

# PB-Loss: a future candidate for seismic risk classification guidelines

*Gerard J. O'Reilly<sup>1</sup>, Al Mouayed Bellah Nafeh<sup>2</sup>*

*1 – Associate Professor, IUSS Pavia, Italy*

*2 – Seismic Risk Modeller, GEM Foundation, Pavia, Italy*



**IUSS**

Scuola Universitaria Superiore Pavia

Powered by



**DJURA**

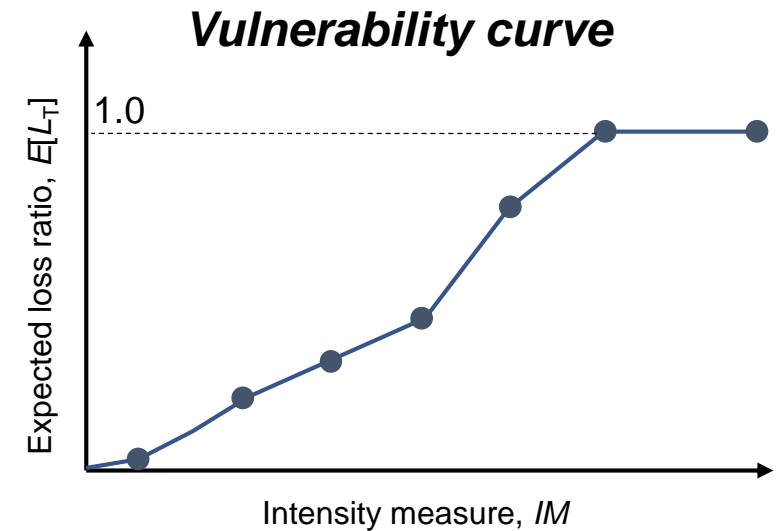
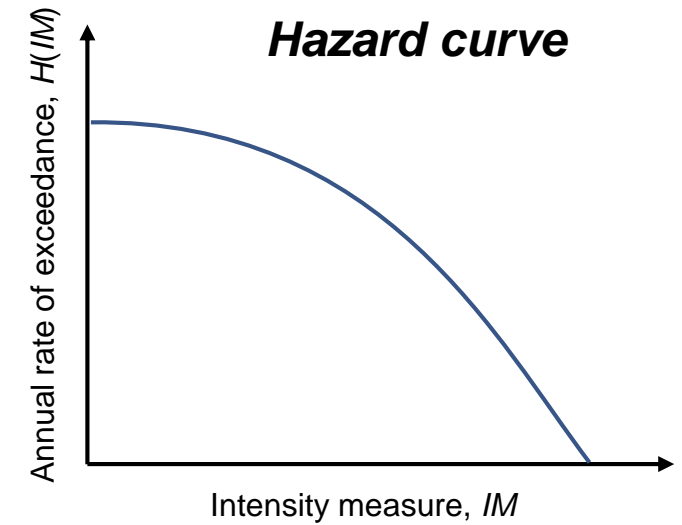
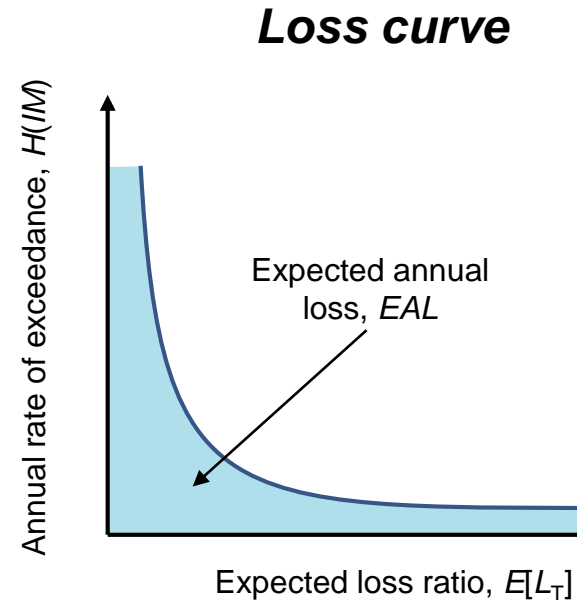
RISK-DATA-ENGINEERING

