Research Centre for Civil Engineering Structure
Seminar Series
London, April 27, 2017

(Some) Recent advances and perspectives in CAT risk engineering for earthquake and wind

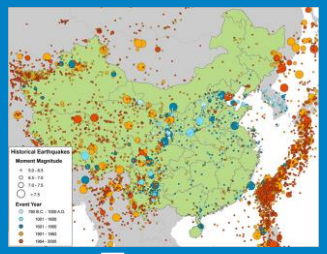
Dr Carmine Galasso

Lecturer in Catastrophe Risk Engineering &
Director MSc in Earthquake Engineering with Disaster Management

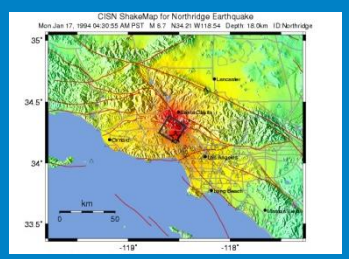
Dept. of Civil, Environmental & Geomatic Engineering (CEGE) +
Institute for Risk & Disaster Reduction (IRDR)

✉c.galasso@ucl.ac.uk

CATastrophe Risk Engineering

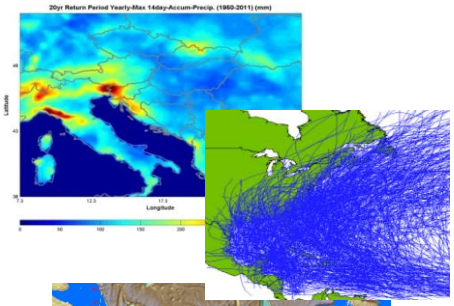


Event Generation



Intensity Calculation

HAZARD



EXPOSURE

VULNERABILITY

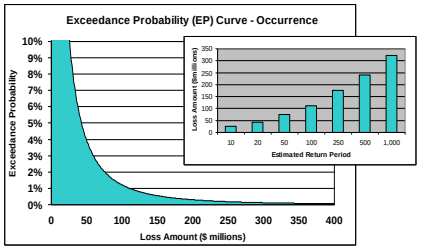
Damage Estimation

Limit

Deductible

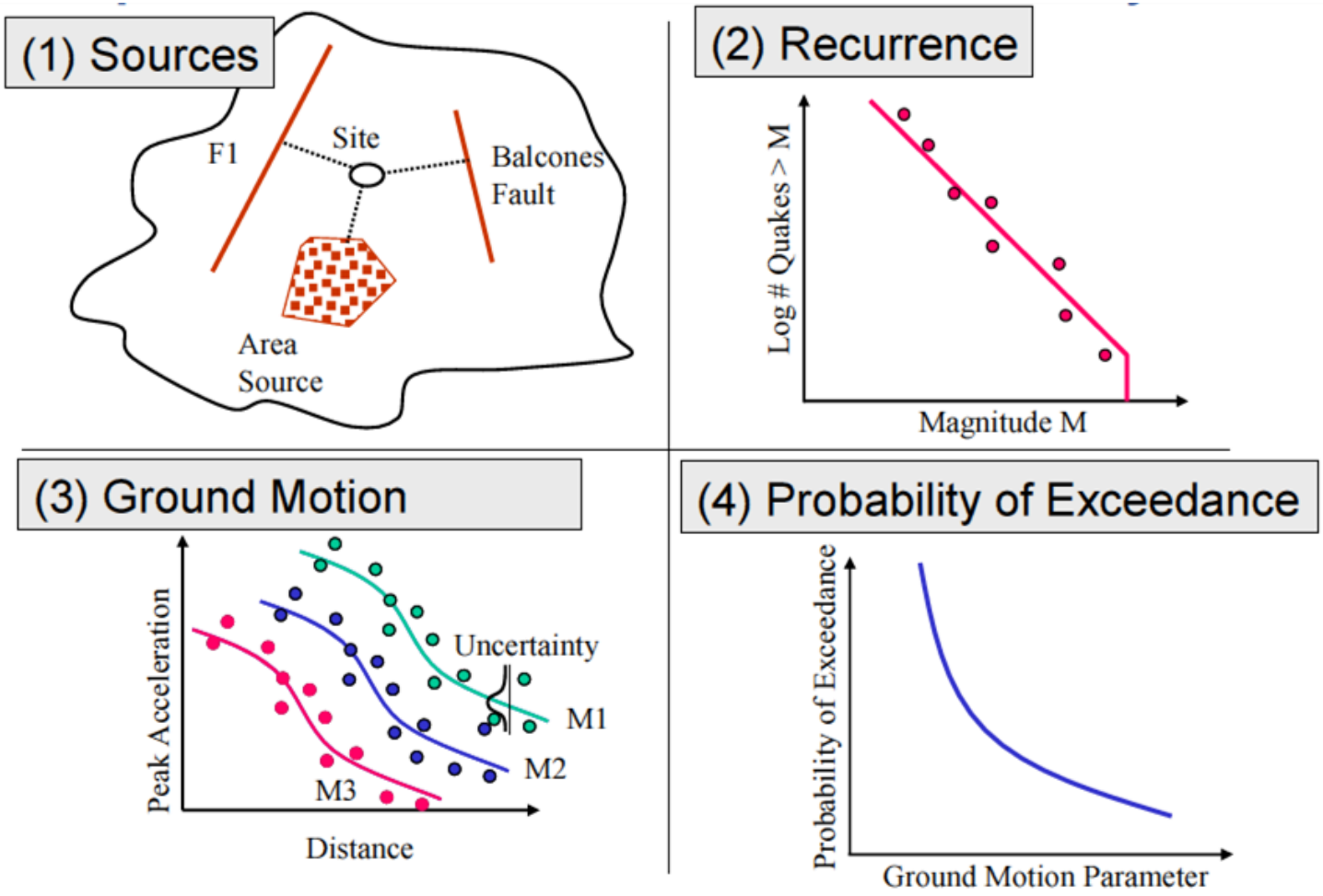
Policy Conditions

Loss Calculation



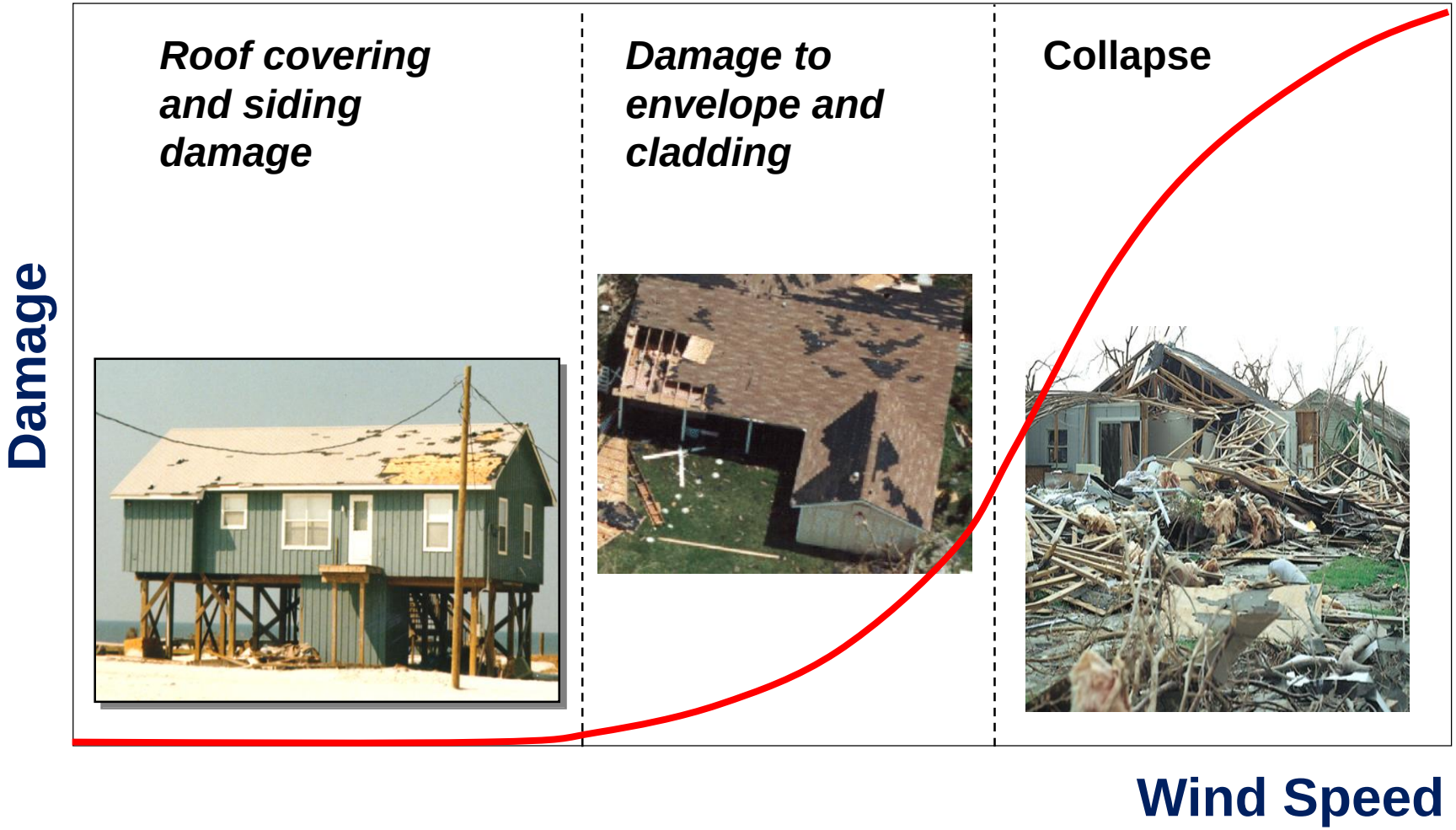
Courtesy of AIR Worldwide

CATastrophe Risk Engineering

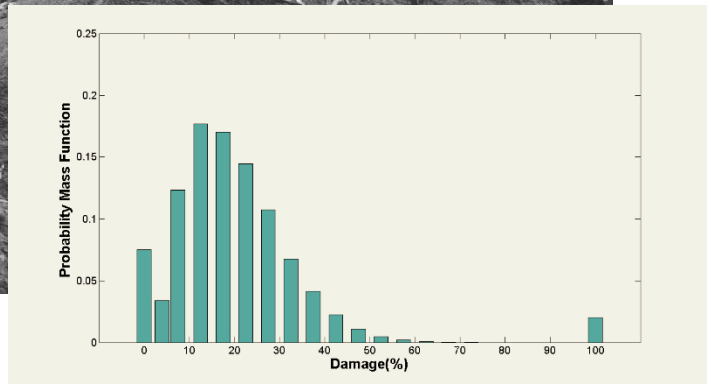


Courtesy of FEMA

CATastrophe Risk Engineering



Courtesy of AIR Worldwide



Courtesy of AIR Worldwide

CATastrophe Risk Engineering

GROUND-MOTION SIMULATION

REAL-TIME

OFFSHORE WIND

MULTI-HAZARD

CATastrophe Risk Engineering

GROUND-MOTION SIMULATION

REAL-TIME

OFFSHORE WIND

MULTI-HAZARD

Research student:
Alexandra Tsioulou
funded by
Engineering and Physical Sciences Research Council (*EPSRC*) DTA

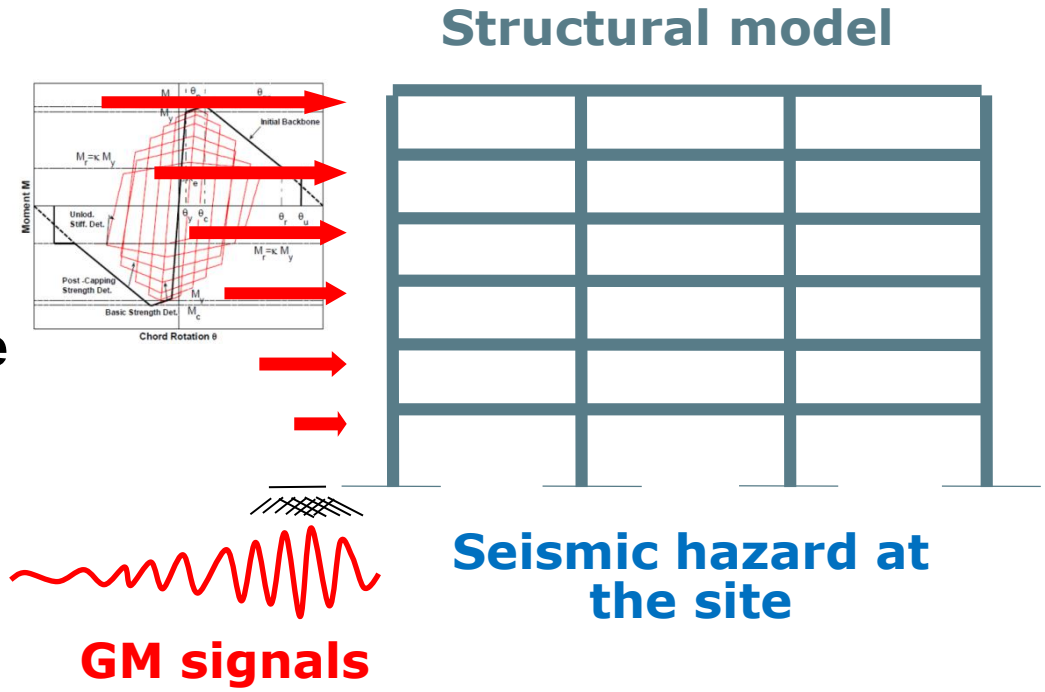
Nonlinear Dynamic Analysis of Structures

- Most accurate tool for seismic analysis/assessement of structures
- Modeling of inelastic member behavior under cyclic earthquake GMs
- NLDA requires:

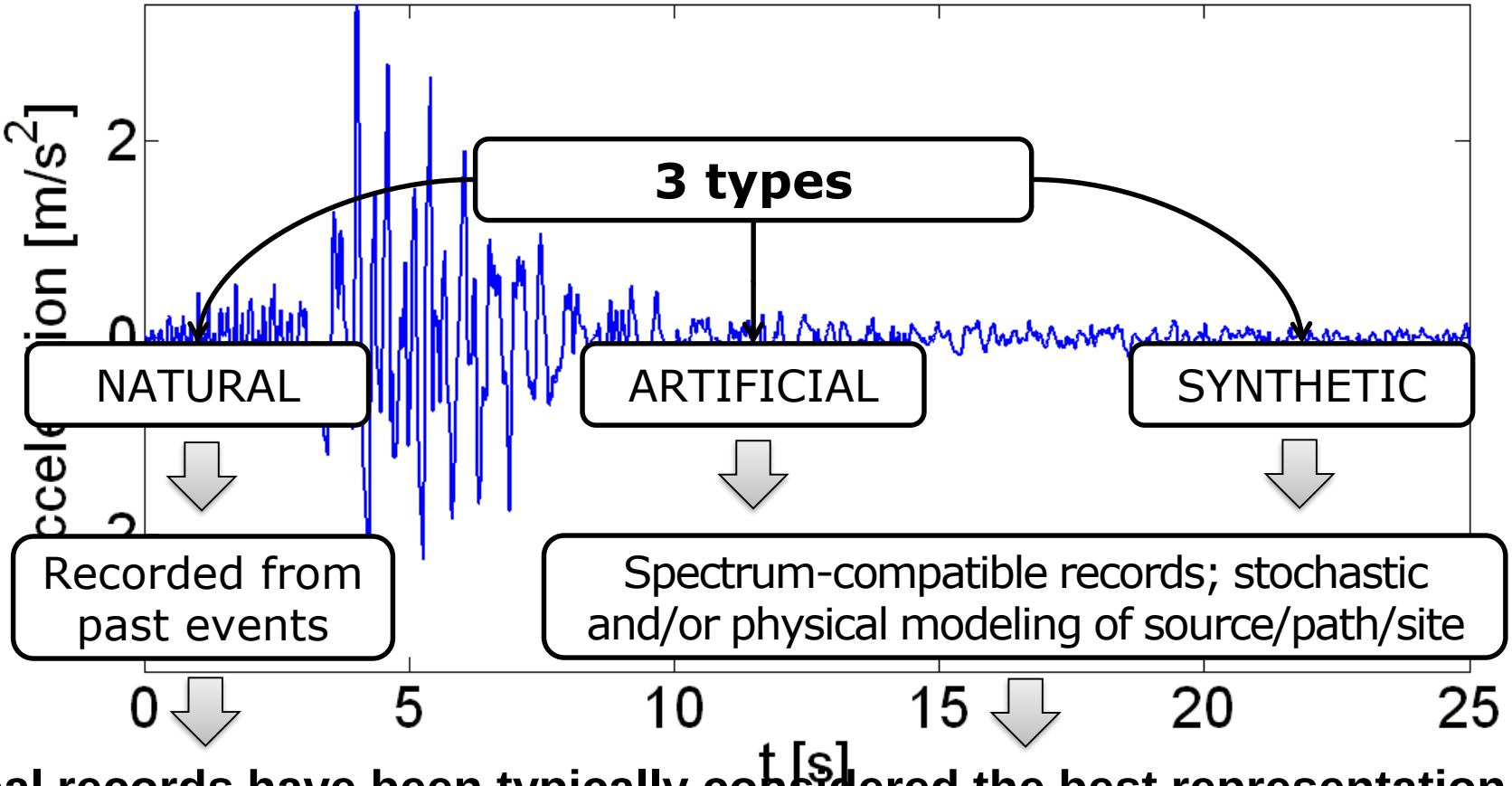
1) **Detailed structural model**

2) **Seismic hazard for the site**

3) **Ground motions**



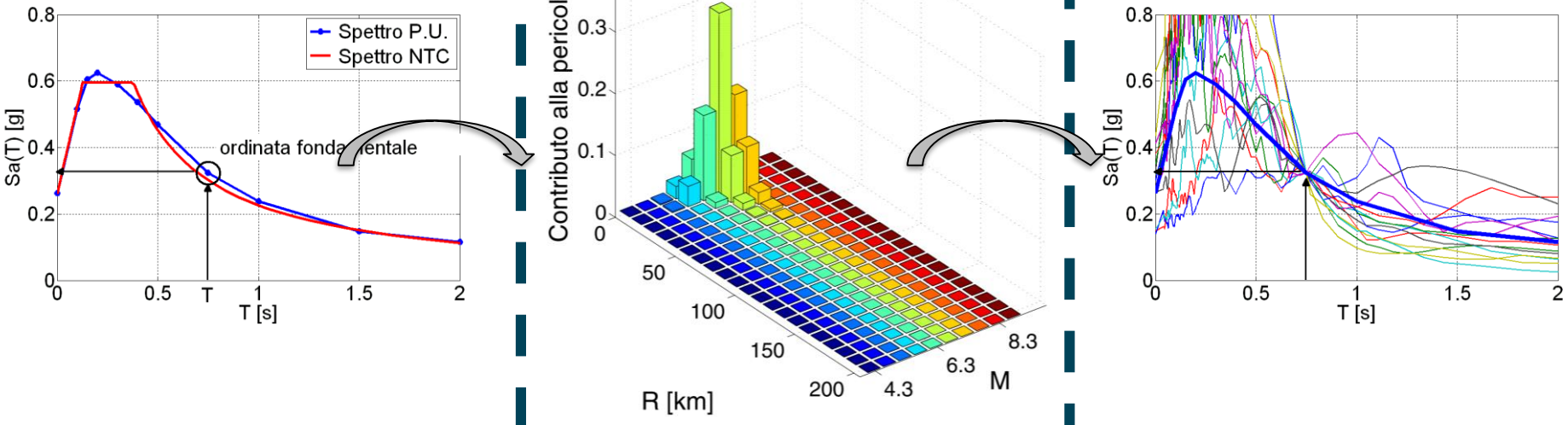
Ground motions for NLDA



Real records have been typically considered the best representation of seismic loading

