National Technical University of Athens
School of Civil Engineering

QqQqQqqqQqQQqQqqqQQqqQq?

Funky Structure Behavior Factors

Q?

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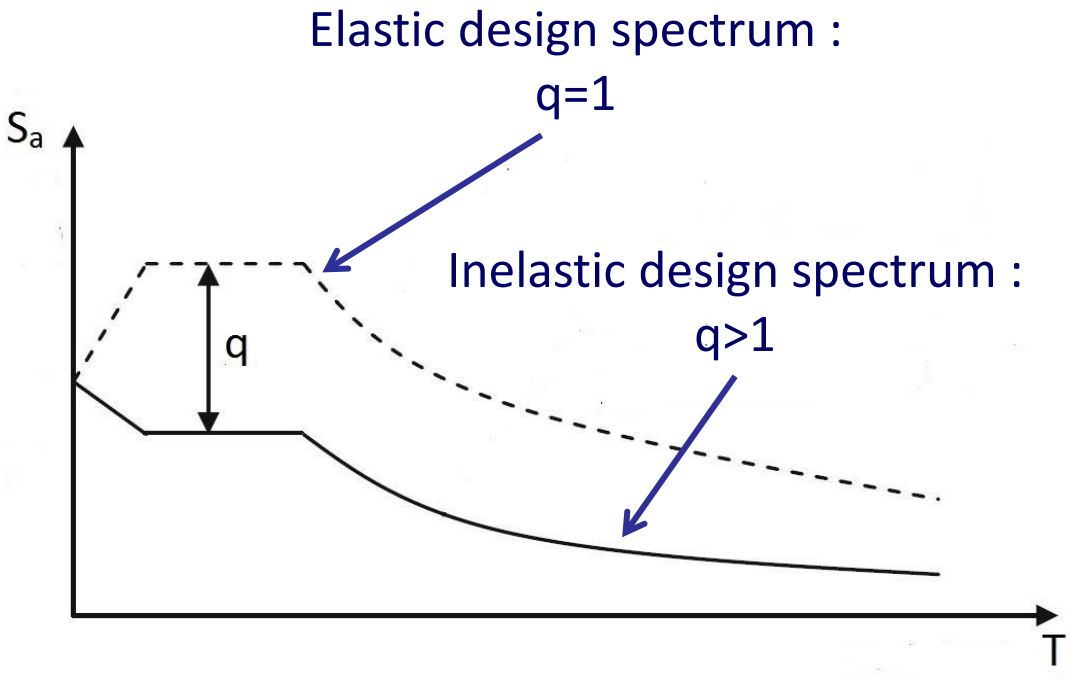
q?

Eurocode 8 is now a teenager….

- It was conceived circa 1990
- It came to the world in 2005
- It is now 14 years old
- …. and we should finally get to have this **awkward conversation** that every responsible parent should have with his/her child at this age….