**ROSE**

CENTRE FOR TRAINING AND  
RESEARCH ON REDUCTION  
OF SEISMIC RISK

# Expected annual loss

- The computation of EAL is conceptually simple: it integrates the vulnerability and hazard curves
- The computation of seismic hazard is (relatively) standardised, with many countries or regions possessing standardised hazard models (e.g., ESHM20)
- The computation of losses is less standardised
- FEMA P-58 and other work have formalised the procedure, but many components are still subject to large variations



# Motivation

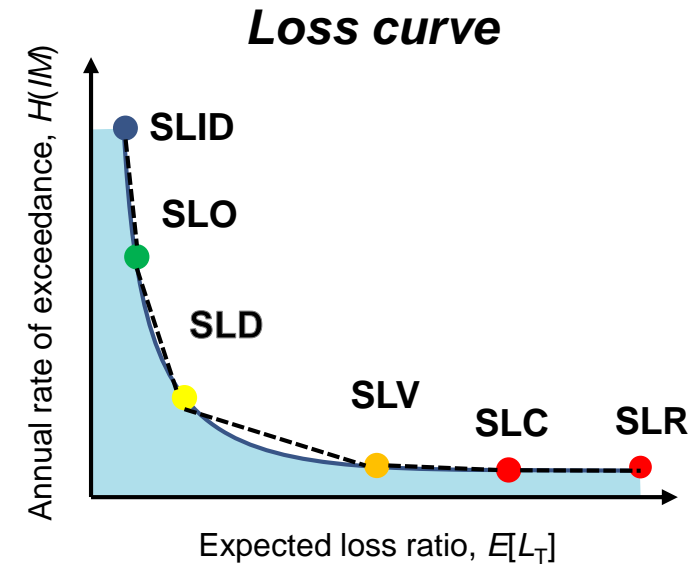
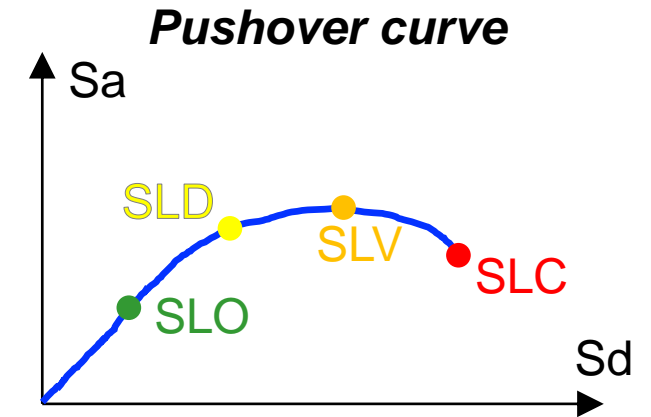
- Complex structural system
- Additional complexity for existing structures designed prior to the introduction of modern seismic guidelines
- Brittle non-ductile failure mechanisms (e.g., shear failures expected to occur in columns)
- Past earthquakes highlighted their increased vulnerability to ground-shaking



