Some Thoughts on Methods to Compare the Seismic Performance of Alternate Structural Designs

Dimitrios Vamvatsikos & Michalis Fragiadakis
University of Cyprus

Introduction

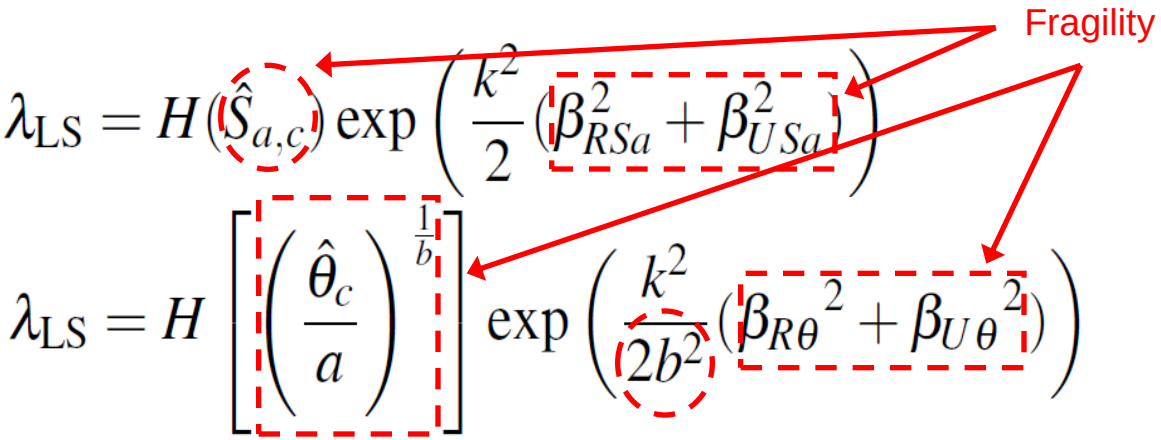
- Structural design needs to compare different buildings
  - Different structural systems
  - Different configurations of a system
- How to perform such a comparison in PBEE?
  - MAF or annualized losses are one way. Can we go lower?
  - Use static pushover curve or dynamic analysis?
  - Use EDPs, IMs or base shear as the basis?
- Such concepts are already in use. Let’s check them.

Options based on PEER integral

$$\lambda(D_V) = \iiint G(D_V|D_M) \cdot |\mathrm{d}G(D_M|E_{DP})| \cdot |\mathrm{d}G(E_{DP}|I_M)| \cdot |\mathrm{d}\lambda(I_M)|$$

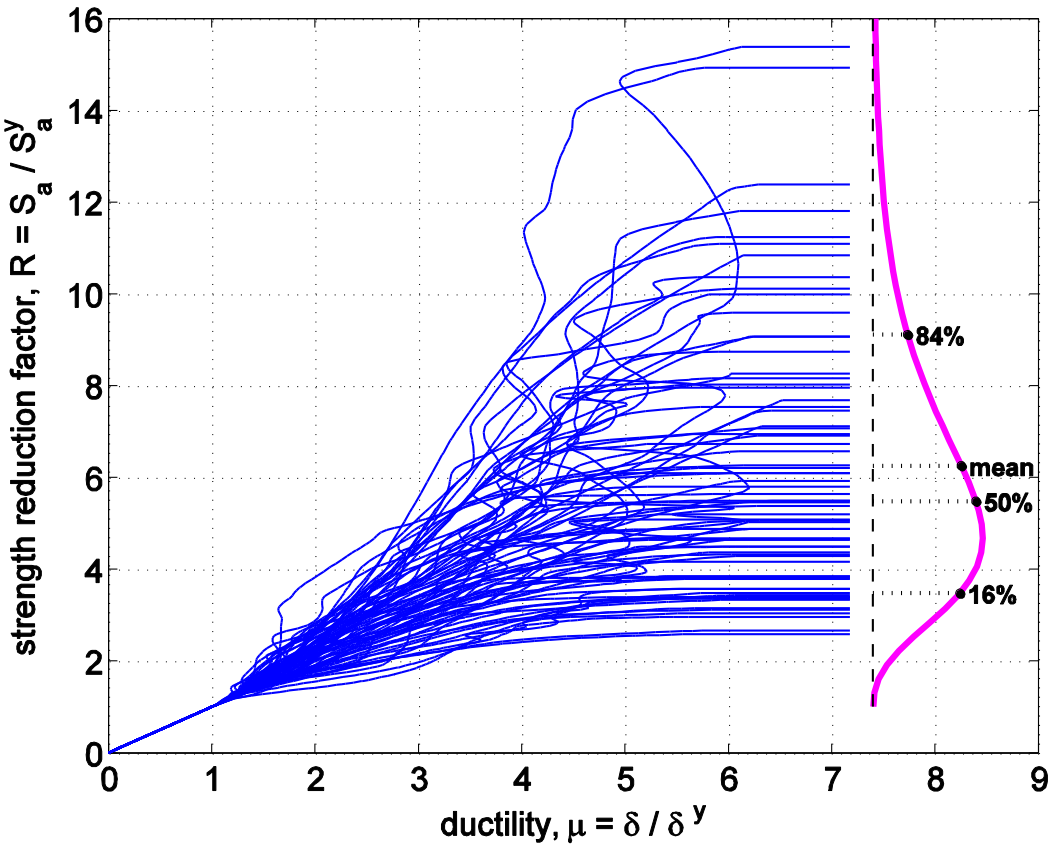
- Life-cycle Cost > Annualized Loss > All Rest
  - Include downtime/casualties? Perfect e.g. for base isolation
  - Still, engineering quantities are preferable
- Can we go down to fragility?
  - EDPs and IMs are intuitive
  - One step lower, static pushover results are even more so.