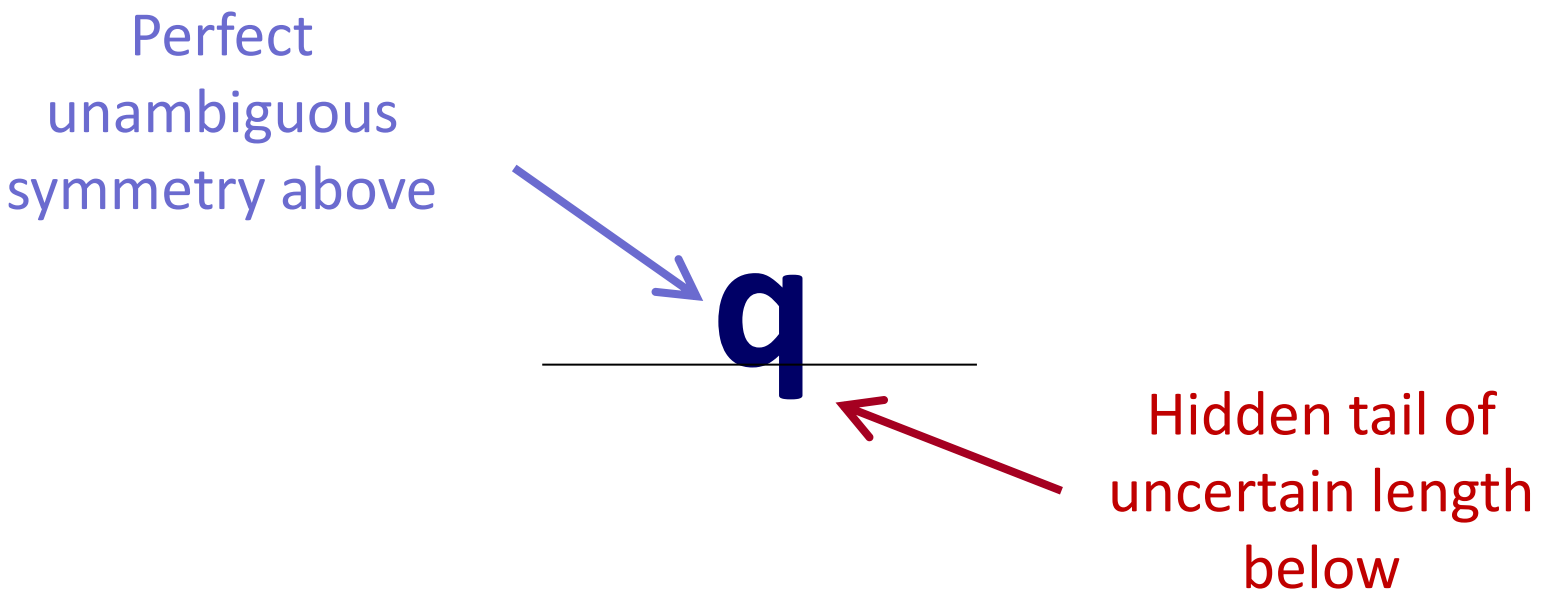
What are we going to do with q?

- Elastic design spectrum to inelastic via q
- Reduces elastic forces by taking into account the effect of ***system*** ductility and overstrength
- Standardized, **period-free** values for each system type
- It condenses **everything** we need to know on nonlinearity & safety into a single scalar
- For example, we design at 475yrs for **severe damage** and expect to satisfy **collapse** requirements at 2475 or 5000 yrs intensities!



Wave your wand, shout “q-factorum” and make Harry Potter jealous!

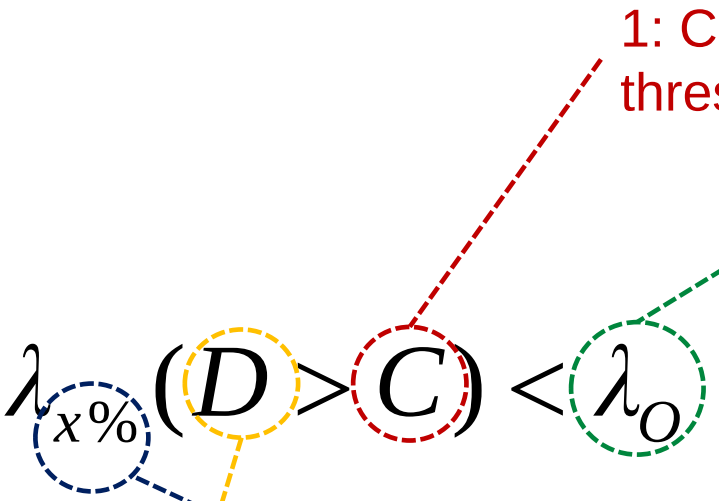
Before quantifying, we need defining



- 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

First we need to define performance objectives

PO = A triplet of values



1: Capacity: An EDP threshold to define LS

2: maximum allowable MAF of exceeding C

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

seismic demand (variable)

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%.

Now we can mathematically define q

Nobody will accept q<1
(although it may be needed!)

