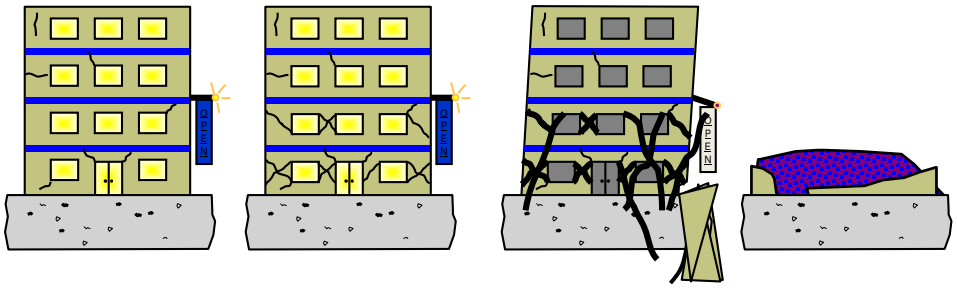
MAF of:

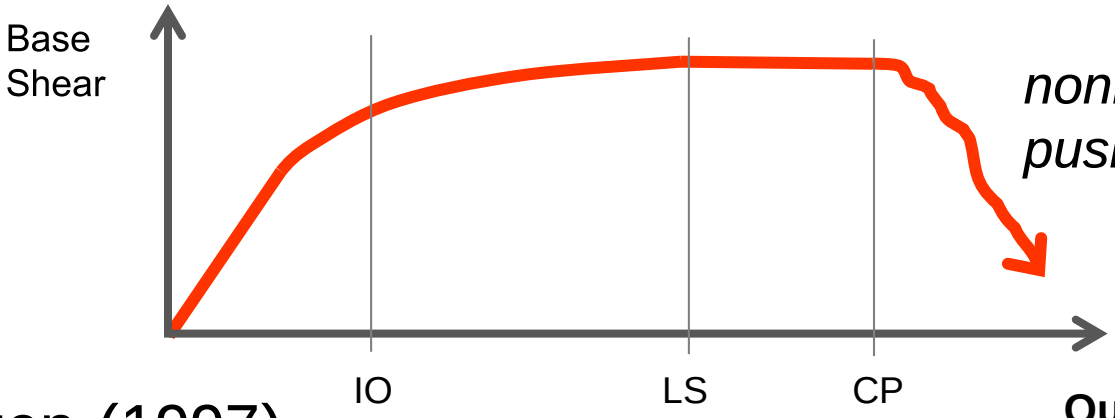
- *collapse*
- *loss > $*
- *downtime > t*

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

Impact | **Performance (Loss) Models and Simulation** | **Hazard**

Performance-Based Earthquake Engineering





nonlinear static pushover analysis

Qualitative Targets (ASCE 41)

Explicit Measures (FEMA P-58)

1st-gen (1997)

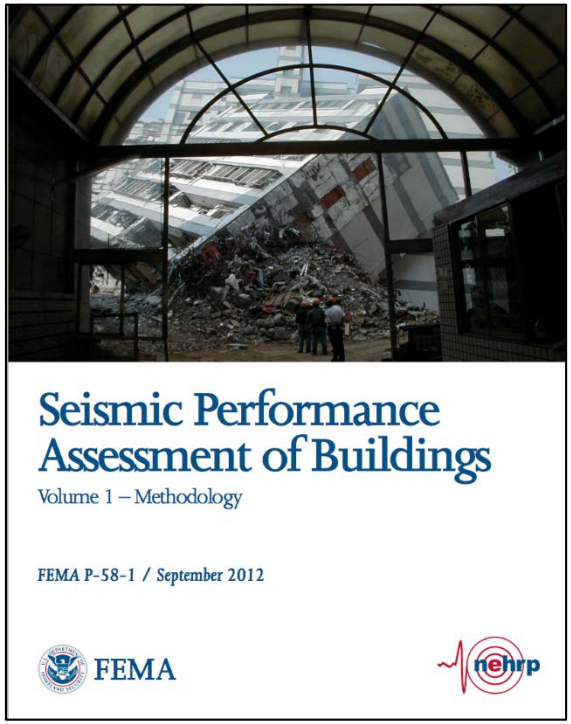
Today

0 — 25% — 50% — 100% → $, % replacement

0.0 — 0.0001 — 0.001 — 0.01 — 0.25 → Casualty rate

0 — 1 — 7 — 30 — 180 → Downtime, days

FEMA P-58 (2012) Performance Assessment of Buildings



Provides a methodology, basic building information, response quantities, fragilities and consequence data to evaluate the seismic performance of buildings

Procedures are probabilistic

Performance metrics:

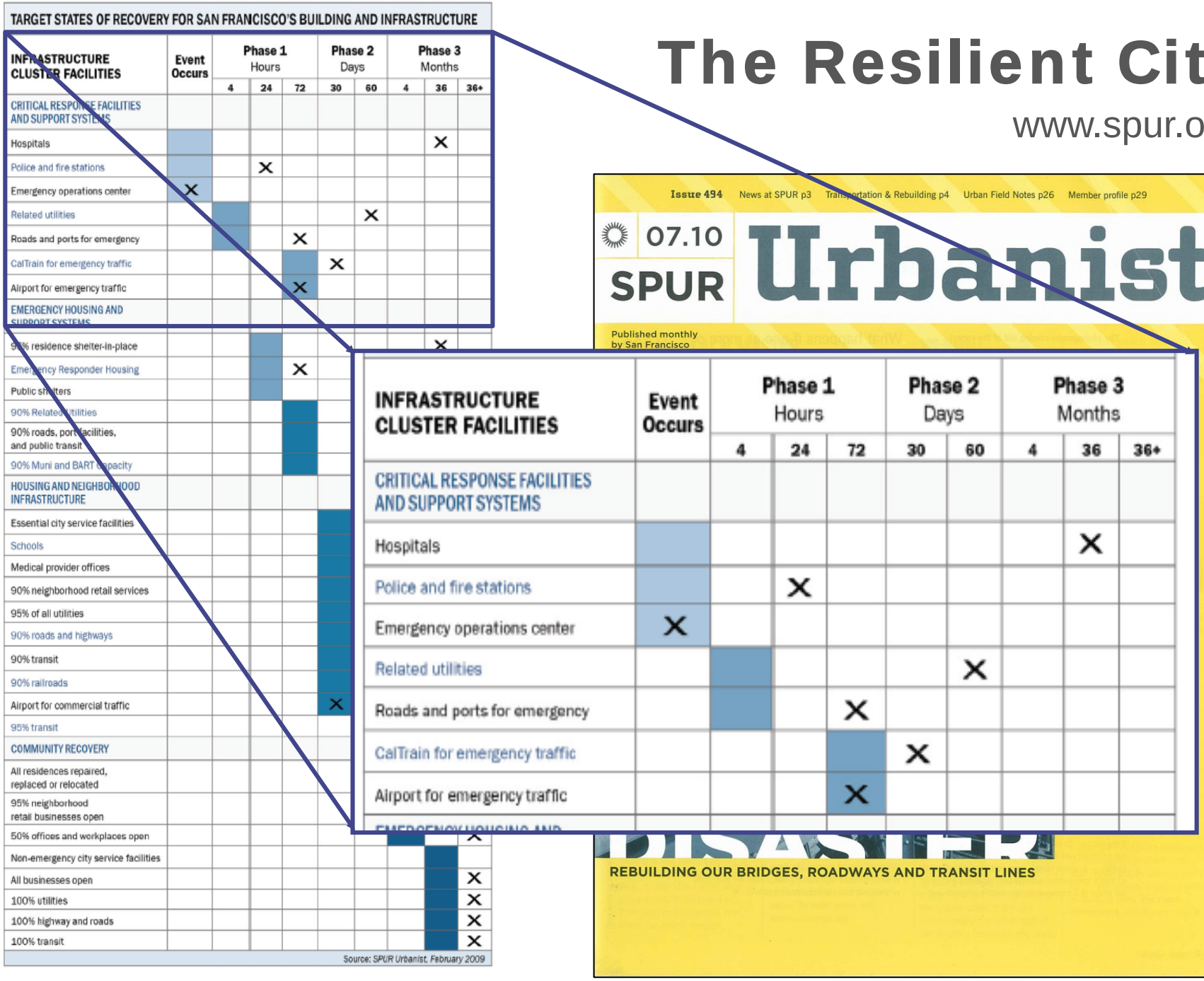
- *life safety risks*
- *direct economic losses*
- *downtime and indirect losses*

Recommended Use –

- ✓ Evaluate performance of new and existing buildings
- ✓ Provide the basis for performance-based design of new buildings and retrofit of existing buildings

The Resilient City

www.spur.org



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				
Airport for emergency traffic				X					
EMERGENCY HOUSING AND SUPPORT SYSTEMS									
95% 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