Understand Fragility via SAC/FEMA formula



- Let's focus on a single Limit-State
  - Ultimately need to compare several
- For common site and IM, simplifications are possible
  - Comparison result may depend on site characteristics
  - EDP-based comparison is more complex: "a", "b".

IM-based comparison (1)

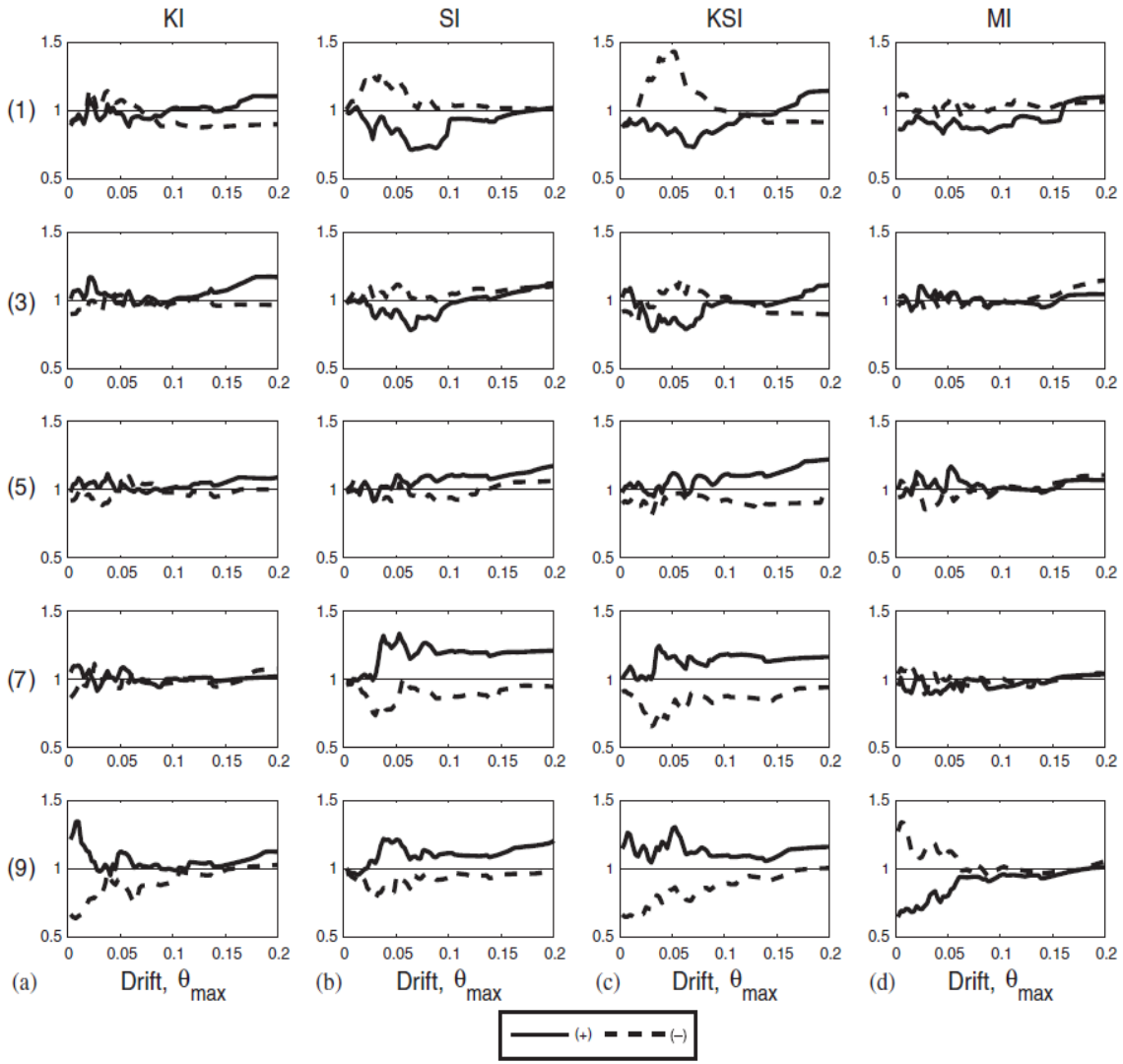


- Showing collapse capacities of an oscillator in R vs μ.
- Based on “vertical statistics”
- Must find a common IM

