University of Naples Federico II

Some issues with risk-targeted seismic design

Workgroup:

George Baltzopoulos

Iunio Iervolino

Antonio Grella

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- Design for uniform-hazard seismic actions does not lead to uniform seismic reliability

- There are two major contributing factors to this
- differences in shape of the hazard curves between sites
- overstrength not dictated by seismic actions al low-hazard sites

- Can we obtain uniform reliability by tweaking design seismic actions?
- Maybe, but we can only do that for medium to high seismic hazard sites
- We can't really tell from 475y return period elastic demand spectra
- We'd need to be site- and structure-specific

Tinker with the q factor

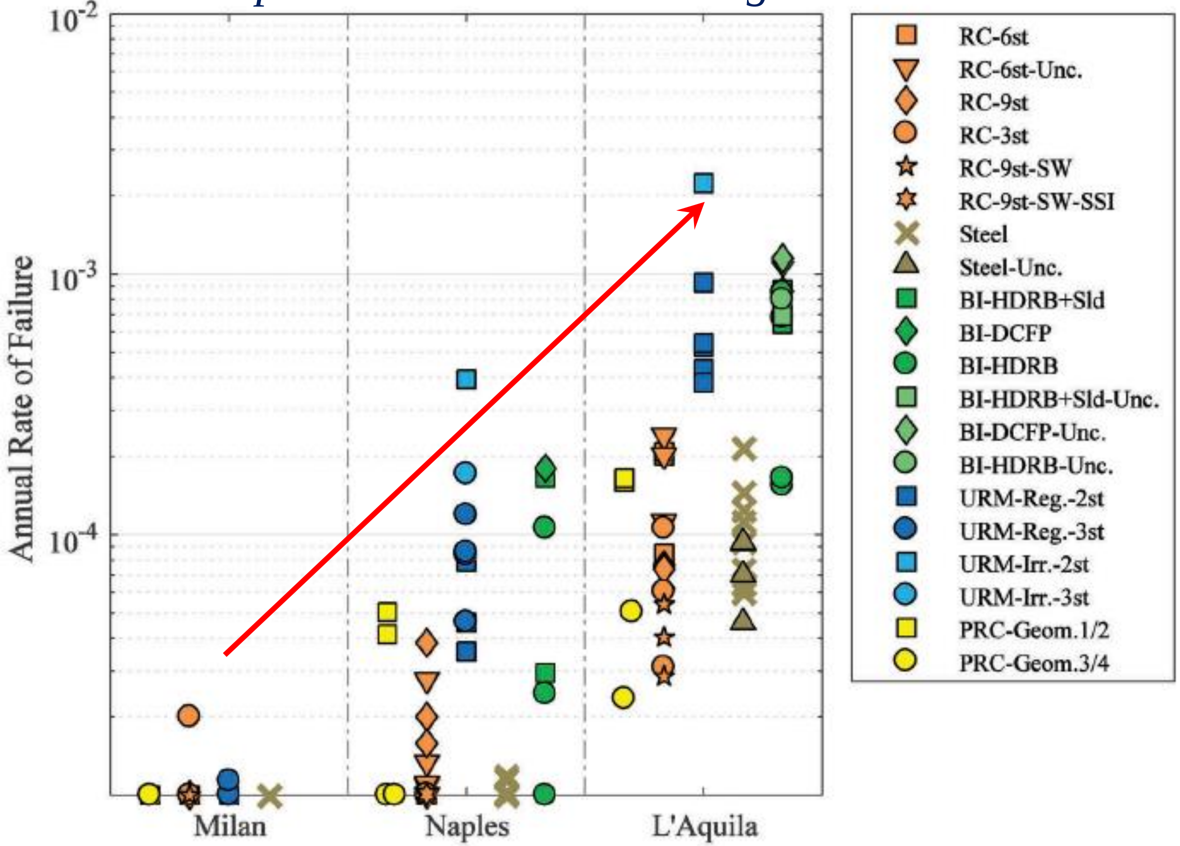
- Can we define a Risk-Targeted design spectrum to fix this?
- Assuming collapse fragility a-priori will still leave us with uneven reliability
- We will run into the known shortcomings of Sa(T) as intensity to predict collapse

Tinker with the design spectrum

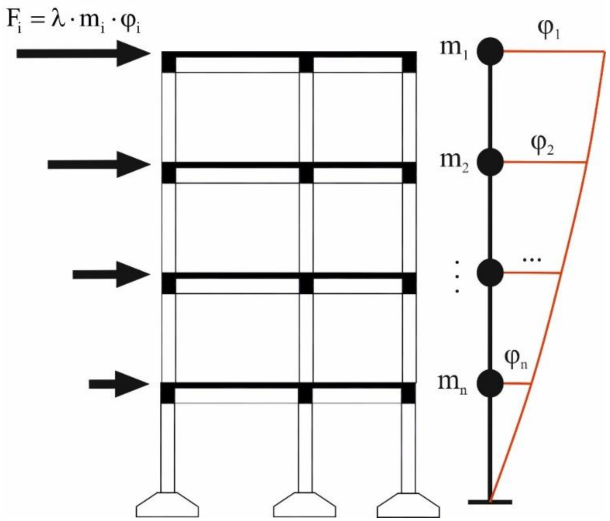
Seismic risk across Italian sites

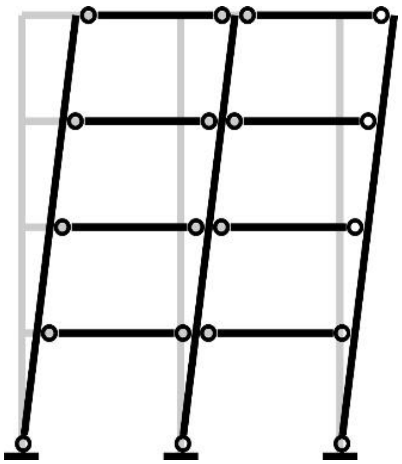
*Building structures designed under seismic actions with the **SAME RETURN PERIOD**, do **NOT EXHIBIT** the same level of seismic reliability*

***RINTC**-Rischio Implicito delle Strutture Progettate Secondo le NTC18 (WP3)*



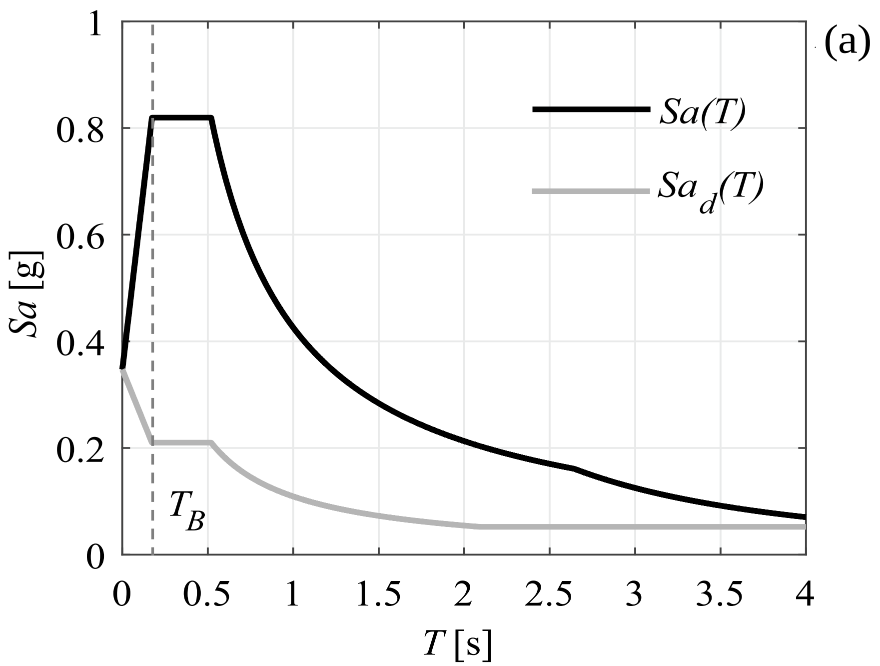
Iervolino I, Spillatura A, Bazzurro P. ***Seismic Reliability of Code-Conforming Italian Buildings.*** *Journal of Earthquake Engineering 2018; 22(sup2): 5–27. DOI: 10.1080/13632469.2018.1540372.*