Source: SPUR Urbanist, February 2009

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

07.10 SPUR **Urbanist**

Published monthly by San Francisco

DISASTER

REBUILDING OUR BRIDGES, ROADWAYS AND TRANSIT LINES

INFRASTRUCTURE CLUSTER FACILITIES	Event Occurs	Phase 1 Hours			Phase 2 Days		Phase 3 Months		
		4	24	72	30	60	4	36	36+
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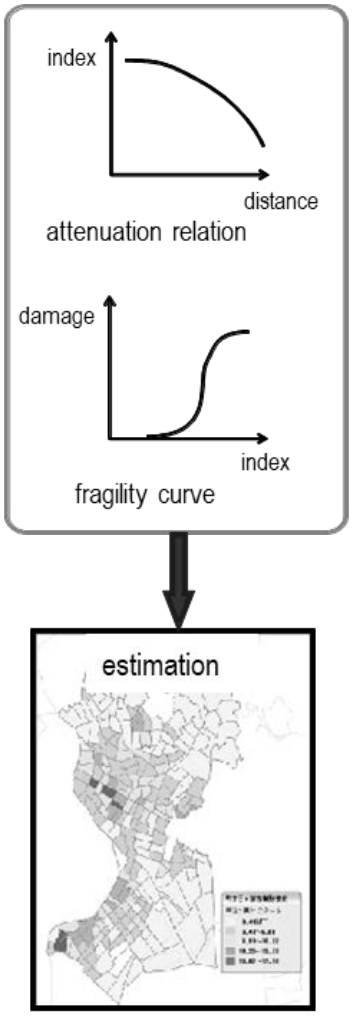
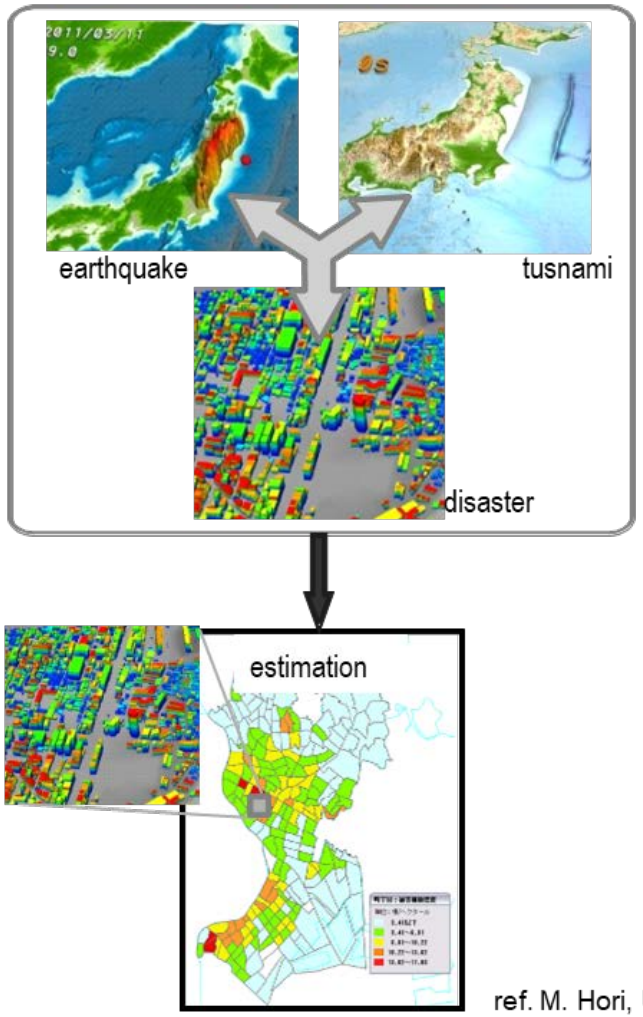
Roads and ports for emergency				X					
CalTrain for emergency traffic					X				
Airport for emergency traffic				X					

Simulation-Based Regional Risk/Resilience Assessment

CURRENT (e.g., HAZUS)
Empirical Models
Census Block Inventory



GOAL
Direct Simulation
Detailed Inventory
Multiple models



ref. M. Hori, Univ. of Tokyo

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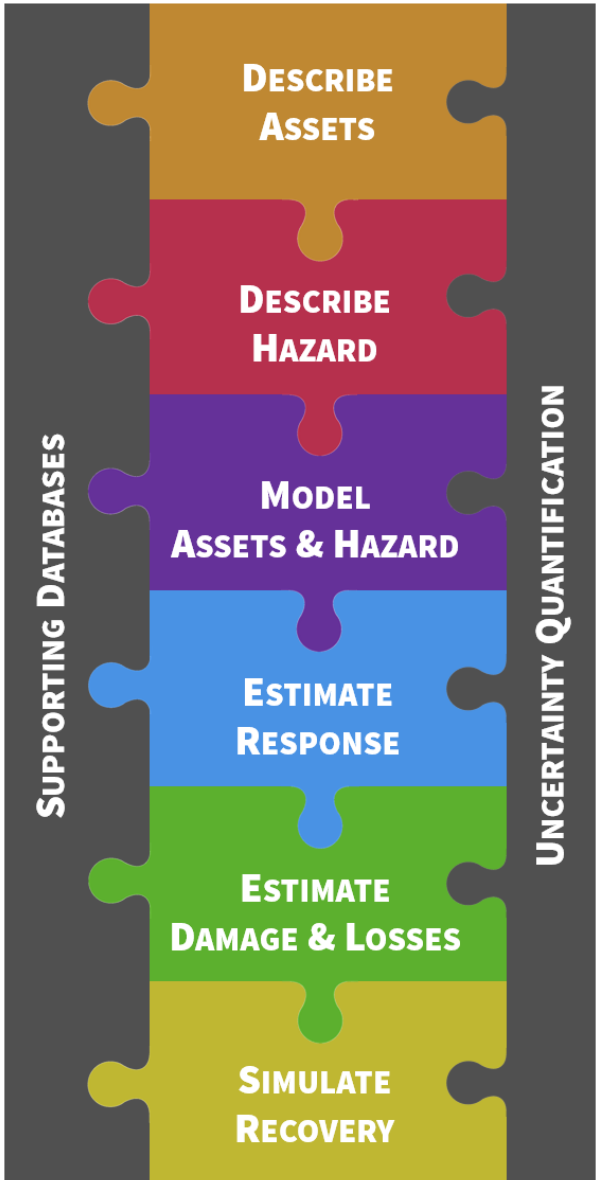
DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY



describe the region
specify characteristics of buildings and infrastructure in the region

describe the hazard
specify the regional distribution of ground shaking, wind, or water

for each random region-hazard sample:
propagate uncertain characteristics of the regional assets and the hazard

for each asset in the region:

describe the asset
create stochastic models for response, damage, and loss estimation

describe the event at the site
specify hazard-consistent loads for response estimation

for each random asset-event sample:
propagate uncertainties in asset models and event description

estimate asset response to the event
describe the response with engineering demand parameters

estimate asset damage and its consequences
prepare a stochastic description of damage and loss for the asset

CWE
EE
FEM
PBE

describe regional damage and direct losses
aggregate damages and losses in the region considering dependencies

estimate indirect regional consequences
describe regional consequences of infrastructure- and social disruption

simulate regional recovery
estimate the temporal and spatial variation in the recovery of communities

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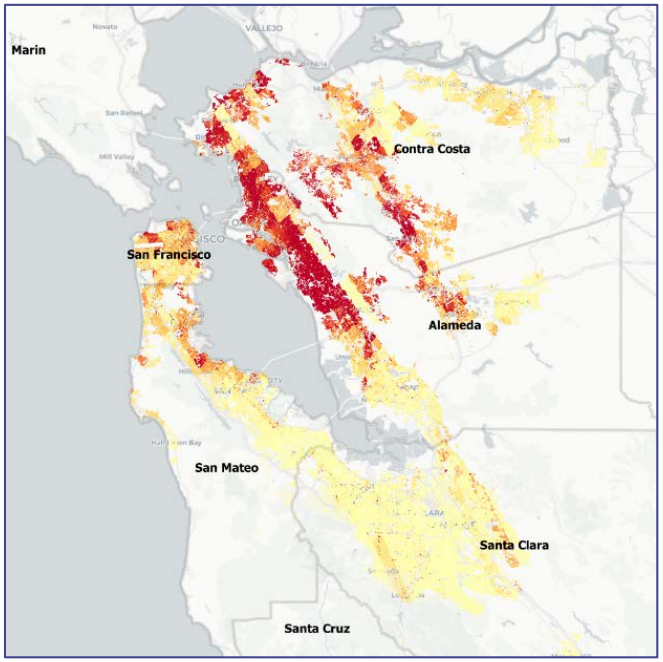
SF Bay Area Regional Testbed Study

- M7.0 Hayward rupture modeled using SW4 [1]
- 1.84 M buildings were included in the simulation
- Building information is based on UrbanSim data
- Damage and Loss is based FEMA_P58_LU [2]
- OpenSees structural analysis models are based on MDOF_LU
- Run on DesignSafe HPC Resources
- Example of Results:
  - *Red-tagged buildings 141,400*
  - *Net buildings damage ratio 5.6%*



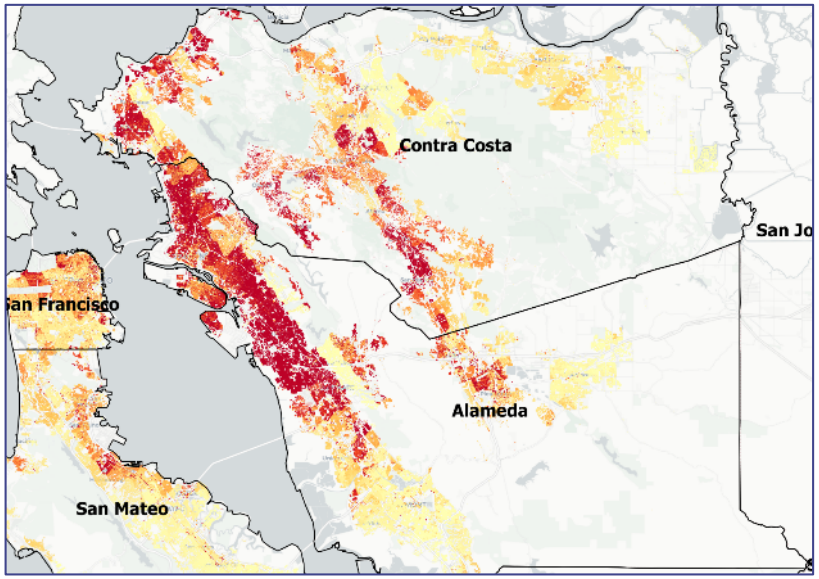
Building Loss Ratio

[1] Petersson, N.A.; Sjogreen, B. (2017), SW4, version 2.0 [software], Computational Infrastructure of Geodynamics, doi: 10.5281/zenodo.1045297, url: https://doi.org/10.5281/zenodo.1045297

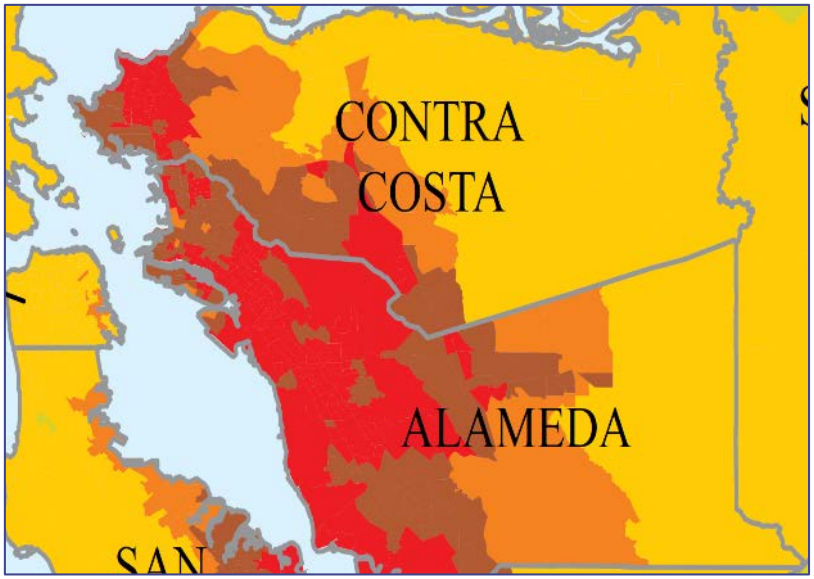
[2] Zeng X., Lu X.Z., Yang T., Xu Z., "Application of the FEMA-P58 methodology for regional earthquake loss prediction", Natural Hazards (2016), 10.1007/s11069-016-2307-z