IM-based comparison (2)

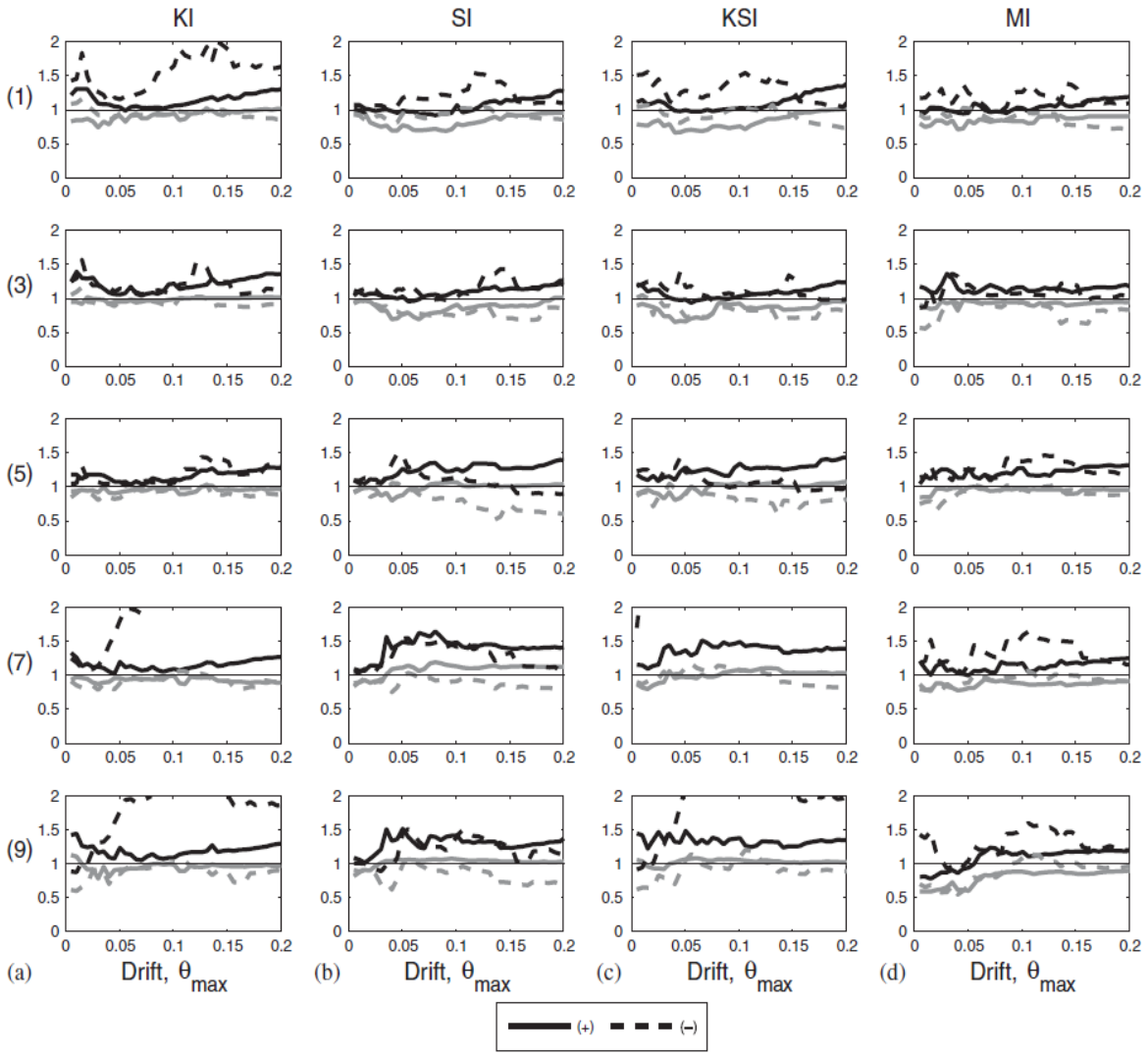
- Complex IMs are problematic
  - Cannot compare vectors: $\{S_a(T_1),\varepsilon\}$
  - Cannot easily compare structure-dependent IMs: S_{di}
  - Even the simple $S_a(T_1)$ needs a common period.
- Fall back to PGA and PGV?
  - Sometimes it is a good idea, but sufficiency?
- $S_a(T_1)$ can work if we change to a common period.
  - Avoid large period changes.