*Photos from [www.reluis.it](http://www.reluis.it)*

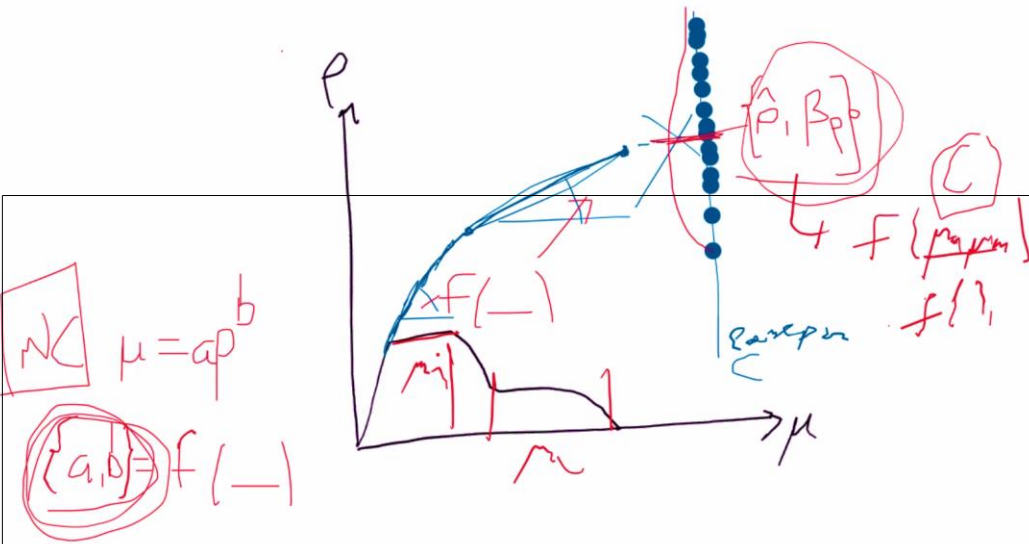
# Identifying loss ratios

Limit state	Loss Ratio	Justification
SLID	0%	Assumption
SLO	7%	Approximately half of SLD
SLD	15%	Based on 2497 buildings (1598 RC and 899 masonry) classed as either B or C via AeDES These averaged a repair cost of €196/m <sup>2</sup> , which considering €1200/m <sup>2</sup> as replacement cost, gives 16.3%
SLV	50%	Based on 760 buildings (447 RC and 313 masonry) classed as E via AeDES These averaged a repair cost of €498/m <sup>2</sup> , which considering €1200/m <sup>2</sup> as replacement cost, gives 41.5%
SLC	80%	Judgement
SLR	100%	Assumption



Cosenza, E., Del Vecchio, C., Di Ludovico, M., Dolce, M., Moroni, C., Prota, A., & Renzi, E. (2018). The Italian guidelines for seismic risk classification of constructions: technical principles and validation. *Bulletin of Earthquake Engineering*, 16(12), 5905–5935. <https://doi.org/10.1007/s10518-018-0431-8>  
Taucer F, Pinto Vieira A, editors. *Field Manual for Post-Earthquake Damage and Safety Assessment and Short Term Countermeasures (AeDES)*. EUR 22868 EN. 2007. JRC37914

# PB-Loss: Concept Doodles



IUSS

PB-loss: a future candidate for seismic risk classification guidelines  
Gerard J. O'Reilly, Al Mouayed Bellah Nafah