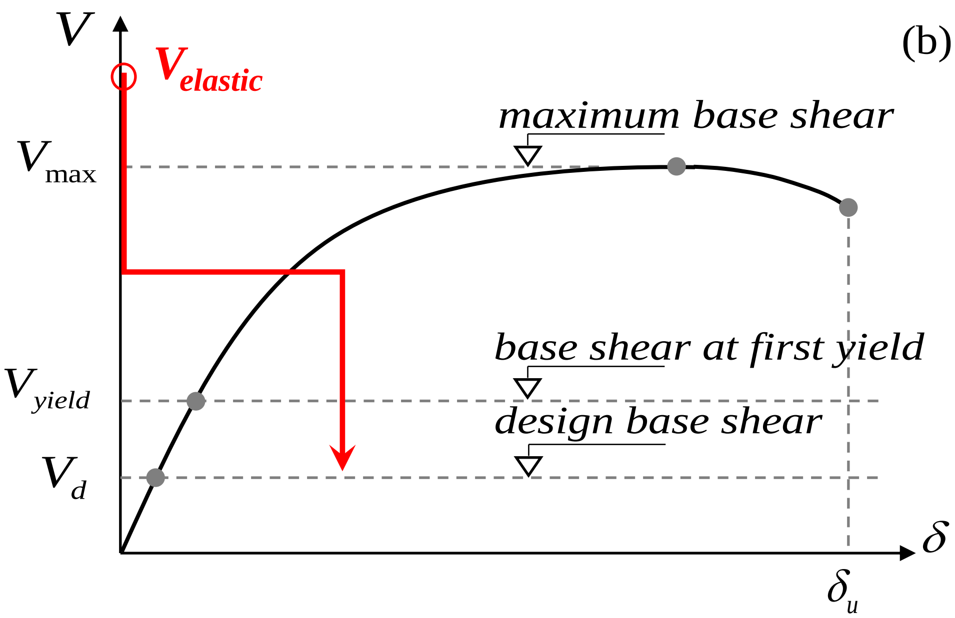




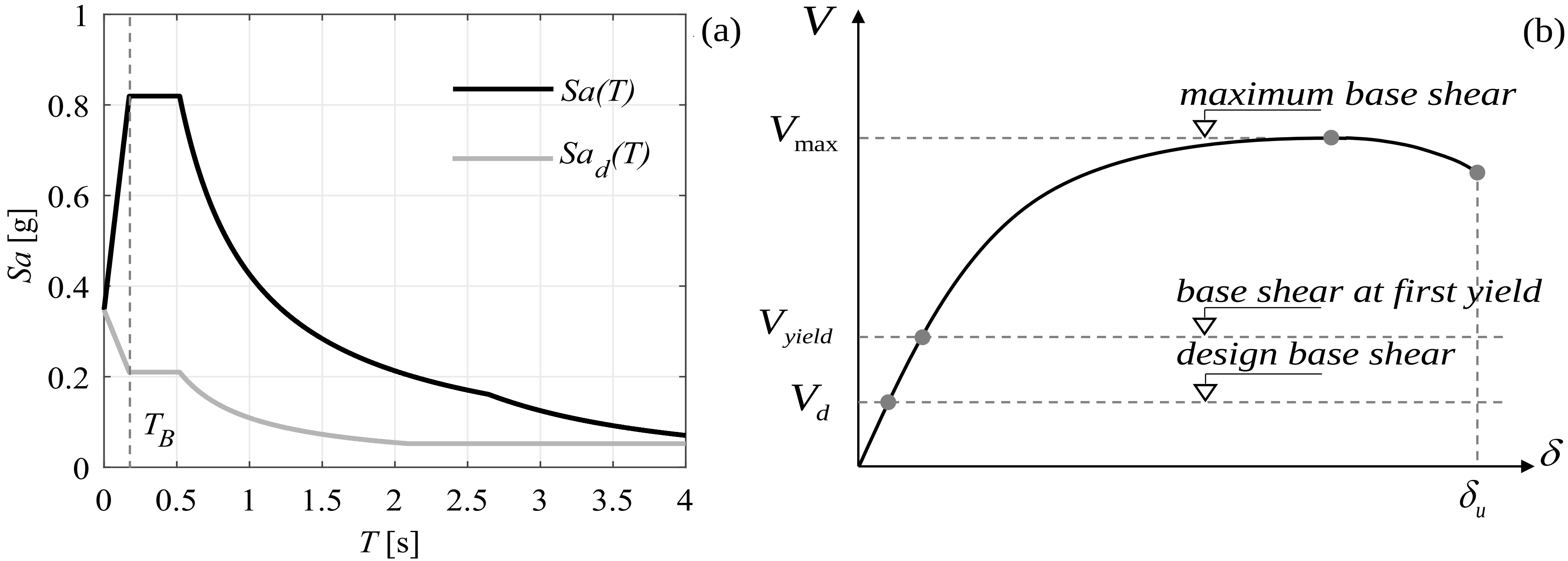
- **Keeping it simple: design is done using linear-elastic analysis (static, modal, dynamic)**
- **We do expect the structure to dissipate energy hysteretically once the seismic actions exceed some threshold**
- **But we don't explicitly control when inelastic response starts!**

- **Start from elastic spectrum with given return period (e.g. 475 years)**
- **Obtain elastic demand (base shear)**
- **Reduce it using a "behavior factor" or "reduction factor"**

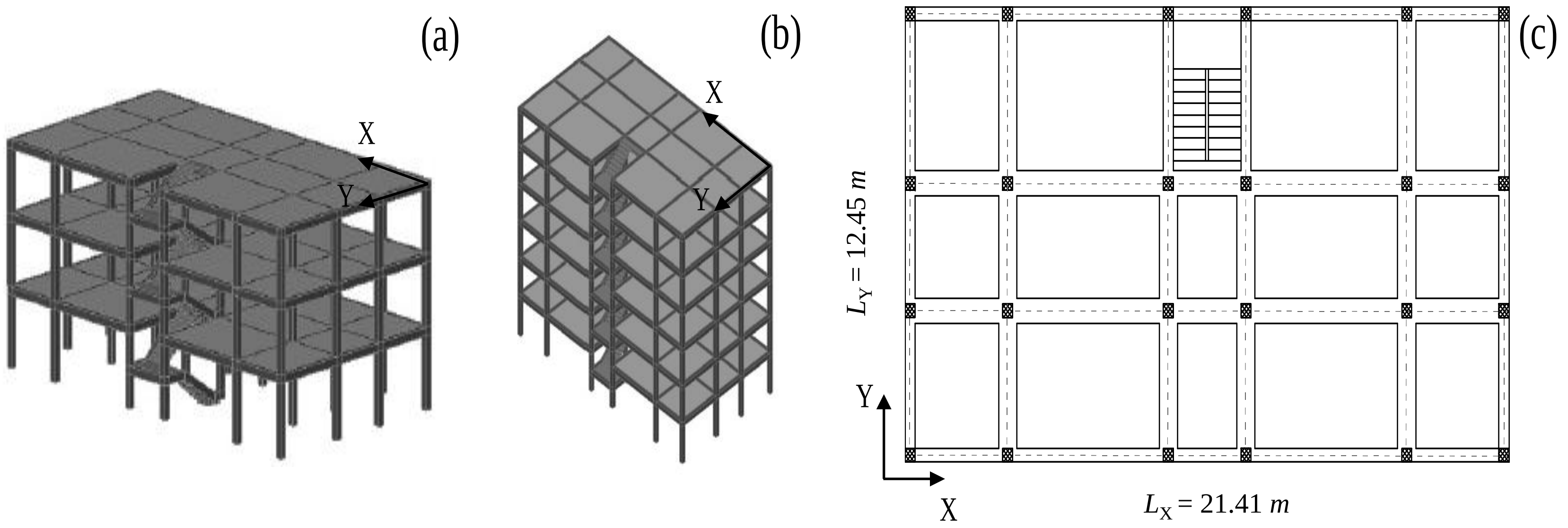




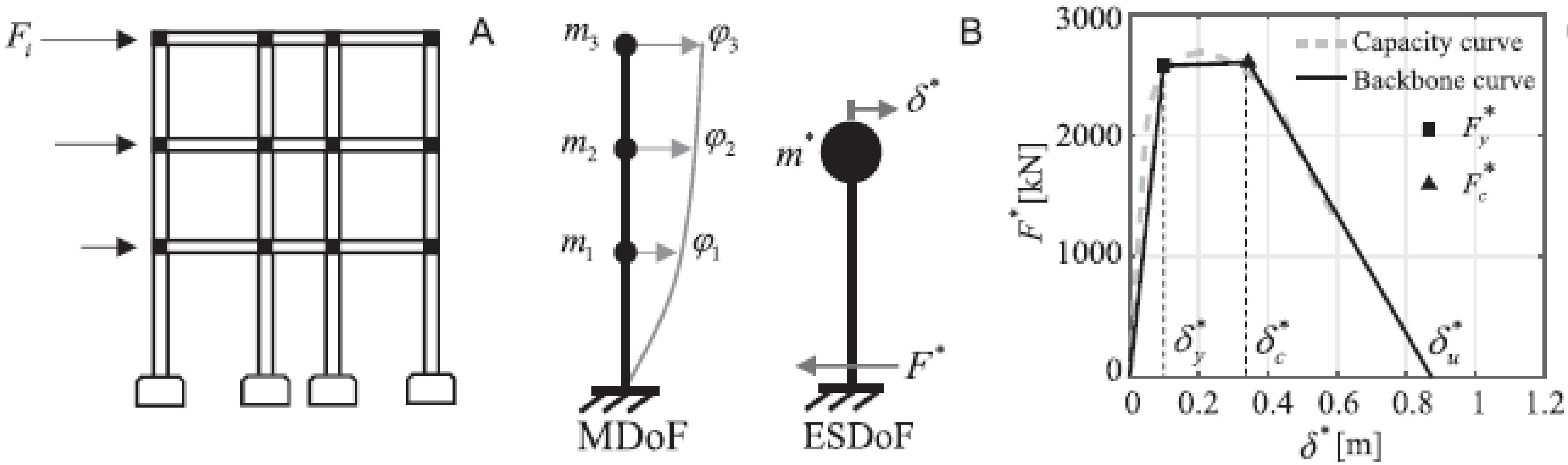
- The structure will not go into the nonlinear range upon occurrence of design actions
- There will be overstrength due to material partial safety factors
- Also because of provided reinforcement overshooting exact requirement in each section
- Redundancy and redistribution means a plastic mechanism is still far off