[Bommer and Acevedo, 2004]

Building-code GM selection (intensity-based)

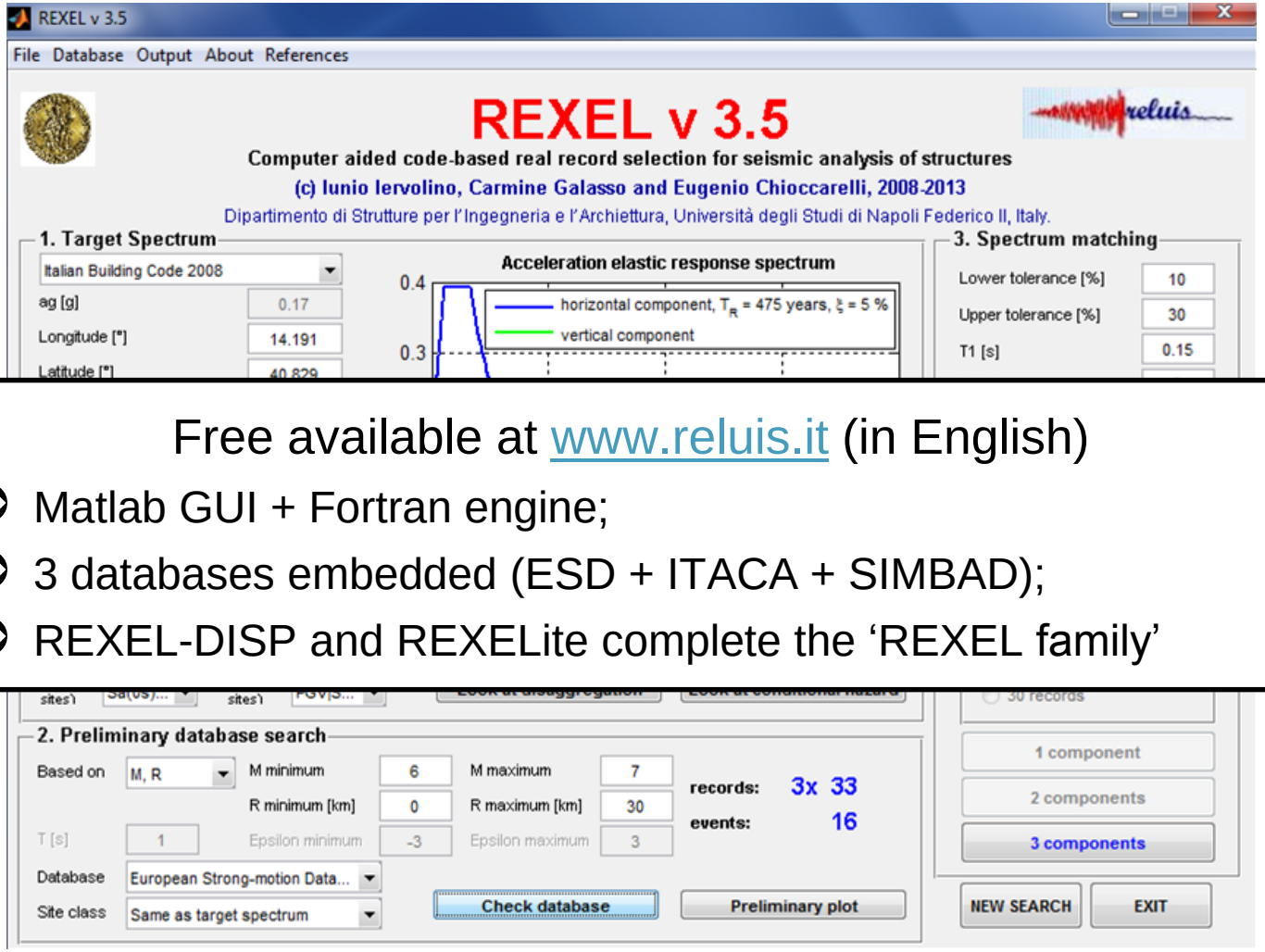


1. PSHA derived target spectrum (for a given return period)

2. Disaggregation of Seismic Hazard

3. (M, R)-based selection and *scaling*

For several seismically active regions (e.g. in Europe), the hazard-controlling earthquake scenarios are large magnitude events on nearby faults…

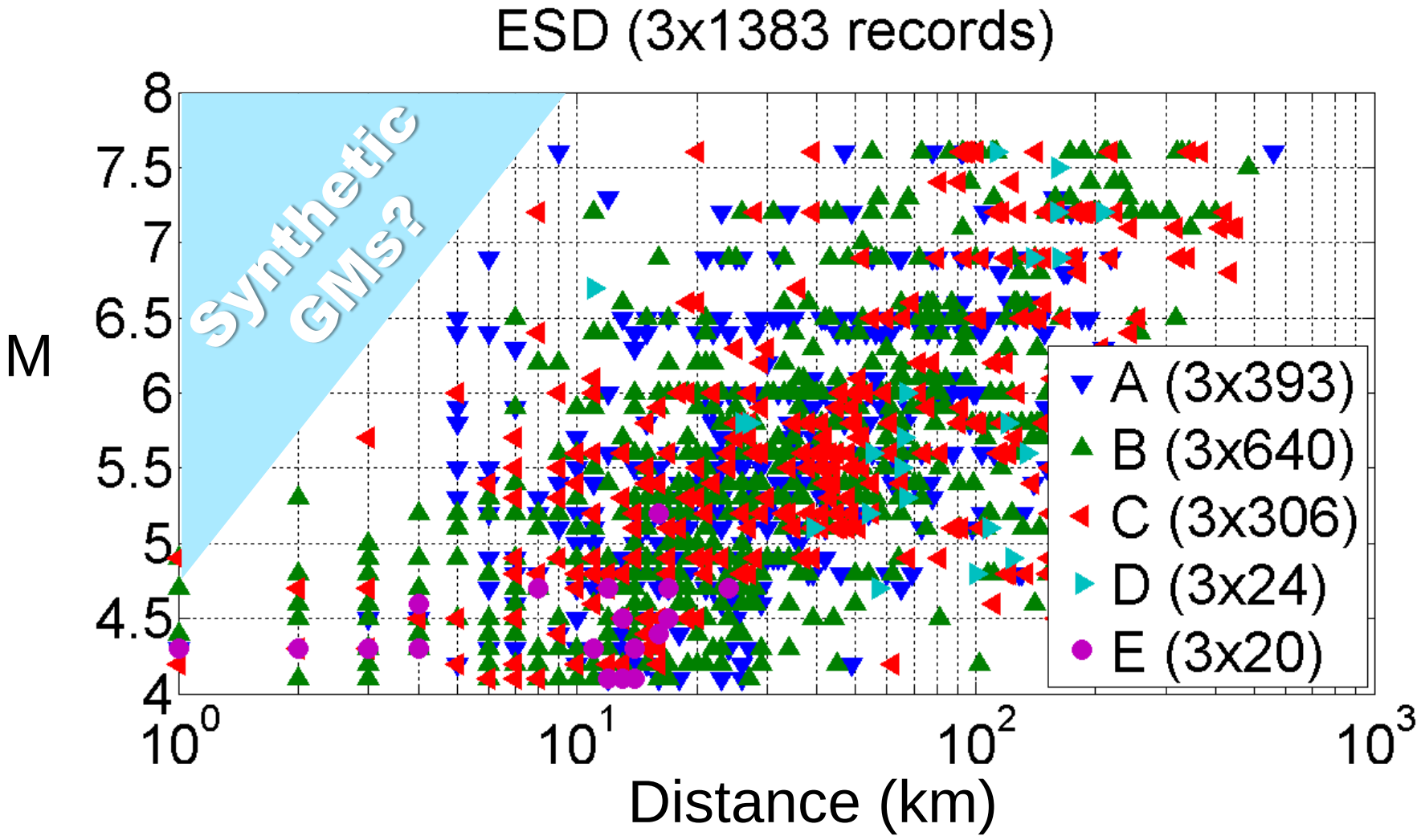


Free available at www.reluis.it (in English)

- Matlab GUI + Fortran engine;
- 3 databases embedded (ESD + ITACA + SIMBAD);
- REXEL-DISP and REXELite complete the 'REXEL family'

[Iervolino I., Galasso C., Cosenza E. (2010). REXEL: computer aided record selection for code-based seismic structural analysis. Bulletin of Earthquake Engineering, 8:339–362.]

Looking at Real GMs Databases…

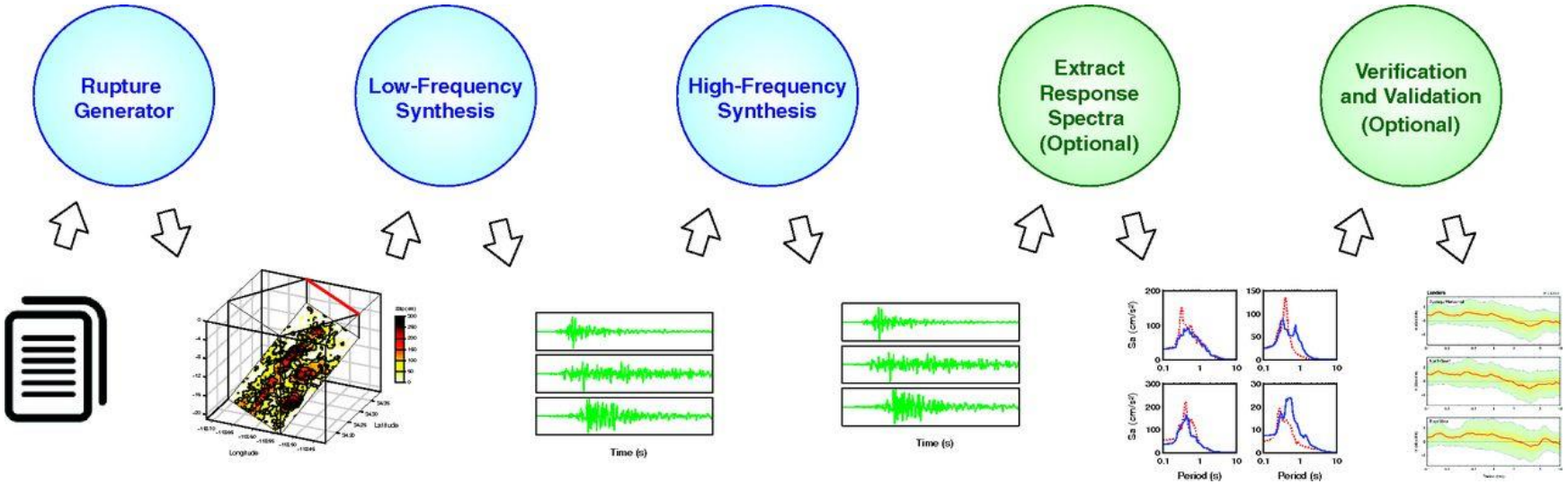


The SCEC GMSV TAG

- Developing and implementing testing/rating methodologies via collaboration between GMs modelers and engineering users
- Focused on validation for use in “engineering applications” (e.g., geotechnical site response analysis and structural nonlinear response history analysis of buildings)
- GMSV TAG “kickoff” workshop held in January 2011, monthly meetings since then (http://collaborate.scec.org/gmsv/Main_Page)
- All researcher are using simulated GMs from Broadband Platform Validation Project (simulated GMs for 23 historical and 3 future scenario earthquakes at ~40 stations each, 50 realizations for each earthquake).

The SCEC Broadband Platform

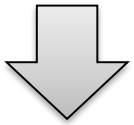
- The SCEC Broadband Platform (BBP) is an open-source software distribution that contains physics-based GMs models capable of calculating earthquake GMs at frequencies up to 10Hz across regional distances (http://scec.usc.edu/scecpedia/Broadband_Platform).
- The BBP contains several physics-based ground motion simulation models.



[Philip J. Maechling, Fabio Silva, Scott Callaghan, and Thomas H. Jordan. SCEC Broadband Platform: System Architecture and Software Implementation Seismological Research Letters, January/February 2015, v. 86, p. 27-38]

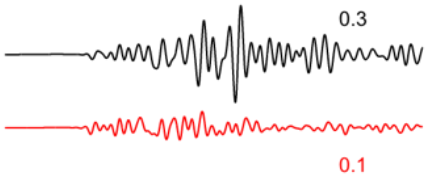
Some Questions…

- How well do synthetic waveforms fit recorded data? (e.g., Olsen et al., 2003 in BSSA)
- How well do synthetic intensity measures fit recorded data? (e.g., Olsen et al., 2010 in SRL)
- How well do synthetic intensity measures fit GMPEs? (e.g. Star et al., 2011 in EQS)
- How well do structural response to synthetic GMs fit **structural response** to recorded GMs?



AIM: performing statistical analysis to evaluate the level of similarity between the structural responses (elastic and inelastic) to recorded and simulated ground motions

Examples of (engineering) validation

Visual Inspection	Conventional IMs	SDOF systems' response (elastic/inelastic)	MDOF systems' response (elastic/inelastic)
	PGA, PGV, PGD, $S_a(T_1)$	$\Delta_{inelastic}$, N_e, etc.	MIDR, PFA, etc
(e.g., Olsen et al., 2003)	(e.g., Olsen et al., 2010)	(e.g., Galasso et al., 2012)	(Galasso et al., 2013, Burks et al., 2015, Bijelic et al., 2014)

Type I

- Validation conditioned on similarity of spectra

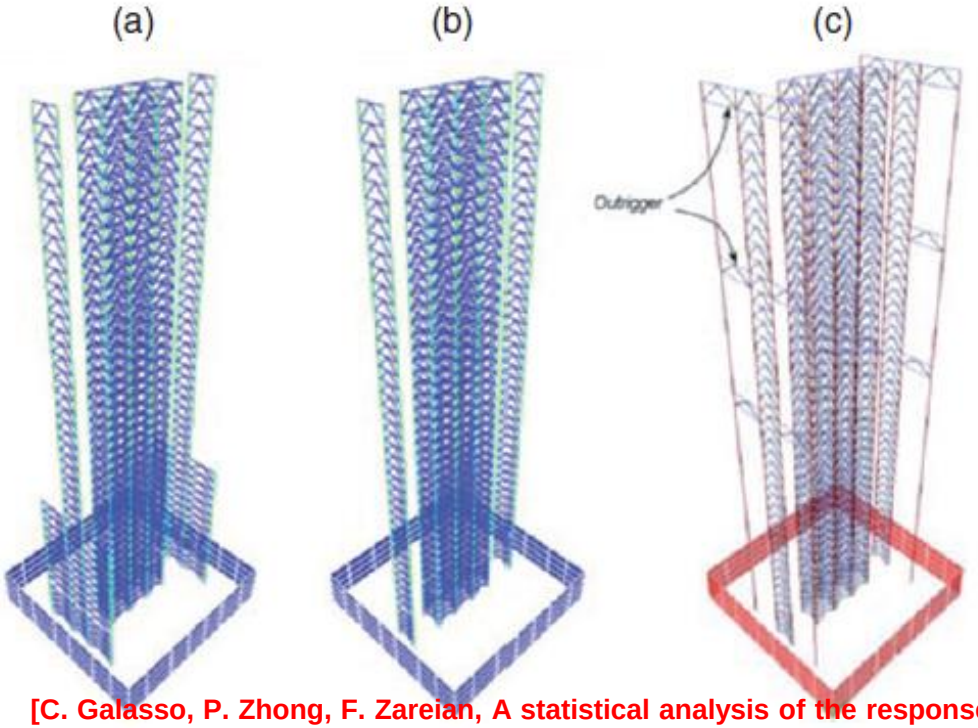
Type II

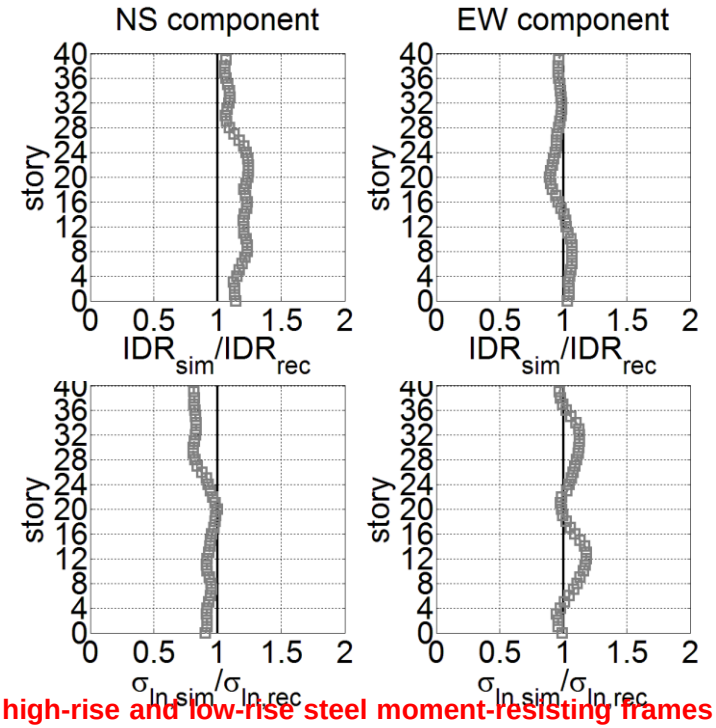
- Validation conditioned on similarity of event

Tall Buildings Response

Table 1. Periods, mode numbers and direction of mode shape for the structural models.

