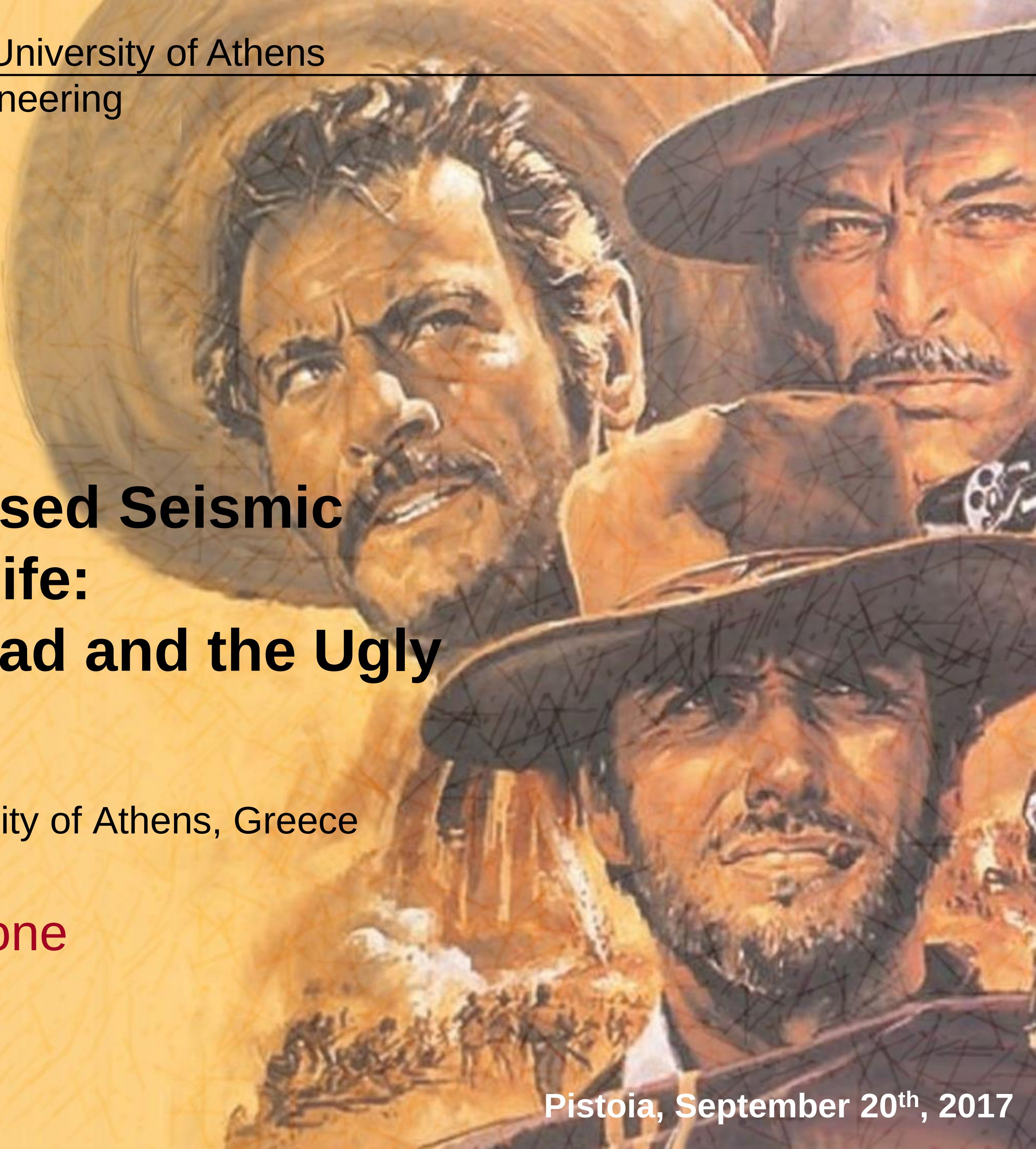

Performance-Based Seismic Design in Real Life: The Good, the Bad and the Ugly

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OPENING SCENE
REMINISCING UPON DEFINITIONS

Problem statement

Izmit refinery (Kocaeli 1999)

Japan (Tohoku 1999)

How to design critical facilities for the desired seismic performance?

What is a performance objective?

A triplet of values

1: Capacity: An EDP threshold to define LS

2: maximum allowable MAF of exceeding C

$$\lambda_{x\%}(D > C) < \lambda_O$$

3: confidence level of meeting objective vis-à-vis epistemic uncertainty

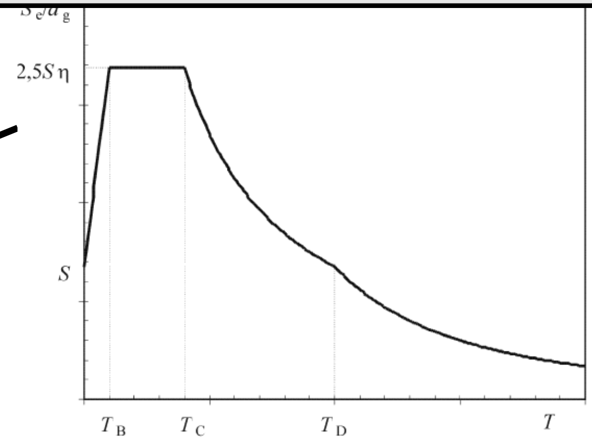
Examples

- direct monetary losses exceeding C = 500,000€ with a maximum MAF of λ_O = 0.0021, or 10% in 50yrs, at a confidence of x = 75%;
- downtime exceeding C = 1 week with λ_O = 10% in 10yrs, at x = 60%;
- no more than C = 20% of the columns enter Damage State 3 with λ_O = 5% in 50yrs, at x = 90%;
- maximum interstory drift less than 2% with λ_O = 10% in 50yrs, at x = 75%.

THE BAD:
NO PROBABILITY MEANS NO PERFORMANCE

BAD: Design code approach (EN1998)

