National Technical University of Athens
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Industrial structure design on the edge of seismic performance:
Lessons learned from three little pigs

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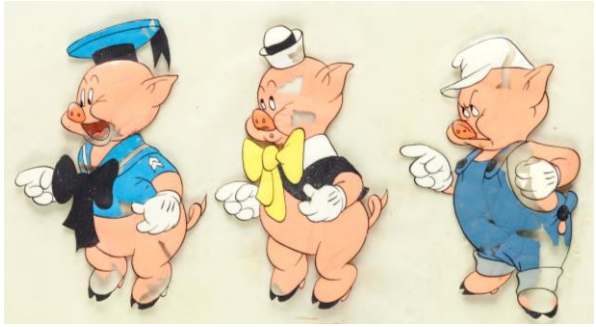
SeDIF Conference

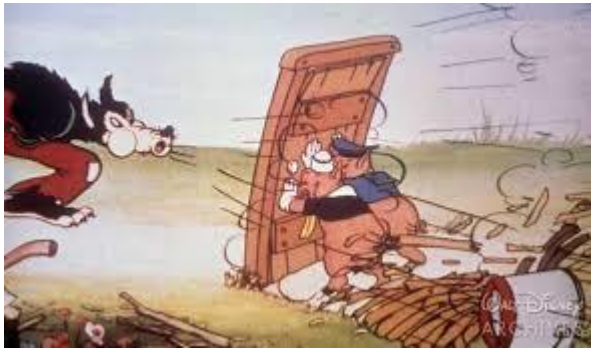
Once upon a time….

- Three little pigs
  - Three little engineers
- Three industrial agriculture buildings
  - Three different structural systems
  - Fiber, Wood, Masonry



Judgement day arrived

- One extreme (Big & Bad) hazard
  - Well known and designed for!
  - Code design was followed
- Two collapsed
  - Design error?
  - Construction error?
  - Hazard improperly quantified?
  - Substandard material?
- History blamed the two engineers

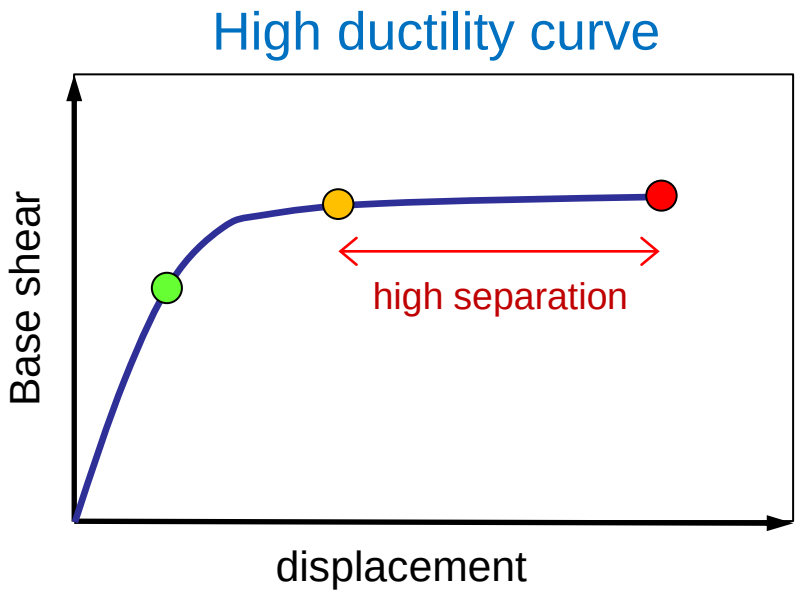


But what really happened?

- A historical & engineering investigation was conducted
- The verdict is clear
  - Two well-meaning engineers mislead by a well-meaning code
  - The margin of safety was never what it should be
  - Why were the engineers blamed?
  - Why nobody saw this?
  - What was the role of the masonry lobby?

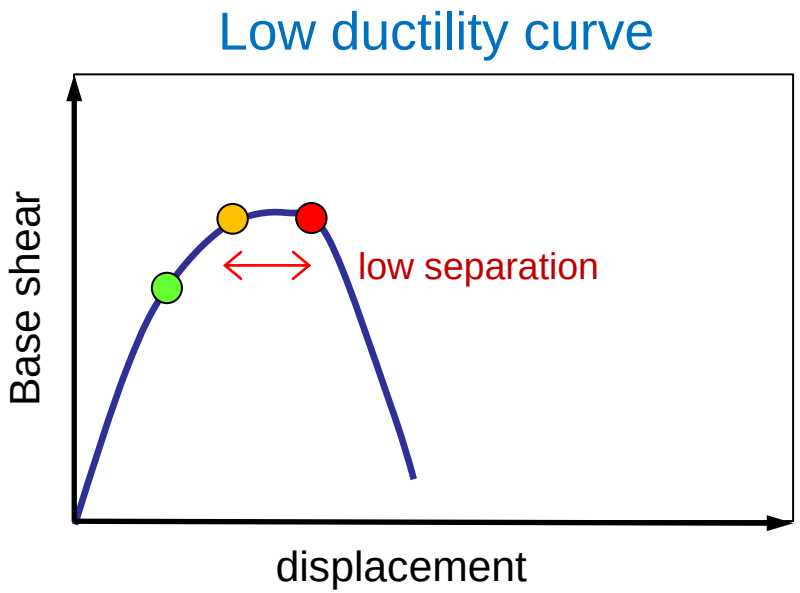
- Let’s rewrite history and clear the names of these innocent little pigs