Structure name		Mode number 1	2	3	4
BRBF40-CBD	period (s)	5.252	3.802	3.74	1.476
	direction	↑ h2	→ h1	↶ tors.	↑ h2
BRBF40-PBD	period (s)	6.47	4.993	4.49	1.774
	direction	↑ h2	↶ tors.	→ h1	↑ h2
BRBF40-PBD+	period (s)	5.736	4.387	4.166	1.639
	direction	↑ h2	↶ tors.	→ h1	↑ h2

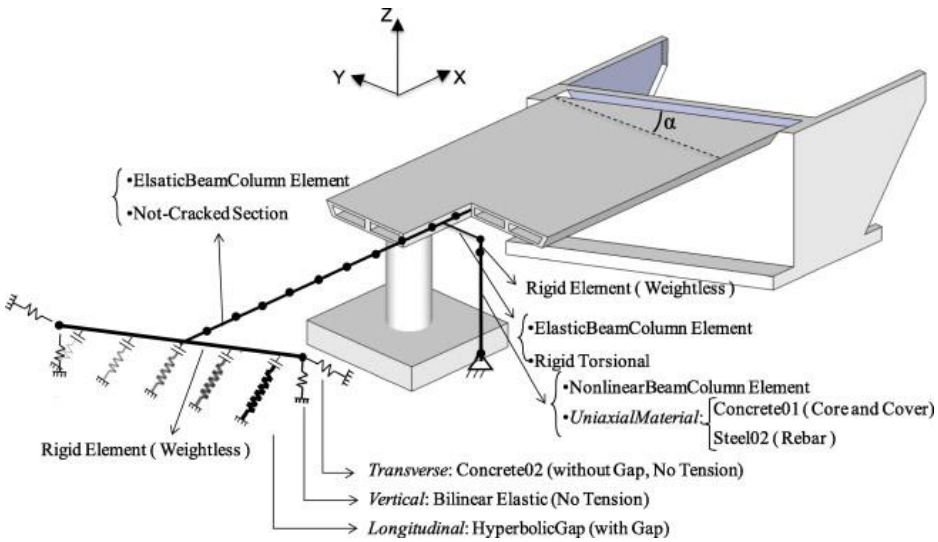


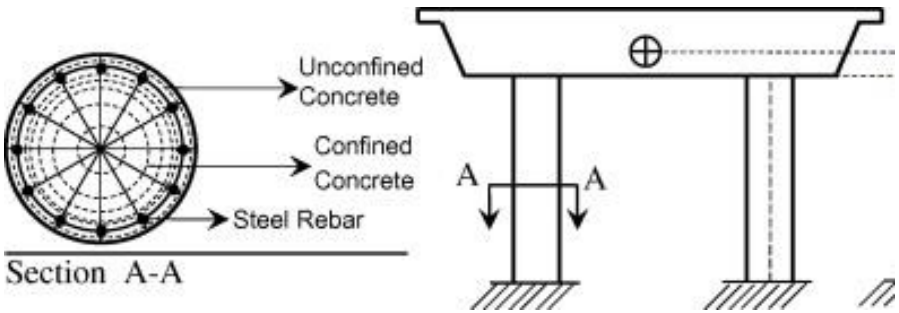


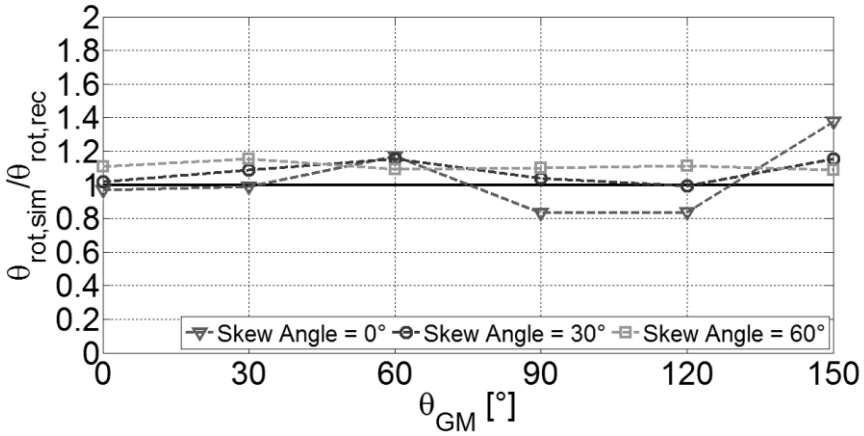
PBD+ structure (Northridge earthquake)

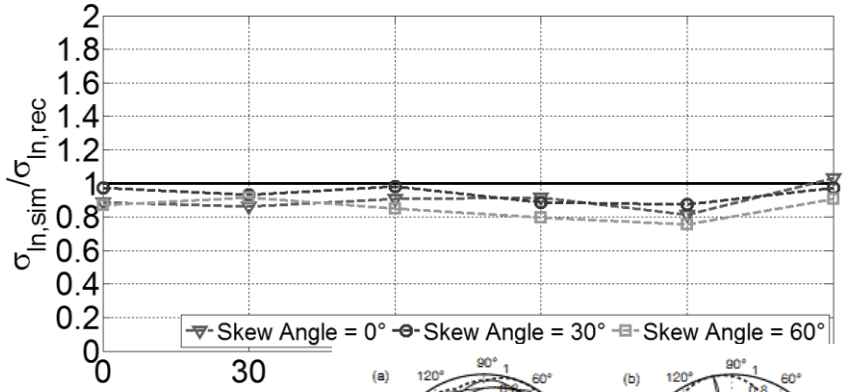
[C. Galasso, P. Zhong, F. Zareian, A statistical analysis of the response of high-rise and low-rise steel moment-resisting frames in Los Angeles to observed and simulated ground motions for past earthquakes, The Structural Design of Tall and Special Buildings (in prep.)]

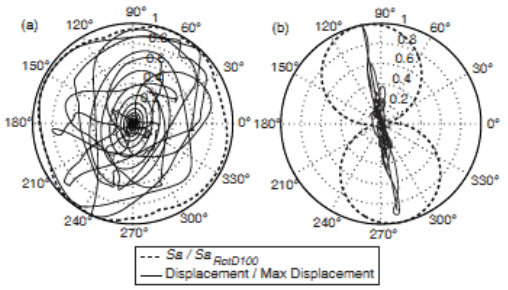
Bridges Response







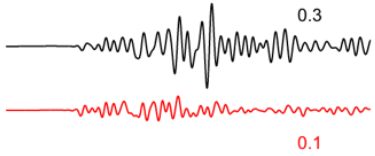




[C. Galasso, P. Kaviani, F. Zareian, Comparing seismic response of skewed bridges to simulated and recorded ground motions, ASCE Journal of Bridge Engineering (in preparation)]

What's next?

Visual Inspection



Conventional IMs

PGA, PGV, PGD, $S_a(T_1)$

Advanced IMs

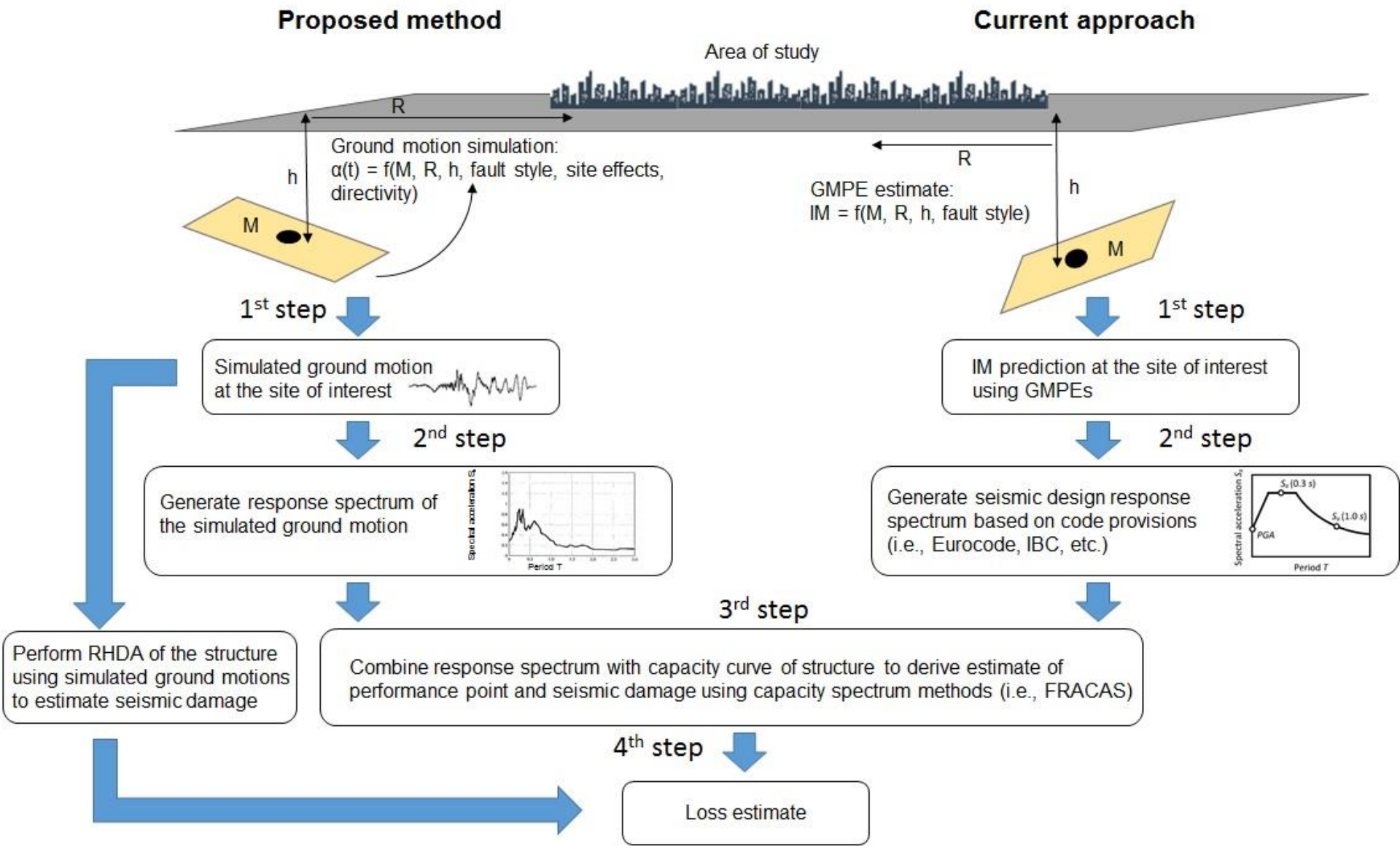
SDOF systems' response (elastic/inelastic)

$\Delta_{inelastic}$, N_e, etc.

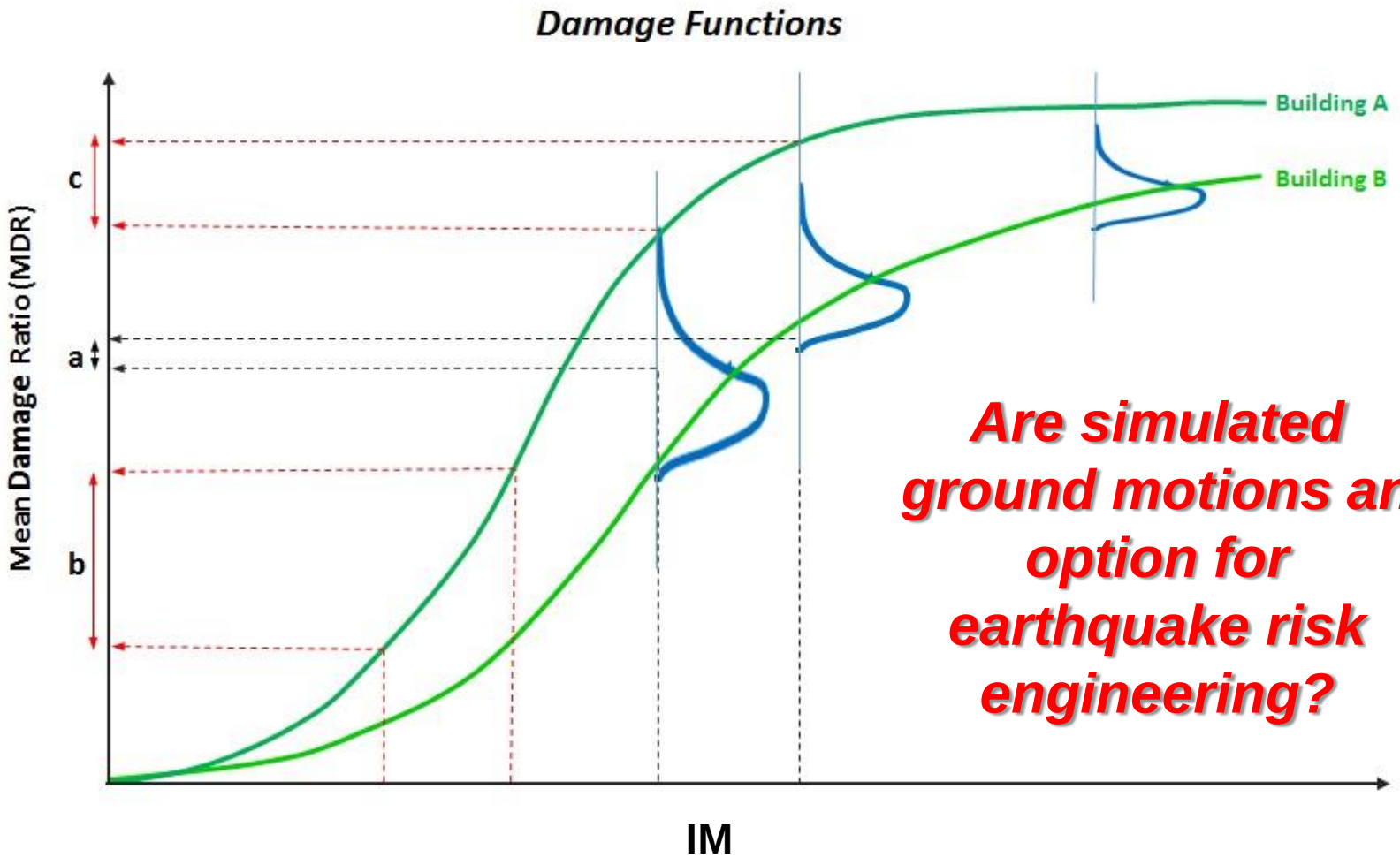
MDOF systems' response (elastic/inelastic)

MIDR, PFA, etc

What's next?


Proposed method
Current approach
Area of study
R
h
M
Ground motion simulation:
α(t) = f(M, R, h, fault style, site effects, directivity)
R
h
M
GMPE estimate:
IM = f(M, R, h, fault style)
1st step
Simulated ground motion at the site of interest
1st step
IM prediction at the site of interest using GMPEs
2nd step
Generate response spectrum of the simulated ground motion
Spectral acceleration
Period T
2nd step
Generate seismic design response spectrum based on code provisions (i.e., Eurocode, IBC, etc.)
Spectral acceleration
PGA
Period T
3rd step
Perform RHDA of the structure using simulated ground motions to estimate seismic damage
Combine response spectrum with capacity curve of structure to derive estimate of performance point and seismic damage using capacity spectrum methods (i.e., FRACAS)
4th step
Loss estimate

What's next?



Are simulated ground motions an option for earthquake risk engineering?