Find the maximum q to satisfy

$q \geq 1$

archetypes

$f\left(S_i, site_i, q\right) = 1, \quad \forall i = 1,\ldots,N$

Ensure all designs satisfy code requirements

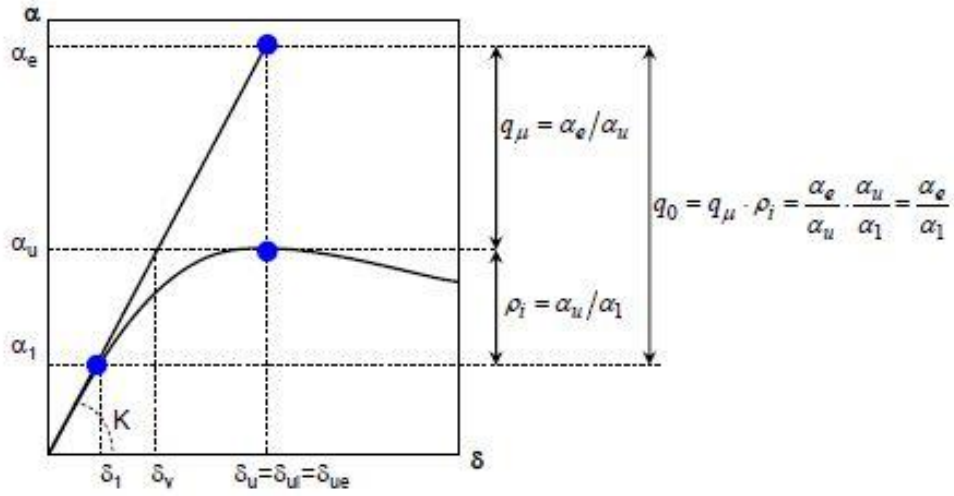
$\lambda_{xj\%}\left[D_j(S_i, site_i, q) > C_j(S_i)\right] < \lambda_{Oj}, \quad \forall i = 1,\ldots,N,\ j = 1,\ldots,M$

Ensure all designs satisfy the set POs

- Estimating q is an optimization problem in probability space:
  - Find the maximum q that when used to design a set of archetype structures at given sites, they will satisfy all performance objectives

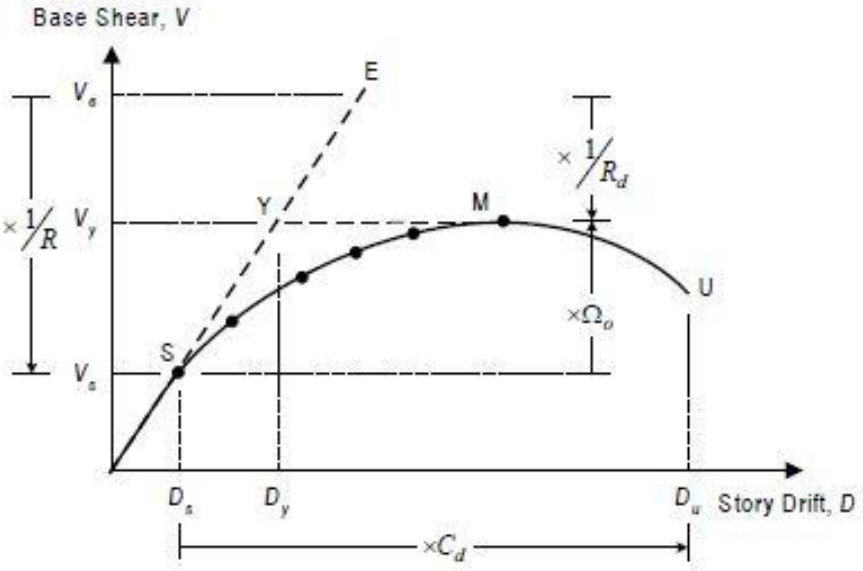
Code approaches: EU versus USA

Eurocode 8



- Modest q factors (2.5 – 6.5)
- Overstrength based on ***first yield***
- No formal approach for introducing new systems