Select: T_1,10%/50yr $S_a(T_1)$



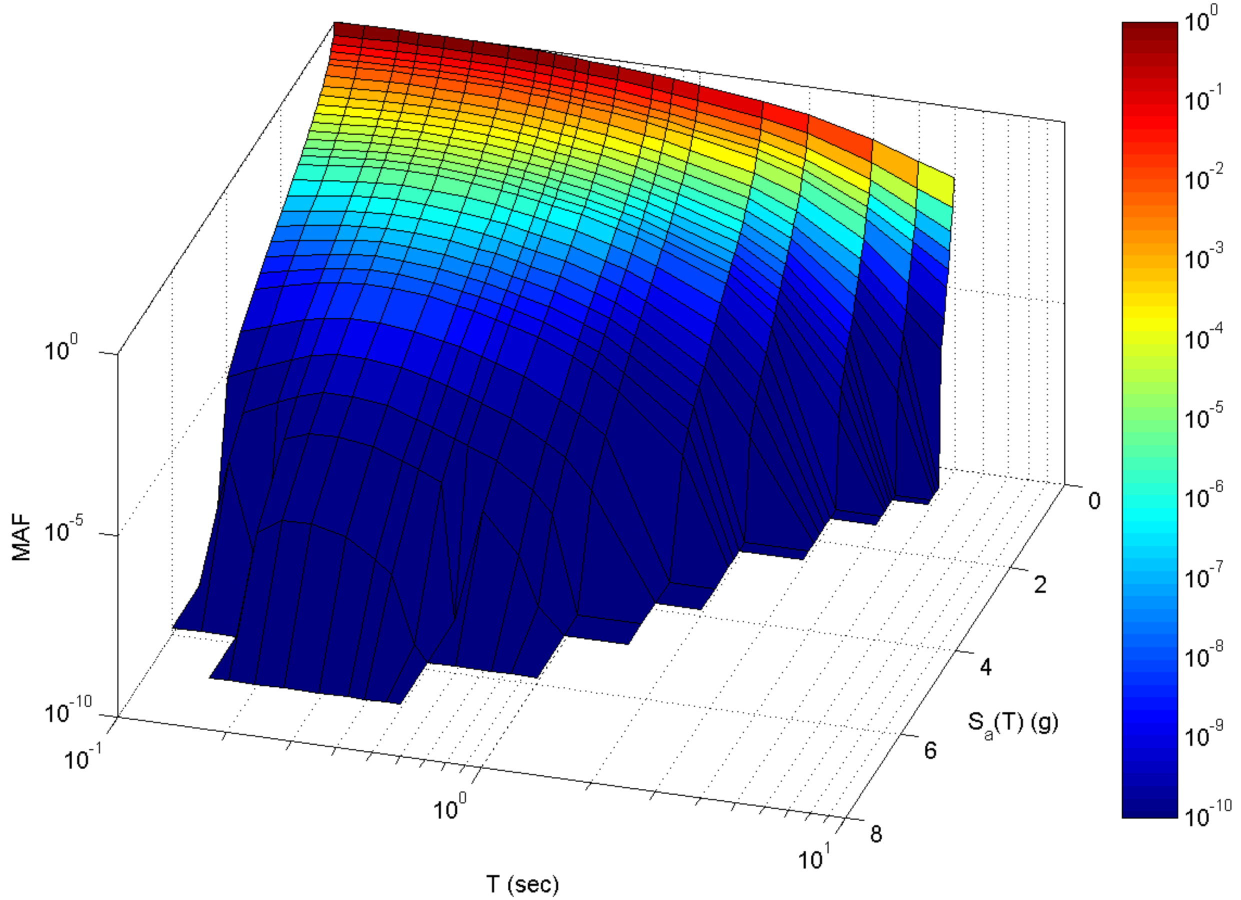
Strength Check: $S_a(T_1)$

Stiffness Check: 0.4 - 0.5 ×$S_a(T_1)$

Member sizing

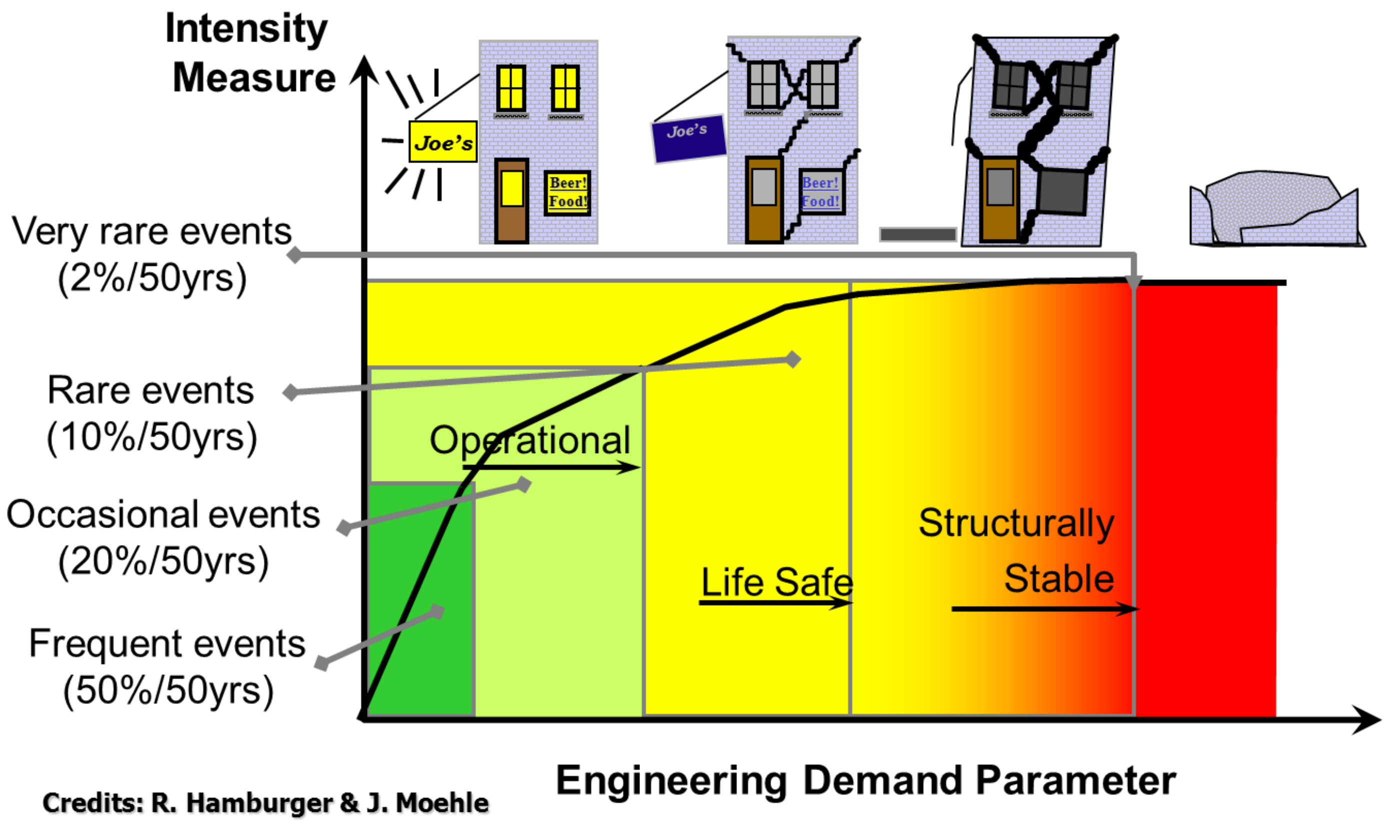
Final Design (?)