18WCEE, Milan, Italy  
1-5 July 2024

# PB-Loss: Basic Components



# PB-Loss: Vulnerability

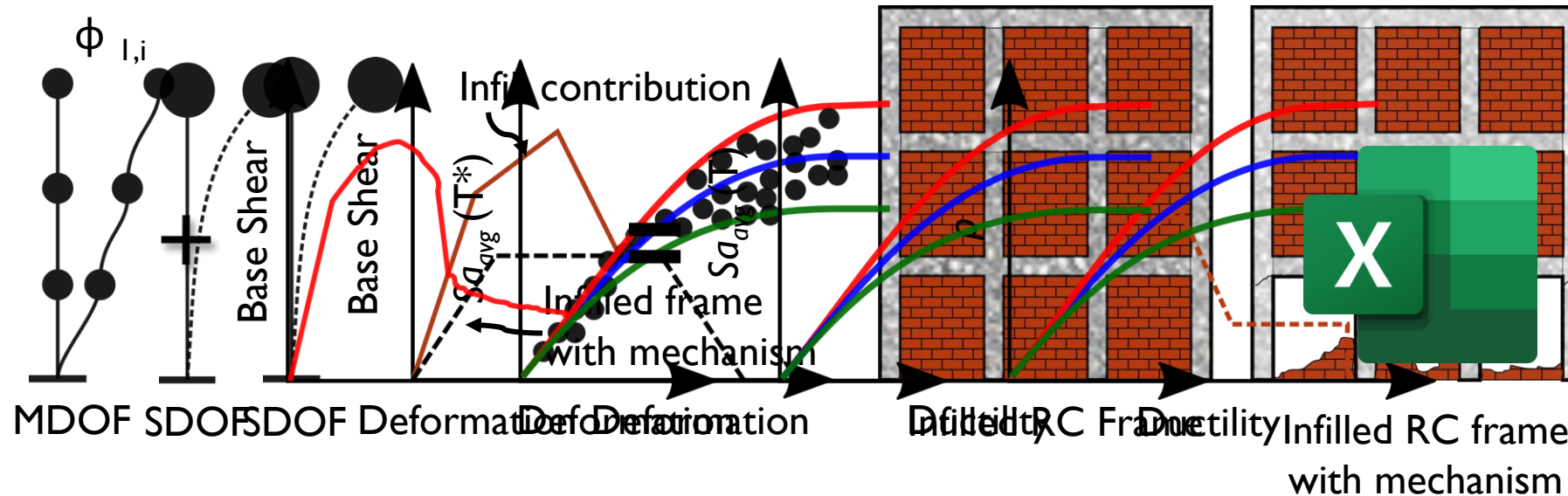




# PB-Loss: Estimation of Dynamic Capacity

- Pushover-based tool for the direct estimation of the seismic demand and capacity of infilled RC structures with multi-linear response using  $Sa_{avg}$  as IM
- Integrates  $\rho$ - $\mu$ -T relationships calibrated on a series of cloud analysis on a large dataset of sampled equivalent SDOF oscillators
- Requires low-level input (modal analysis and SPO results) to estimate probabilistically the dynamic capacity of an MDOF system
- Tool available on GitHub in Excel spreadsheet format for ease of application

Vulnerability



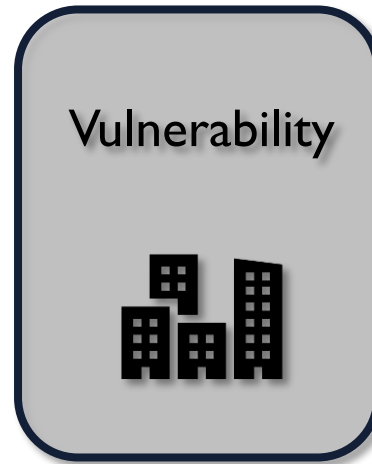
IUSS

PB-loss: a future candidate for seismic risk classification guidelines  
Gerard J. O'Reilly, Al Mouayed Bellah Nafeh

18WCEE, Milan, Italy  
1-5 July 2024



# PB-Loss: Consequences



# PB-Loss: Estimation of Direct Economic Losses

- Building-specific direct economic losses are typically expressed in terms of the expected annual loss (EAL)
- The EAL is evaluated by integrating the vulnerability curves with the site hazard