CATastrophe Risk Engineering

GROUND-MOTION SIMULATION

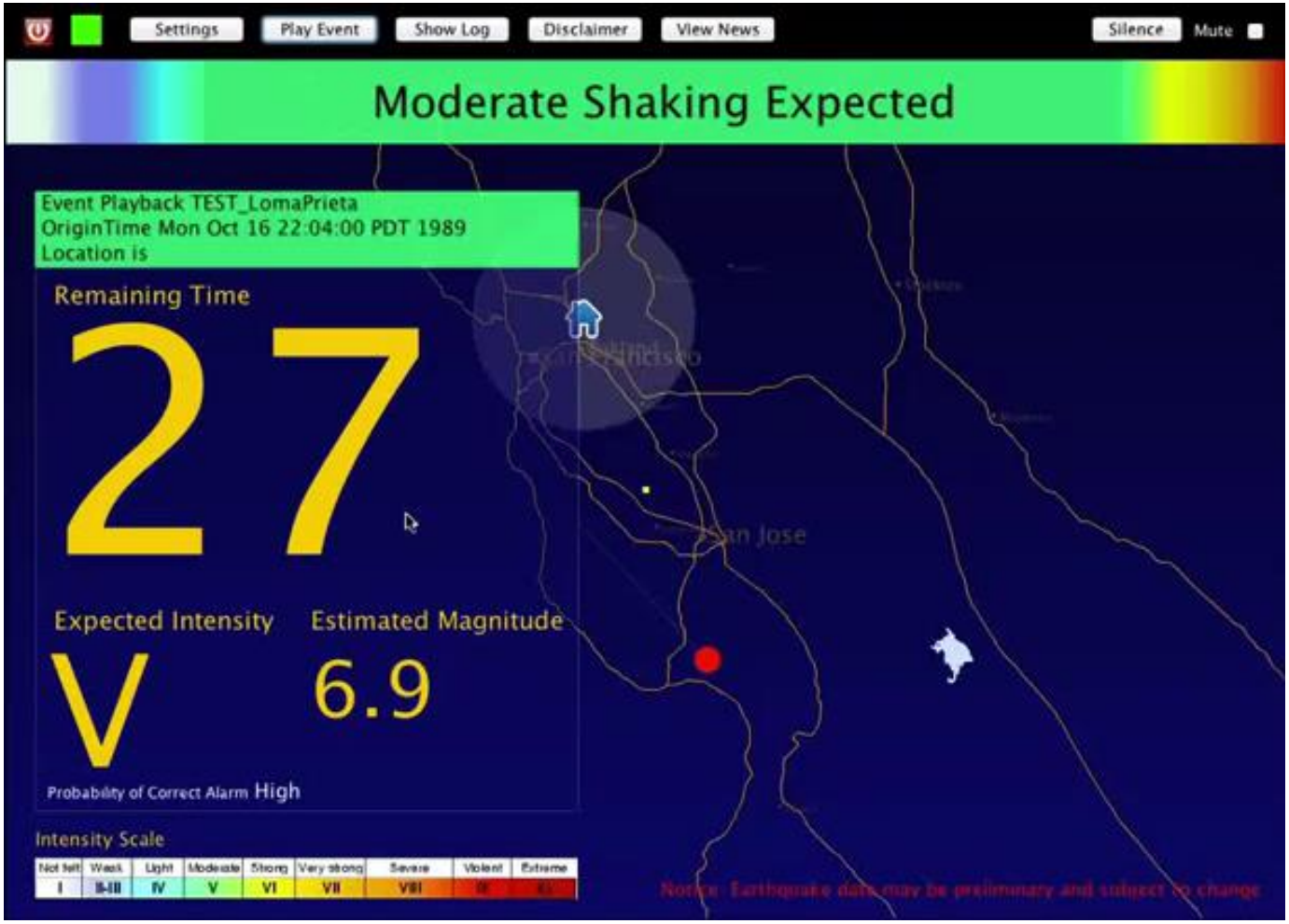
REAL-TIME

OFFSHORE WIND

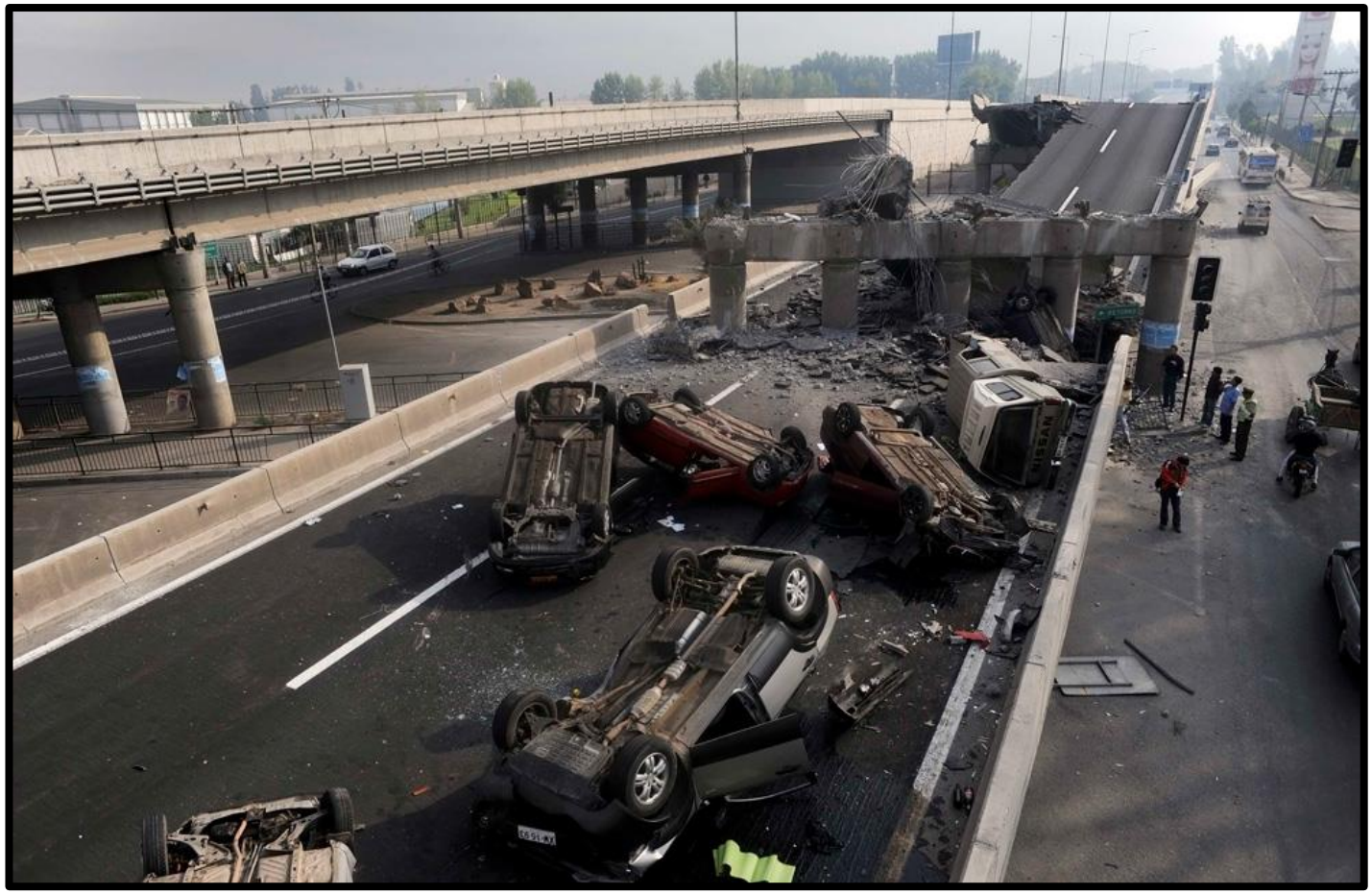
MULTI-HAZARD

Research student:
Omar Velazquez Ortiz
funded by
Mexican Consejo Nacional de Ciencia y Tecnología (Conacyt)

Alert! Earthquake hitting this area in 20 seconds!



Fukushima Daiichi Nuclear Power Plant Explosion
Tohoku Earthquake
March, 2011

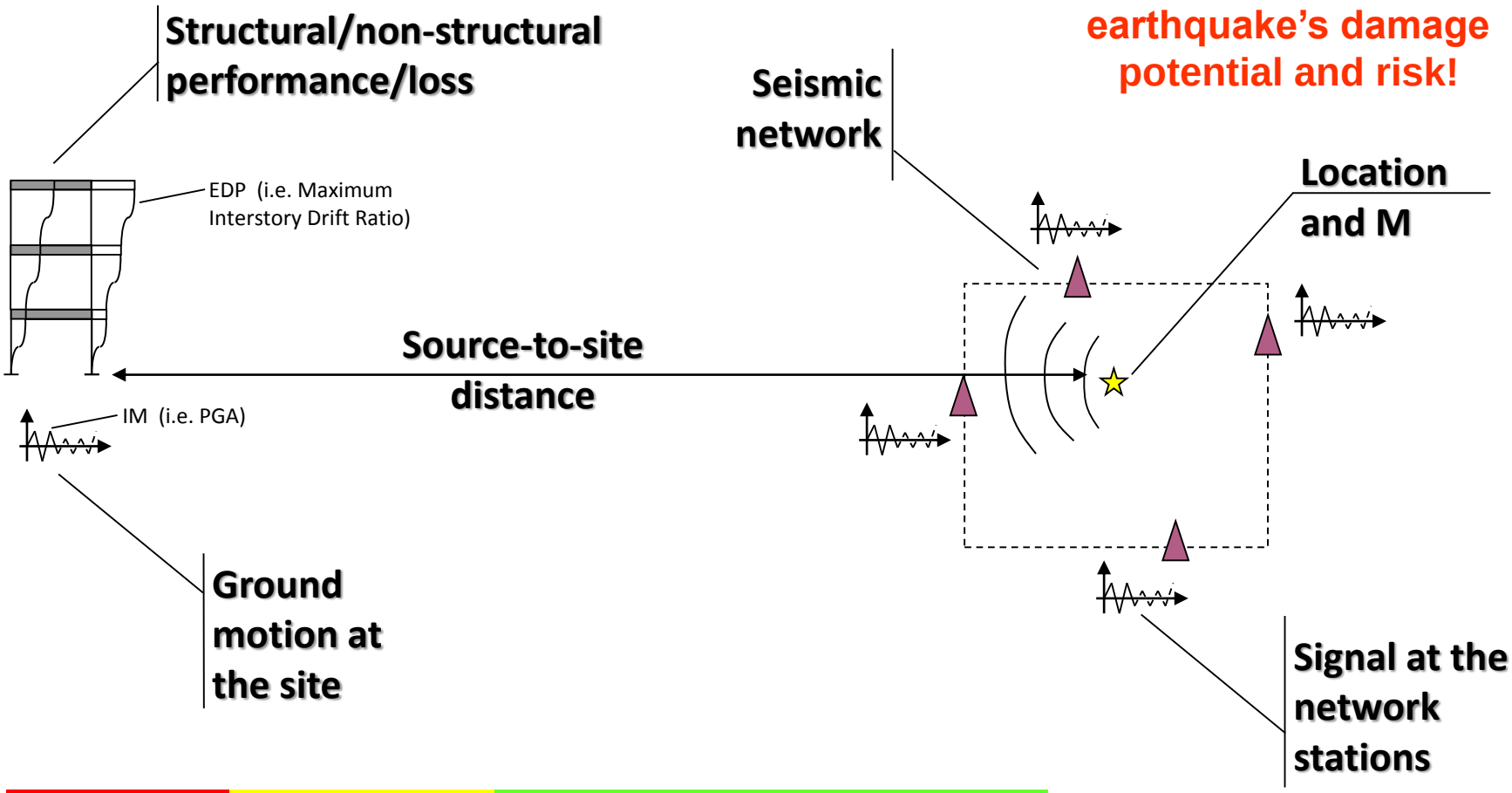


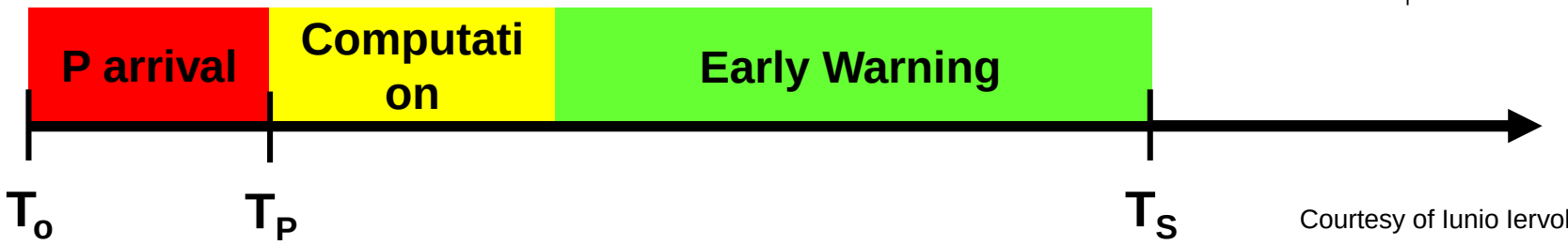
Collapsed bridge in Santiago, Chile Chile Earthquake
February, 2010

Derailed train carrying hazardous material
Northridge Earthquake
January, 1994

Collapsed school in Port-Au-Prince
Haiti Earthquake
March, 2010

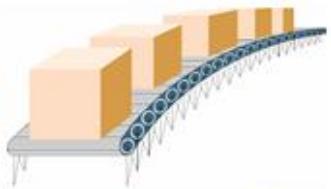
Objective: to estimate in a fast and reliable way the earthquake's damage potential and risk!





Courtesy of Iunio Iervolino

Controlling trains



Controlling factory lines
--> To mitigate damage

To prevent
traffic accidents

Controlling elevators
--> To prevent people from
being trapped

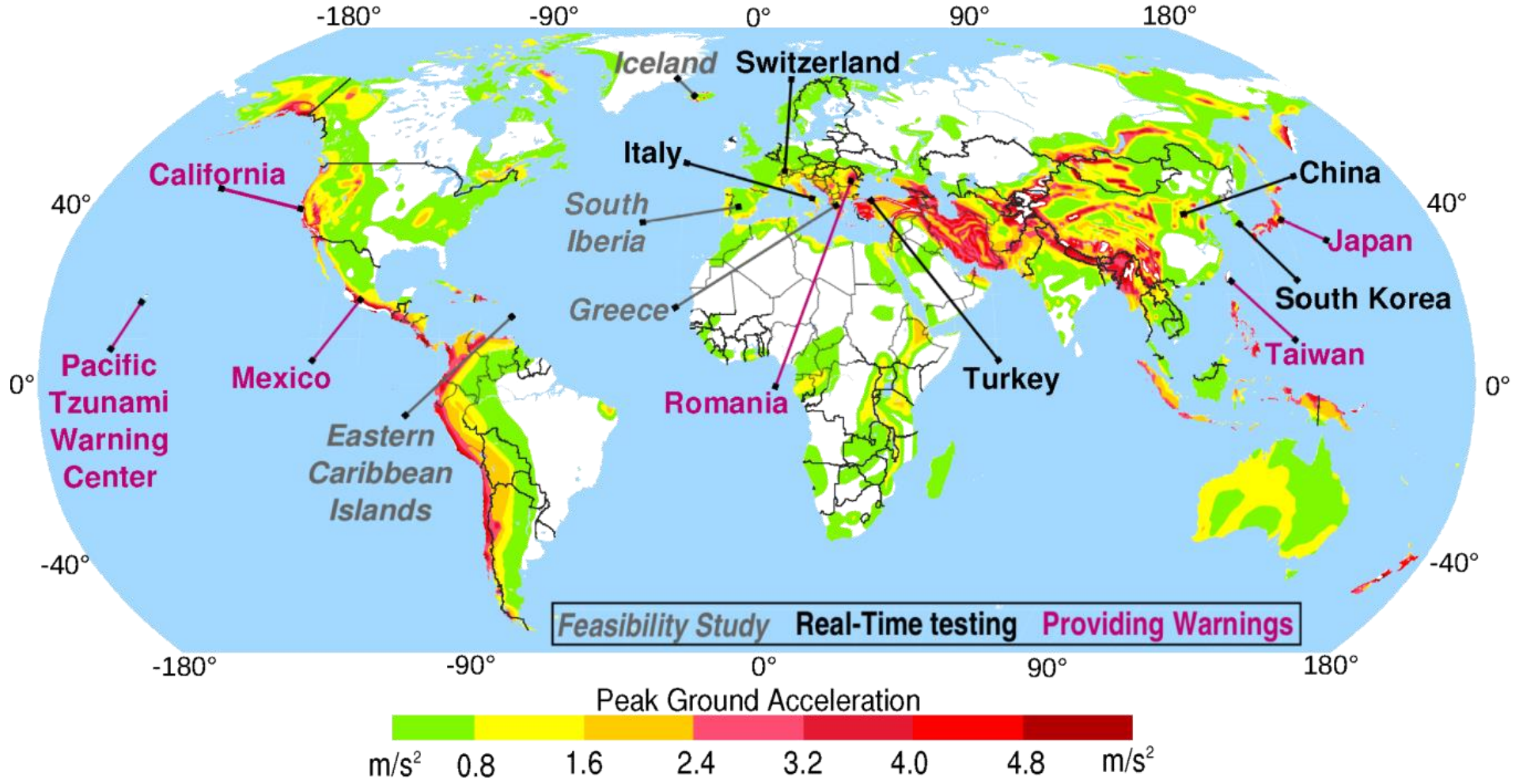
At home
--> To enable personal protection

Workers performing
hazardous tasks
--> To secure safety

Suspending work in progress
--> To avoid mistakes

Alerting schools and assembly halls
--> To guide evacuation

Worldwide EEWS

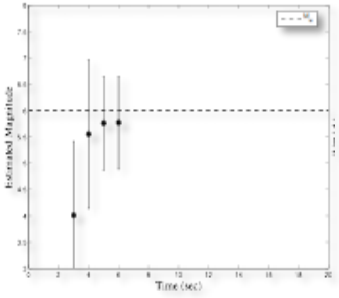


Real-time (probabilistic) hazard analysis

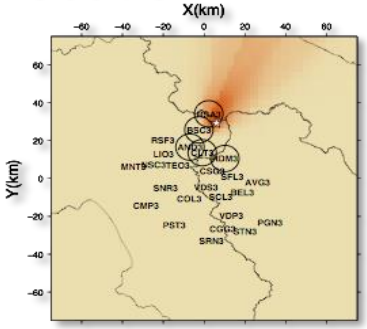
Automatic (advanced) procedures for the probabilistic and evolutionary real-time estimation of source parameters and prediction of ground motion shaking… RTPSHA!