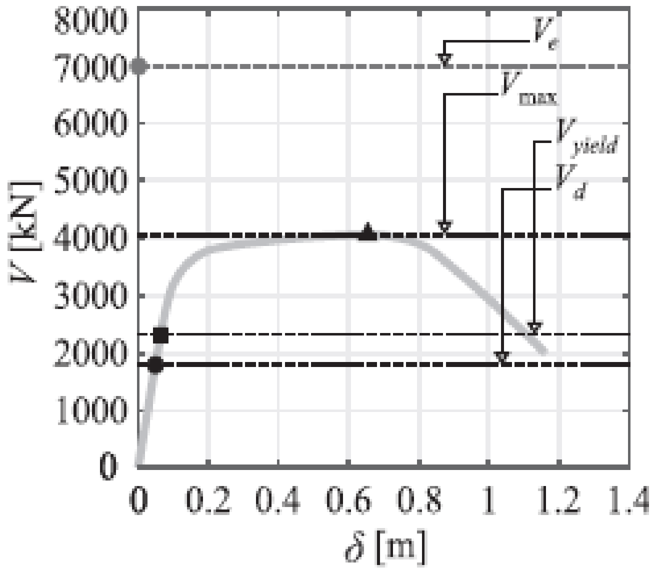


Buildings used from RELUIS RINTC project

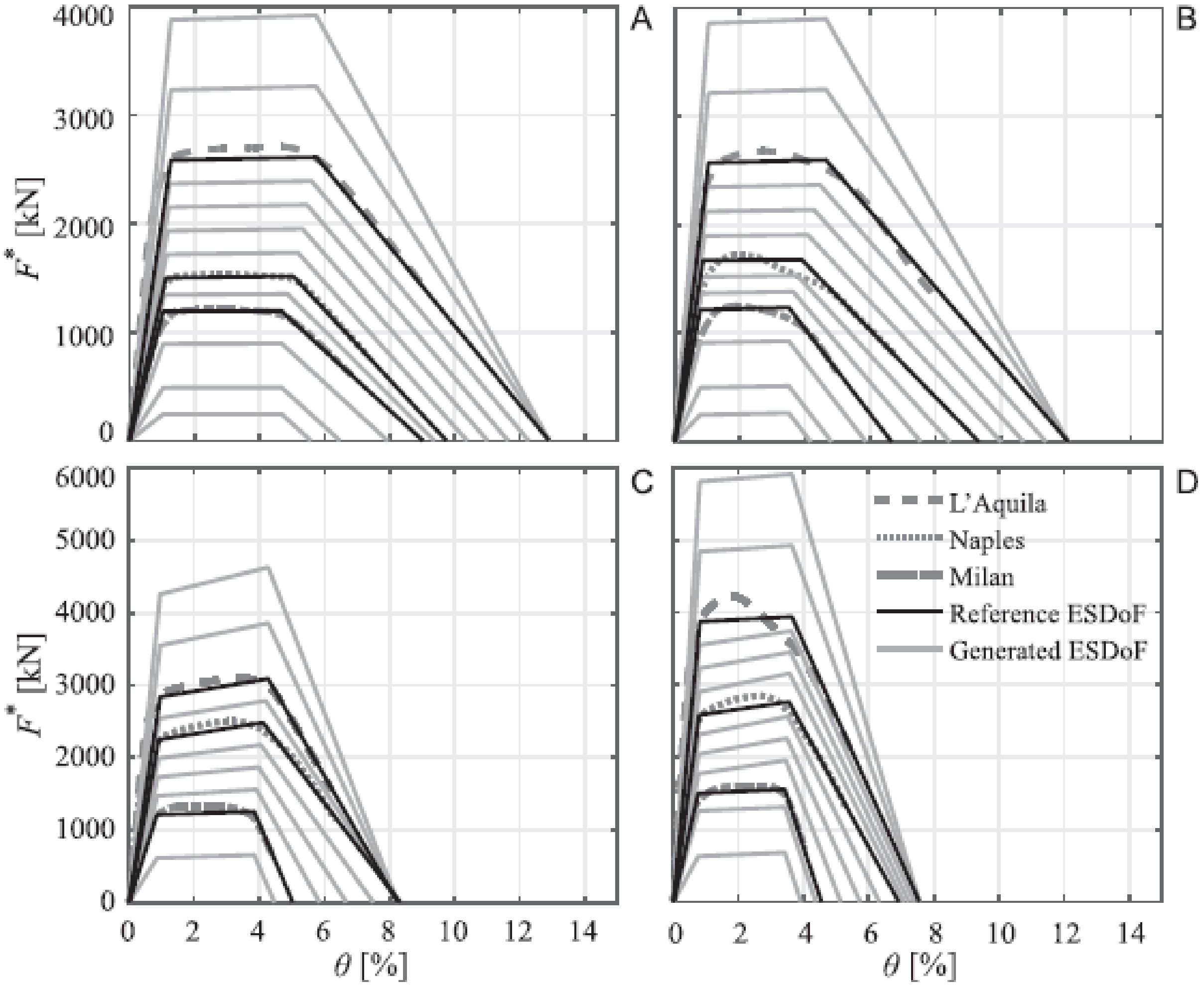


- **Regular, three- and six-storey RC moment resisting frames**
- **We treat each principal direction as a separate structure**
- **These were designed, according to the Italian code, at three different sites with different seismic hazard!**