Issue 1: Design spectrum ≠ Seismic hazard



Seismic hazard surface, hazard curve & UHS

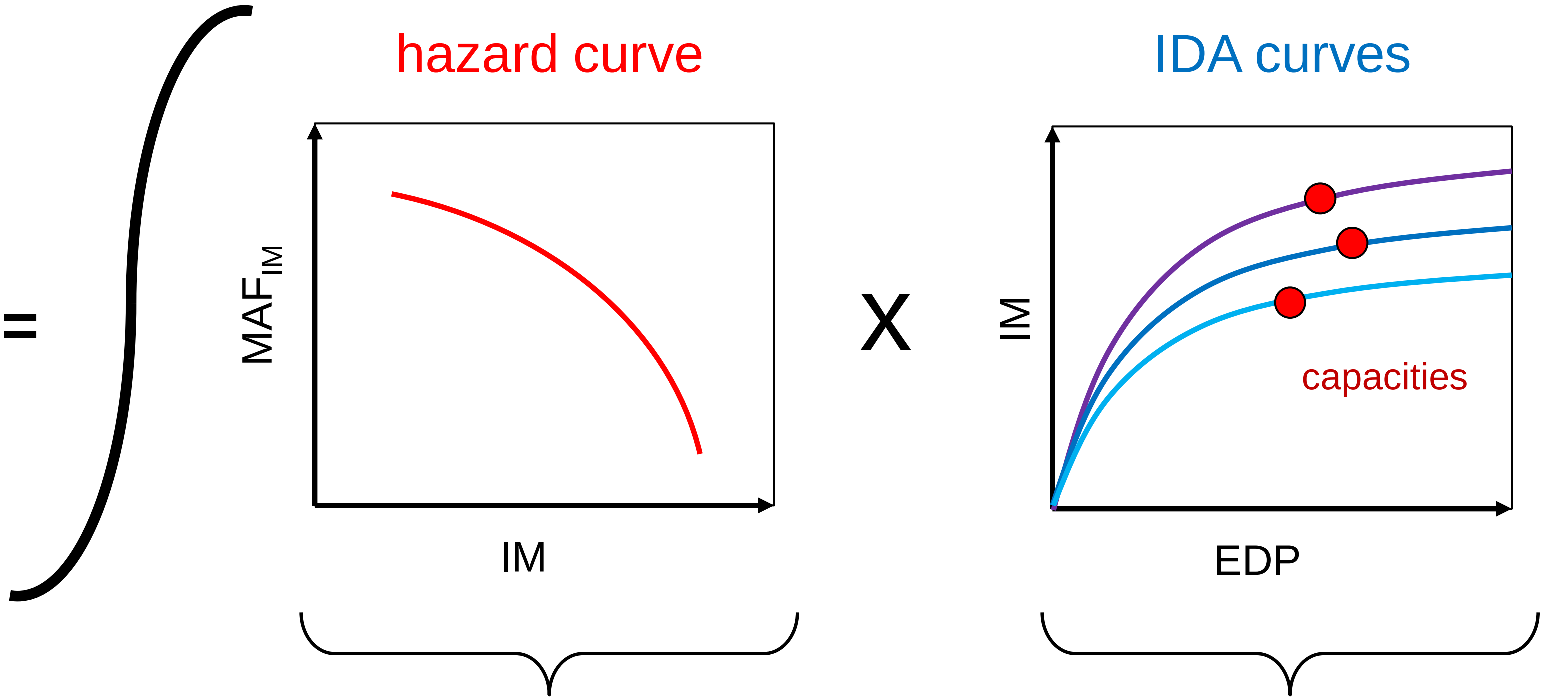
Issue 2: Where is the variability?



Unfortunately, each record has its own IDA curve

Variability cannot be ignored

MAF_{LS} =

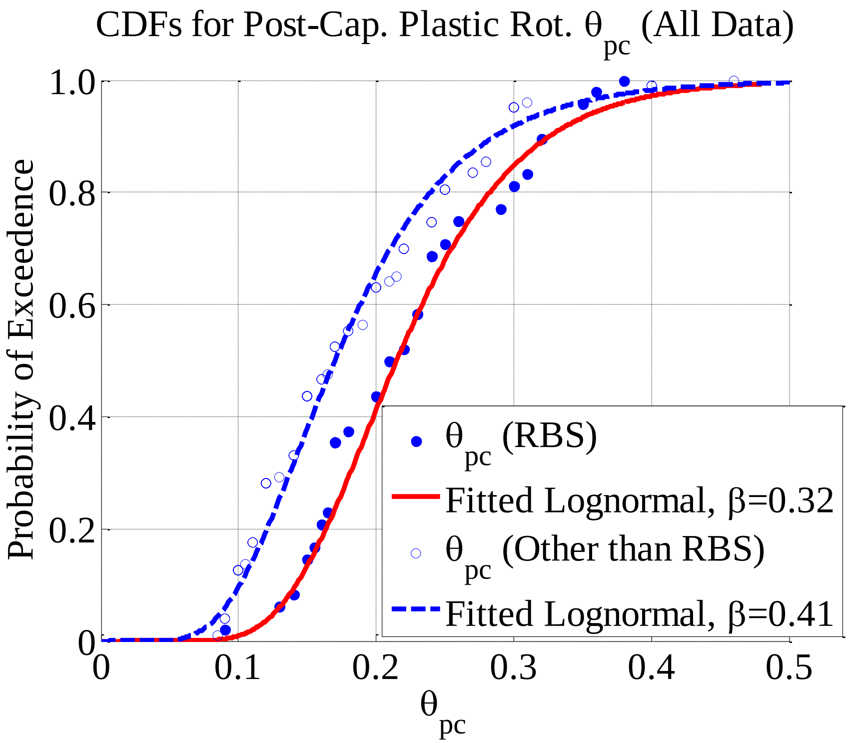


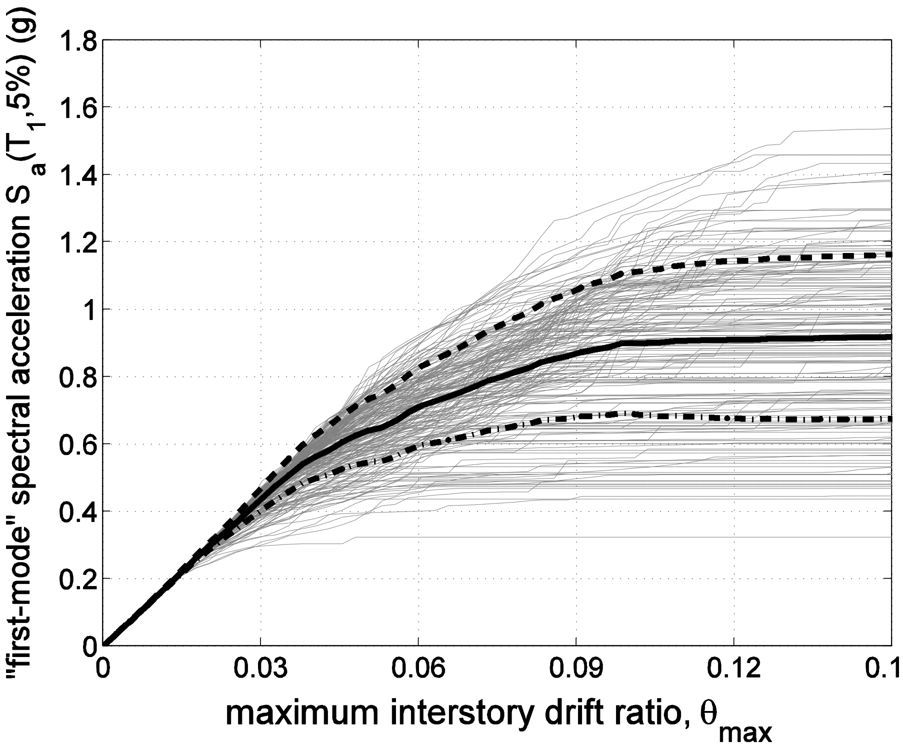
PSHA

Structural Analysis

- Frequent lower intensity earthquakes also do damage
- MAF of damage > MAF of $S_a(T_1)$!