RT Intensity Prediction at Targets

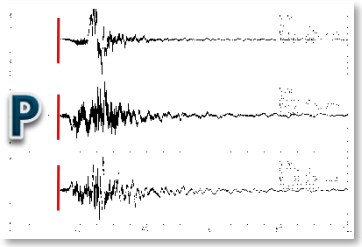
RT Magnitude Estimation



RT Earthquake Location

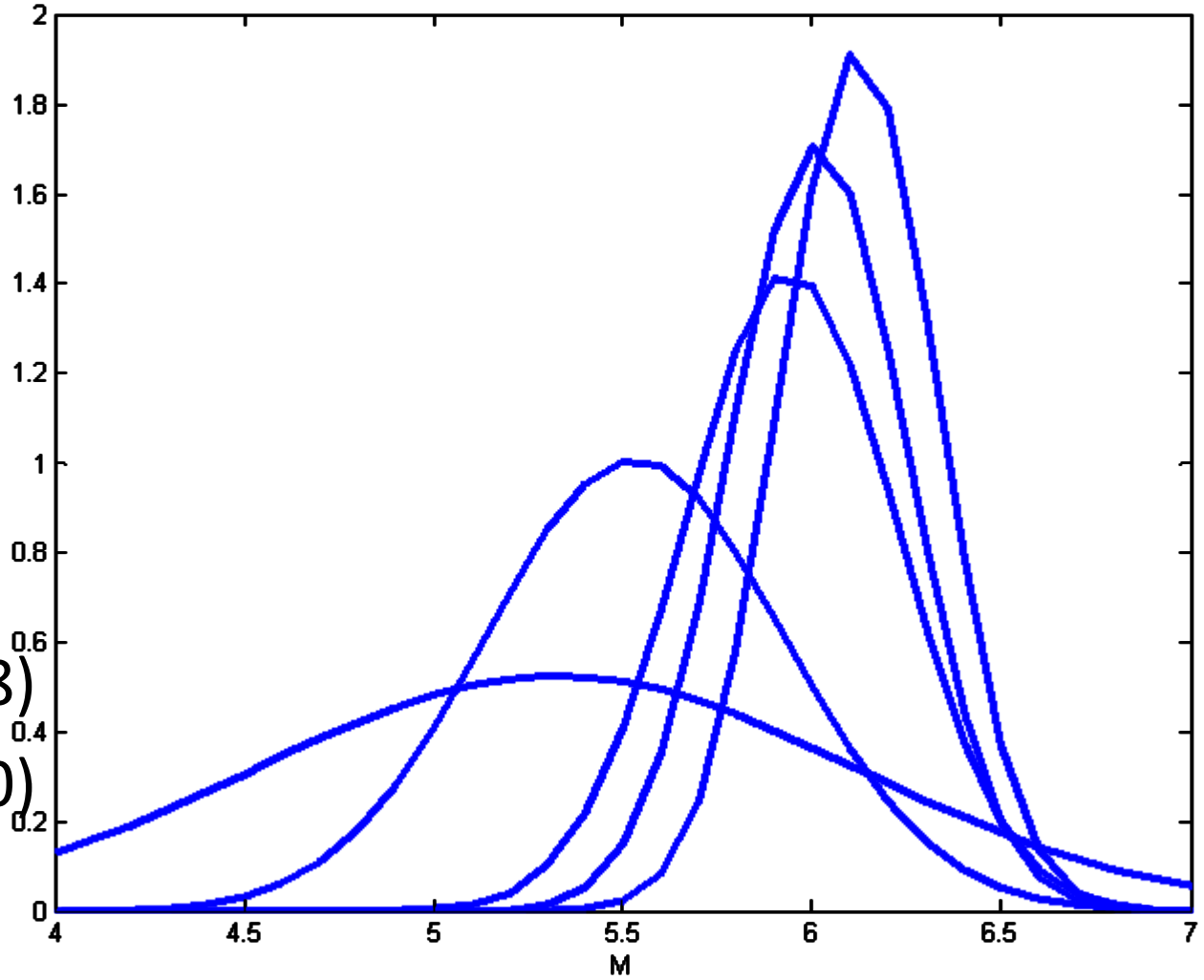


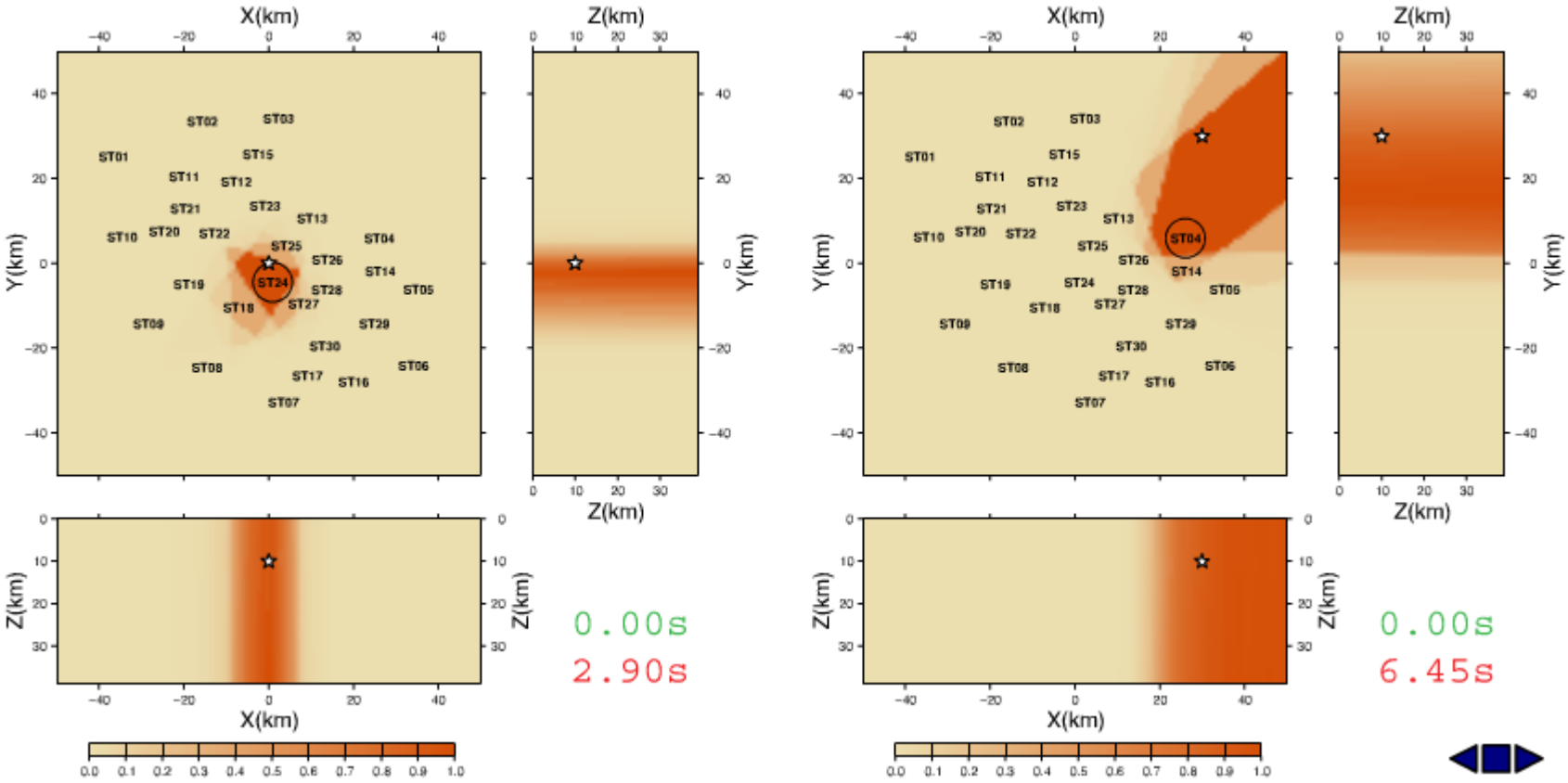
Automatic Detection



M=6 R=110km Event Simulation

t = 5s (2)
t = 6s (8)
t = 9s (23)
t = 11s (28)
t = 12s (30)





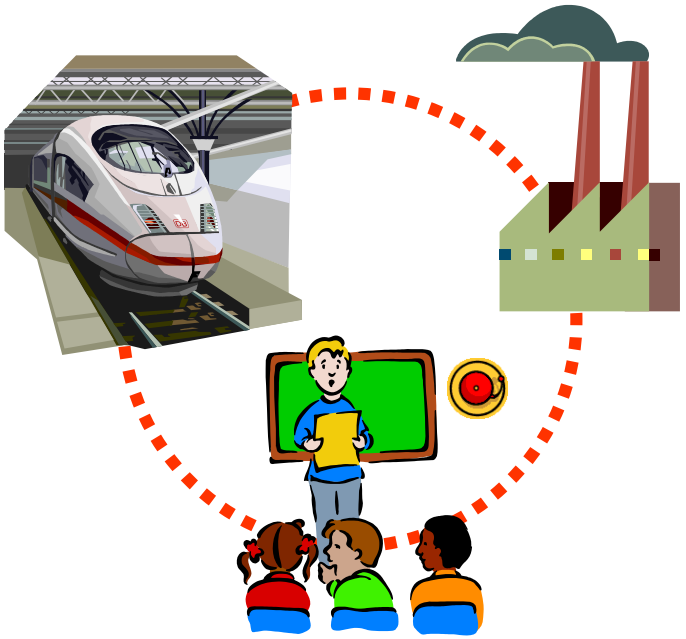
Seconds from first trigger

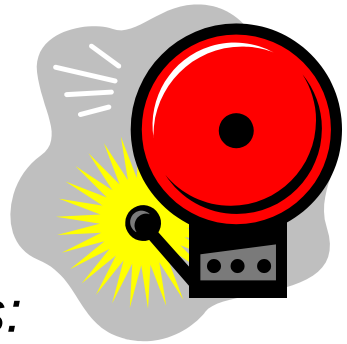
Seconds from earthquake Origin Time

○ **Triggered stations**

Courtesy of Aldo Zollo

Decisional rule





Two possible decisional rules:

Alarm if

E[intensity] > critical value

Alarm if

Pr[intensity > critical value] > critical risk

Two critical issues:

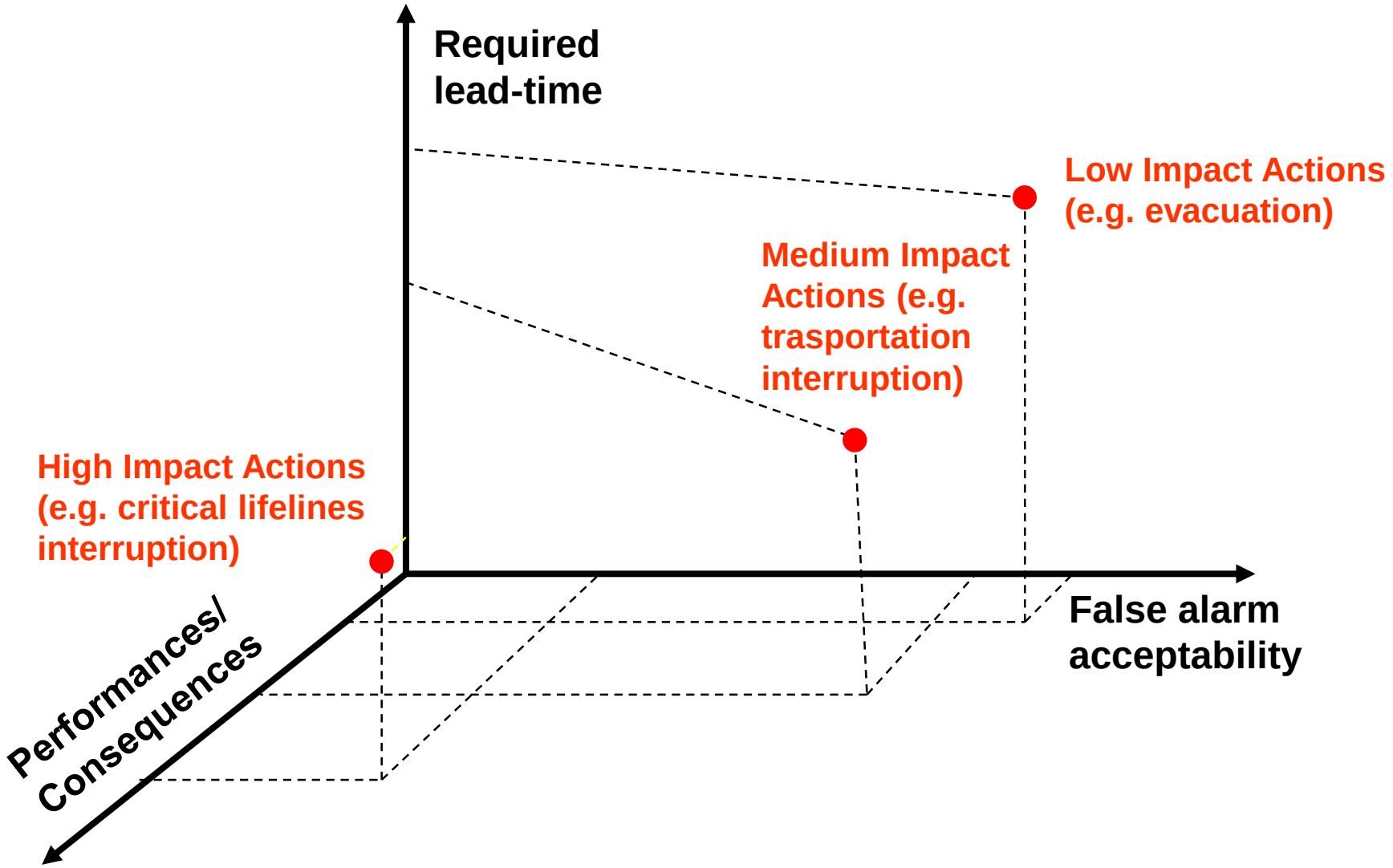
Missed alarm if

{NO alarm ∩ true intensity > critical value}

False alarm if

{YES alarm ∩ true intensity < critical value}

Design engineering applications



Courtesy of Iunio Iervolino

Success story

At the time of the earthquake…

- **24 trains were running in the Tohoku Shinkansen system**
- 9 seismic sensors along the coast, and 44 sensors along the train track
- detected the initial tremor; automatic shutdown of power; activation of the emergency brakes
- **all trains stopped without derailment**
- they did not sustain any damage on bridges and tunnels, and could restore the operation very quickly

Information-dependent lead-time Maps

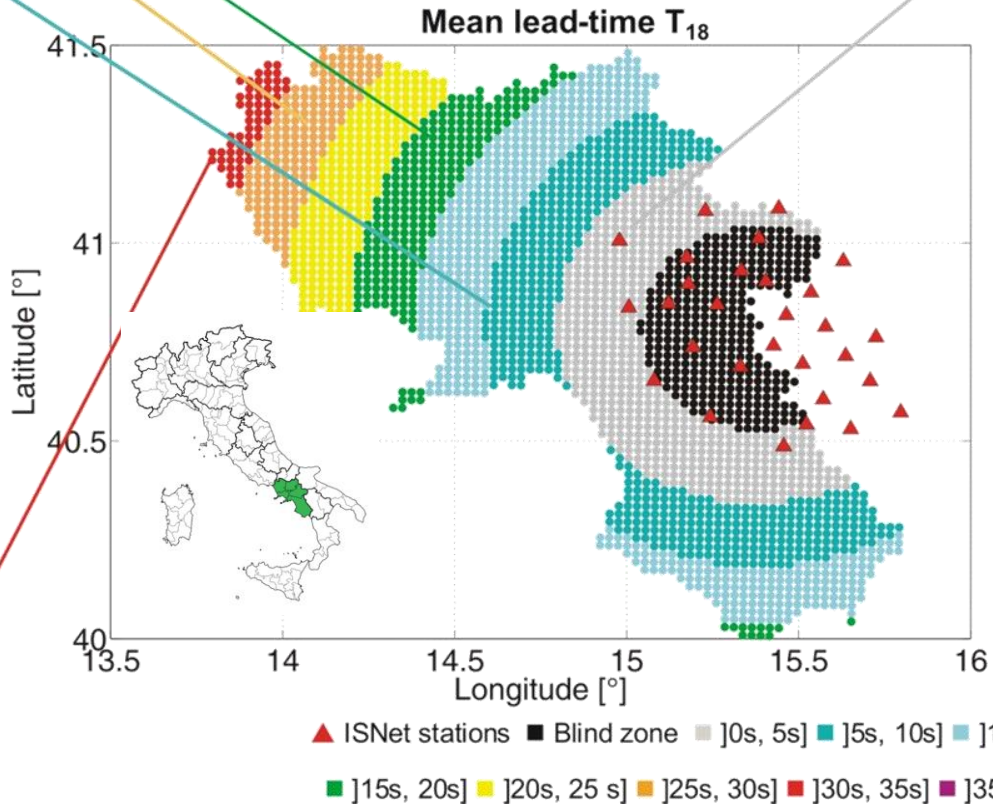
- Suspending work in progress in operating rooms (~ 20–30 sec).

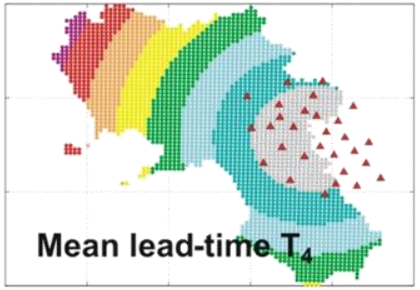
- At home, moving away from large appliances or pieces of furniture and taking cover under a table or other object that provides protection (~ 5–10 sec).
- Outdoors, looking out for collapsing objects and taking shelter in a sturdy building (~ 5–10 sec).
- Stopping hazardous work (e.g., in building yards) (~ 5–10 sec).
- Moving away from hazardous chemical systems and machinery (~ 5–10 sec).
- In public buildings, do not panic and do not rush for the exit or stairs, following the attendant's instructions (~ 10 sec).
- Stopping elevators at the nearest floor and opening its doors immediately (~ 5–10 sec).
- Activating backup and turning off important computers (~ 5–10 sec).

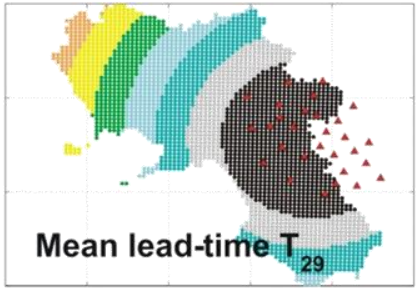
- Slowing down trains and stopping them if necessary/possible (a few tens of seconds dependent on train speed).
- Preventing planes from landing (a few tens of seconds).

- Controlling production lines (~ 15 sec).
- Shutdown of critical systems (bio-medical equipments in hospitals, reactors and hazardous equipments in energy and chemical plants) and lifelines/pipelines (~ 20 sec).

- Semi-active structural control (~ 1 sec).
- Turning all the traffic lights on the freeway to red to alert drivers and stop traffic (~ 5 sec).