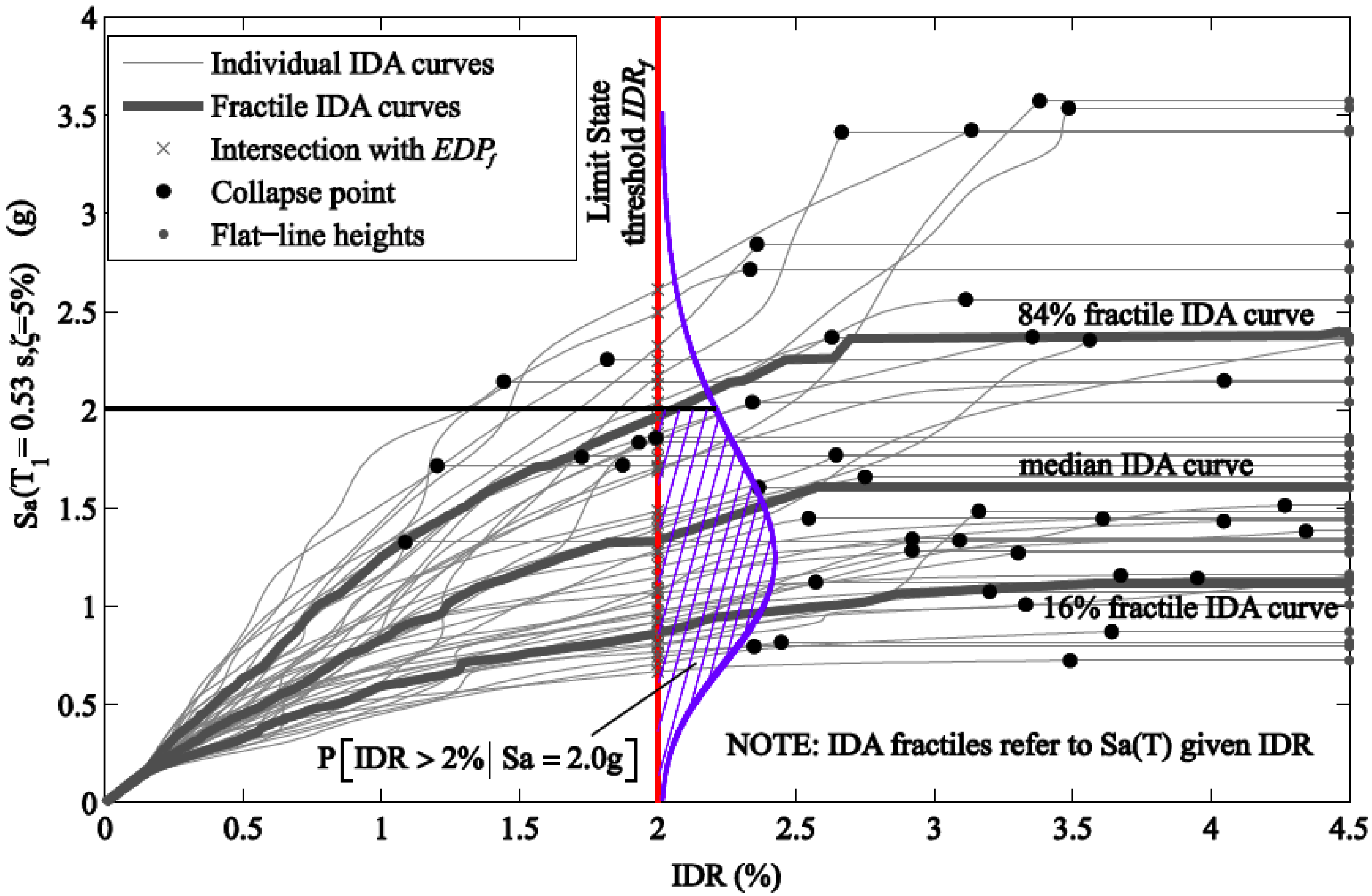


- **<u>STEP 1</u>: We use the results of RELUIS RINTC project (pushover curves) to get equivalent SDOF systems for these RC buildings**

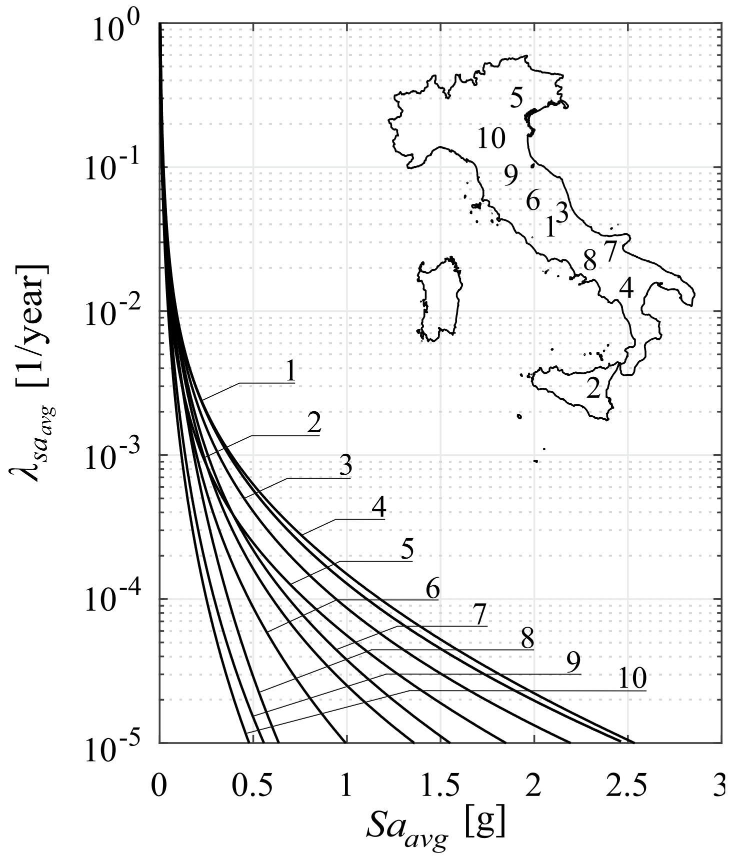


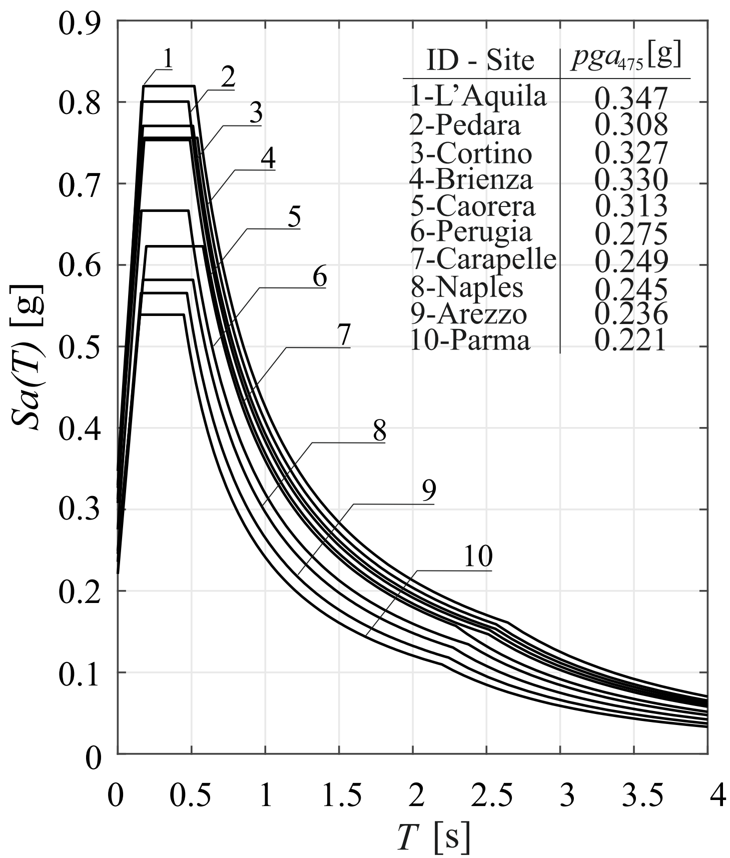
- <u>STEP 2</u>: We interpolate among the three designs for each structure (at 3 sites)
- We obtain pushovers (ESDOF backbones) for different levels of lateral strength

Seismic Fragility Functions



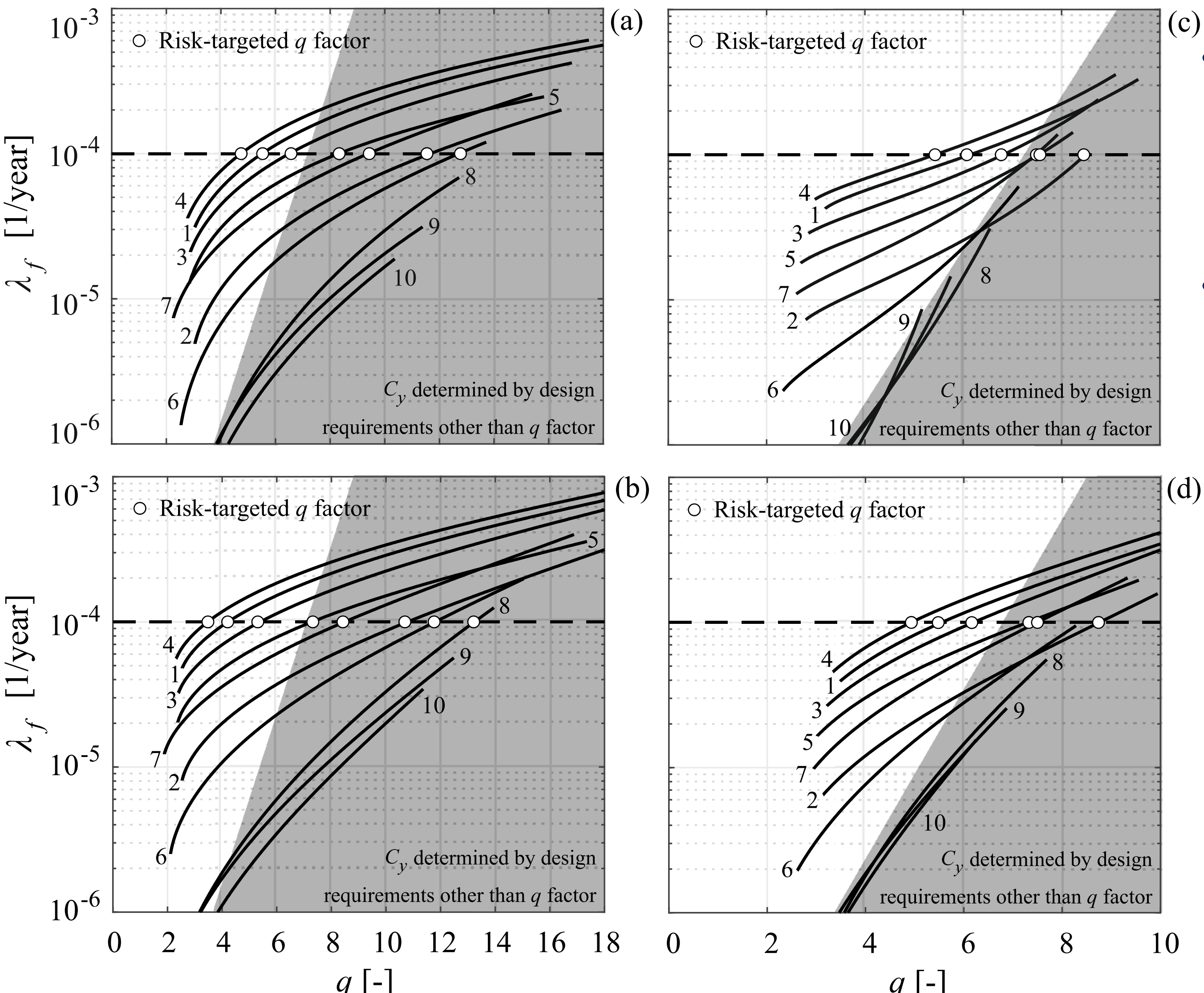
- **STEP 3: We use IDA to obtain fragilities for each generated backbone-structure**