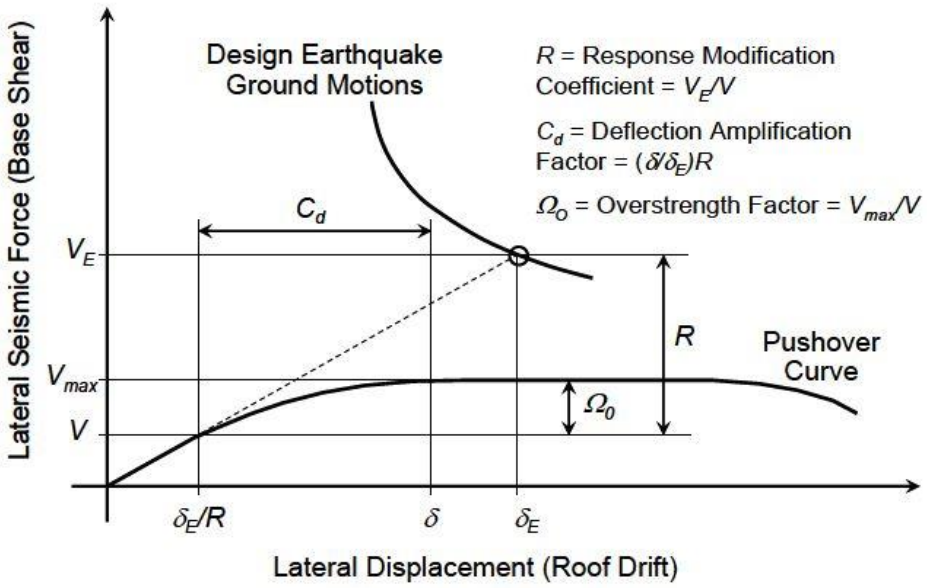
ASCE-7



- Larger R factors (3 – 8)
- Overstrength based on **design base shear**
- New systems via FEMAP695
- Adopt it for Eurocode use?

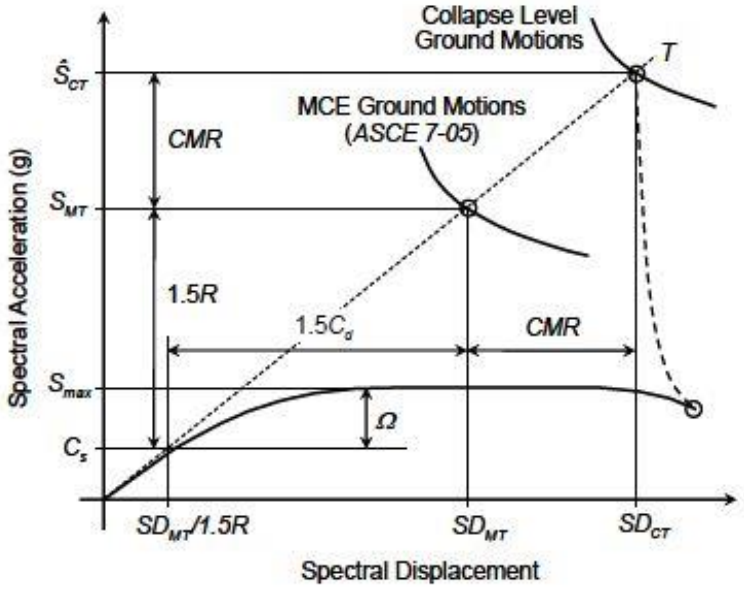
1 - Static or dynamic analysis?

Static



- Just a single static pushover!
- Equal displacement rule employed for ductility: $q_\mu = \mu$ **(really?)**
- Direct estimation of overstrength: $\Omega=V_{max}/V_{design}$ ή a_u/a_1
- Multiply: $q = q_\mu \cdot \Omega$

Dynamic



- Many nonlinear dynamic analyses needed
- A **new daemon** appears: Uncertainty
- Overstrength cannot be estimated easily

2 - Direct or indirect assessment?

- Direct approach = Straightforward evaluation

  1. Select a trial q-factor.
  2. Design a set of archetypes
  3. Estimate an updated value of q

  Can only be achieved via the static approach. Careful if initial and final q-values differ considerably

- Indirect approach = Requires iteration

  1. Select a trial q-factor.
  2. Design a set of archetypes
  3. Check performance objectives. If inadmissible, return to 1.

3 - Which intensity measure?

Classic: $S_a(T_1)$

- Neglects higher/elongated modes
- Moderate dispersion
- The only choice available in the static approach
- Requires large scale factors to achieve collapse, potentially needing correction for bias.