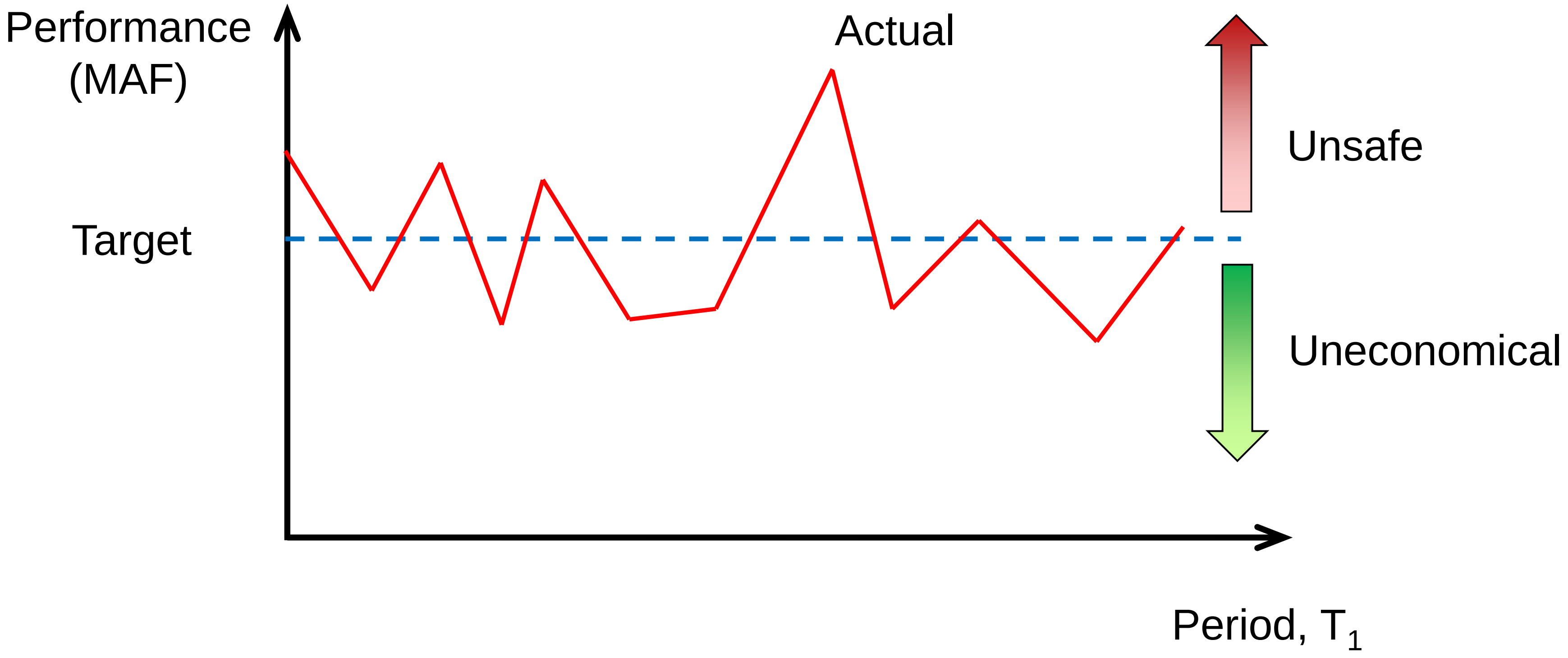
Uncertainty should not be ignored





- Plastic rotation capacity of beam-column connections (Lignos & Krawinkler)
- Potential realizations of dynamic response IDA curves for 9-story steel frame

Result: Inconsistent / Unknown Safety



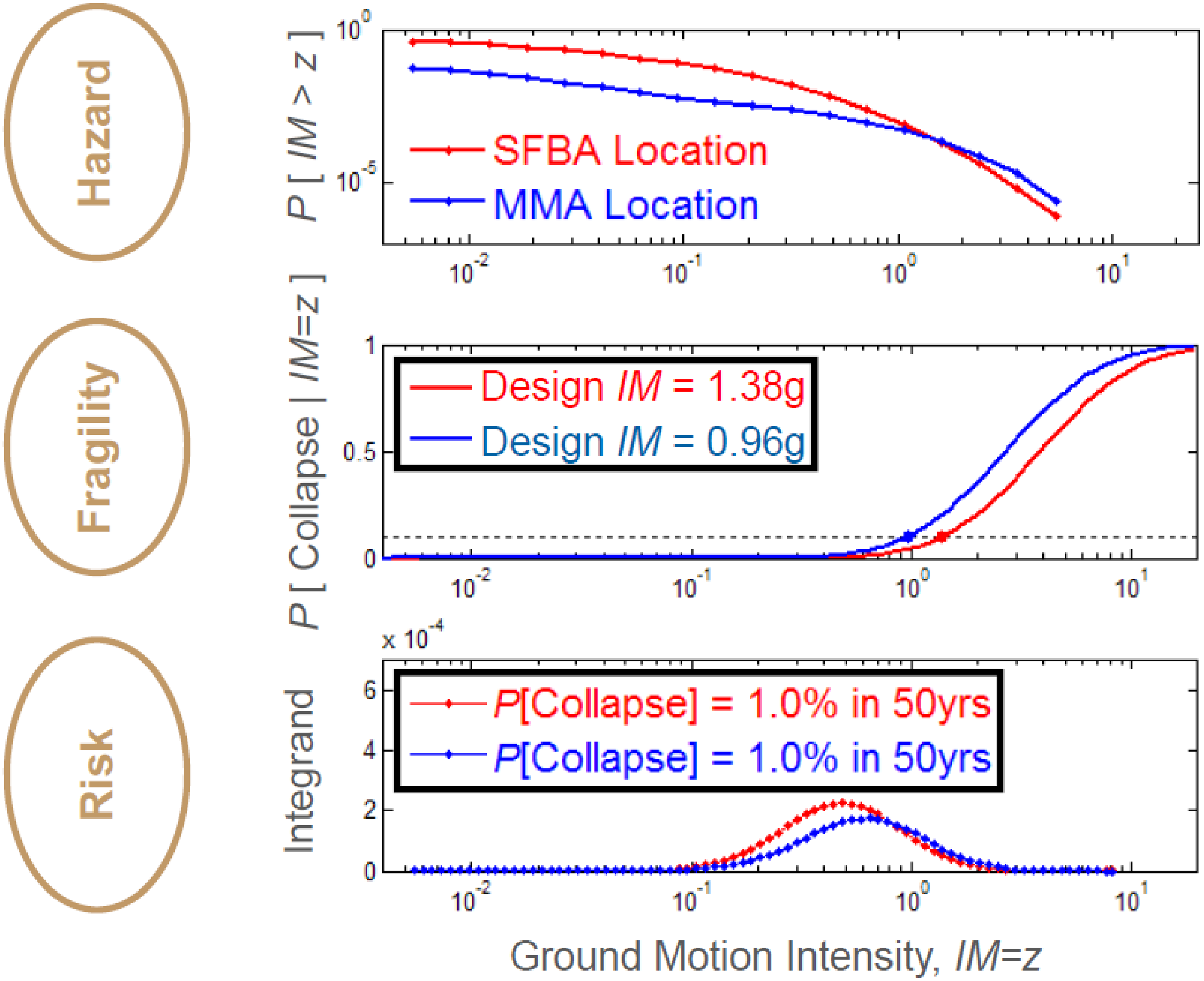
Behavior factor, overstrength, nominal material properties add conservativeness

BAD: Displacement-based design

- Is Stefano Pampanin in the audience?

- Confusion dates back to SEAOC Vision 2000
… and even Priestley (2000) "Performance based seismic design"
- Saying that your objectives are expressed in terms of displacement is not the same as PBSD
- Displacement-based design is not that bad, it is simply not PBSD
- That does not mean it cannot be upgraded….