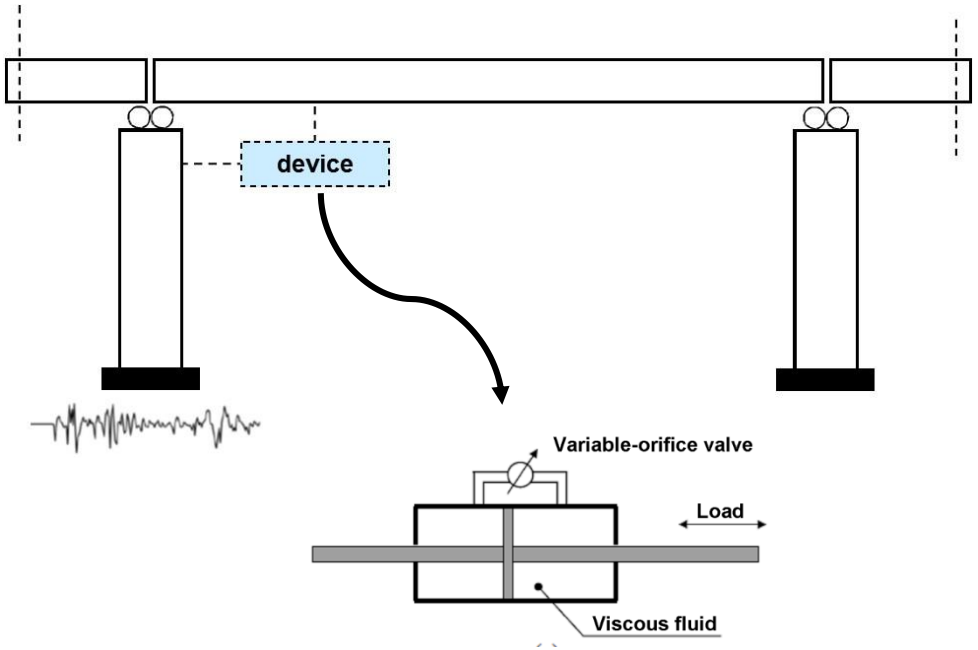


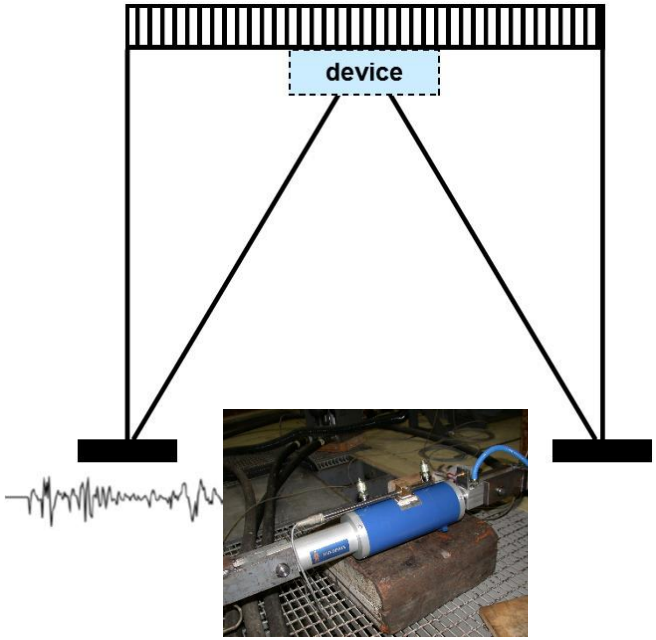




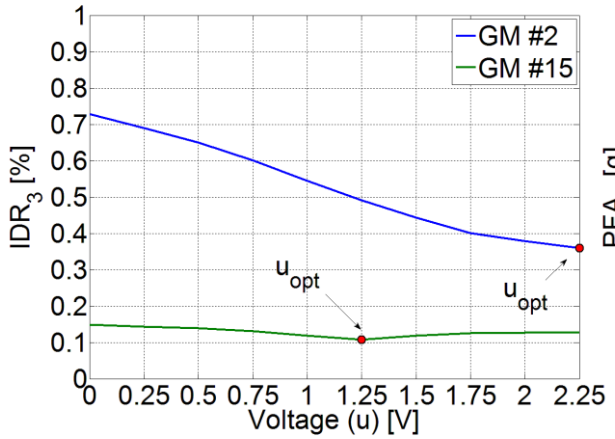
Is structural control an option for EEW?

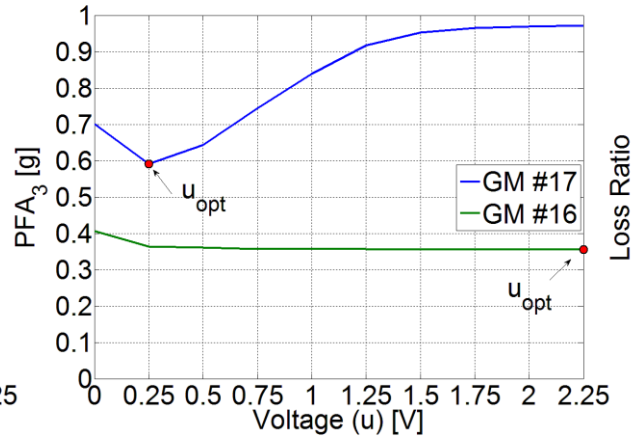
- ✓ **<u>Smart Passive (Structural) Control</u>:**
  to modify just-in-time the dynamic characteristics (stiffness/damping) of a structure to achieve the optimal response

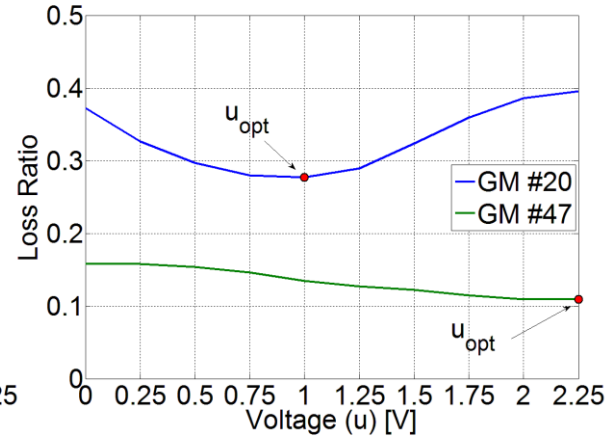


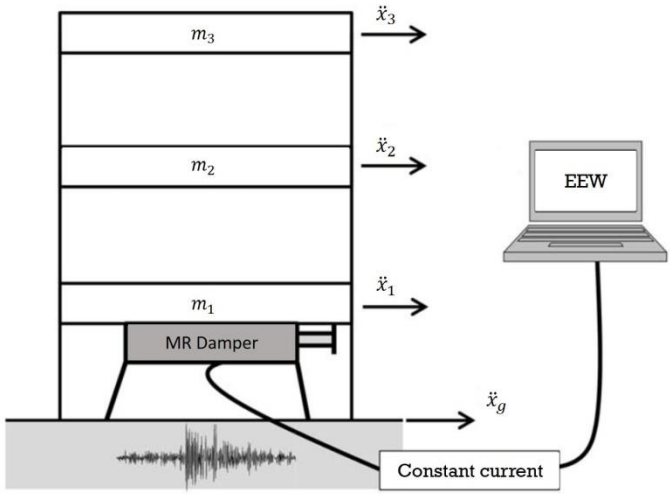


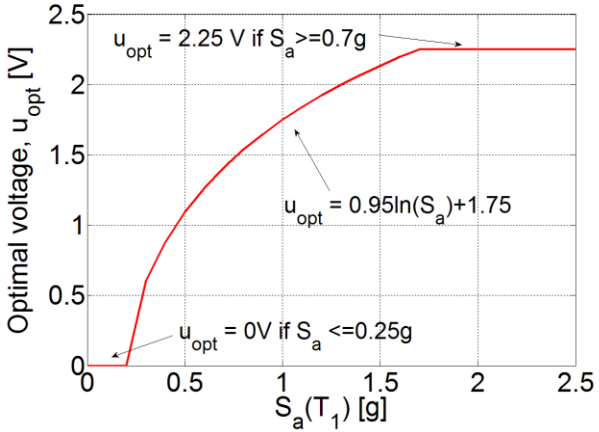
Feasible? ($) Convenient? Best option?

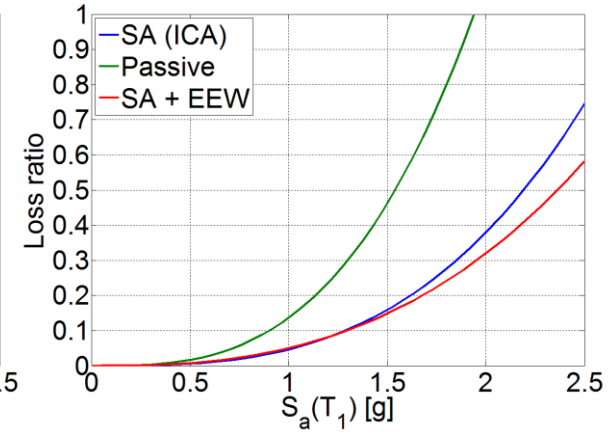


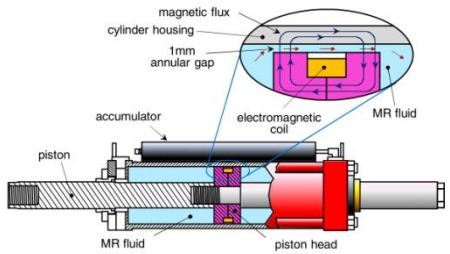




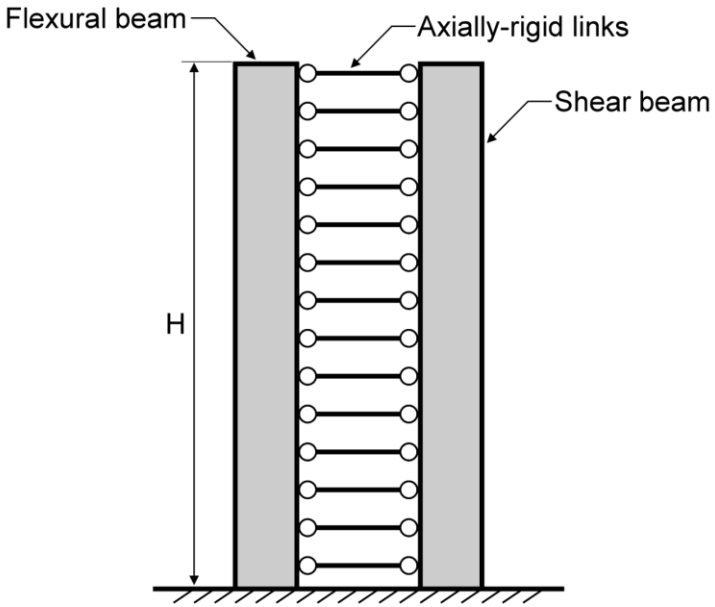


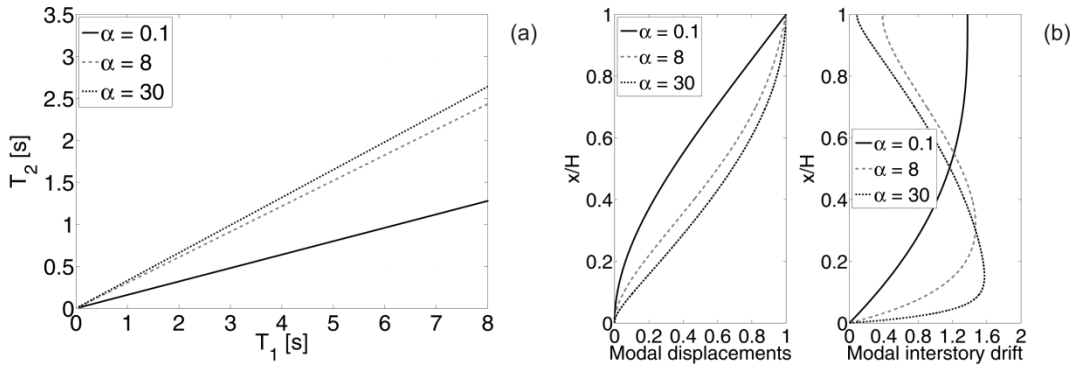






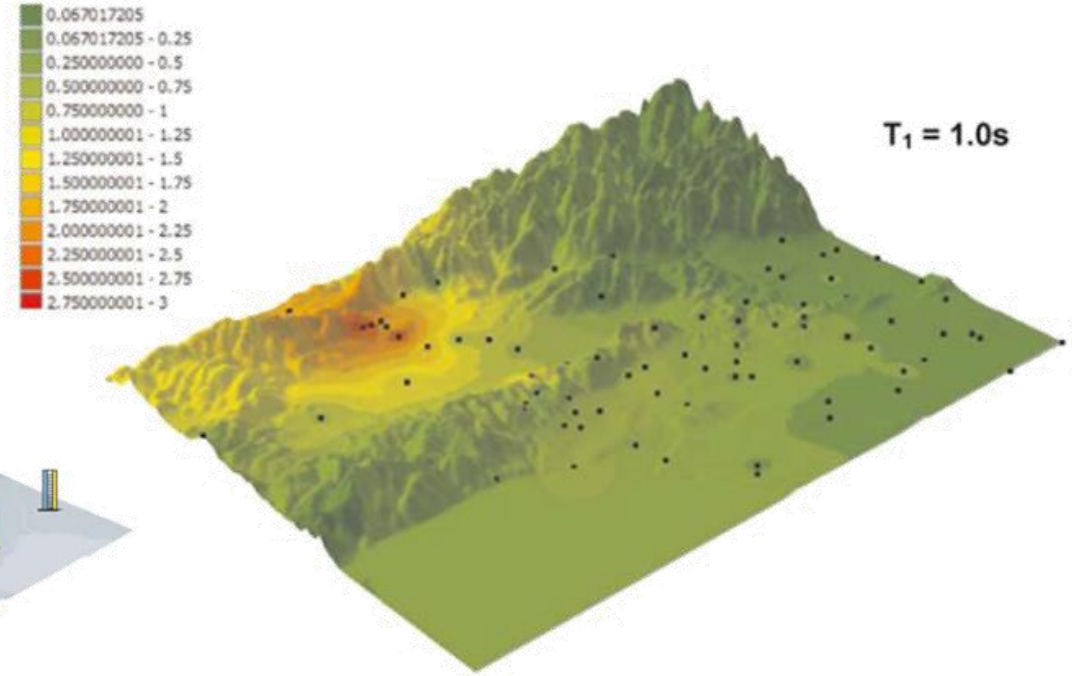
- **Investigation on semi-active structural control to modify just-in-time the dynamic characteristics of a structure based on EEW info to achieve the optimal response (i.e., minimum loss).**

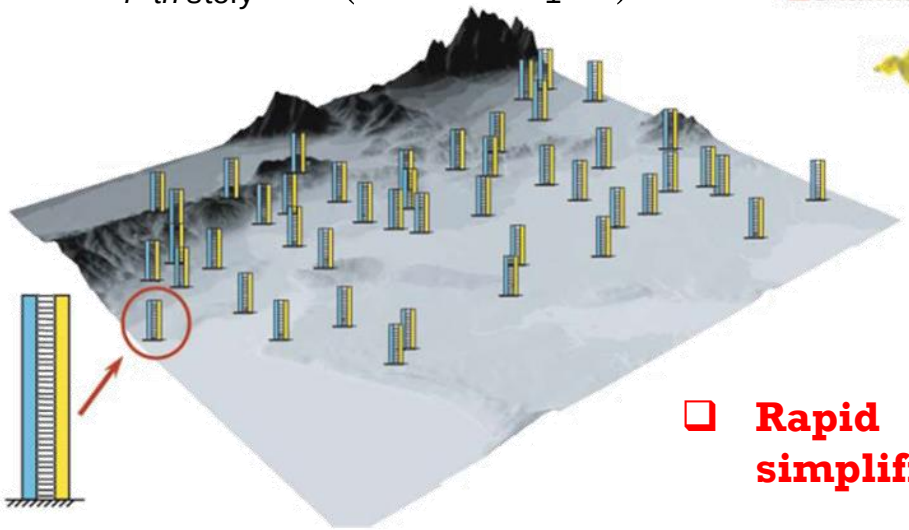




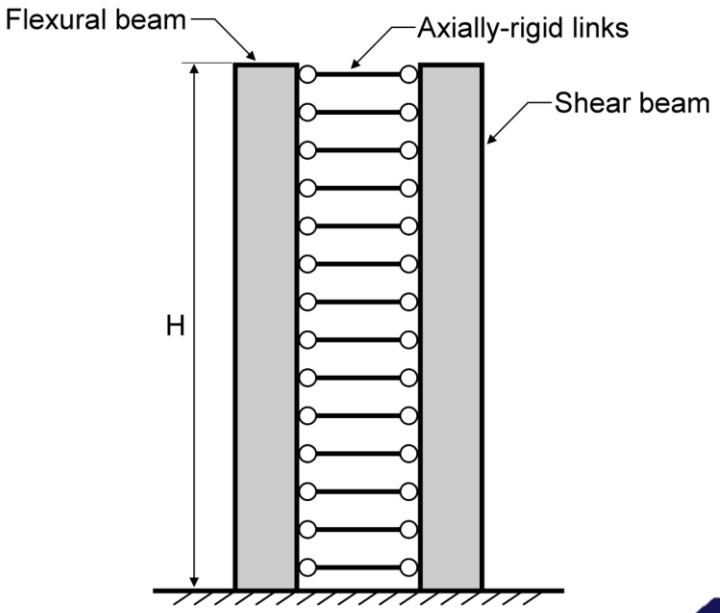
$$IRD_{i-th\ \text{story}} = f(M,R,S,T_1,\alpha) + \varepsilon$$

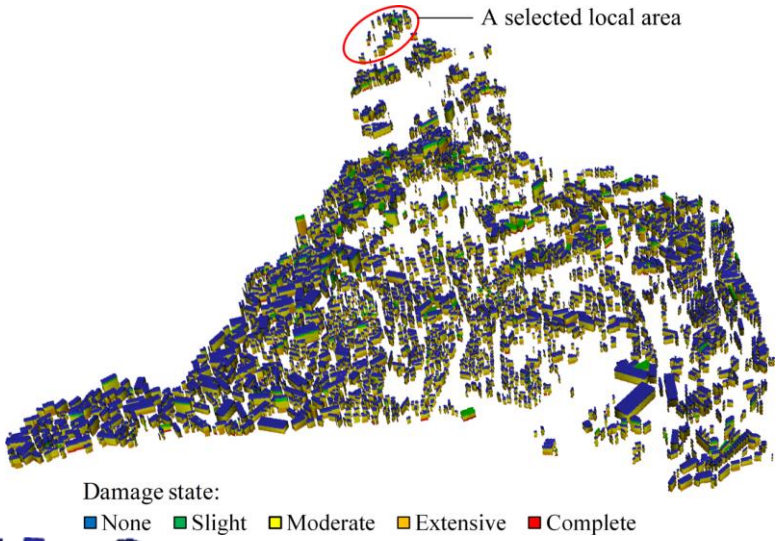
$$PFA_{i-th\ \text{story}} = f(M,R,S,T_1,\alpha) + \varepsilon$$