High Resolution Models

Building parcel versus census block resolution of damage and downtime



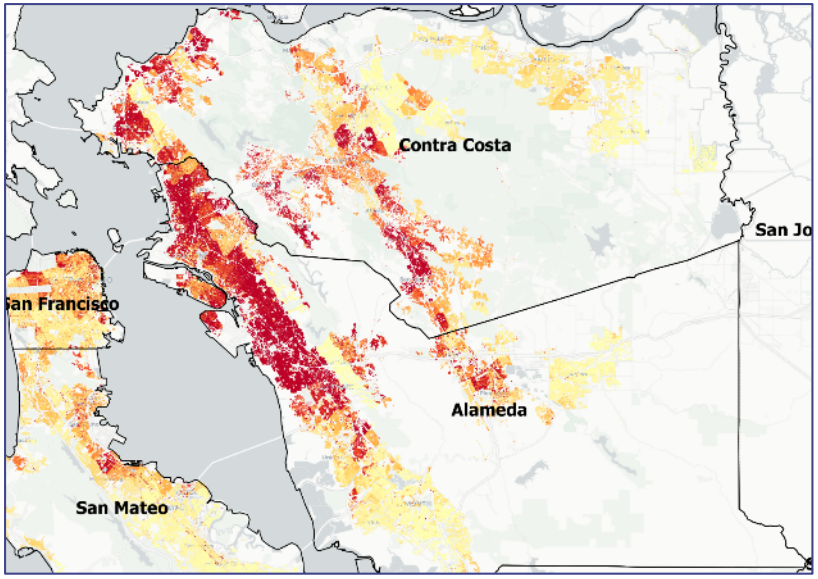
SimCenter Simulation



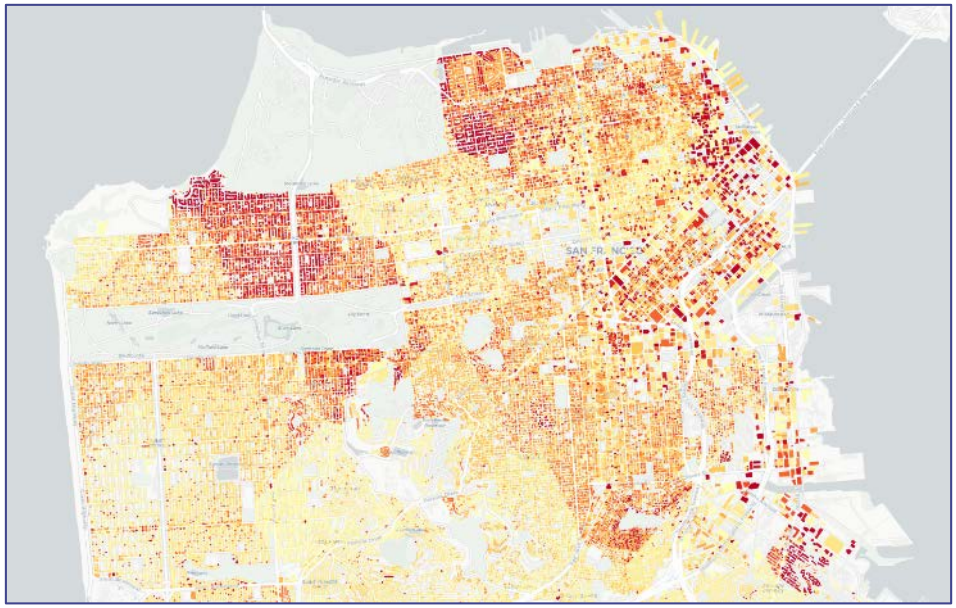
USGS Haywired (2018)

High Resolution Models

Parcel-level resolution enables unprecedented quantification of engineered interventions for policy level decisions



SimCenter Simulation



San Francisco Parcels

Component Performance Toolbox

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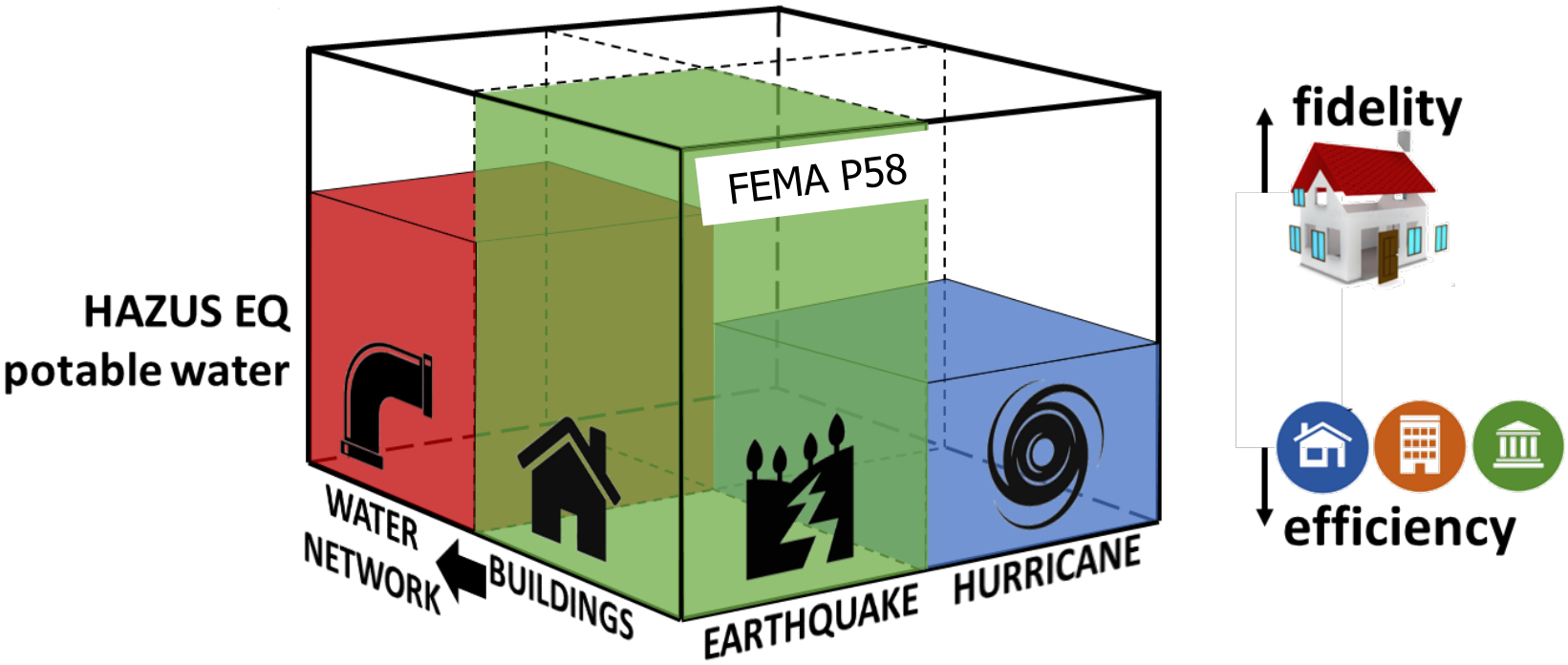
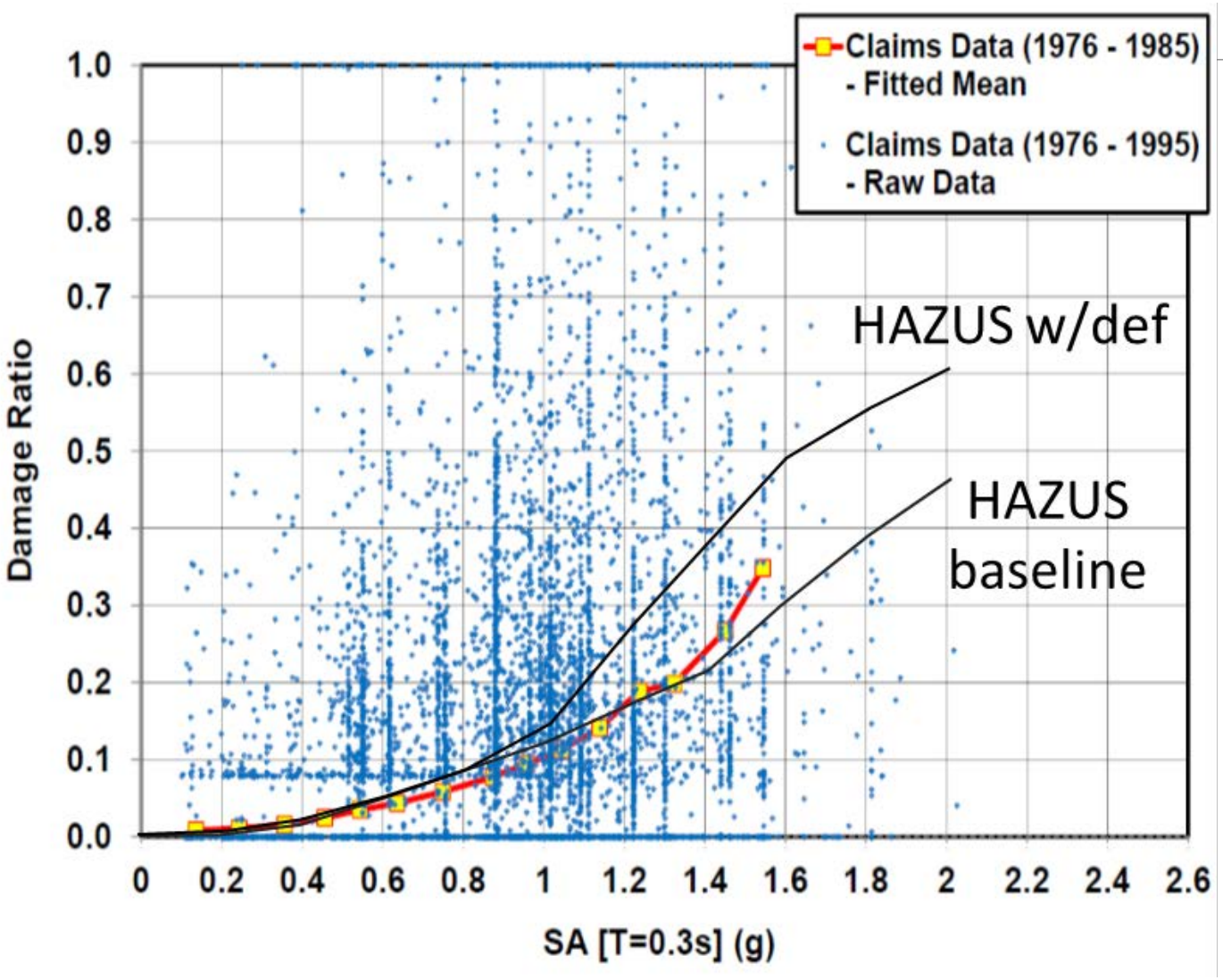