Another BAD candidate: Risk targeted spectra

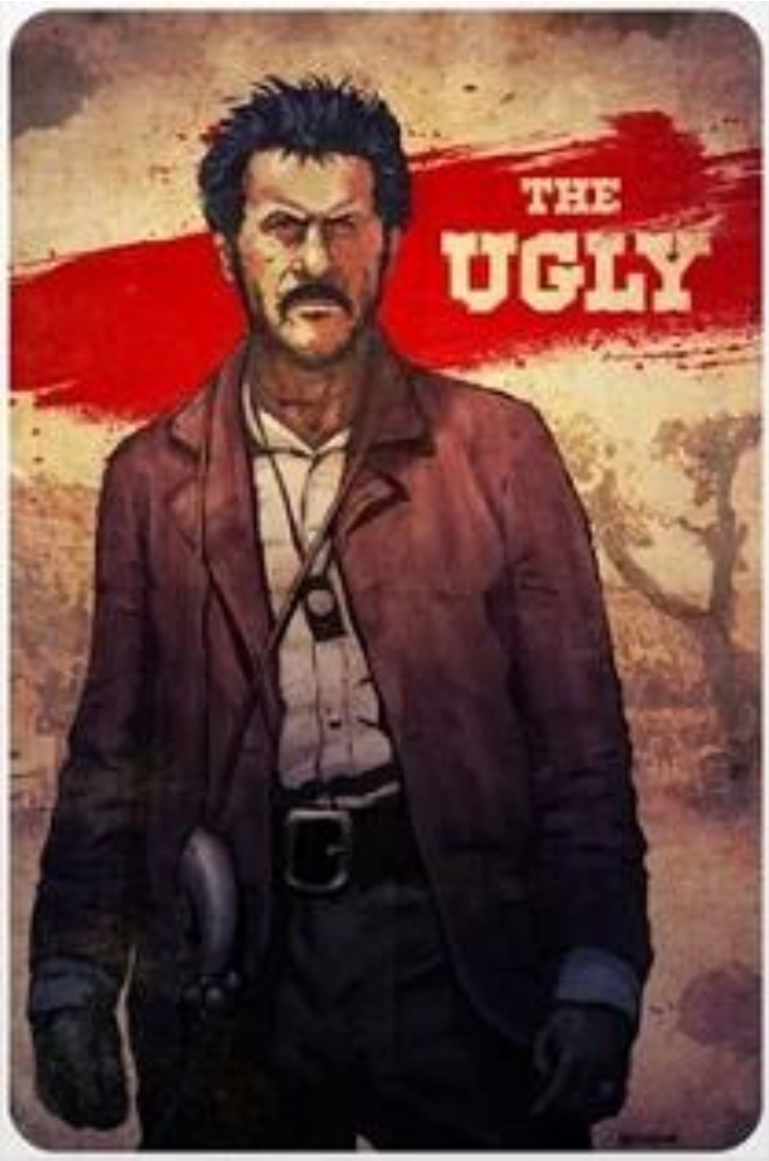


$$P[Collapse] = \int_0^\infty \frac{dP[Collapse|IM=z]}{dz} P[IM>z]\,dz$$

RT spectra ≠ performance

- They do account for hazard and risk…
  … but for all structures at the same time
- They are site-specific but building-ignorant
- I like RT spectra, just not on their own and not for performance-based design
- We will take another look at them later on…

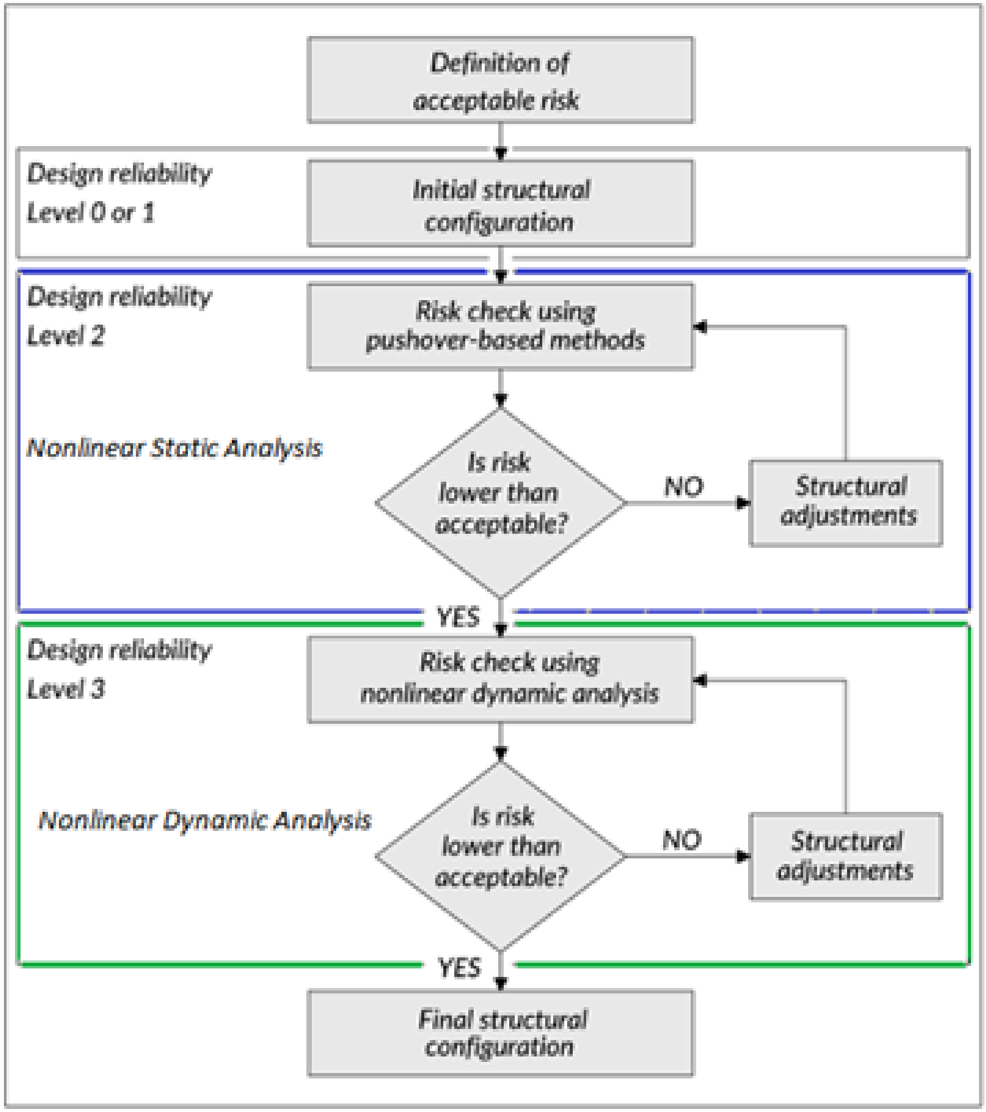
THE UGLY:
WIN SOMETHING – LOSE SOMETHING



Performance-Based Design = Iterations

- Set performance targets
- Determine preliminary design (not always easy)
- Assess performance
- Iterate to convergence
  - Redesign and reassess in each cycle!
- Expensive!