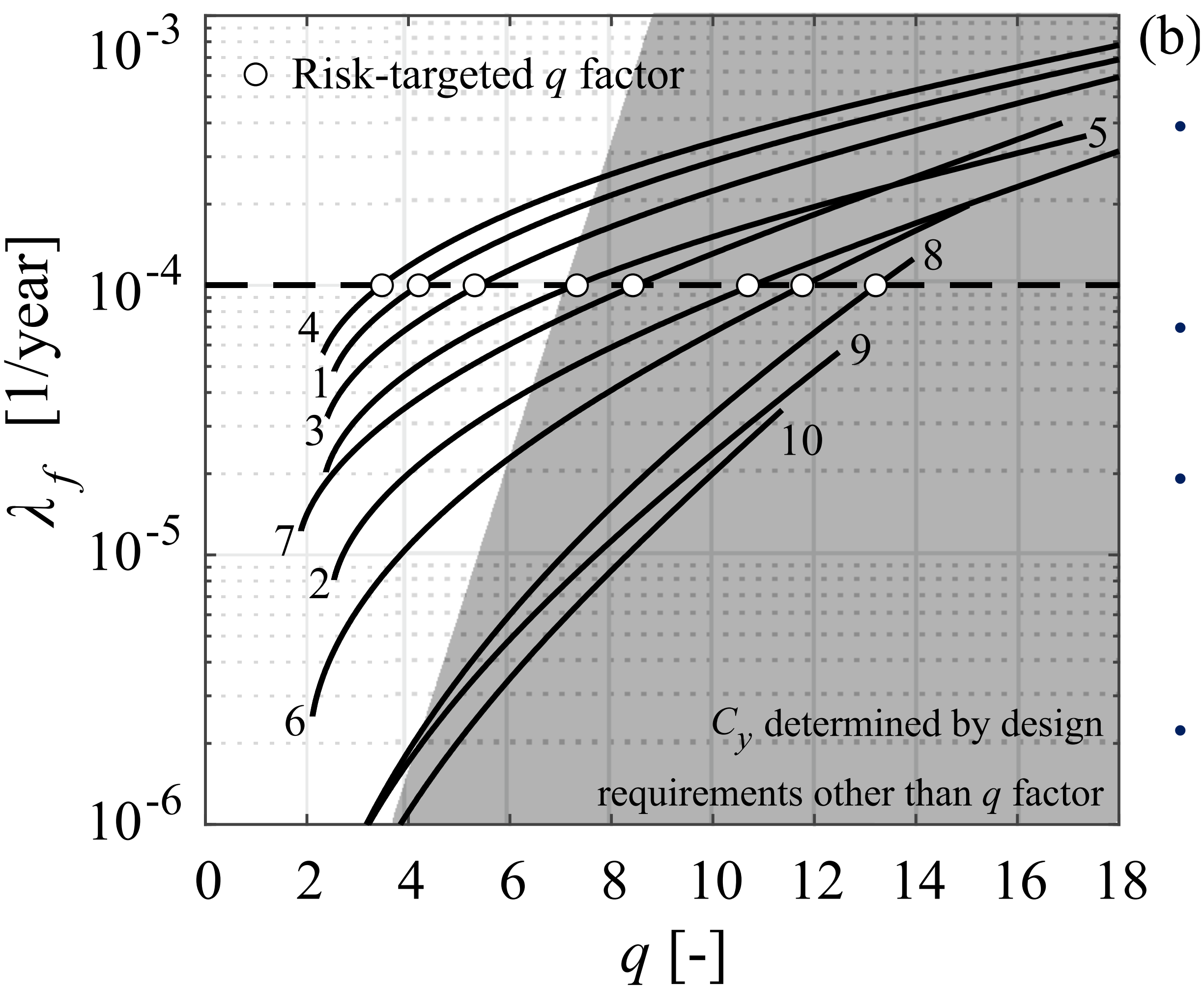


$$\lambda_f = \int_0^{+\infty} P\left[f \,\middle|\, IM = im \right] \cdot \left| d\lambda_{im} \right|$$

- **STEP 4: We assume 10 sites across Italy**
- **STEP 5: We define a limit state and calculate its exceedance rate for all structures and all lateral strengths at all sites!**

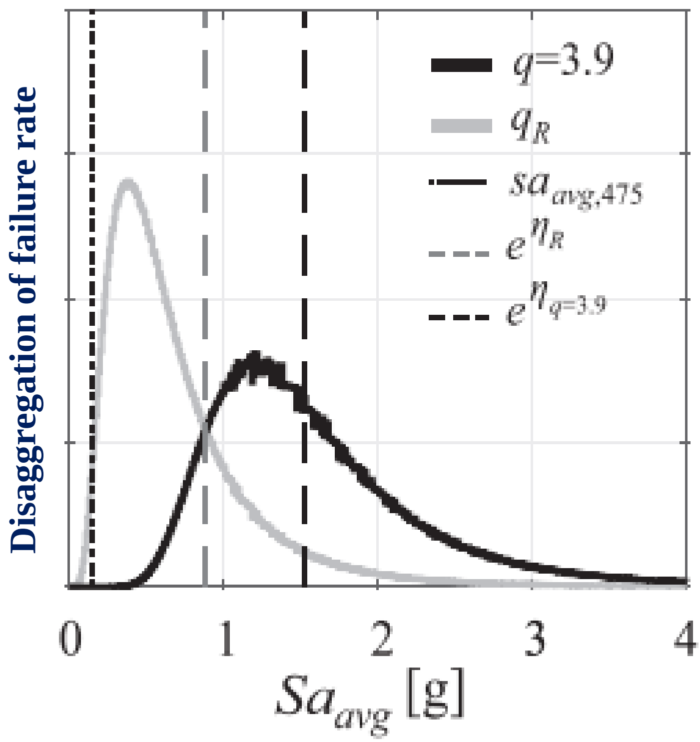


- **STEP 5**: We define a risk threshold and find the strength needed at each site to achieve it.
- **STEP 6**: We back calculate the corresponding behavior factor, considering overstrength

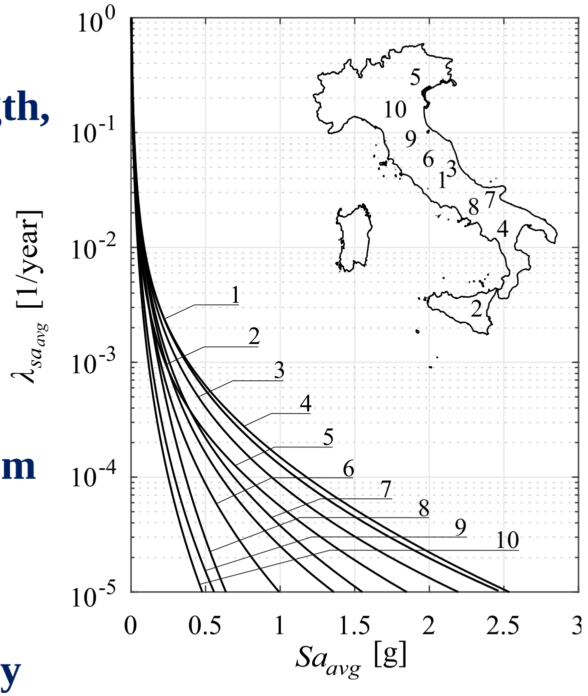


- **Behavior factor needed for uniform reliability across sites varies (same structure!)**
- **It is only realistic for a few higher-seismicity sites!**
- **In the other cases (shaded area), other design considerations would determine lateral strength**
- **These would be minimum requirements, gravity load design etc.**