$$EAL = \int E[L_T | IM = im] \left| \frac{dH(IM > im)}{dim} \right| dim$$

Expected loss  
@ limit state IM

Economic  
Losses



# PB-Loss: Estimation of Direct Economic Losses

$$E[L_T|IM] =$$

Non-collapse requiring repair

$$E[L_T|NC \cap R, IM](1 - P[D|NC, IM])(1 - P[C|IM])$$

+

Non-collapse requiring demolition

$$E[L_T|NC \cap D]P[D|NC, IM](1 - P[C|IM])$$

+

Total replacement due to collapse

$$E[L_T|C]P[C|IM]$$

Economic  
Losses



# PB-Loss: Estimation of Direct Economic Losses

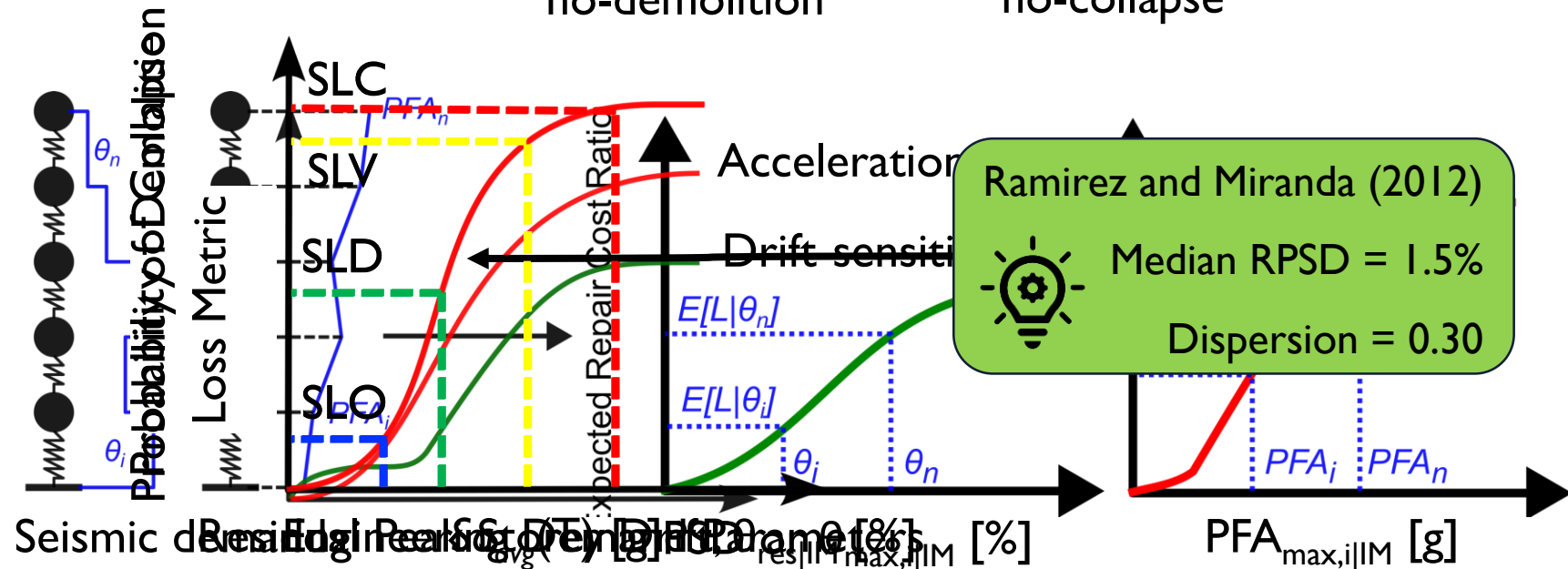
- Non-collapse requiring repair

$$E[L_T | NC \cap R, IM](1 - P[D | NC, IM])(1 - P[C | IM])$$

Repair Costs

Probability of  
no-demolition

Probability of  
no-collapse



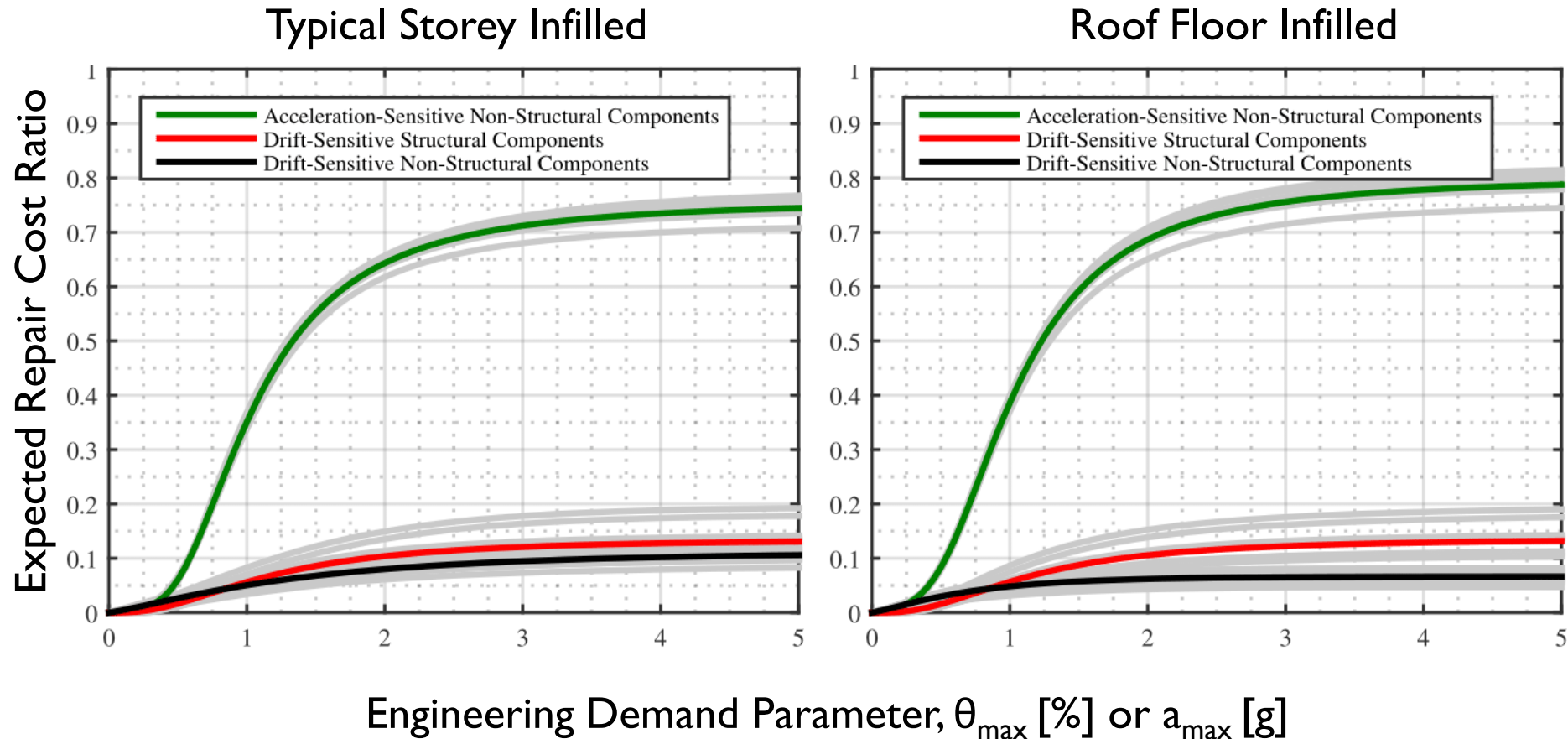
Economic  
Losses



# PB-Loss: Estimation of Direct Economic Losses

- Non-collapse requiring repair