UGLY: Iterate without guidance

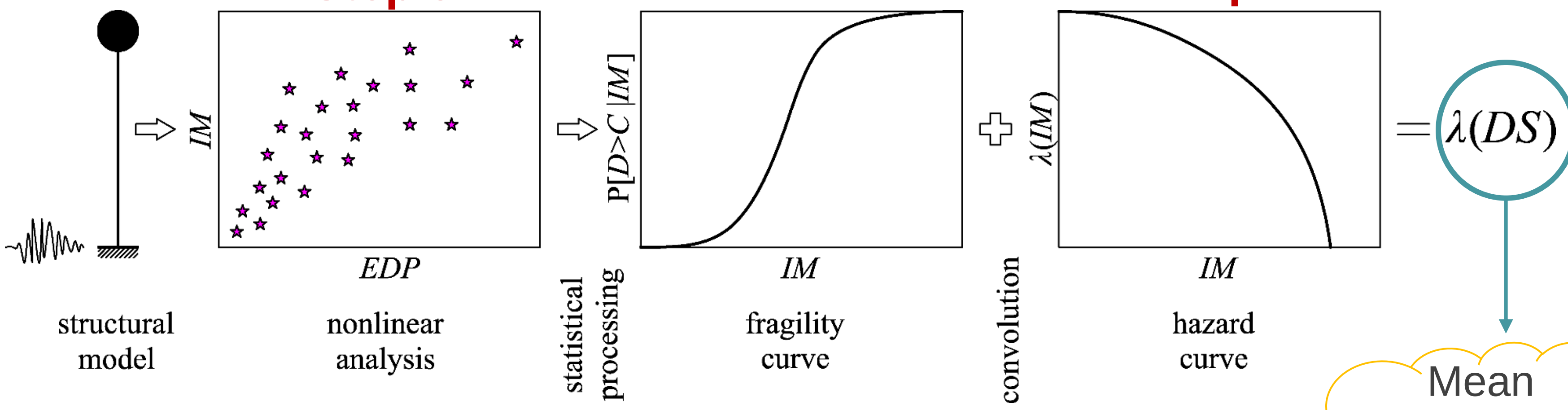


- Trial and error?
  (trust user "expertise")
- Genetic-style optimizer
  (shotgun approach)
- Iterate first on pushover then on dynamics?
  (Dolsek and coworkers)

Sinkovic et al. 2016

UGLY: Risk-based q-factor & RT-spectra guidance

Step 5 **Step 1**



Mean Annual Frequency

Step 6

- λ(LS) < **10%**/50years → q-factor ✓
- λ(GC) < **1%** - **2%**/50years → q-factor ✓

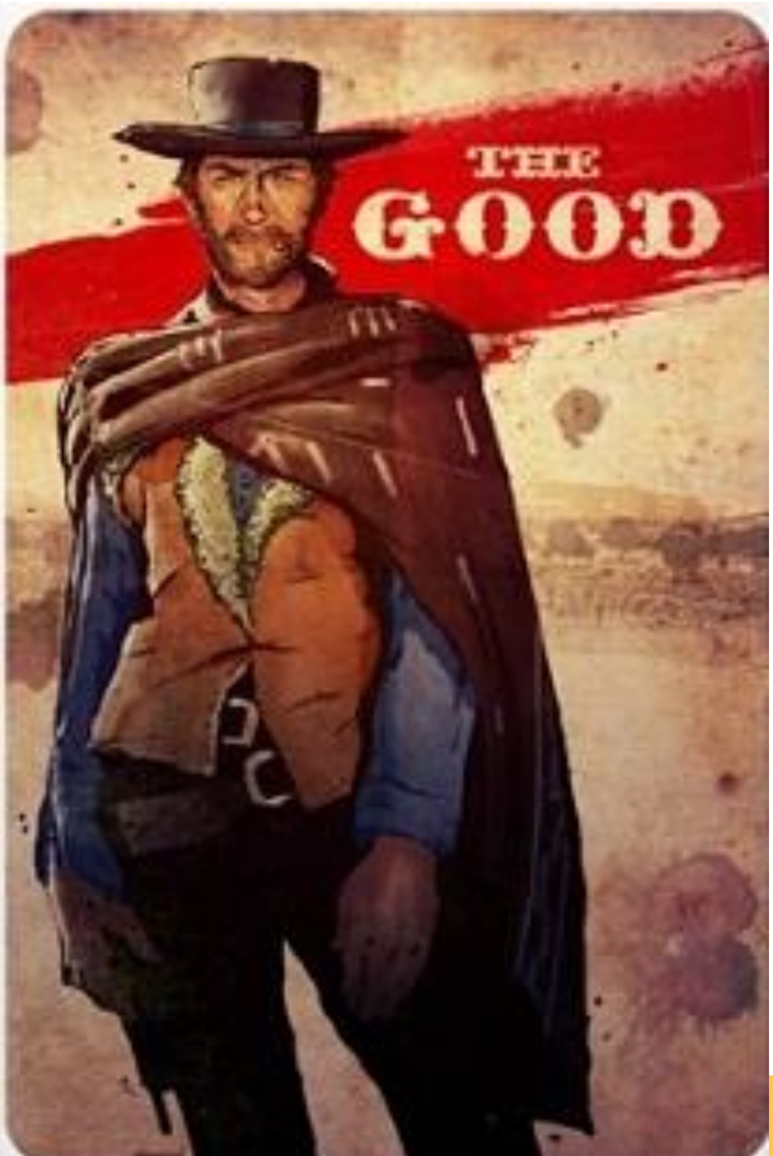
acceptable but maybe non-optimal

➢ otherwise→ q-factor ✘ → Iterations

Rough but workable

- Iterations are done by academics, not engineers
- The more fine-grained the q-factor is, the better
- Unfortunately, can only work for hard-wired objectives
- In the end, some proper nonlinear assessment would help

THE GOOD:
ALWAYS DELIVERS



How to pick a "design invariant" proxy (T_1?)

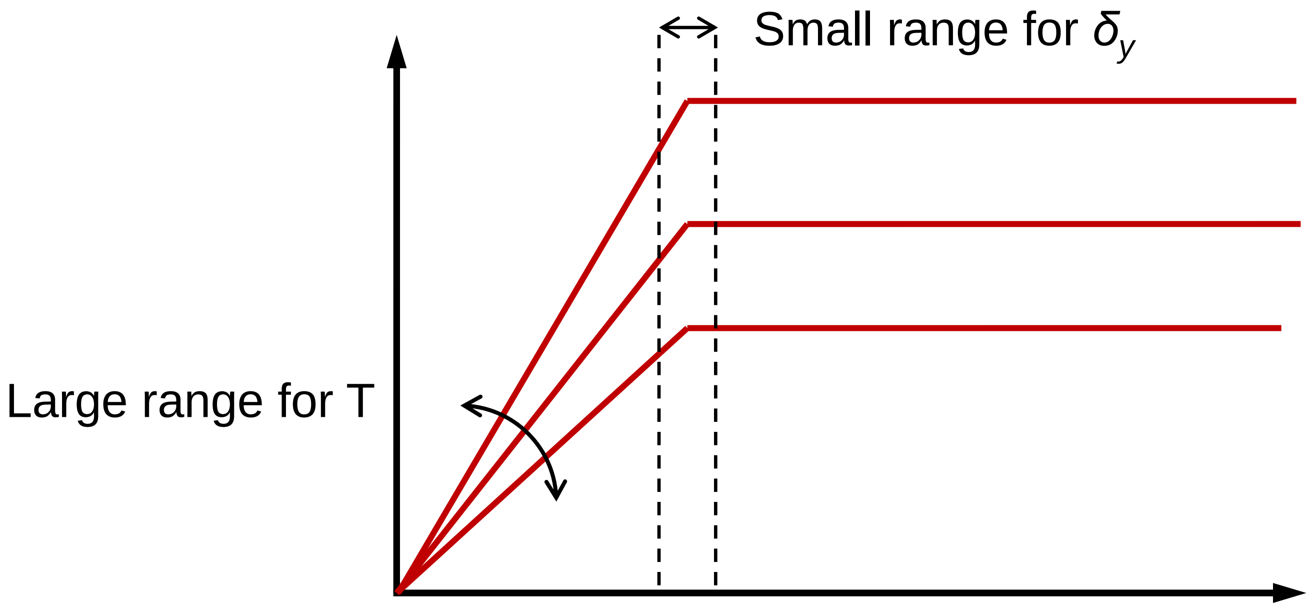
- Easy with experience (usual design case)
- Difficult with novel structures or new requirements
  - Example for ELASTIC 1DOF oscillator:
  - Iterate:
    1. Select initial T
    2. Find $S_a(T)$ from UHS at x% in 50yrs
    3. Calculate new period $T = 2\pi\sqrt{\delta_{\lim} / S_a}$

Potential proxies

- Equivalent linear MDOF? (Franchin et al.)
  - Not trivial. Works best with automated software
- Equivalent nonlinear SDOF
  - Assume constant T_1 per cycle (force basis)
  - Assume constant d_y per cycle (yield disp. basis)

- Is Stefano Pampanin in the audience?