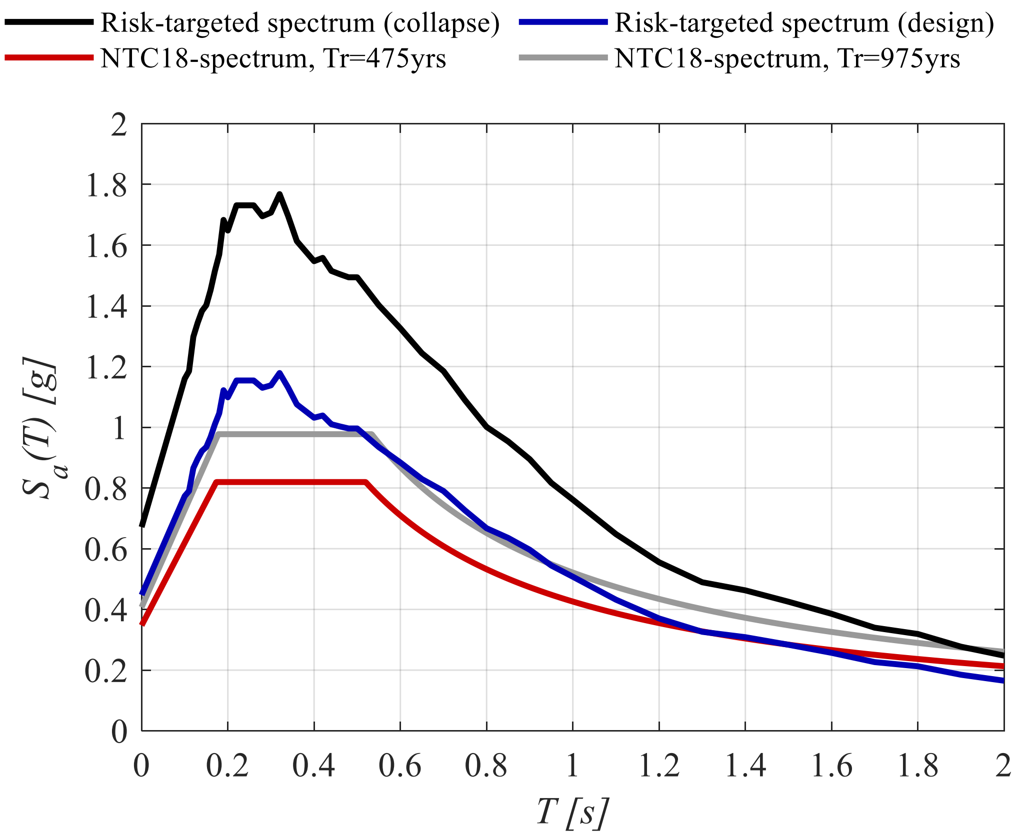
$$Sa_{avg} = \left[\prod_{i=1}^{k} Sa(T_i)\right]^{1/k}$$

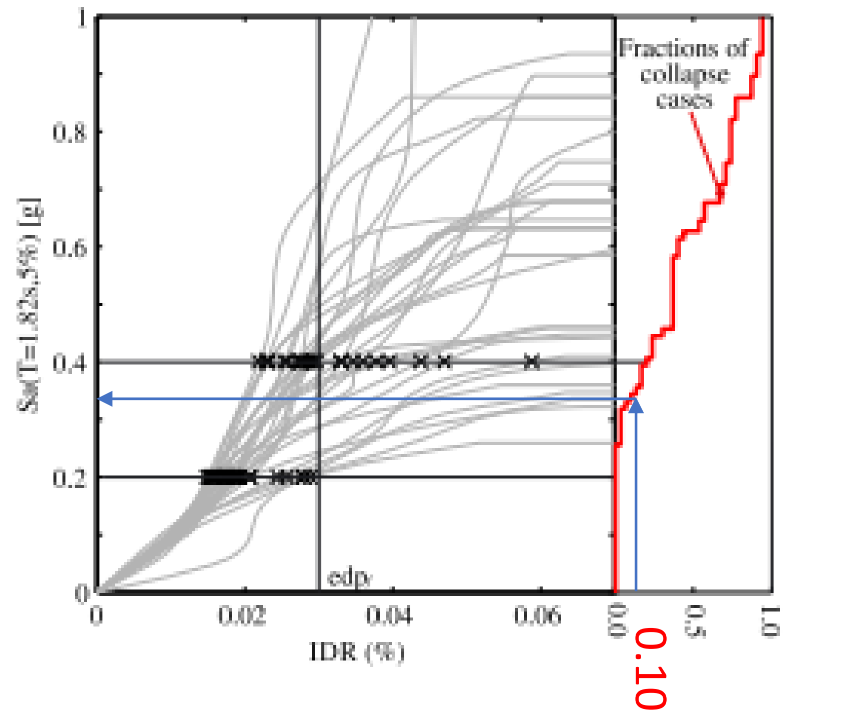


- **There is enough overstrength, for the intensities causing failure to have far longer return periods than design actions**
- **That means we can't easily distinguish high and medium seismicity from 475 year design spectra!**
- **The differences in reliability stem from differences on the hazard curve shape away from that point**



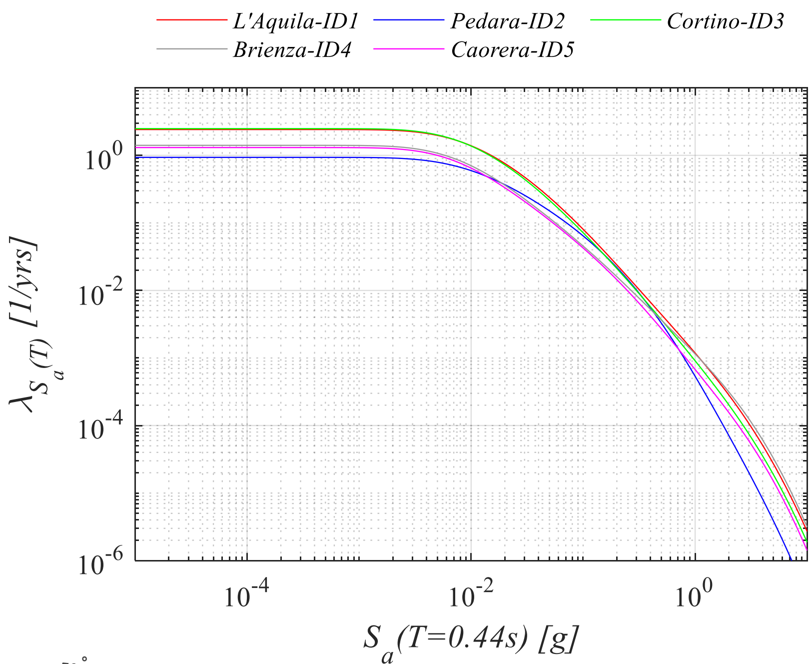
Using an assumed collapse fragility and target collapse MAF to derive design actions

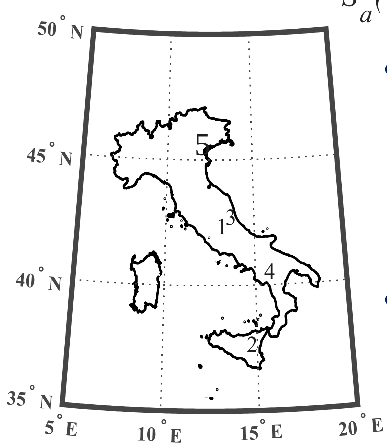




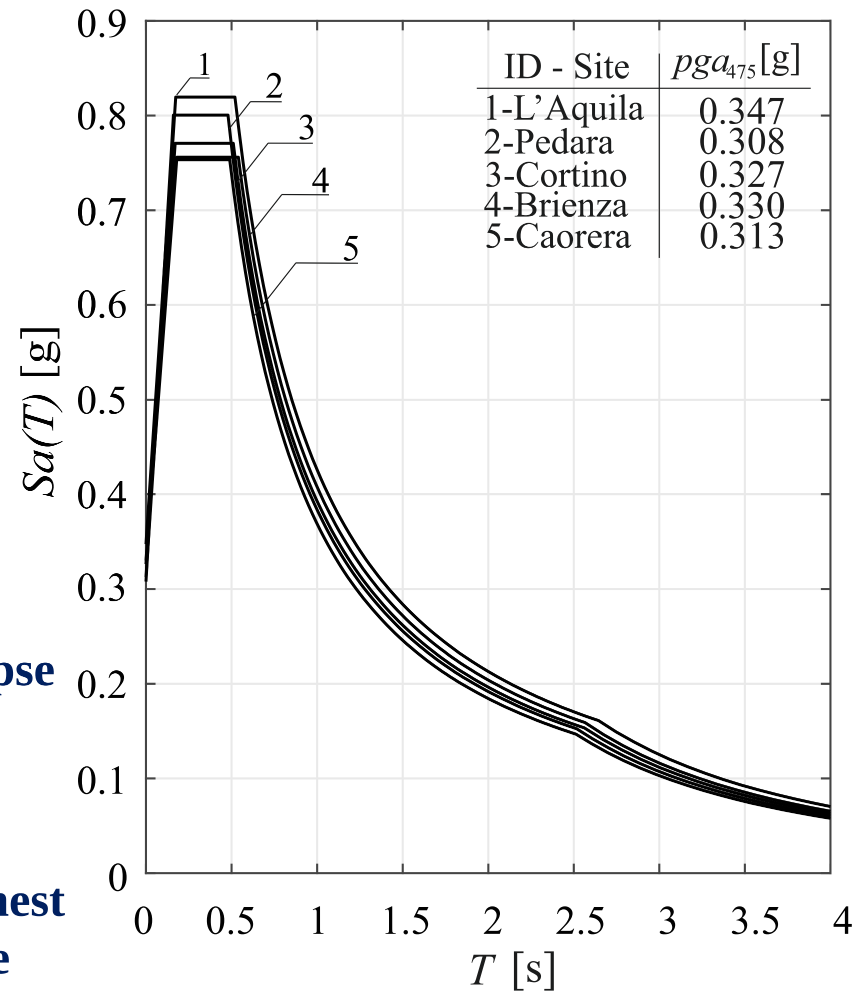
- **Consider that the tenth quantile of the collapse capacity has a given exceedance probability in a time interval**
- **Collapse capacity being shaking intensity causing collapse**
- **Assume the RV's dispersion**