Economic  
Losses



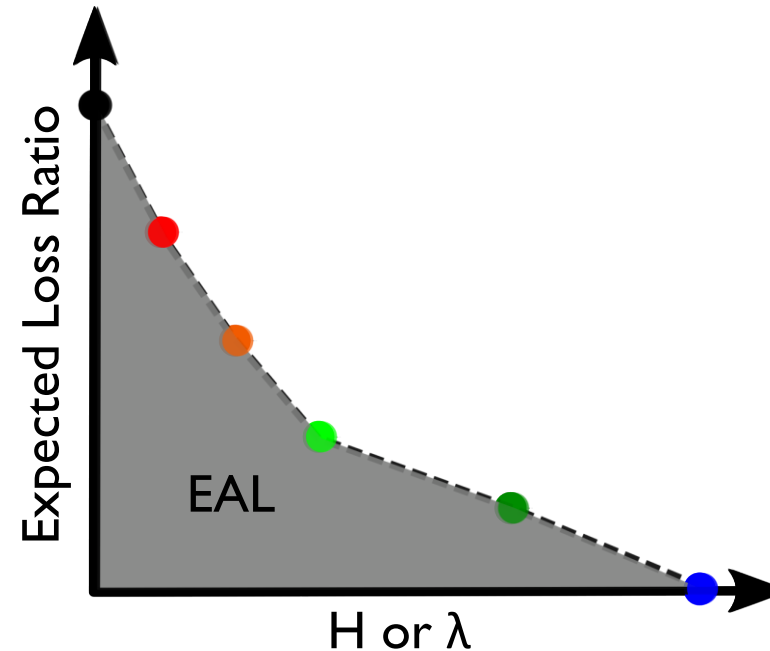
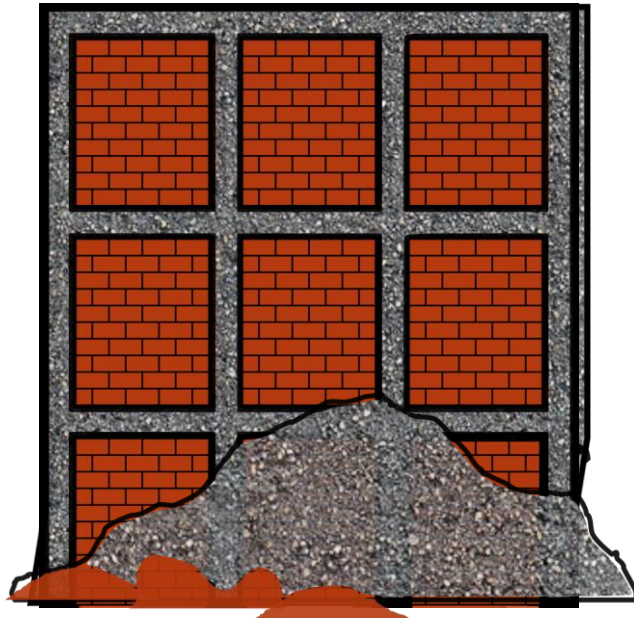
IUSS

PB-loss: a future candidate for seismic risk classification guidelines  
Gerard J. O'Reilly, Al Mouayed Bellah Nafeh

18WCEE, Milan, Italy  
1-5 July 2024

# PB-Loss: Estimation of Direct Economic Losses

- Building the Loss Curve and EAL



Zero-Loss (Undamaged)