Most research deals with high-ductility



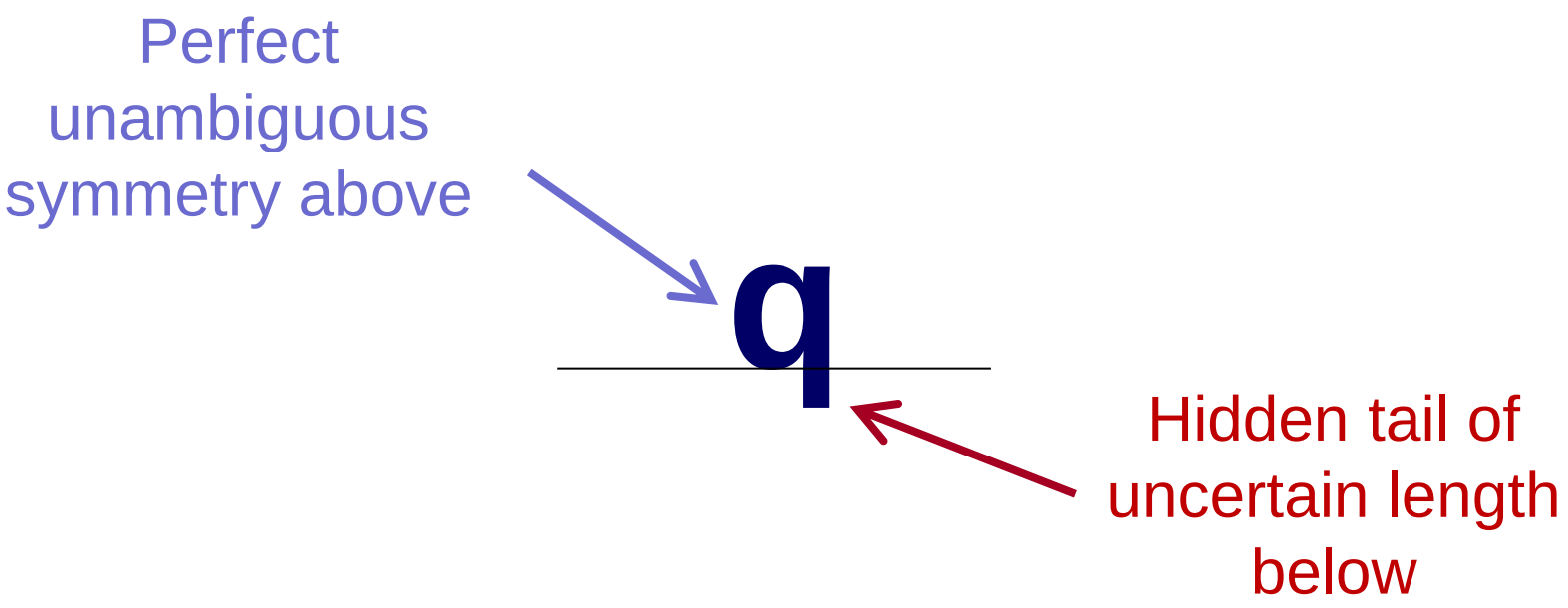
- Our notions on q developed on high-ductility structures
- Capacity design has considerably reduced the potential failure mechanisms
- Many sources of uncertainty removed ► Robustness
- Design for SD and claim to cover CP!