PELICUN (**P**ROBABILISTIC **E**STIMATION OF **L**OSSES, **I**NJURIES, & **C**OMMUNITY RESILIENCE **U**NDER **N**ATURAL DISASTERS

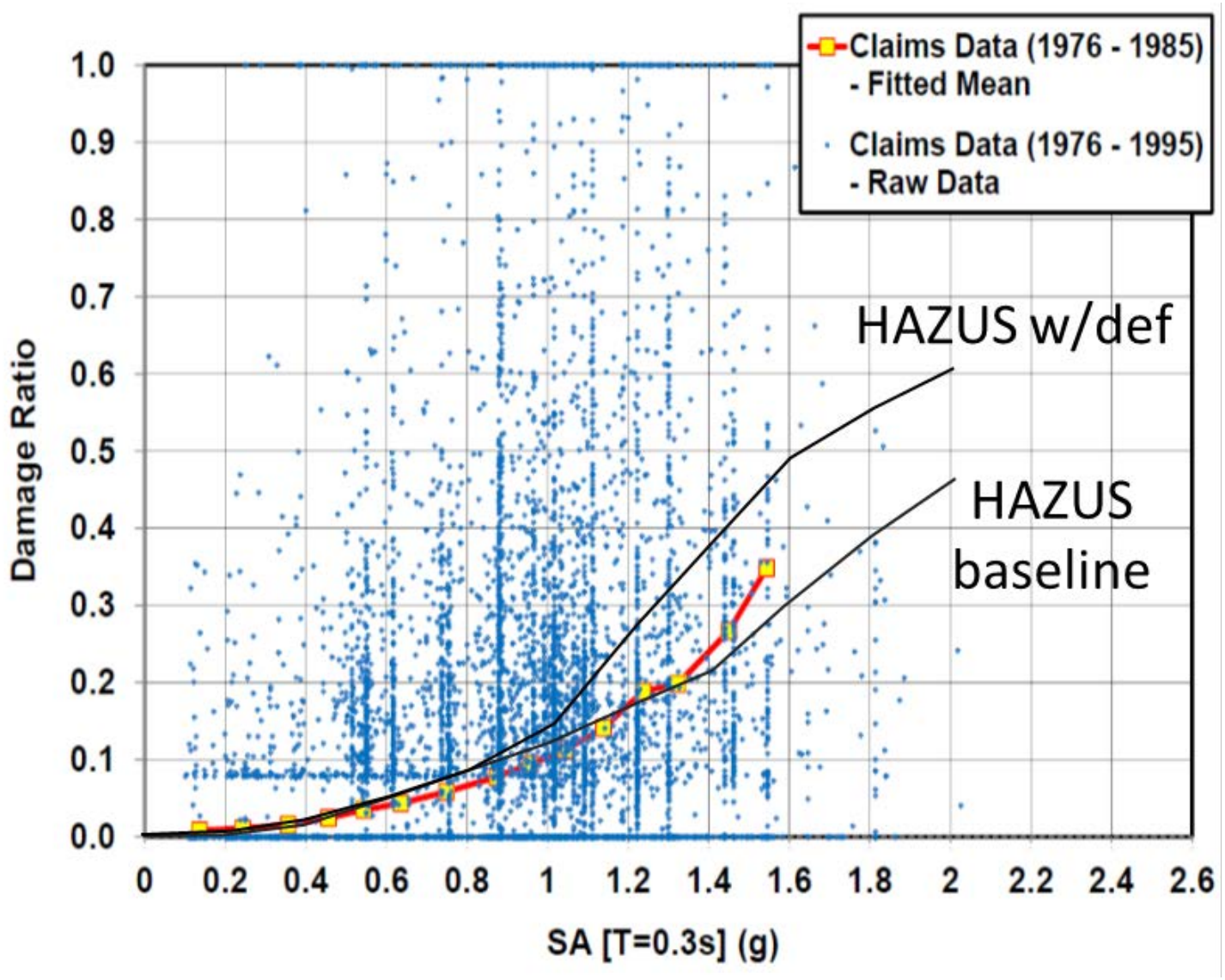
OpenSource :: Multi-Fidelity :: Multi-Hazard

Economic Benefits of Cripple Wall Retrofit

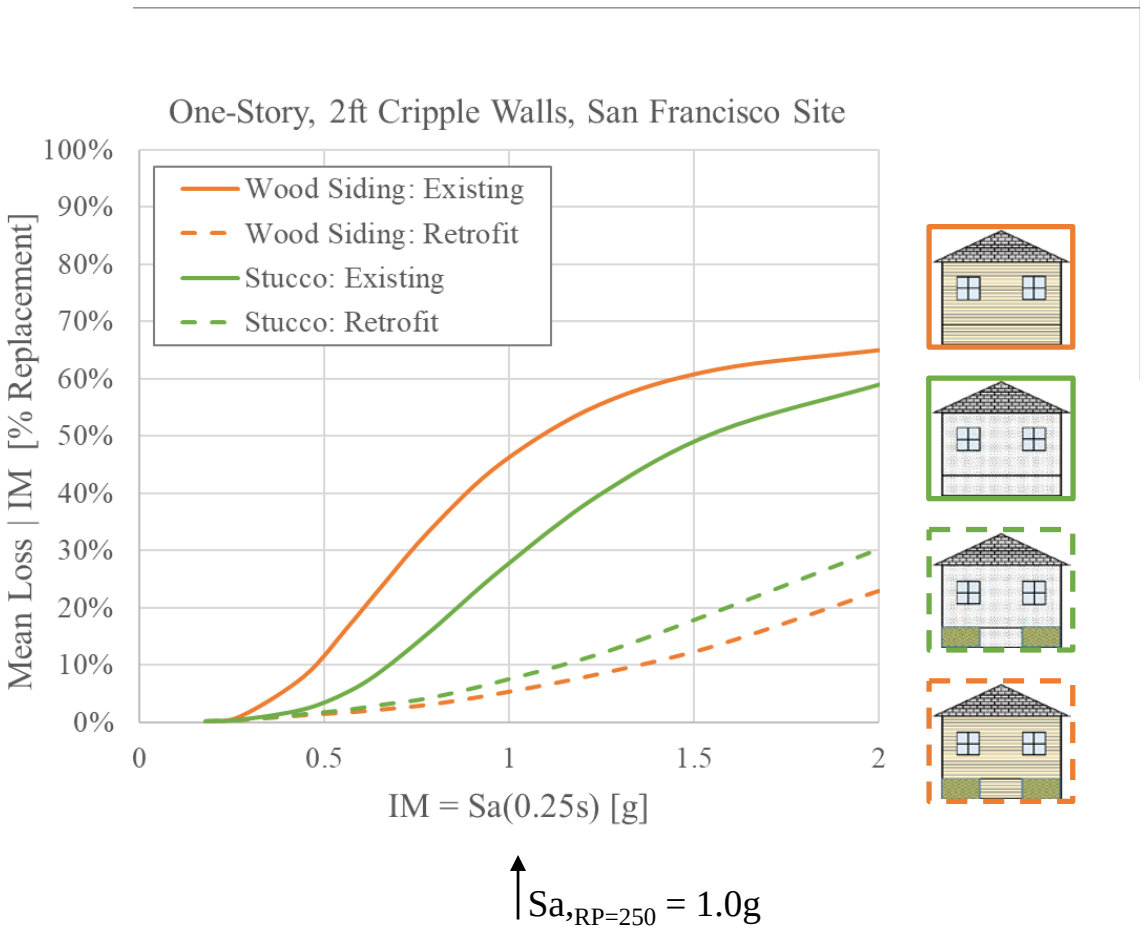
Limitations to “The Law of Averages”