Yield Displacement Basis



- Forget period, let's do yield displacement!
- "Constant" given system mass, general dimensions & material
- Largely independent of strength (Moehle, Priestley et al, Aschheim)
- Some systems (rocking walls?) may work better with constant T_1

Use equivalent nonlinear SDOF with variability

SPO2IDA: Moderate periods

Valid for firm soil, 5% damping and moderate periods

SPO data

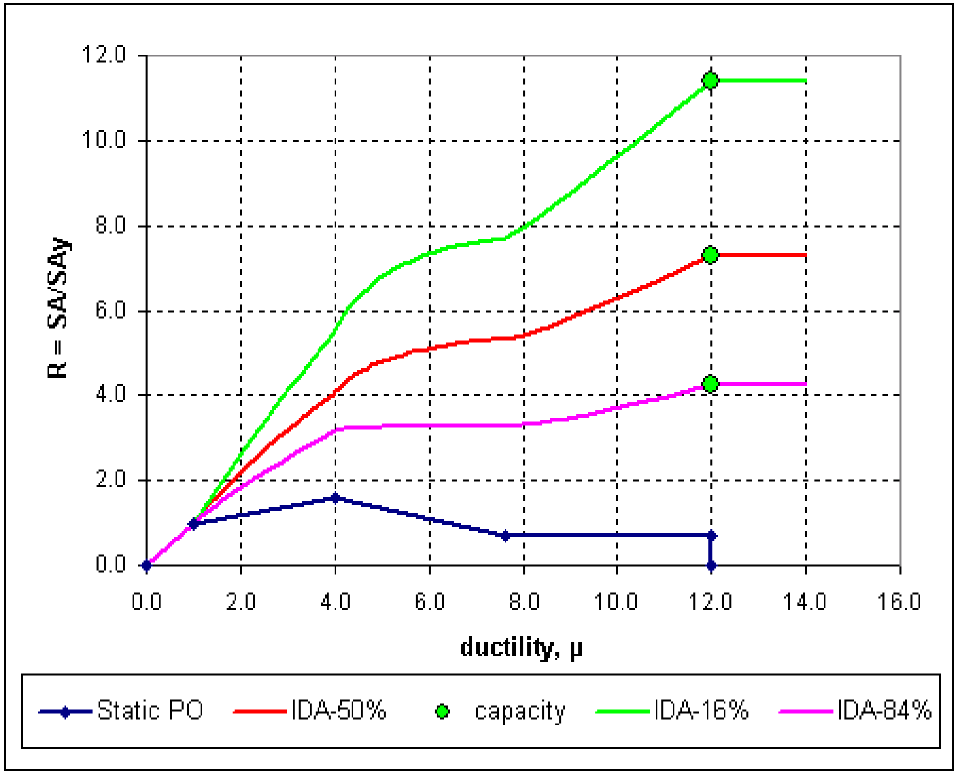
Sayield	0.1036	0.9291
Θyield	0.06	0.018

Segment	Static PO SA/SAyield @ end	Static PO μ @ end
	0.00	0.00
Elastic	1.00	1.00
Hardening	1.60	4.00
Softening	0.70	7.60
Res. Plateau	0.70	12.00
Collapse	0	12.00

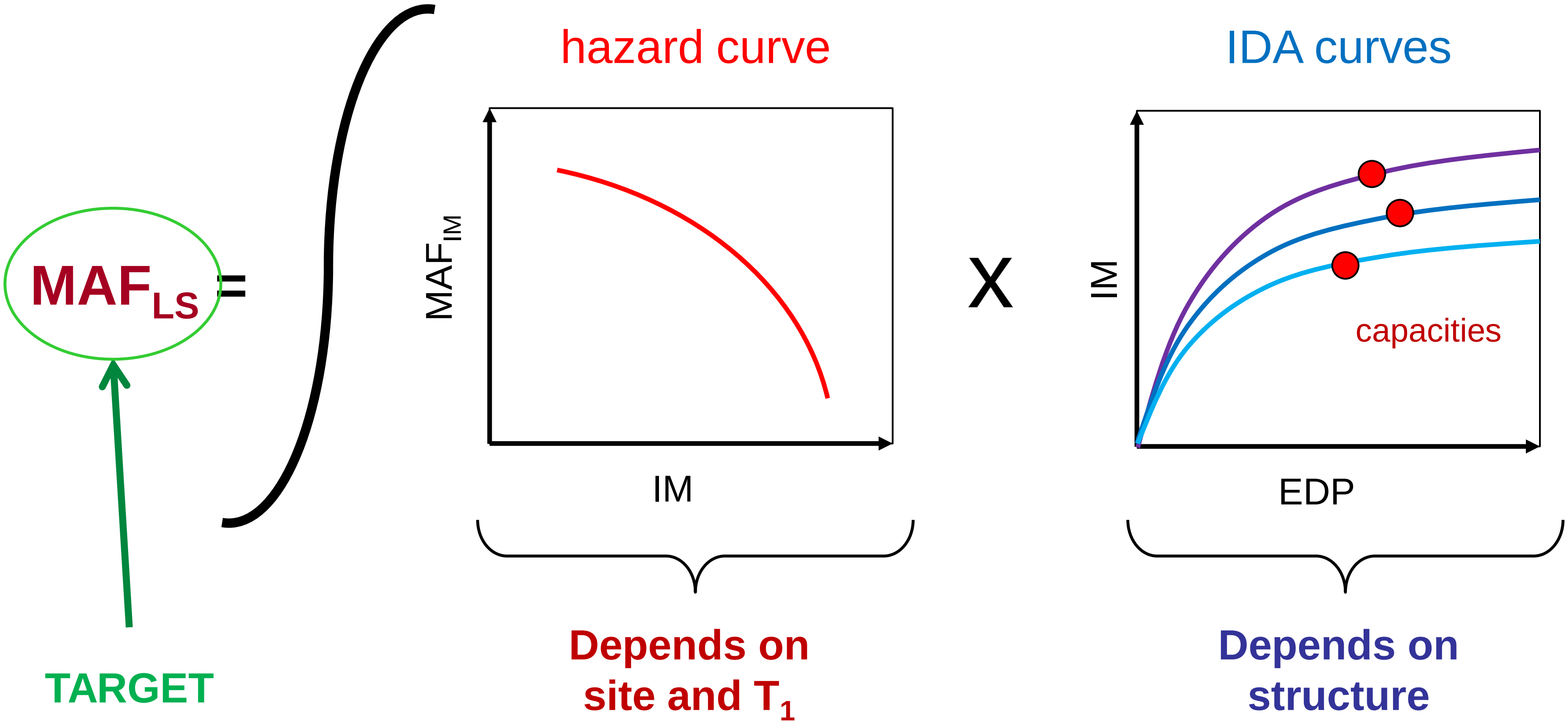
% in SA terms	16%	50%	84%	ISO
				Ad
Capacity μ	12.00	12.00	12.00	Csr
R	11.39	7.29	4.24	Cdr
				Cr