IM-based comparison (4)



- Irregularities:
  Stiffness (KI)
  Strength (SI)
  Both (KSI)
  Mass (MI)
- Ratio to base case for upgraded and degraded case shown.
- Easy to spot large/small/no influence

IM-based comparison (5)



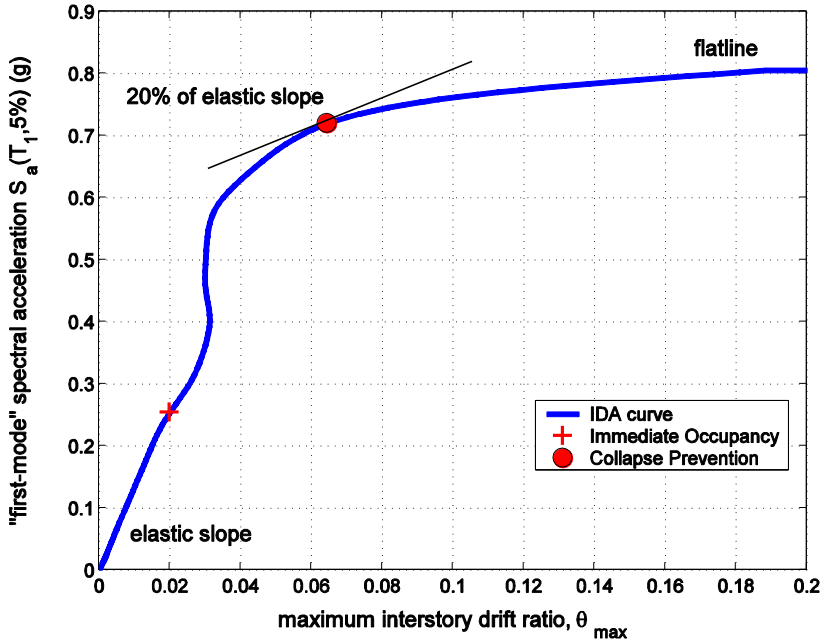
- If dispersion is too different, you can use two-sample comparison or 90% confidence intervals

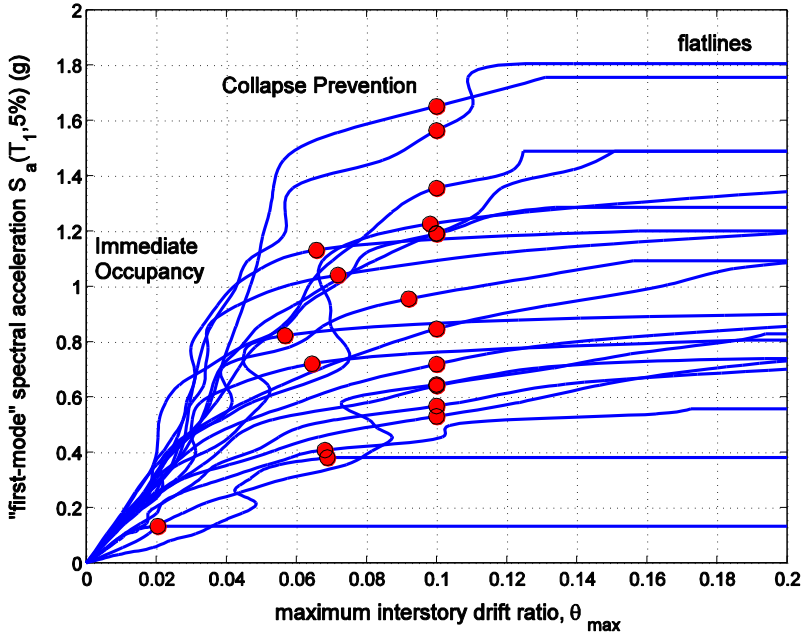
$$\left[\left(\frac{\hat{S}_{\text{irreg}}}{\hat{S}_{\text{base}}}\right)^{(a/2)}, \left(\frac{\hat{S}_{\text{irreg}}}{\hat{S}_{\text{base}}}\right)^{(1-a/2)}\right]$$

Can we go even lower?

- Dynamic analyses and “required IM” basis may be tough
  - Maybe take a step down to something simpler?
- Sometimes works, sometimes does not.
  - Need to exercise care when venturing there
  - Will focus on counter-examples
  - Still, good many good examples may exist for each case.
- So I am not saying everything else is wrong
  - Just be very careful when interpreting

EDP-based comparison?