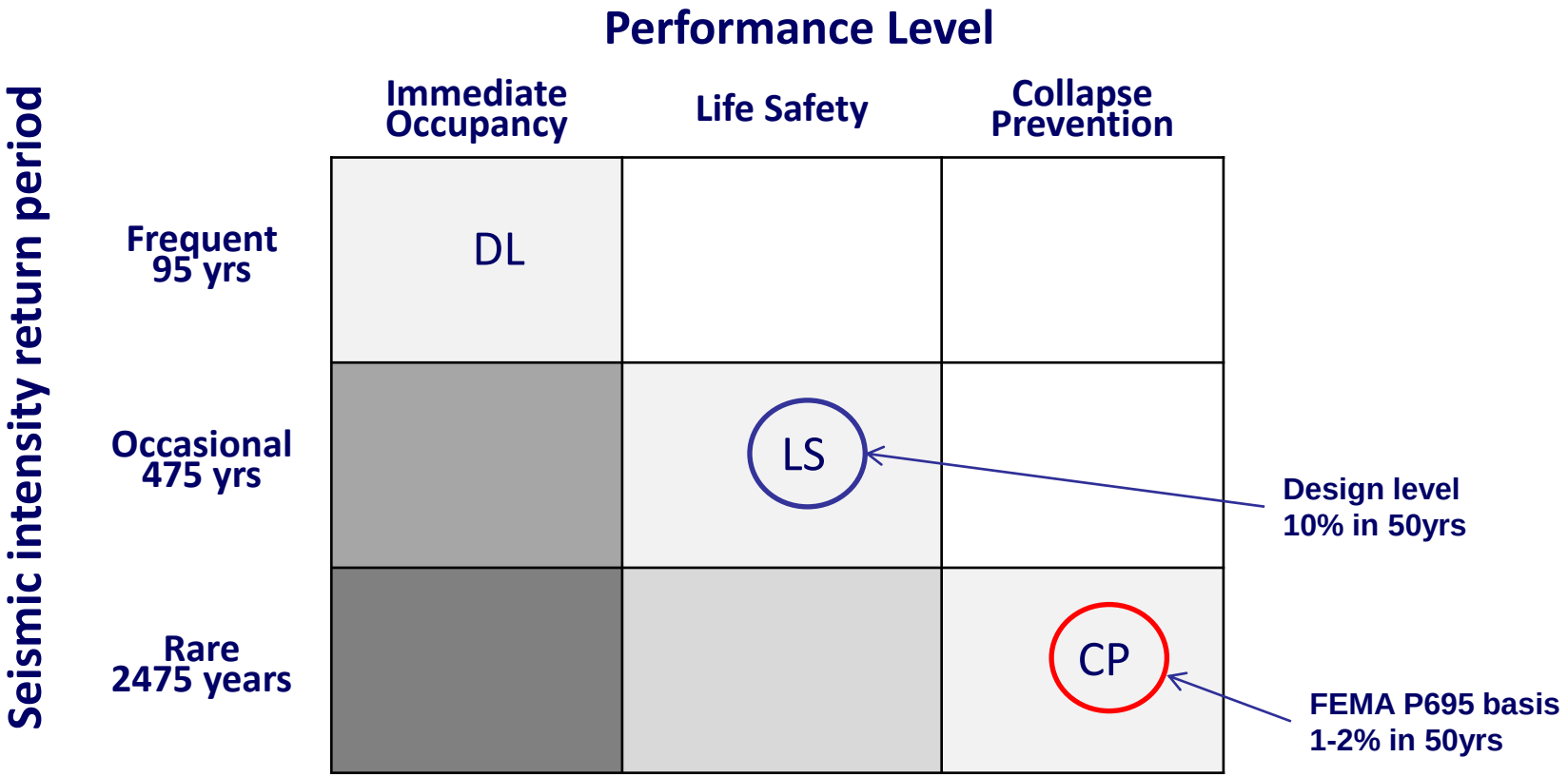
Avant Garde: $AvgS_a$

- Incorporates multiple periods

$$AvgS_a(T_1, \dots, T_n) = \left(\prod_{i=1}^{n} S_a(T_i) \right)^{1/n}$$

- Low dispersion
- Low scaling factors for collapse
- No/little need for bias correction

4 - How many and which performance objectives?