Risk Targeted Design Spectra

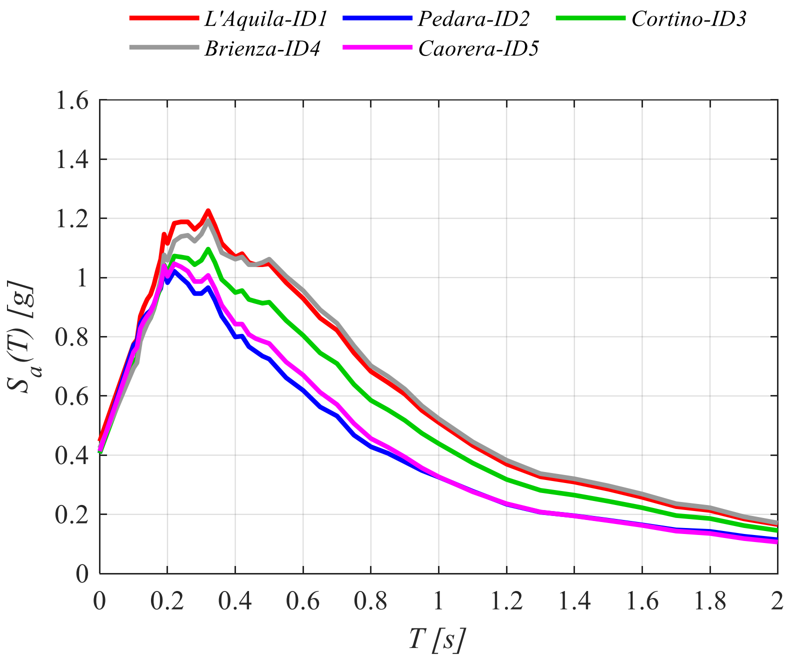


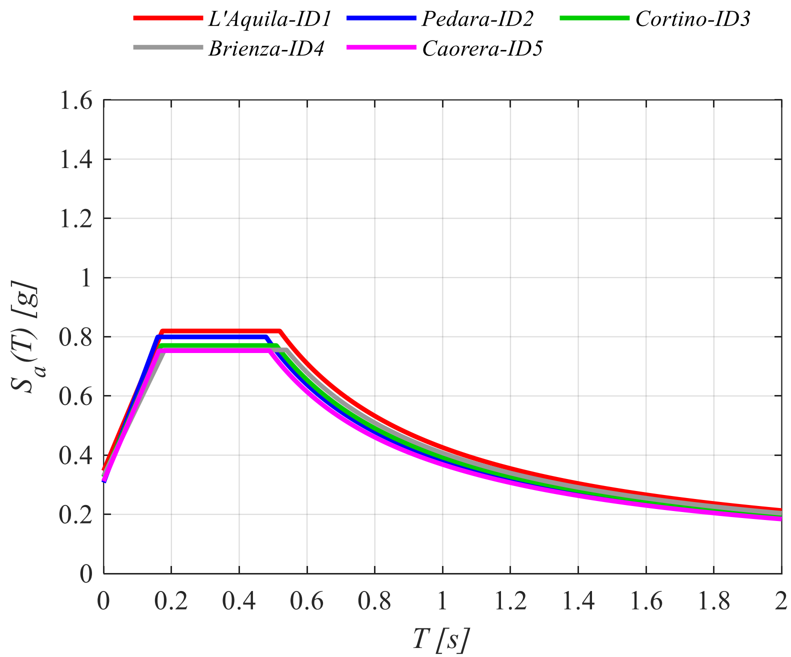


- **Using an assumed collapse fragility and target collapse MAF to derive design actions**
- **We will use the five highest hazard sites from before and see what happens!**



Risk Targeted Design Spectra



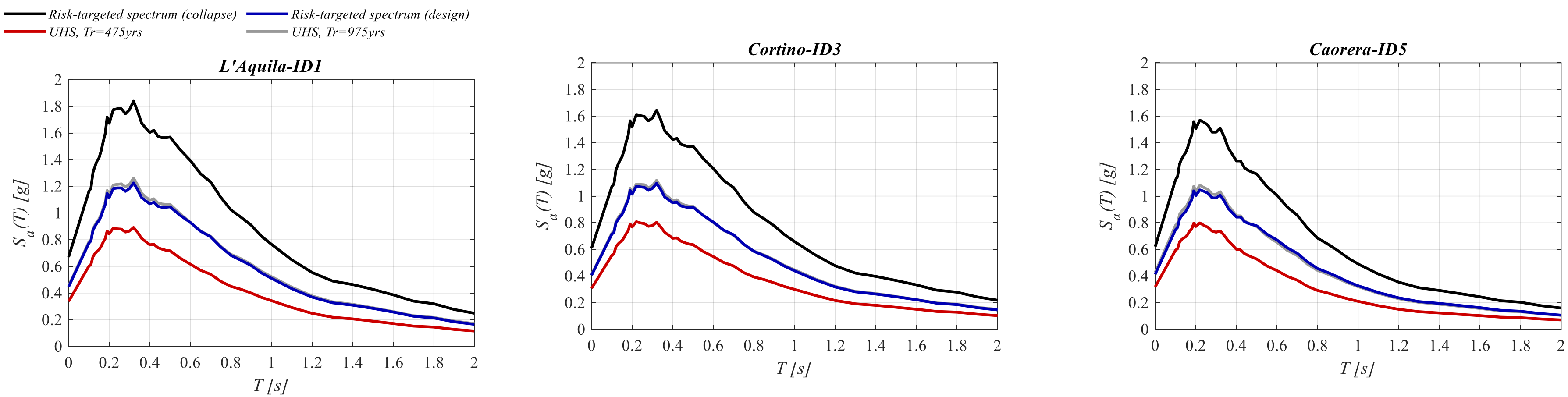


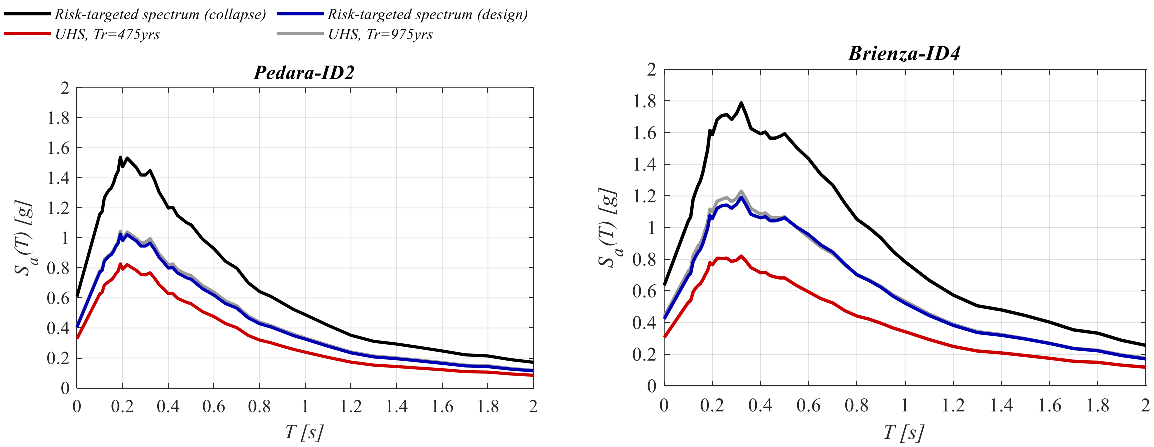
$$f_C(c) = \Phi\left[\frac{\ln c - (\ln c_{10} + 1.28 \cdot \beta)}{\beta}\right] \cdot \frac{1}{c \cdot \beta}$$

$$\begin{cases} \eta = \ln c_{10} + 1.28 \cdot \beta; \; c_{10} = 1.5 \cdot DGM \\ \beta = 0.8 \end{cases}$$

- **Let's use Luco's suggestion assuming standard deviation of log capacity 0.8**