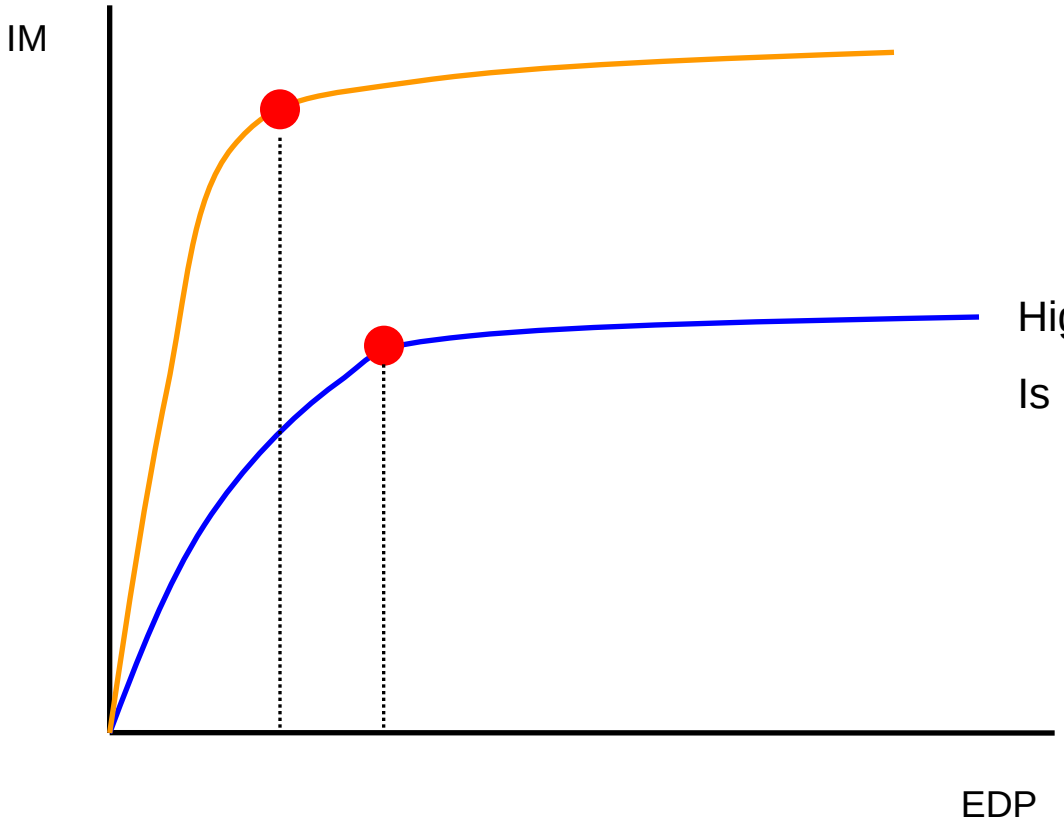




- Why not avoid “common IM” and compare directly on EDP
- Seems intuitive
- Very attractive for SAC definitions

- The 20% slope produces different EDP capacities
- Why not compare e.g. median EDP capacities among different designs?

Try to compare median EDP capacities here



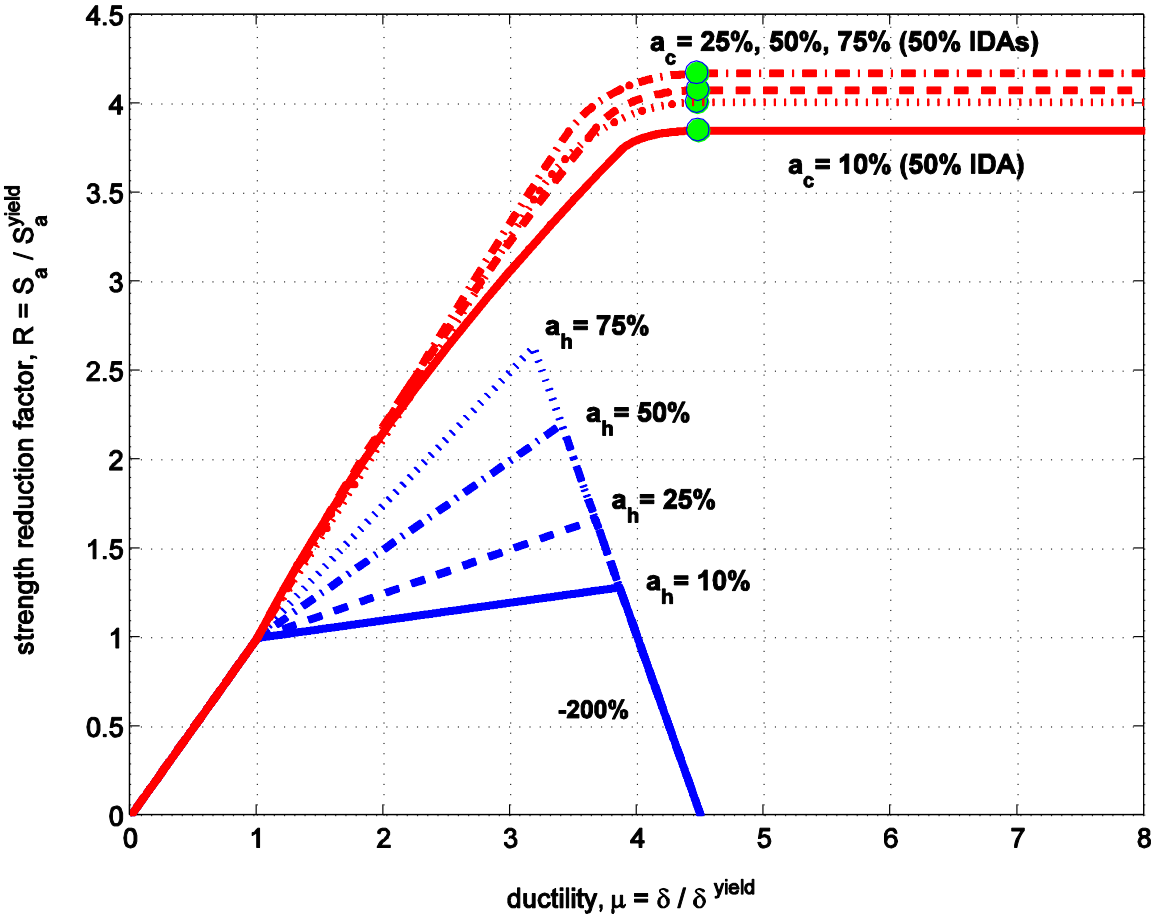
Higher EDP capacity.