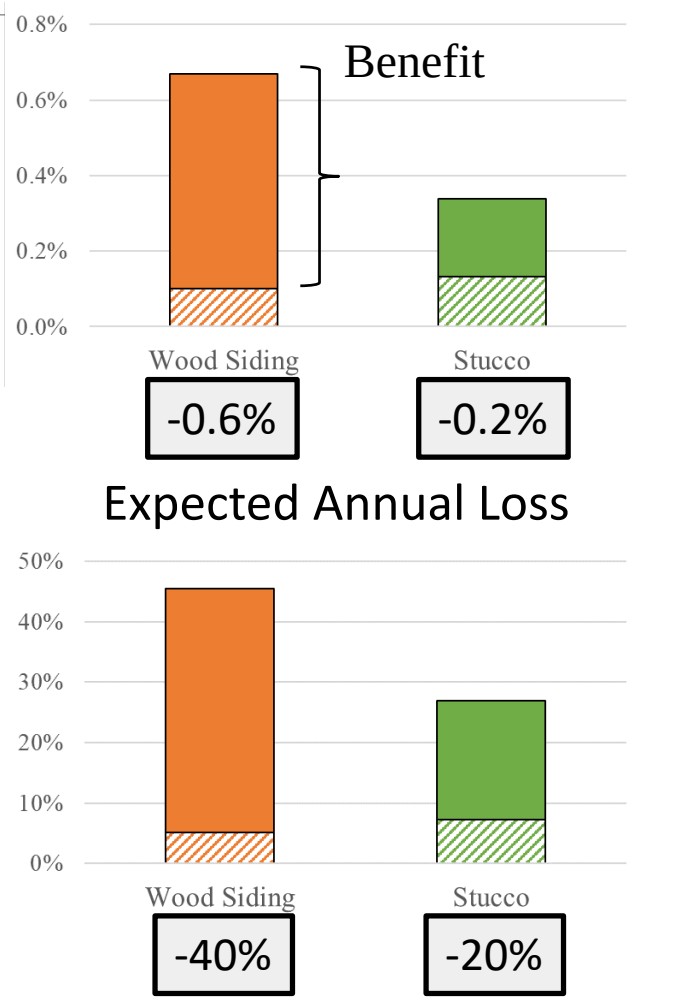
HAZUS Loss Function vs. Observed Data



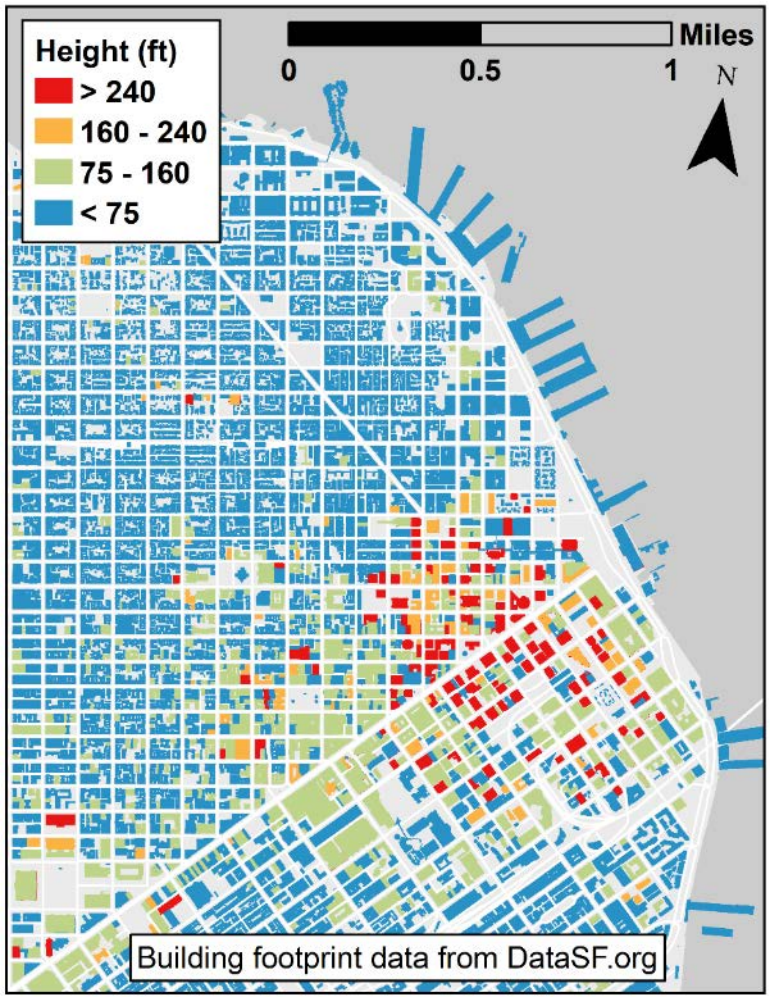
PEER-CEA Damage and Loss Assessment

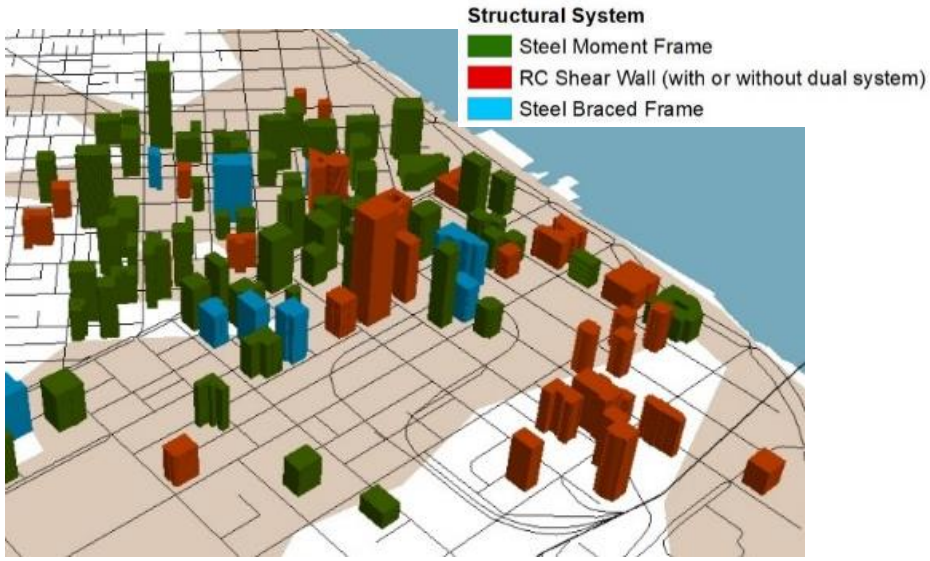


Loss versus Intensity (SF Site)



San Francisco – Tall Building Inventory

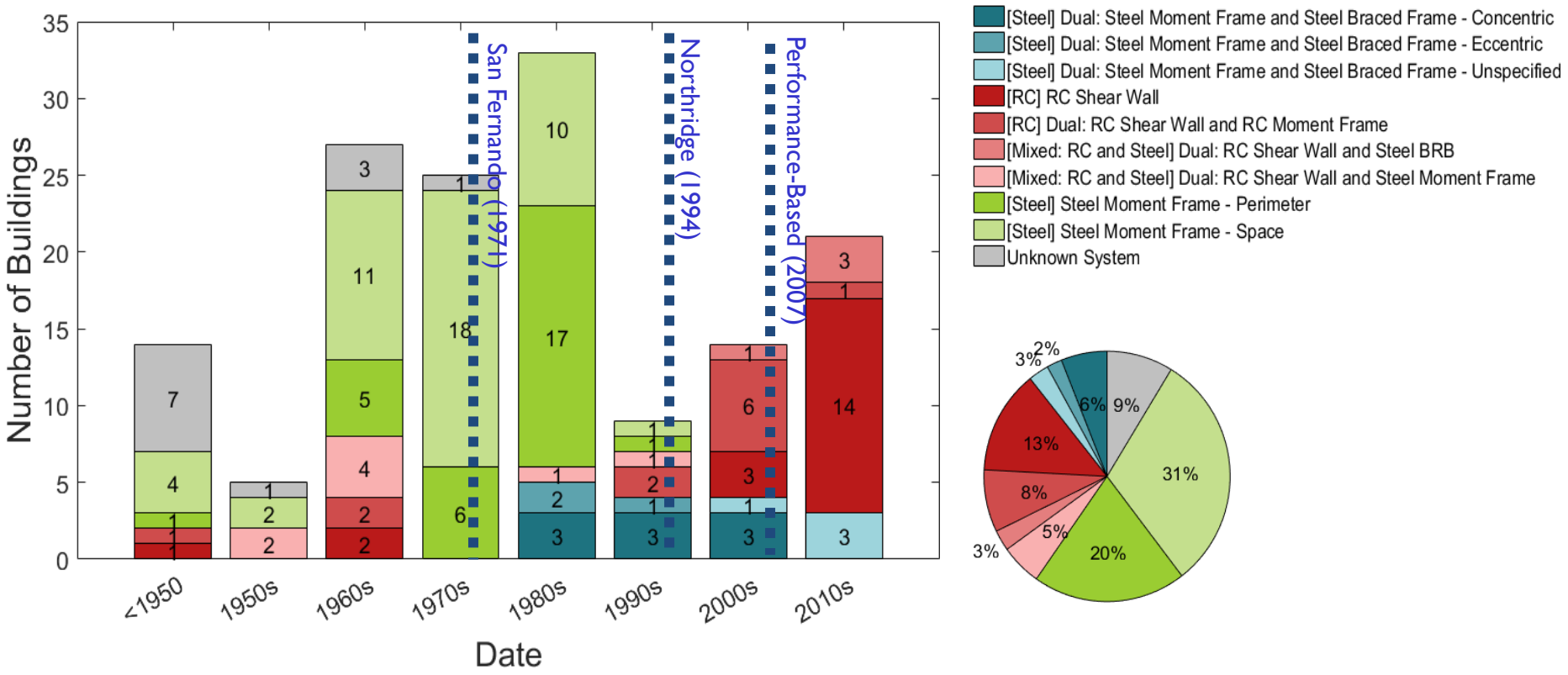




156 Tall Buildings (Over 240 ft)

- Occupancy
- Height & Date/Age
- Structural System & Materials
- Façade, Foundation
- BORP, Instrumentation

San Francisco - Tall Building Inventory



- 69 "Pre-Northridge" Steel Moment Frame Buildings (>240 ft)
- Significant segment of SF's downtown commercial office space
- Major investment of building owners and tenants

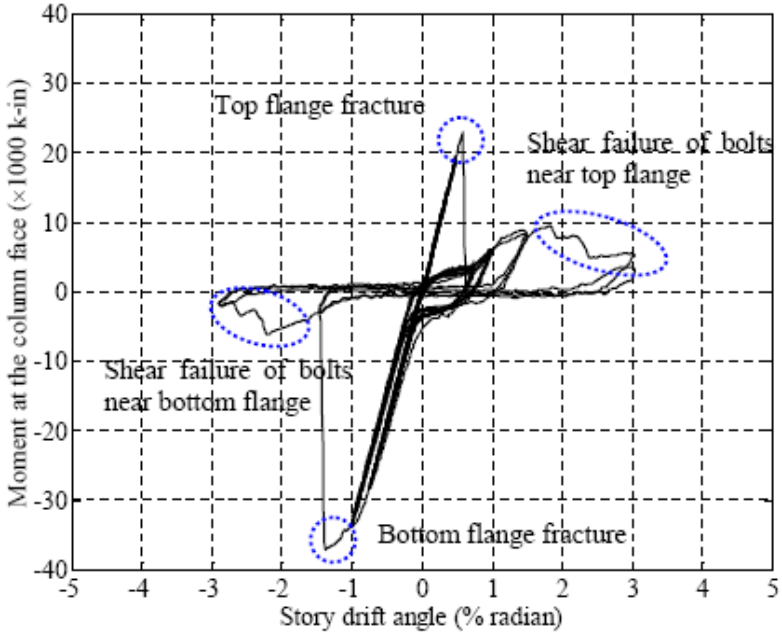
Acknowledgement: *City of San Francisco, Applied Technology Council*