Industrial structures, low ductility



- High-ductility notions **do not** translate to low-ductility
- Many sources of uncertainty close to collapse
- Not obvious that design for SD covers CP
- Overstrength & **informal** dissipating mechanisms ► q
- Design optimization can **hurt** robustness

Before quantifying, we need understanding



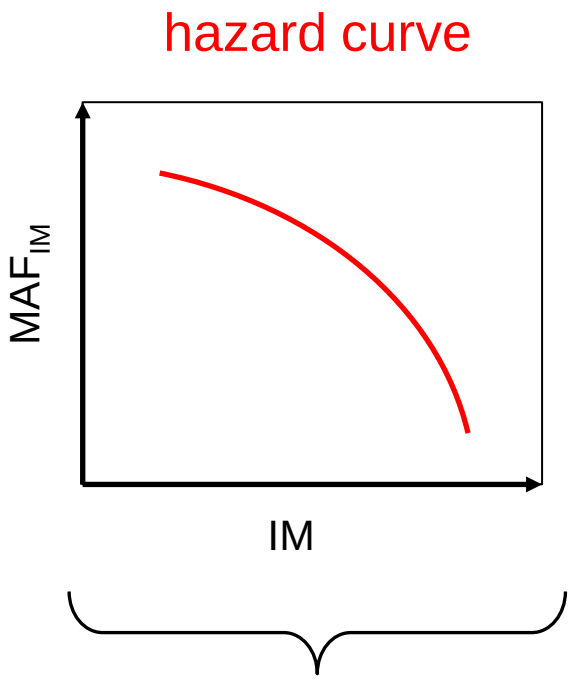
- Let's try figuring out what **should be** contained in this hidden tail before trying to estimate it.
- Then we can quantify and present it to professionals as a perfect value to use, **hiding** the rest under the surface

How to design low-ductility @ edge?

- Pure PBSD!
  - Global & local changes
- Calibrate risk-based q-factors & add RT-spectra
  - Global change
- Enforce additional capacity design rules
  - Local intervention (heavy)
- Increase safety factors on brittle mechanisms
  - Local intervention (light)

The PBSD route

$$MAF_{LS} = \int$$



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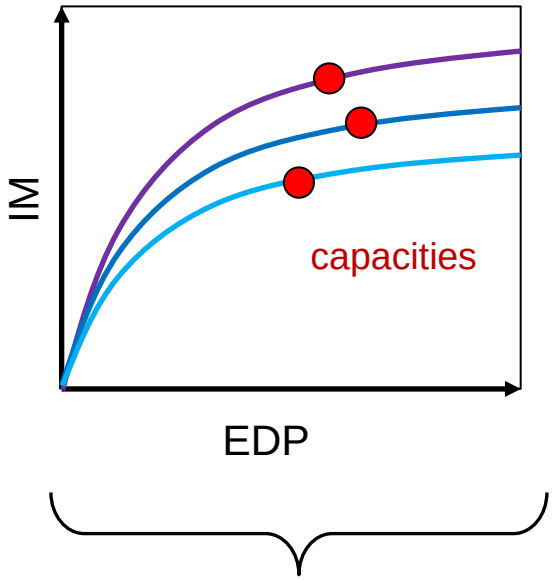


Do we like PBSD?

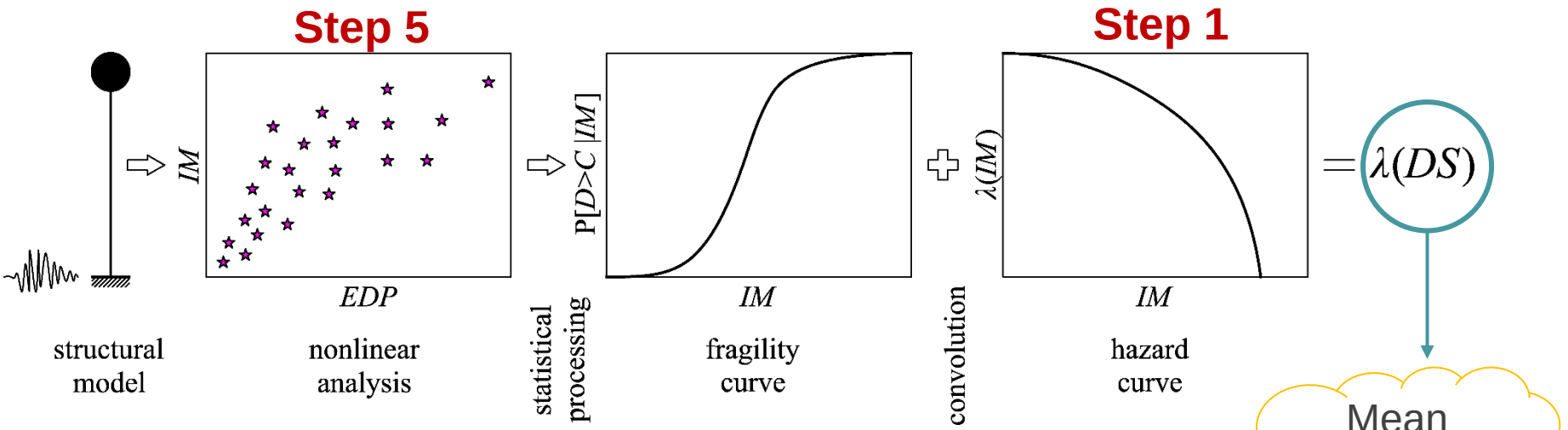
Pros

- Excellent results
- Applicable to any case
- Can account for local & global effects, site conditions etc.
- Can allow any number of performance objectives, long return periods, etc.