Is it better?

Can we use the pushover?

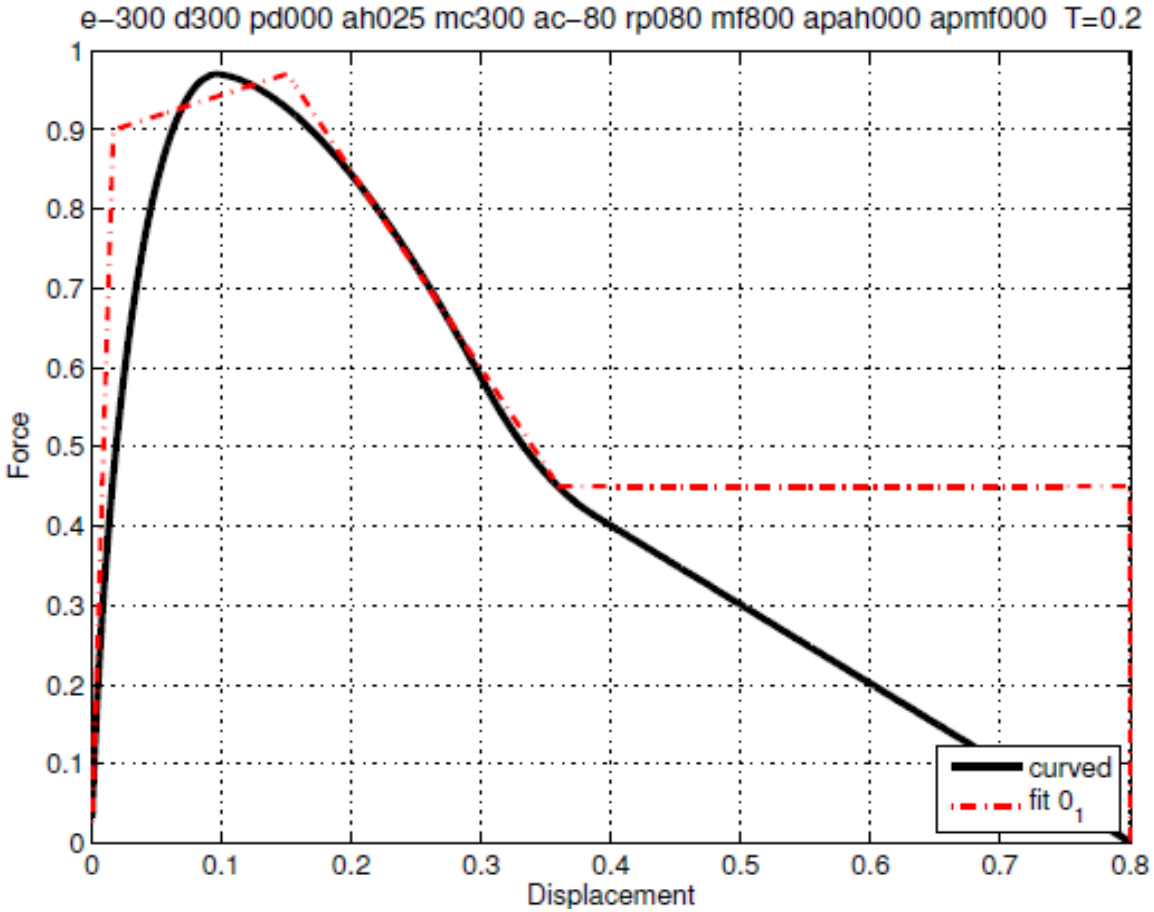
- Clearly represents capacity
  - Expressed in base shear vs roof drift
  - It is actually being done a lot!
  - We compare pushovers for ductility and overstrength.
- Obviously cannot work for different periods
  - Very small differences are ok
  - Adjustment schemes have appeared (e.g. Alavi & Krawinkler) but they are cumbersome and may lead to quantitative errors.