- FEMA P695 uses CP but (a) modern structures do not collapse (b) it is tough to capture it.
- LS is easier to model and check for.
- Why not use both?

5 - Intensity or risk based?

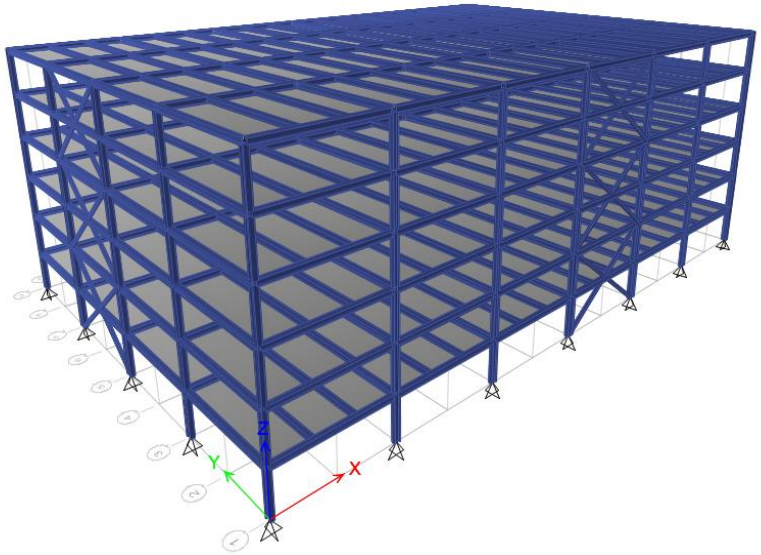
- Intensity-based: The approach of FEMA P695
  - $Sa_{LimitState,x\%} > Sa@MAF_{target}$: Check the x% IM capacity against a desired intensity level for compliance.
  - In principle, incompatible with uniform hazard spectra
  - Risk-check enforced indirectly via **risk-targeted spectra**.
- Risk-based:
  - $MAF_{LimitState} < MAF_{target}$: Check MAF of limit-state exceedance for compliance.
  - Compatible with existing **uniform hazard spectra**
  - Risk-check enforced directly without risk-targeted spectra.

How do we answer for EN1998?

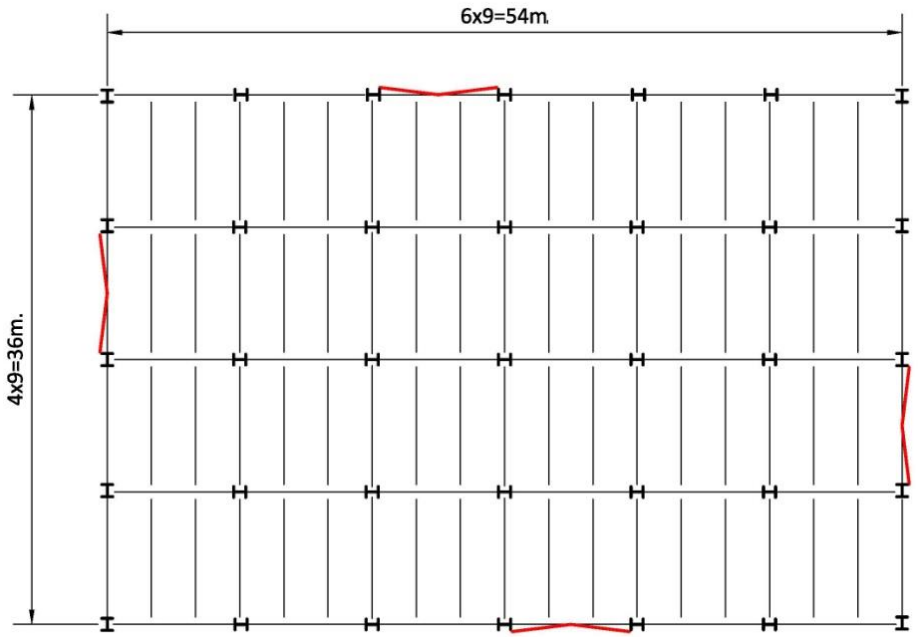
- Static or Dynamic?
  - Dynamic. Static only for initial q determination.
- Direct or Indirect?
  - Indirect. Direct only for initial q determination.
- Which IM?
  - AvgSa, hands down.
- Which performance objective(s)?
  - Use both Life Safety and Collapse Prevention.
- Risk or Intensity basis?
  - Risk always wins