Simulation of Fracture Critical Beam-Column Connections

Figure 3-31: Beam top flange fracture during 0.75% drift cycle in Specimen EC03

Figure 3-36: Bolts failure at 3% drift cycle in Specimen EC03

SAC Joint Venture Test



Modes of Failure:

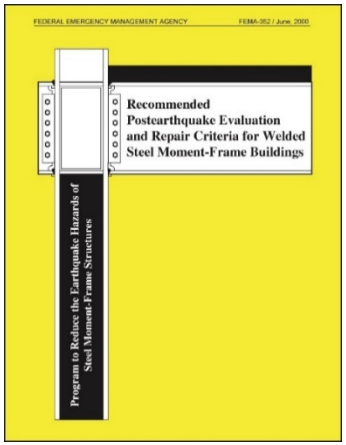
Flange Weld Fracture

- *Brittle (< Fy)*
- *Ductile-Brittle*

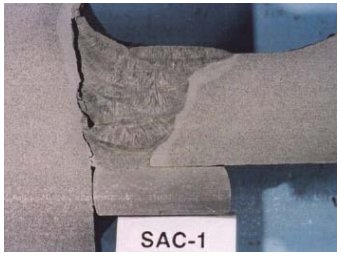
Shear Connection

- *Bolt Shear*
- *Bolt Tearout*
- *Weld Fracture*

Re-Occupancy of Damaged Buildings



FEMA 352 – Evaluation

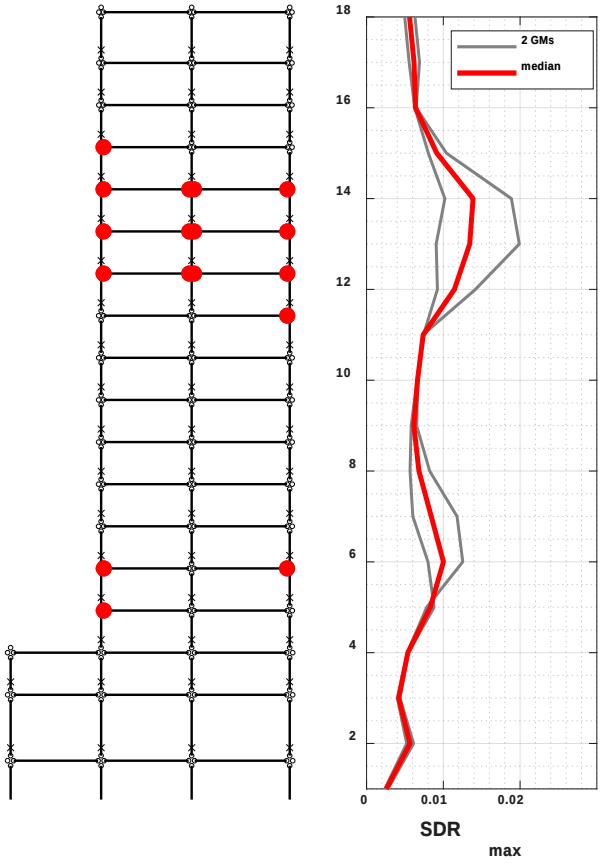


$$\sigma_{cr} = {K_{IC}}/{F(a_0)}$$

$$F(a_0) = 1.2 + 2a_0 \quad \text{(bottom)}$$

$$F(a_0) = 0.5 + 2a_0 \quad \text{(top)}$$

$$K_{IC,dynamic} \approx \sqrt{\alpha\, CVN^{*}\, E}$$



Floor Damage Index:

$$D_i = \frac{1}{n}\sum_{j=1}^{n}\frac{d_j}{4}$$

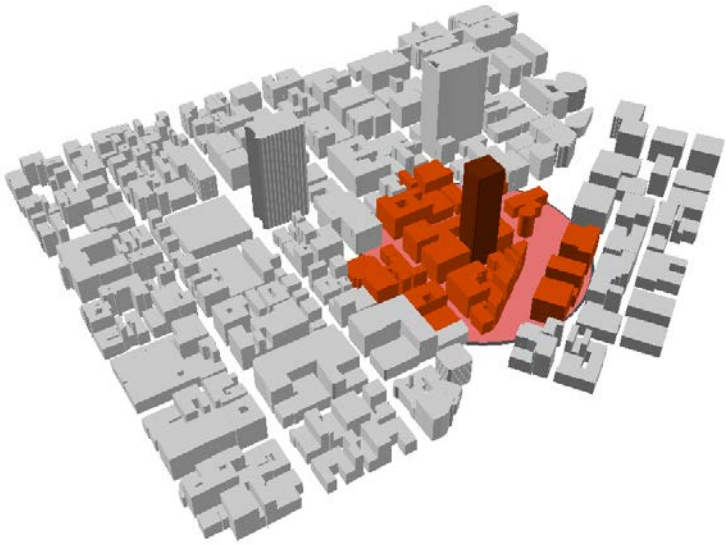
$0 < D_{max} \leq 0.5$ *Safe to occupy during repair*

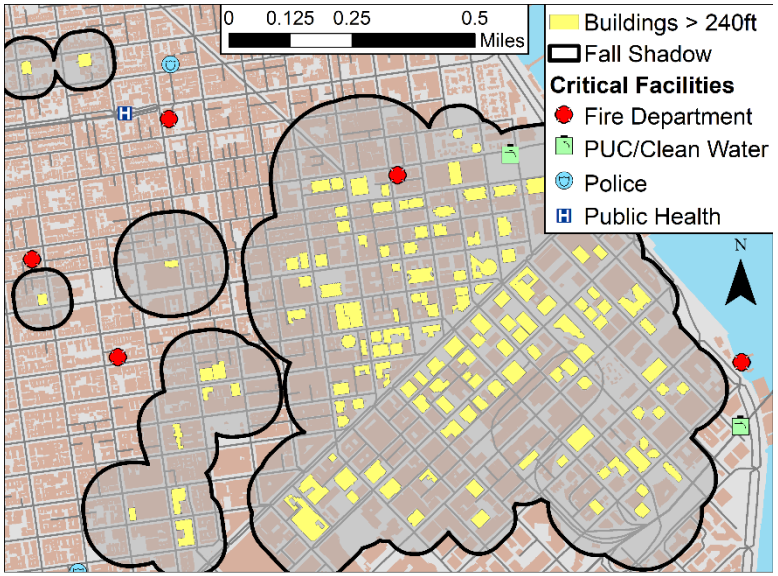
$D_{max} > 0.5$ *Potentially unsafe to occupy during repair (advise owner)*

Impediment of Building Cordons on Recovery

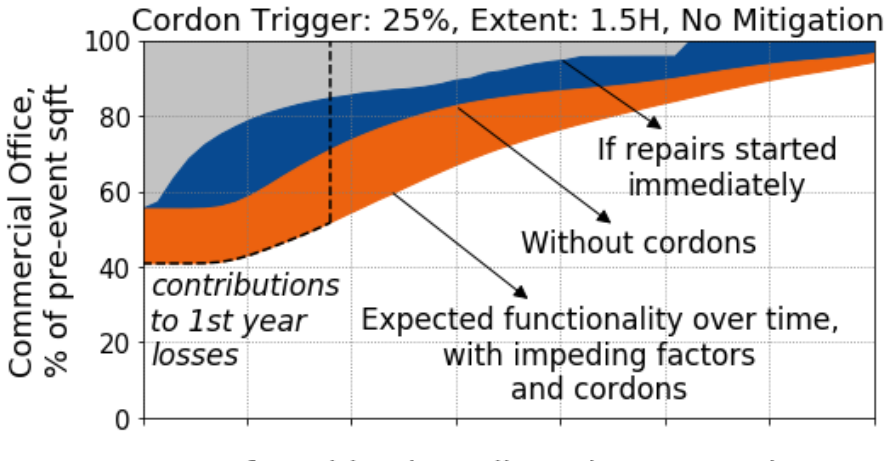
Impact on:

- Emergency Response
- Neighboring Buildings
- Recovery/Reconstruction
- Downtown Economy