Static pushover comparison (1)



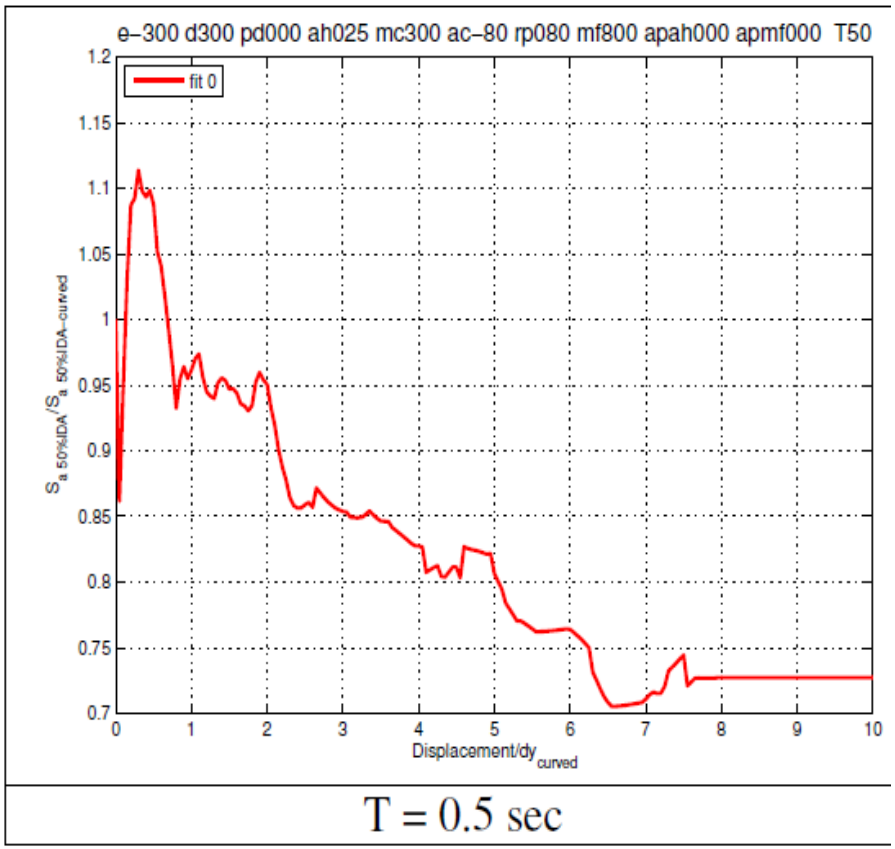
- Even with common period, tough to say!

Static pushover comparison (2)

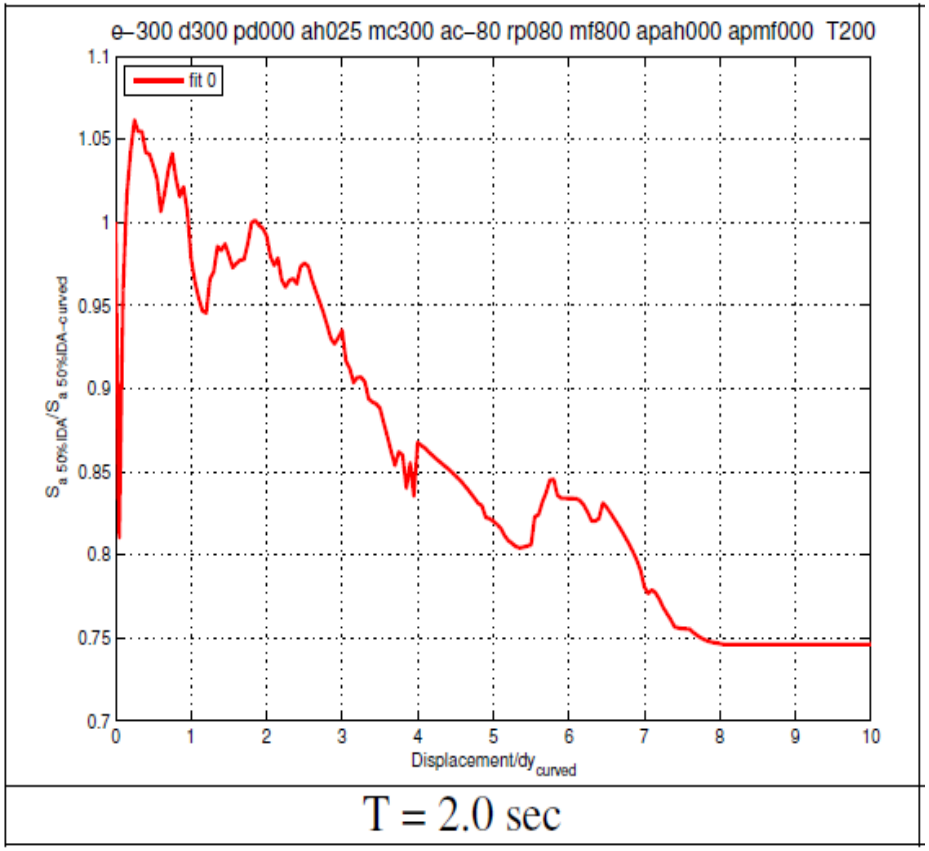


- Periods are the same.
- Clearly the multilinear pushover should be superior. Is it truly?