- $H = 0.01$
- $E[L_T|ZL] = 0.0$

SLO: Operational

- $H = 0.033$
- $E[L_T|SLO]$

SLD: Damage Limitation

- $H = 0.020$
- $E[L_T|SLD]$

SLV: Life-Safety

- $H = 0.0021$
- $E[L_T|SLV]$

SLC: Collapse Prevention

- $H=0.0010$
- $E[L_T|SLC]$

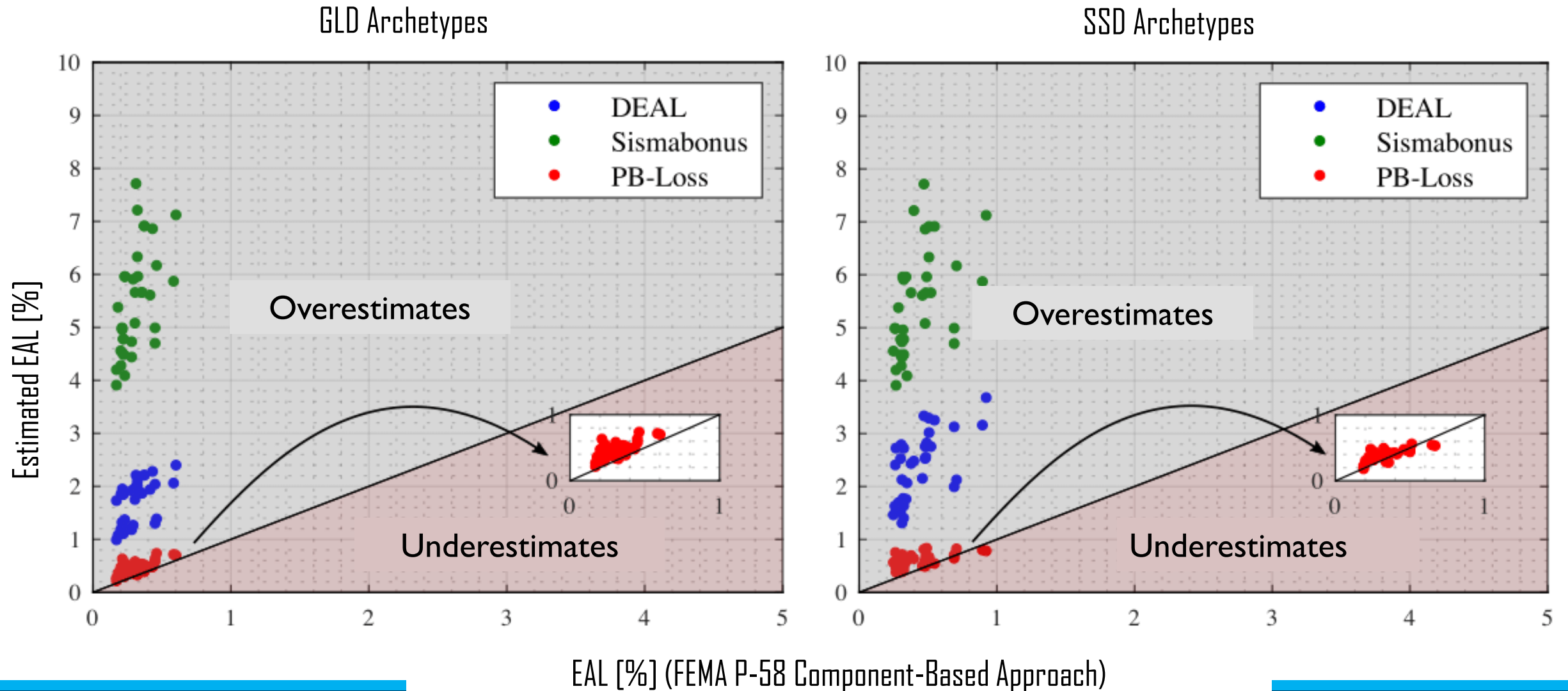
Collapse

- $\lambda_C$
- $E[L_T|C] = 1.0$

Economic  
Losses



# PB-Loss: Validation





# Conclusions: On PB-Loss

- Simplified pushover-based procedure (PB-Loss) was derived and proposed for the risk- and loss-based assessment and classification of existing non-ductile infilled RC buildings
- The procedure:
  - Integrates state-of-the-art closed-form solutions
  - Probabilistic (due consideration of uncertainty)
  - Reduces significantly the computational demand
  - Offers acceptable levels of accuracy and reliability
  - Reproducible to other building classes
  - Ready for integration with the current Italian guidelines for risk classification of existing buildings



Questions?



IUSS

Scuola Universitaria Superiore Pavia

Powered by



**DJURA**

RISK-DATA-ENGINEERING

ROSE

CENTRE FOR TRAINING AND  
RESEARCH ON REDUCTION  
OF SEISMIC RISK