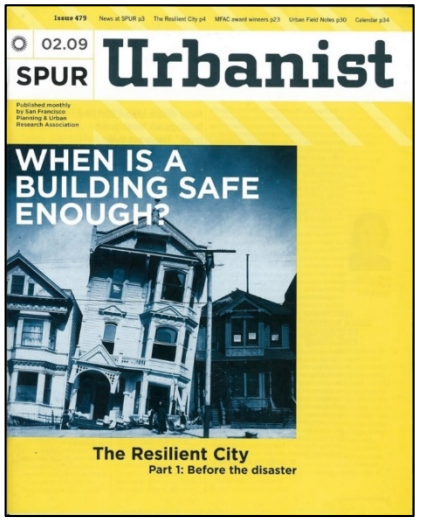


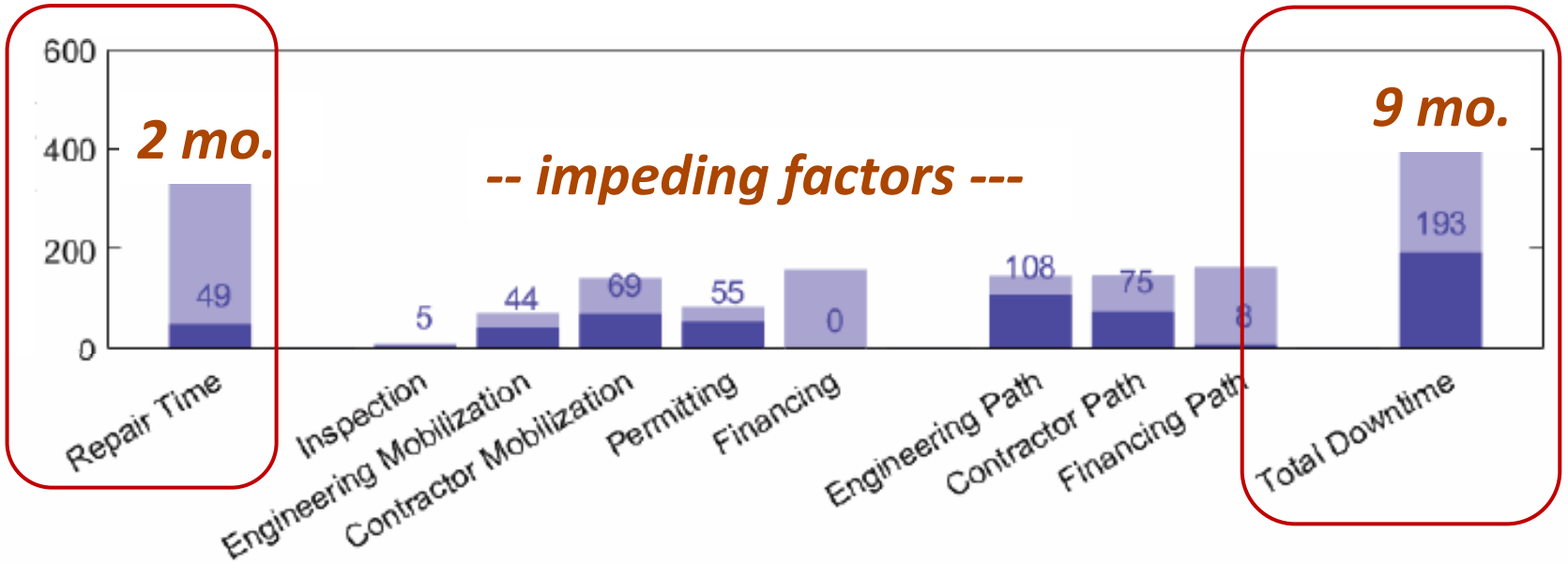
Data Sources: Critical Facilities, Building Footprints, and Streets from DataSF.org



Impeding Factors to “Functional Recovery”

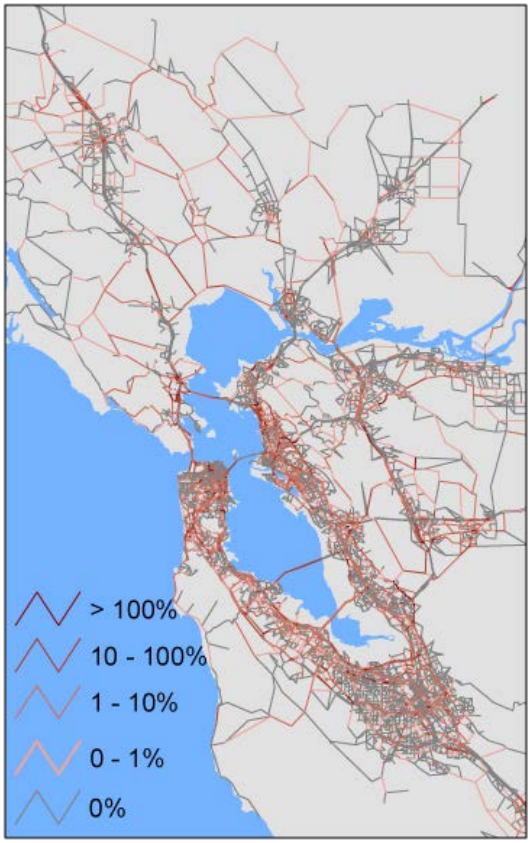
- What are the ***minimum criteria to allow reoccupancy*** and functional recovery of buildings?
  - structural collapse safety & falling hazards
  - occupant health and safety
- ***What repairs are essential*** for occupancy & functional recovery?
  - structural
  - MEP systems (elevators, water, power, fire suppression)
  - architectural (partitions, doors, cladding, etc.)

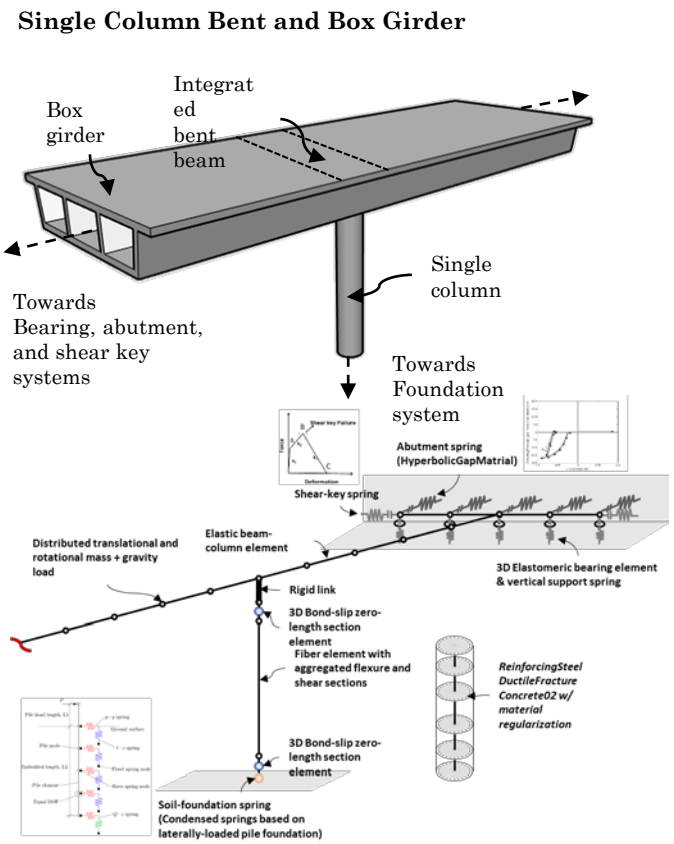




ATC 119 (Molina-Hutt, Hulsey, Yen, Hooper, Deierlein)

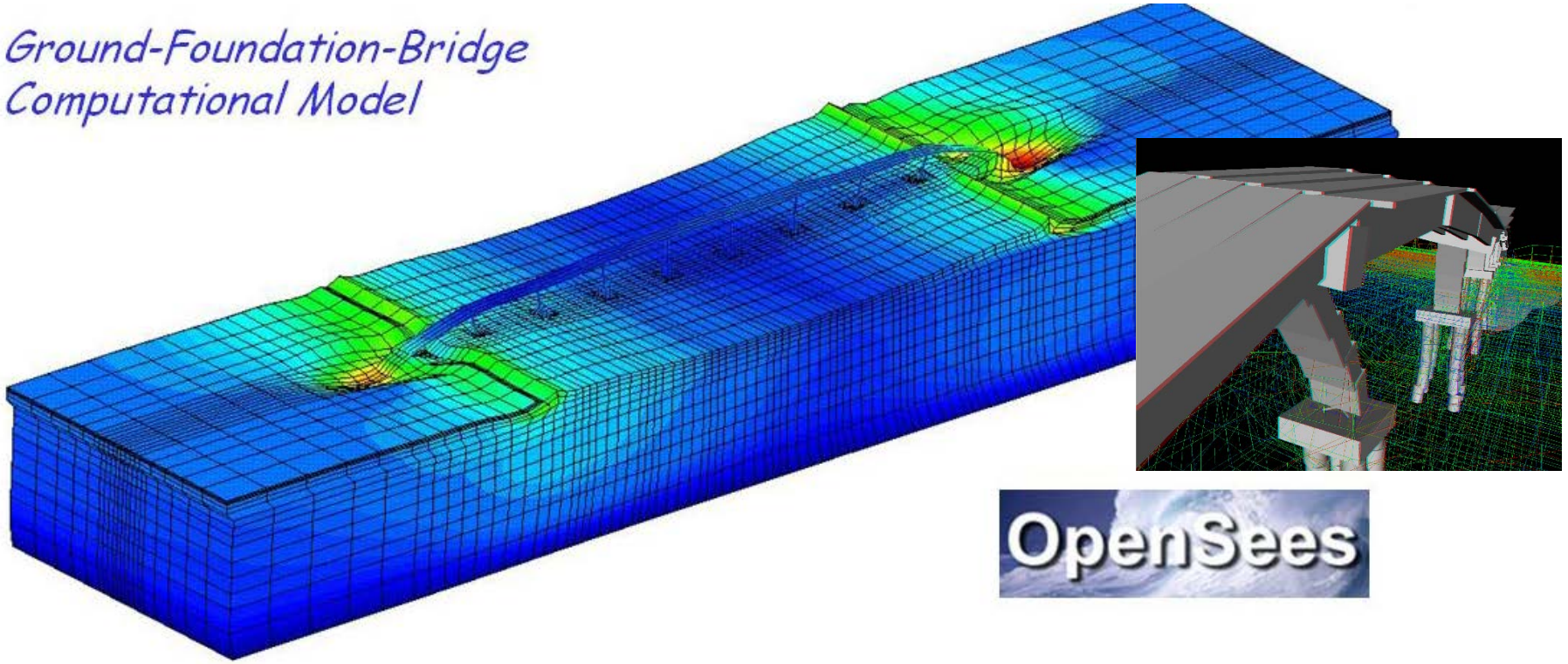
Distributed Systems





Detailed Component Models Linked with Rigorous System Evaluation

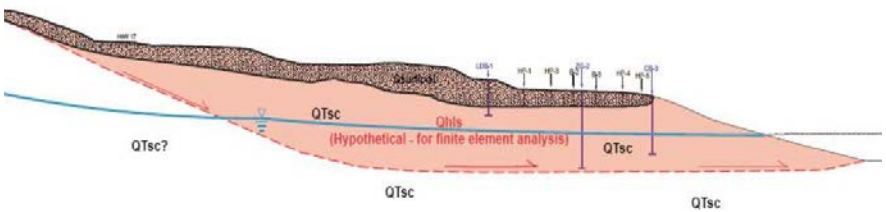
Geotechnical Models



Humboldt Bay Bridge (Elgamal et al.)