Static pushover comparison (2)



T = 0.5 sec



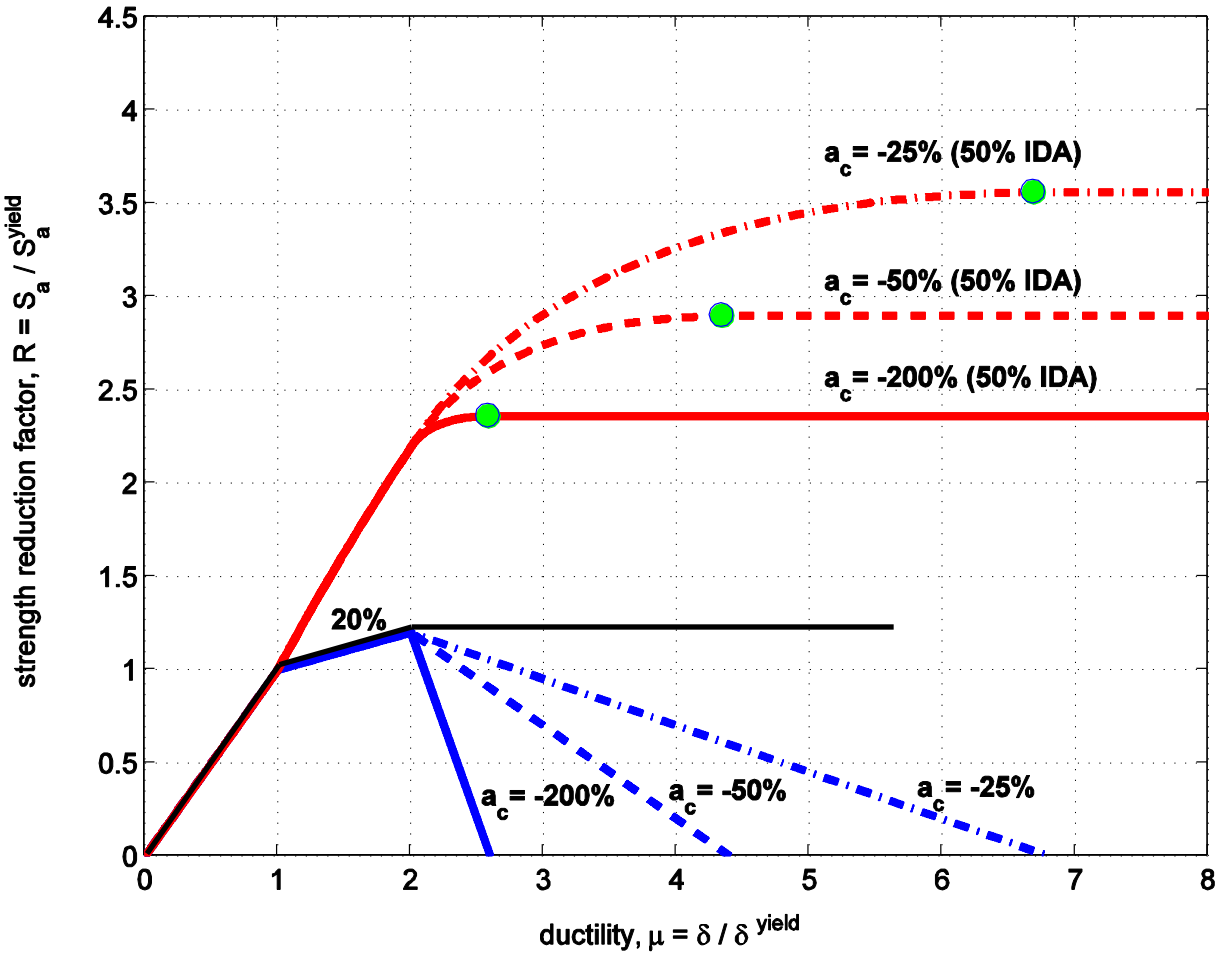
T = 2.0 sec

- Comparison of medians clearly favors the lower curve!
- Curved segments vs straight-segments

How about the “dynamic” pushover?

- Based on dynamic analyses
  - Expressed in base shear vs roof drift
  - Uses (nearly) concurrent quantities
  - Popular when comparing load patterns
- Sometimes useful but not without problems
  - Shares some common issues with plain static pushover
  - Resolution remains a problem.

“Dynamic” pushover



- Median IDAs can tell the difference
- Dynamic pushover remains the same! Perhaps ok pre-peak. P-Delta?

Conclusions

- Comparing design alternatives is not straightforward
  - Lot's of pitfalls and fallacies
  - Decision variables are a sure way to go (e.g. loss)
- Moving to fragility has benefits and costs
  - A common IM-basis is difficult but useful
  - A common EDP-basis should be avoided
- Moving to the pushover needs a lot of care
  - Better to use SPO2IDA or IN2 to "upgrade" to dynamic