Controls

Hardening μ	4
Hardening slope	20%
Softening slope	-25%
Residual plateau	70%
Fracturing μ	12.0
Period T (sec)	1.00
Damping	5.0%

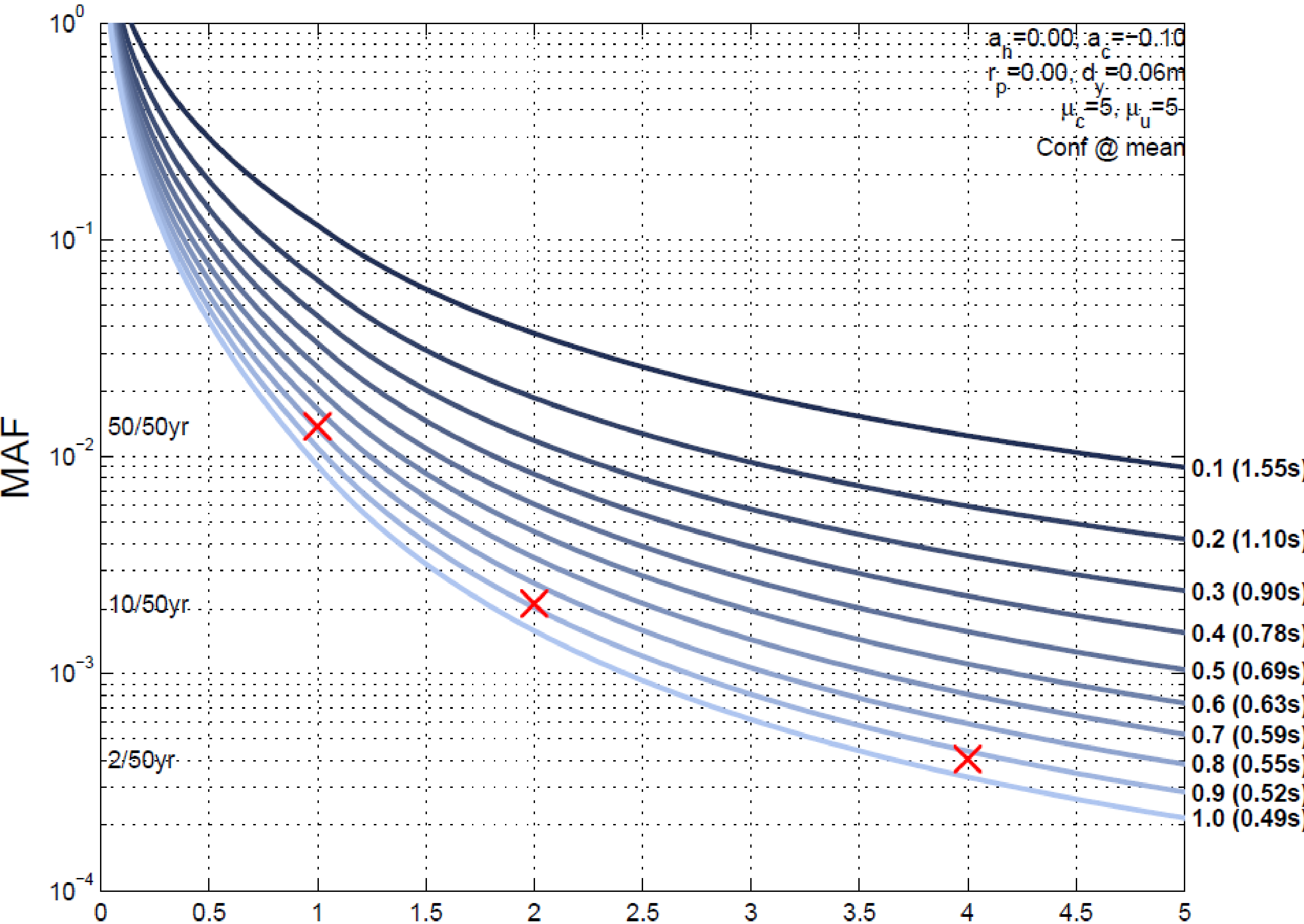


“Invert” Performance Integral



- Structural parameters: Backbone shape, Base shear coefficient, dy
- Limit state definition: MAF and ductility
- Map entire parameter space to solve

All together: Yield Frequency Spectra



Given
- site
- backbone shape
- δ_y

Get
- *Base shear*
- *Period*

How to compute?

- Numerically
  - As S_{di} hazard curves (Inoue & Cornell, Jalayer & Cornell, Ruiz-Garcia & Miranda etc)
  - Dynamic analysis or R-μ-T with dispersion (e.g. SPO2IDA)
- Analytically
  - Invert Cornell & Jalayer or DV's closed-form solutions

$$C_y = \frac{1}{g\mu_{lim}^{1/b}} \cdot \exp\left[\frac{1}{2k_2}\left(-k_1 + \sqrt{\frac{k_1^2}{\phi'} - \frac{4k_2}{\phi'}\ln\frac{P_o}{k_0\sqrt{\phi'}}}\right)\right]$$

Introduce uncertainty

- Assume it adds to the total variability
  - Not perfect: Bias is also possible
  - ….. but tough to quantify
- Use “required confidence” to guard against uncertainty
  - Say 90-95% against brittle failure mechanisms
  - Only 60-75% for ductile, low-consequence failures
- Tune design to user and problem requirements

A code-compatible approach

- Invert Cornell & Jalayer equations
  - Adopt power-law fit for hazard, IM vs EDP response
  - Derive solutions given the design spectral shape
- Constant accel: $C_y = \dfrac{S_{amax}}{g\mu_{lim}^{1/b}} \cdot \exp\left[\dfrac{k_1}{2b^2}\beta_{T\theta}^2\right]$
- Constant vel: $C_y = \left(S_{amax} \cdot \dfrac{T_c}{2\pi}\right)^2 \dfrac{1}{\delta_y g \mu_{lim}^2} \exp\left[k_1 \beta_{T\theta}^2\right]$
- Constant disp: "Any" result is ok!

THE FINAL DUEL:
THE GOOD DOES NOT ALWAYS WIN IN REAL LIFE

Can we let the BAD win?

- Bad methods are currently dominating
  - Will continue to do so for run-of-the-mill design
  - …not everybody needs accurate performance
- Good methods are lovely and will probably get better
  - Still, this does not mean engineers or codes will adopt them
- Ugly concepts may have a better chance
  - Create automated optimization (and modeling) software?
  - “Hack” the code with RT-spectra and risk-based q-factors

What is my opinion as a cinephil?

Academics love perfection, but in real life we need to be practical. Sometimes “better” is the enemy of “good enough”

So Ugly it is going to be for quite a while

For sure though, please do not let the Bad guy win

End Credits

The eternal genius and running commentary of Prof. Ulysses R. Garbaggio

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Collaborators in crime: Mark Aschheim, Paolo Bazzurro, Michalis Fragiadakis

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