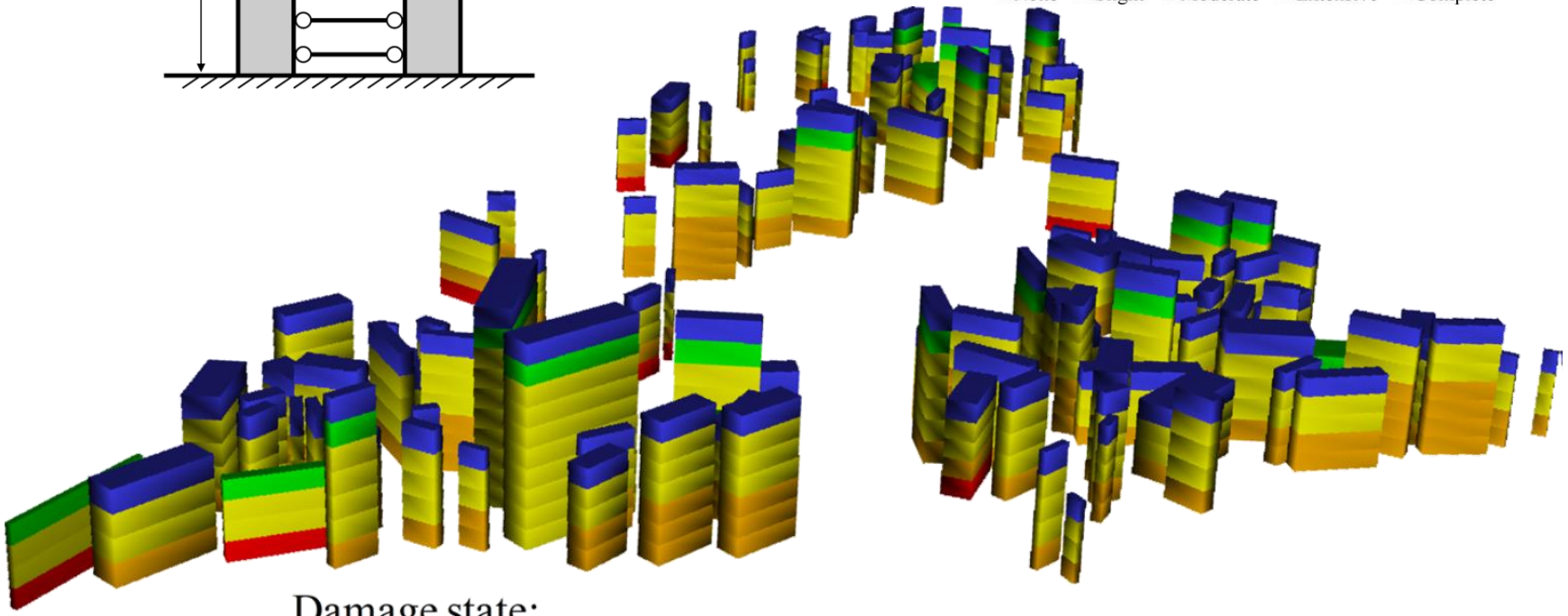




- **Rapid assessment of building response using simplified structural systems (to control elevators)**


Flexural beam
Axially-rigid links
Shear beam
H


A selected local area
Damage state:
None
Slight
Moderate
Extensive
Complete


Damage state:
None
Slight
Moderate
Extensive
Complete

- Control of Elevators:

PFA > 0.08g (Japan)
PFA > 0.5g (California)

- Human Comfort:

PFA	Comfort Level	Warning
<0.05g	Not perceptible	No shaking
0.05g – 0.15g	Barely perceptible	Minor shaking
0.15g – 0.5g	Annoying	Moderate shaking
>0.5g	Very annoying	Strong shaking

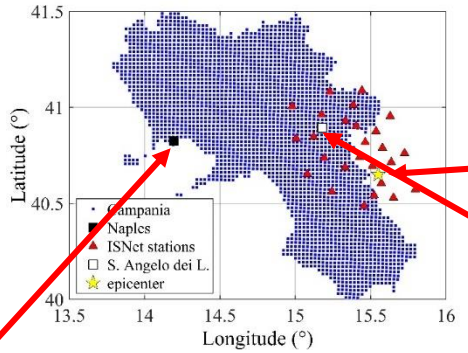
Alarm if:

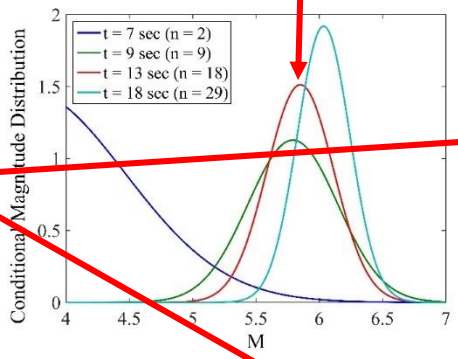
Expected[EDP] > critical value

Probability[EDP > critical value] > critical risk

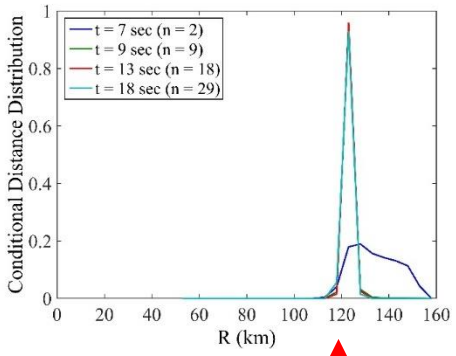
Real-Time Simulation for the Campanian Region

- Simulated 6Mw earthquake

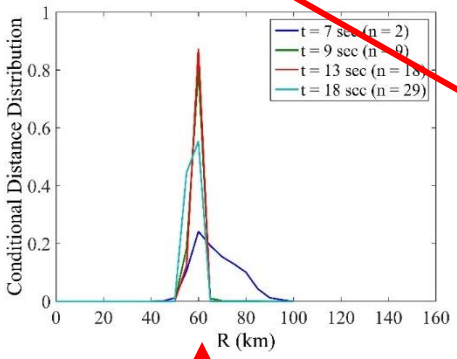




Mw = 6



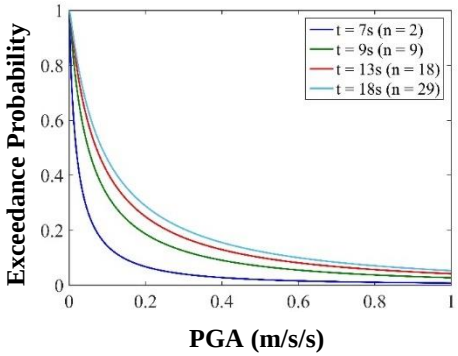
Naples
(R_epi = 120km)

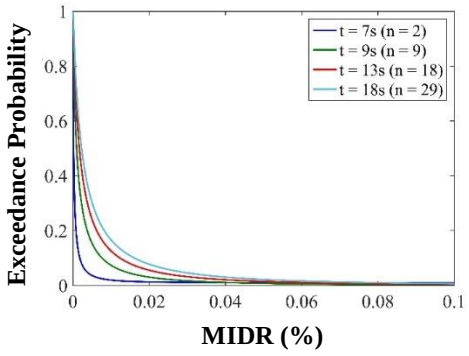


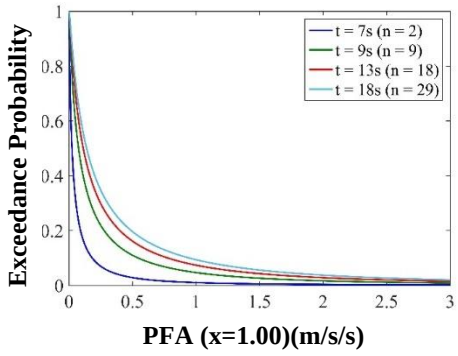
S. A. dei Lombardi
(R_epi = 60km)

Real-Time Simulation for the Campanian Region

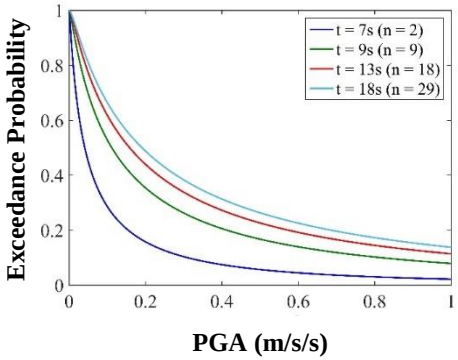
Naples

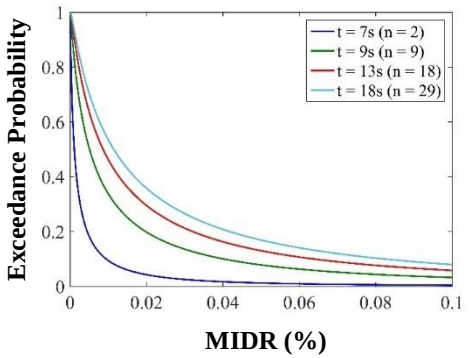


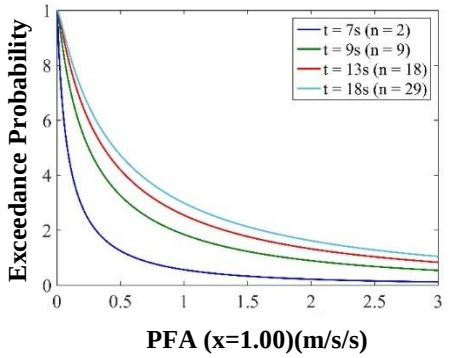




S.A. dei Lombardi



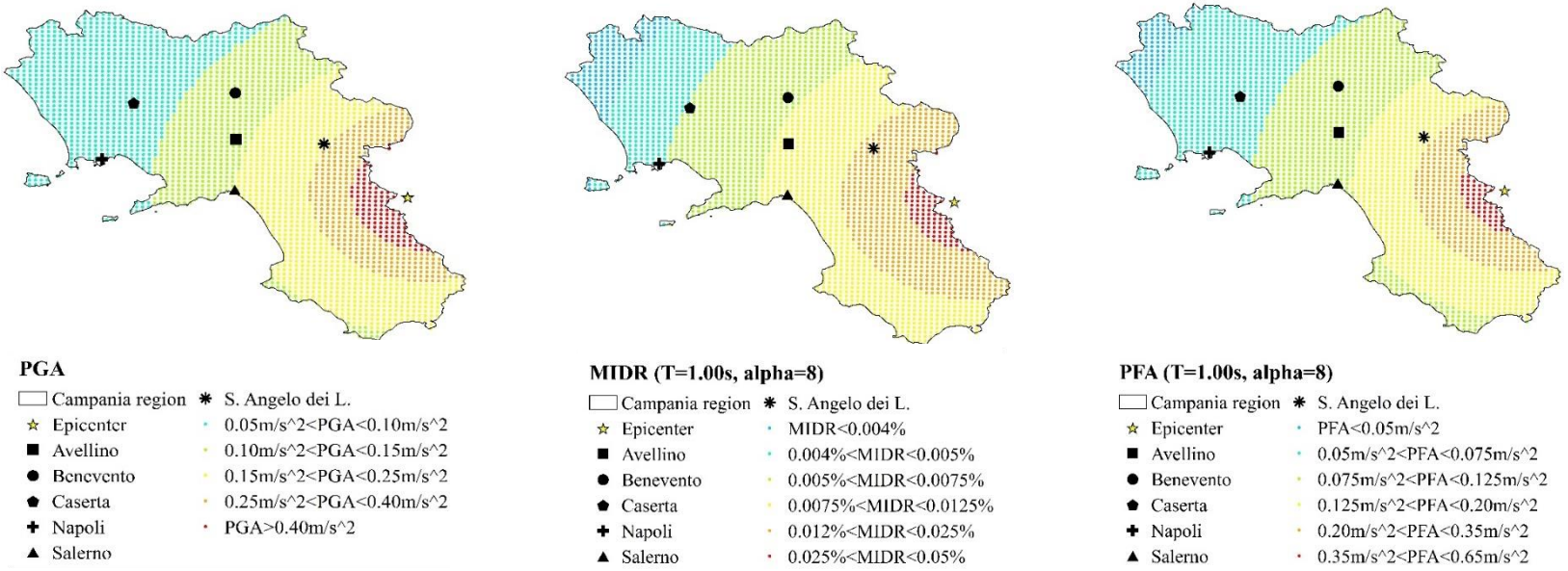




PGA **MIDR** **PFA**

Real-Time Simulation for the Campanian Region

- Real-time EDP maps (after 13s, n=18 stations)



PGA **MIDR** **PFA**

CATastrophe Risk Engineering

GROUND-MOTION SIMULATION

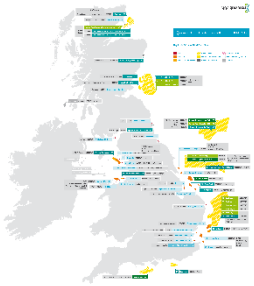
REAL-TIME

OFFSHORE WIND

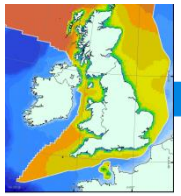
MULTI-HAZARD

Research student:
David Wilkie
funded by
Engineering and Physical Sciences Research Council (*EPSRC*) DTA