Cons

- Requires good knowledge of structure
- Some data is not there
- Requires considerable expertise
- Iterations!
- Best option for future
- ….but perhaps not for now

Risk-based q-factor & RT-spectra



Step 6

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

acceptable but maybe non-optimal

➢ otherwise→ q-factor ✘ → Iterations

Do we like risk-based q & RT-spectra?

Pros

- Good results @ class level
- Applicable to any case
- Can account for local & global effects, site conditions etc.
- Can allow any number of POs, long return periods, etc.

Cons

- Requires considerable upfront research
- POs are predefined
- Iterations (but only for researcher)!
- What to do if q<1?
- Excellent midterm option!

The capacity design route

Make brittle mechanisms stronger

$$C_{brittle} > C_{ductile}$$

Ensure ductile mechanism activated first

- A classic approach.
- As long as we identify all brittle-mechanisms and protect them, all should be well

Do we like capacity-design?

Pros

- Excellent, time-tested approach
- Brittle mechanism “guaranteed” never to occur
- Local intervention only

Cons

- There should be at least one competing ductile mechanism!
- Theory ≠ Reality
- Can lead to very high overstrengths if not careful
- Can help structures with some ductility!

The risk-based safety factor route

Make brittle mechanisms stronger

$$C_{brittle} > D \cdot \varphi$$

Increase demand by additional risk-based safety factor

- Less strict that capacity design
- What would that safety factor be?

Do we like risk-based safety-factors?

Pros

- Less conservative than capacity design
- Local intervention only
- Can deliver cost-effective performance right where you need it

Cons

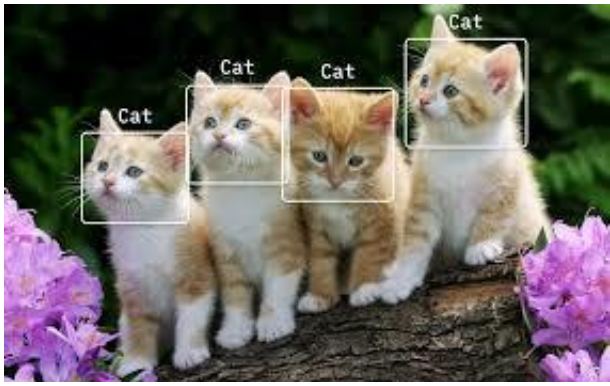
- Less safe than capacity design
- Assessing φ can be costly (but only for researchers)
- Cannot fully guarantee global-level results
- Can help structures having no real ductility, but only up to a point

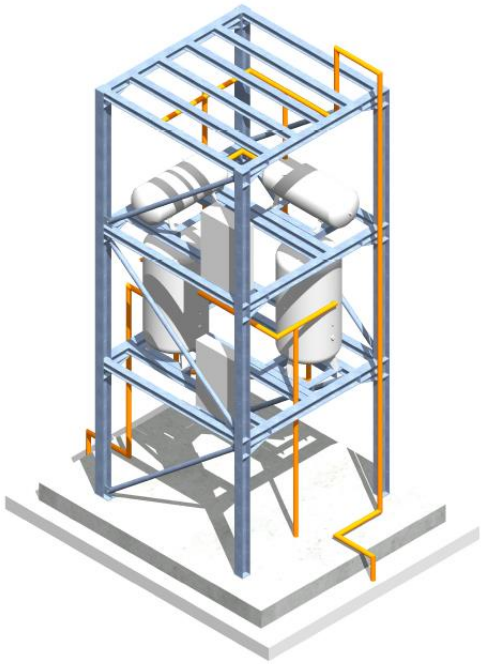
There is no perfect answer

- But perfect is the enemy of good!
- Different structures may require different combos
  - If ductile mechanisms exist ► Capacity design
  - If only brittle mechanisms ► Risk-based Safety factors
  - Add RT-spectra & risk-based factors to ALL
  - Keep PBSD approaches for important structures ONLY
- But there is at least one thing we **100%** clarified today:

A great historical misdeed has been lifted!

- ✓ But what should **code-committees** do?
- ✓ The code is not magic, it feeds on data.
- ✓ Like AI, committees are not omnipotent
  - Millions of images to find a cat
  - Where is our data to find q?
- ✓ No data = Marginal improvements
  - Cats seem to receive more funding
  - ….I do like them, but not that much





I shall not forget!

- ✓ There is still something **you** can do
- ✓ Don’t let the **fake news** spread
- ✓ Tell your children the **truth**

There were three good swine engineers

Two fell through the cracks of the code

It was not their fault

….and let’s make sure we close those cracks

My thanks to

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