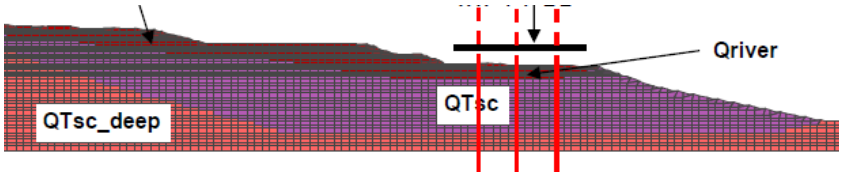
High-Fidelity Models of Landslide Risk

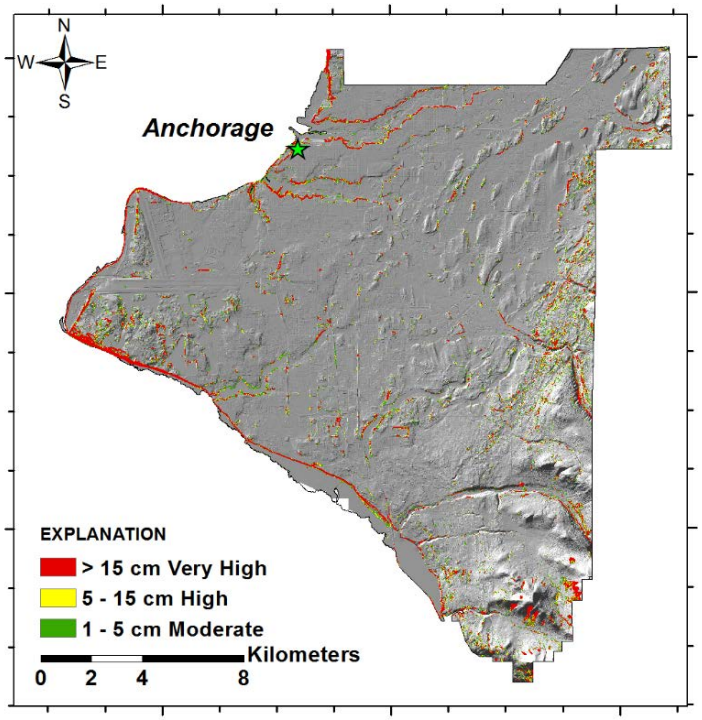
Rathje, 2019 Joyner Lecture



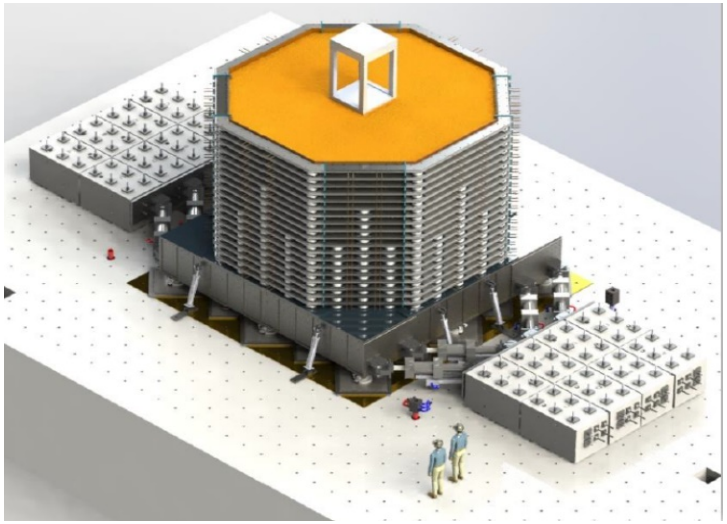
Fugro Consultants (2012)

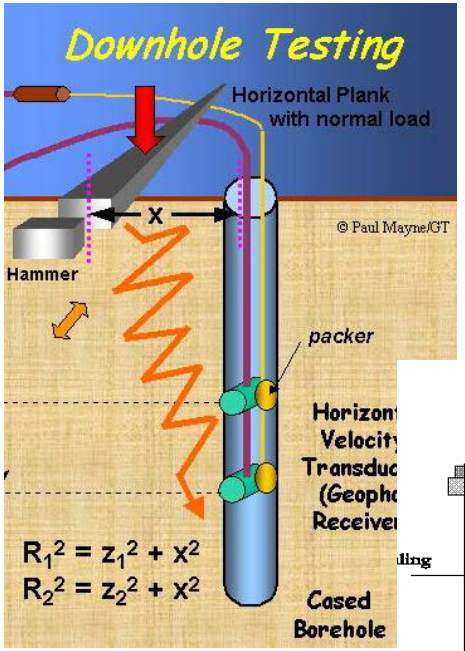
2D/3D Dynamic Finite Element Analysis

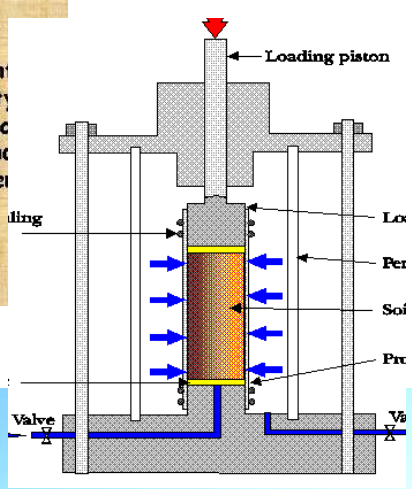


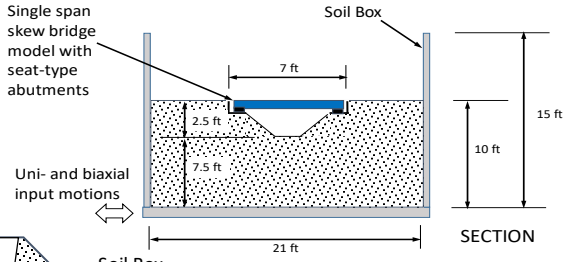


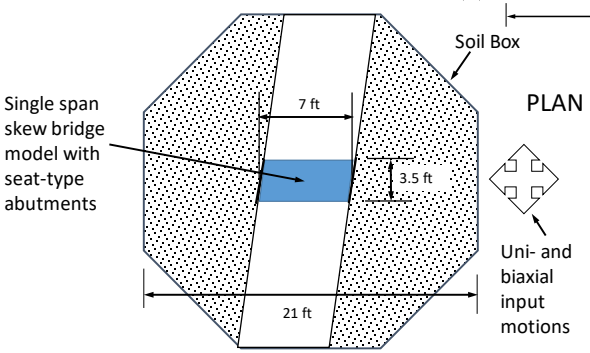
Geotechnical Model Calibration/ Validation

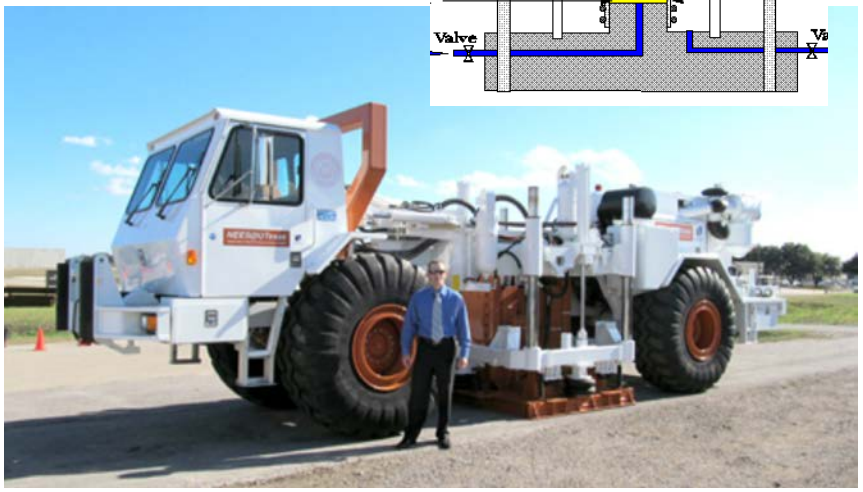










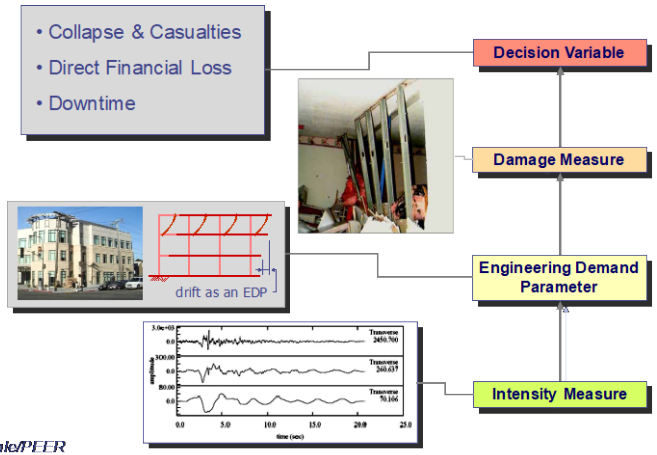


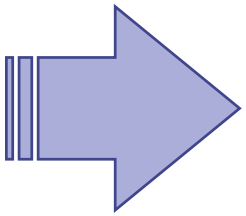
Buckle et al., Rathje et al.

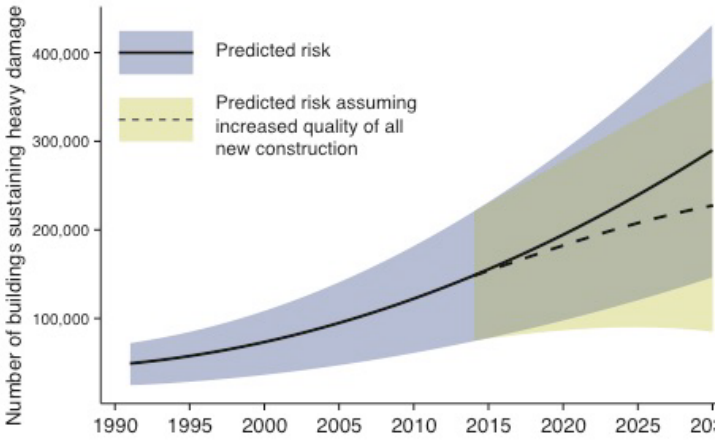
Development & Validation of Models

- Material & Component Testing
- Bechmarking on Shared Community Models
- Data From Natural Hazard Disasters
  - Strong Motion Sensors
  - Optical Photos, SAR, LIDAR
  - Twitter, News Feeds (natural language proc.)
  - Reconnaisance: StEER, EERI
  - Longitudinal Studies
- Final ????

Engineering for a resilient future







1. Risk Landscape
2. Hazards
   - Ground Shaking
   - Liquefaction
   - Landslides
   - Tsunami
   - Flooding
   - Fire
3. Risk/Consequence
4. Capabilities
5. Strategy

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