Modelling Offshore Wind Energy Risk



EXPOSURE DATA



HAZARD

EVENT GENERATION

LOCAL INTENSITY CALCULATION

FRAGILITY

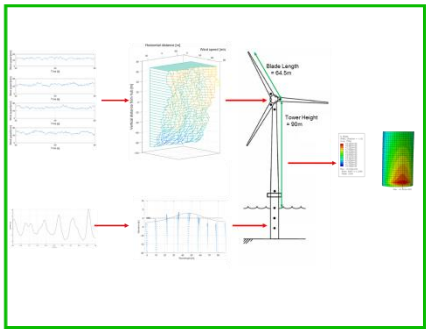
LOSS

ENVIRONMENTAL LOADING

UNCERTAINTY MODELS

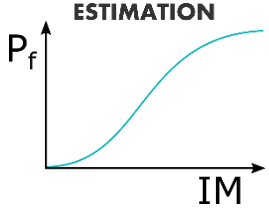
STRUCTURAL PROPERTIES

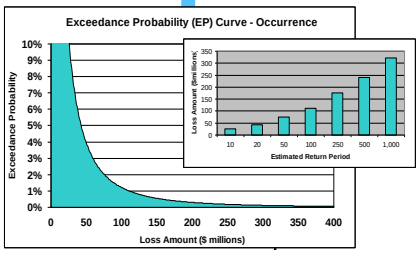
STRUCTURAL ANALYSIS

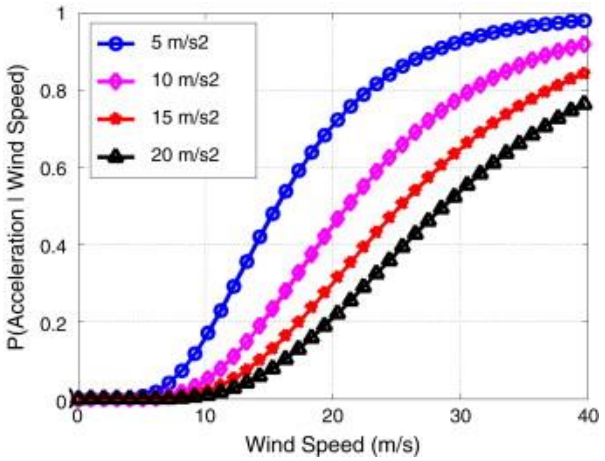


FAILURE MODES

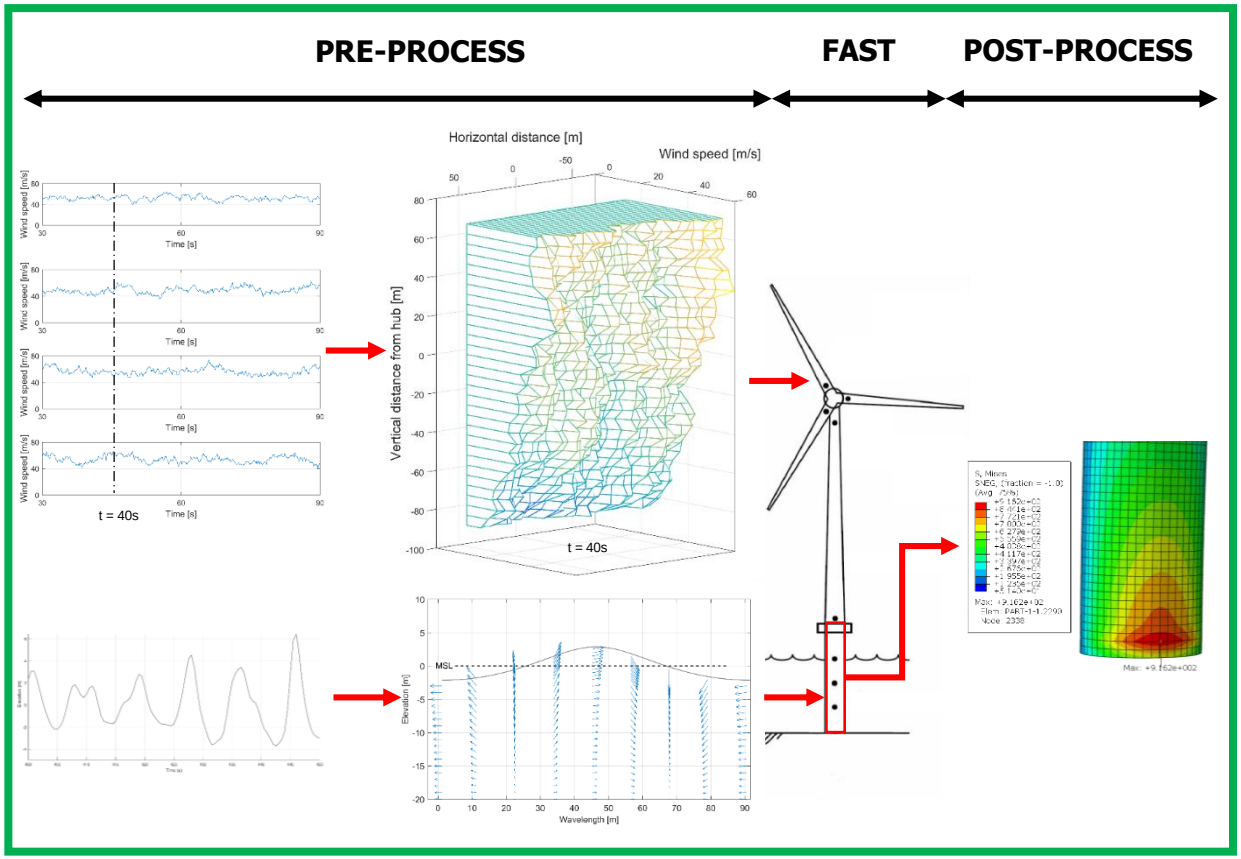
DAMAGE ESTIMATION



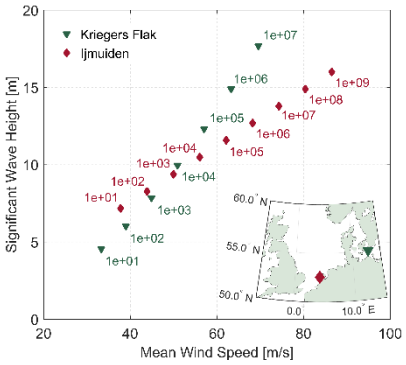




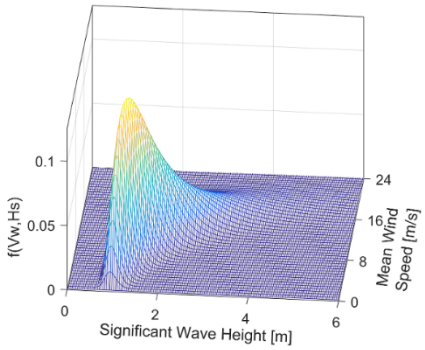
STRUCTURAL ANALYSIS



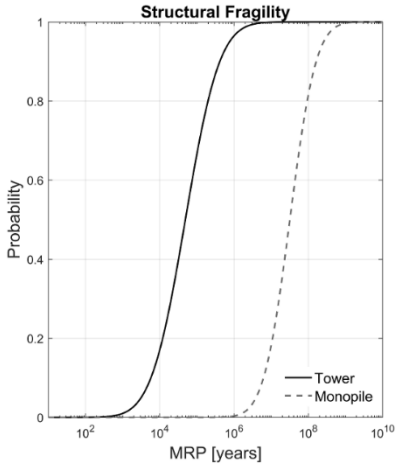
FAILURE MODES

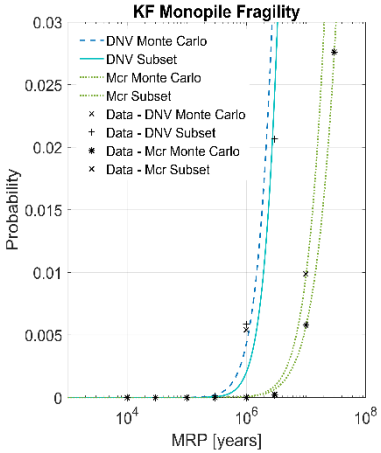


Hazard analysis



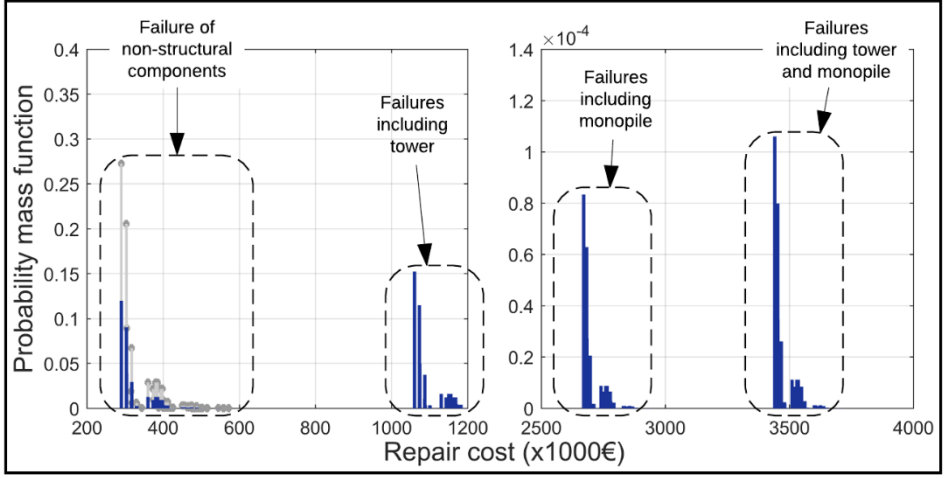
Sturctural and Damage analysis





Non-structural system - failure and loss data (Carroll et al.)

Loss analysis (combined)



CATastrophe Risk Engineering

GROUND-MOTION SIMULATION

REAL-TIME

OFFSHORE WIND

MULTI-HAZARD

Fatigue Followed by Seismic Fracture in High-rise Steel Moment Frames

UC DAVIS
UNIVERSITY OF CALIFORNIA

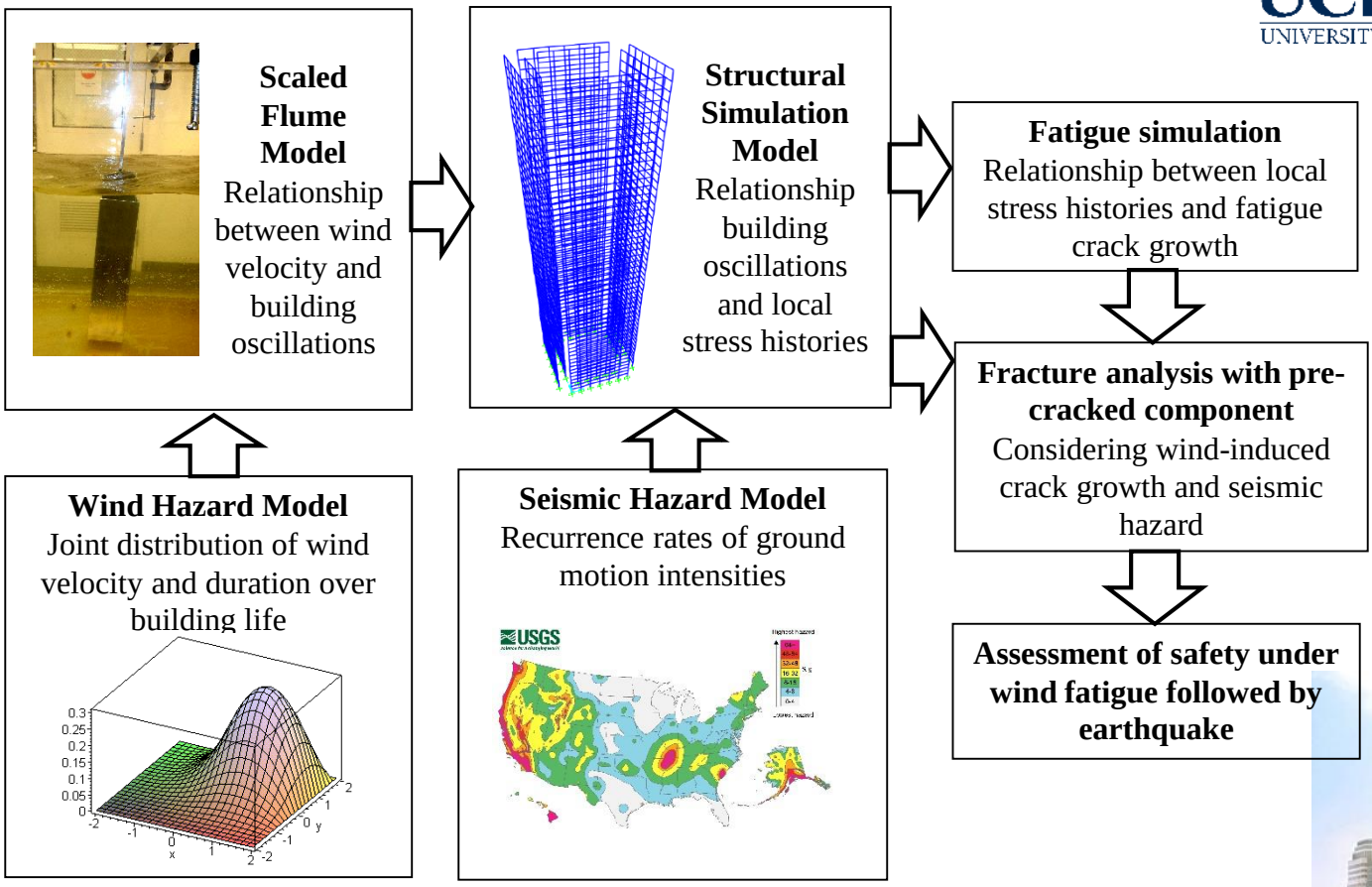
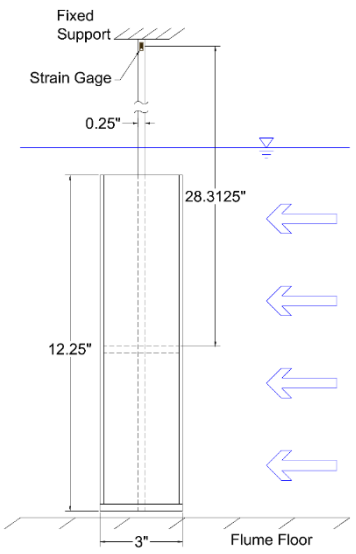
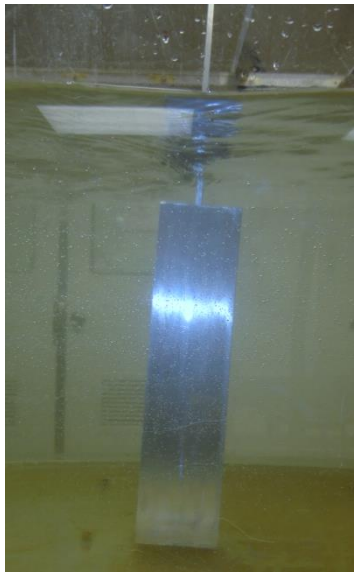


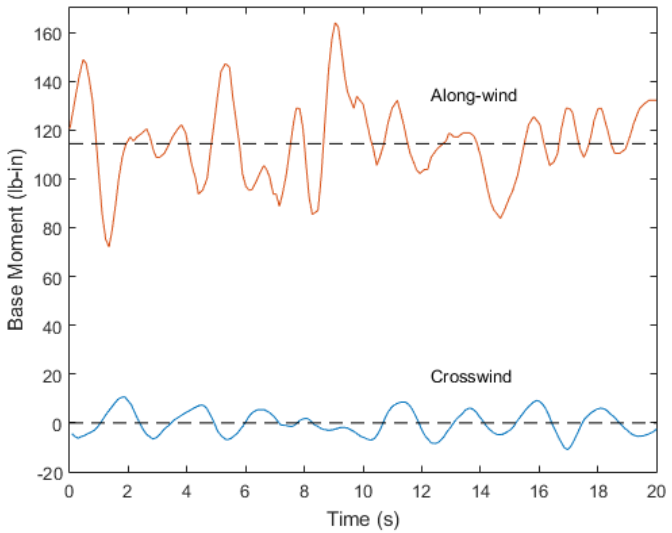
Fig. 1 – Overview of study

Research student:
Biao Song
funded by
China Scholarship Council (CSC) + UCL

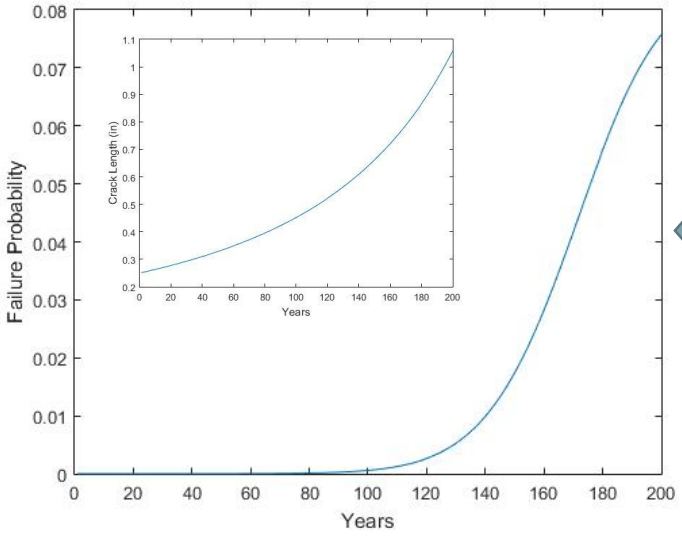
Wilshire Grand Center
(335.3 m)

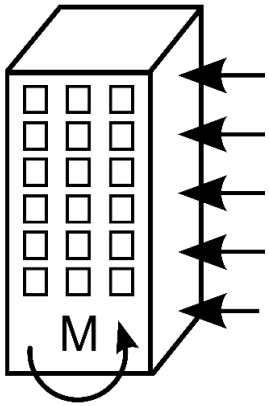


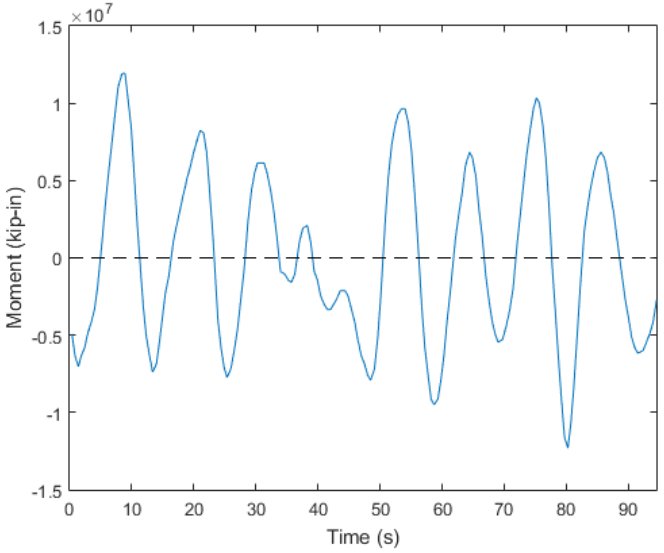




$$P_f^T = \sum_{all\ h_i} P^T(Fracture|H = h_i)P^T(H = h_i)$$



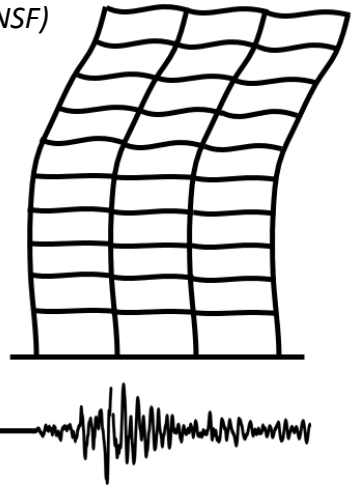


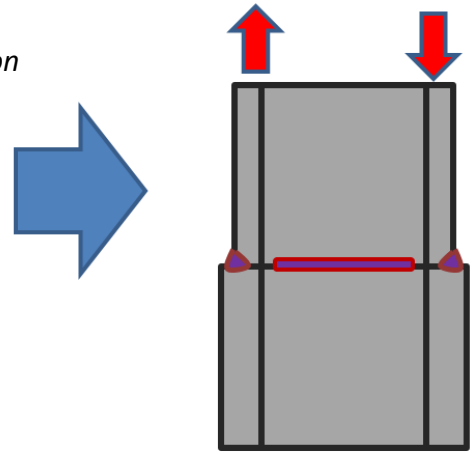


$$P^T(Fracture|H = h_i) = P\left(a(T) \geq a_{critical}|\sigma \geq \sigma_y\right)P\left(\sigma \geq \sigma_y|H = h_i\right)$$

Fracture Vulnerability of pre-Northridge Column Splices in Steel Moment Frames

Research student:
Kimberly Stillmaker
funded by
US National Science Foundation (NSF)

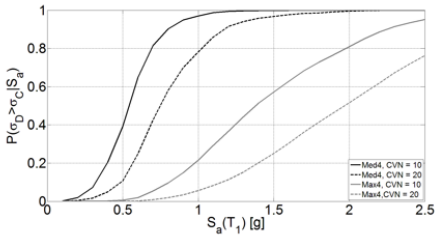


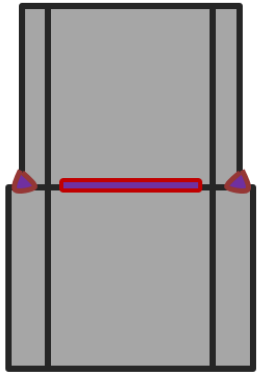


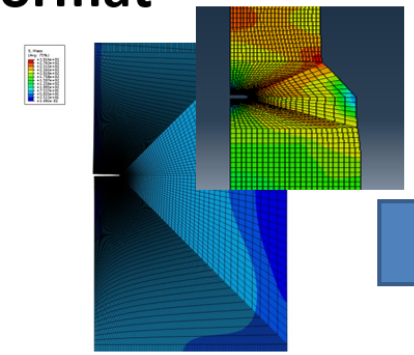
σ_{flange}

Demand Hazard

Time history analysis in PBEE format







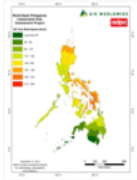
Fracture mechanics FEM

σ_{flange}

Capacity

Assessment of Multi-Hazard Vulnerability of Cultural Heritage in Developing Countries

Wind Hazard



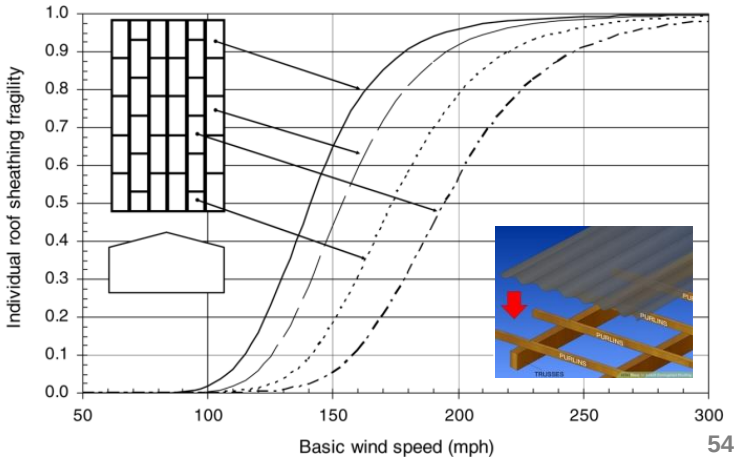
Q: Typhoon Wind Load using NSCP Equations

Assessment of Probability of Uplift Failure due to Typhoon Wind Load

Probabilistic methods (e.g., Monte Carlo)

Site Surveying + Mechanical Models

R: Estimated Uplift Resistance



Research student: **Valentina Putrino** funded by *Amar-Franses And Foster-Jenkins Trust*

Other topics…

- Tools (GMPEs, vulnerability curves, etc.) for multi-hazard risk modelling in developing countries (e.g., Philippines and Nepal), including critical structures (e.g., schools and hospitals).
- New statistical approaches for selection, modification and combination of vulnerability functions for seismic risk assessment.
- Building-specific seismic fatality estimation methodologies.
- Identifying regions with high liquefaction potential close to large populations in Europe.
- Flood vulnerability.

Thanks for your attention

Carmine Galasso
c.galasso@ucl.ac.uk

ucl.ac.uk/EPICentre

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