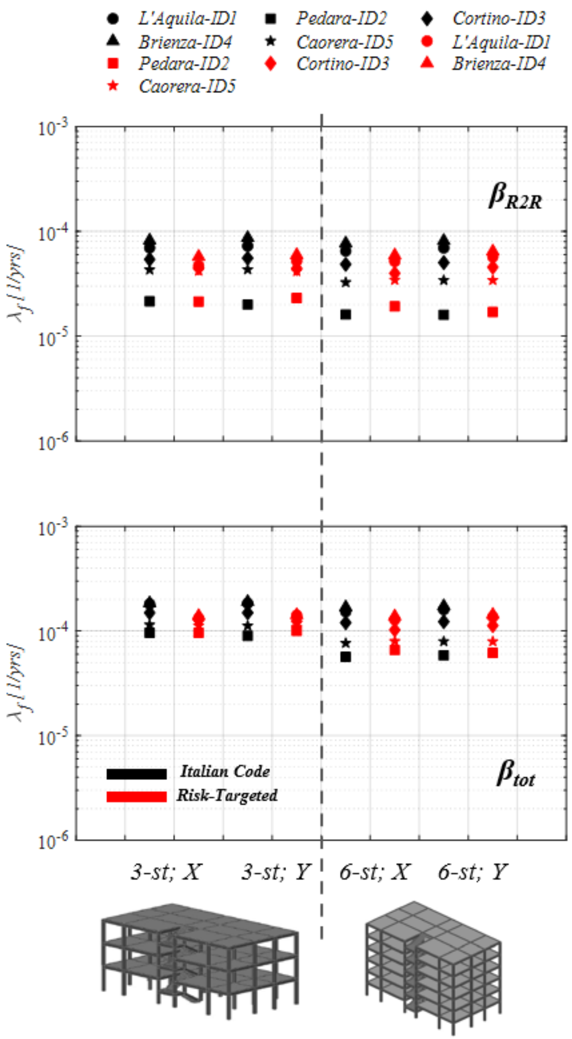
Risk Targeted Design Spectra



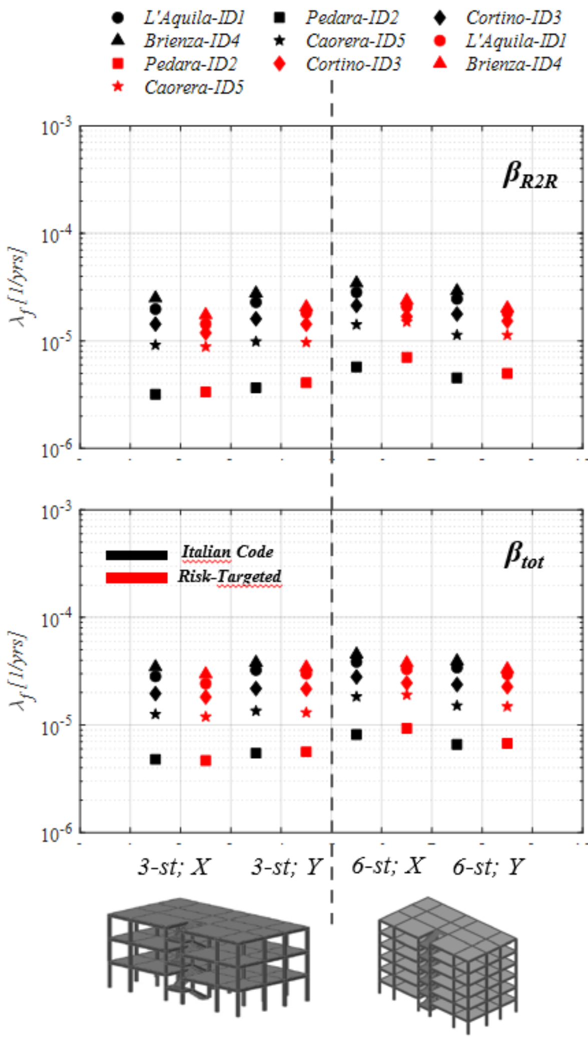


We keep getting a design spectrum that is almost UHS at 975y at all of these sites

Risk Targeted Design Spectra

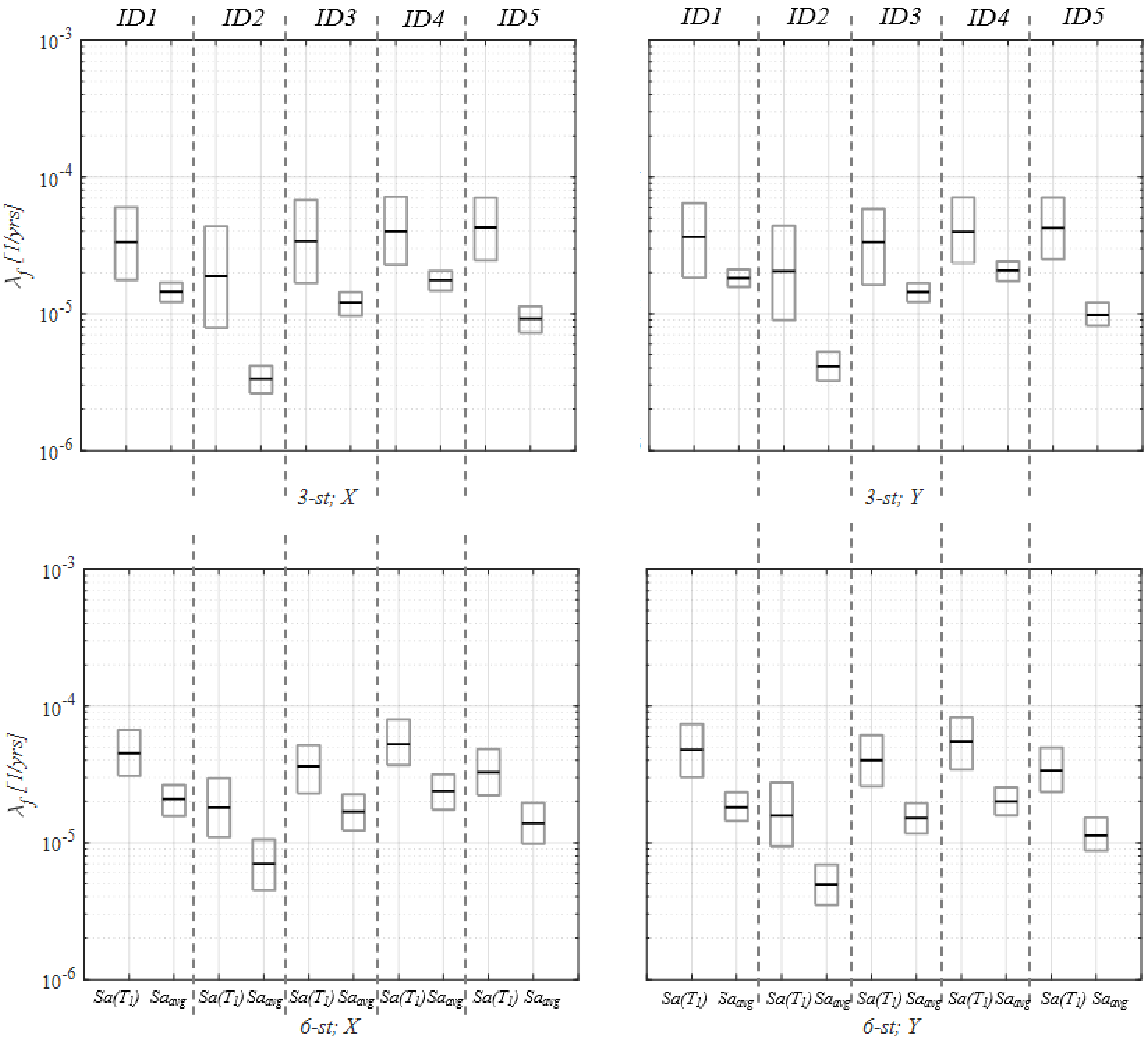


Sa(T_1)



Sa_{avg}

- We redesign the ESDoFs according to the risk-targeted spectra we got
- We then calculate the collapse MAF using IDA-based fragilities
- Apart from a wayward child, it seems to be working but…
- A more sufficient and efficient IM seems to suggest we did not gain much with respect to uniform hazard design spectrum!



A more sufficient and <u>efficient</u> IM seems to suggest we did not gain much with respect to uniform hazard design spectrum!

A look at estimation uncertainty behind collapse MAFs

Conclusions

- Can we obtain uniform reliability via risk-targeted behavior factors?
- Maybe, but we can only do that for medium to high seismic hazard sites
- We can’t really tell which sites from 475y return period elastic demand spectra alone
- We’d need to be site- and structure-specific

- Can we define a Risk-Targeted design spectrum to the same end?
- Assuming collapse fragility a-priori may still leave us with uneven reliability
- Reliability might look uniform using Sa(T) as intensity to predict collapse, but if we look at better predictor IMs, the advantage seems less obvious