Example: 6-story X-braced CBF

3D model



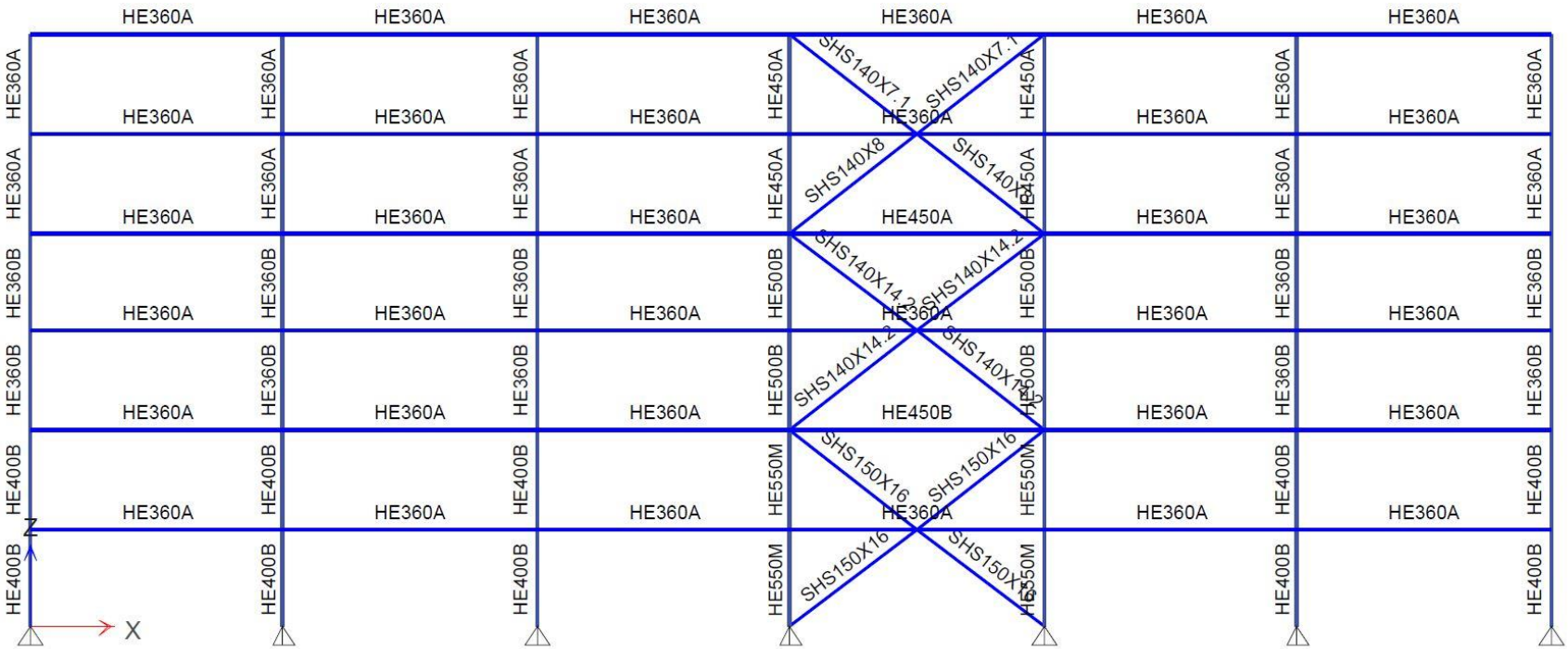
Plan



- One braced bay per side
- Story height 3.5 m, bay length 9m.
- T1 = 1.14sec

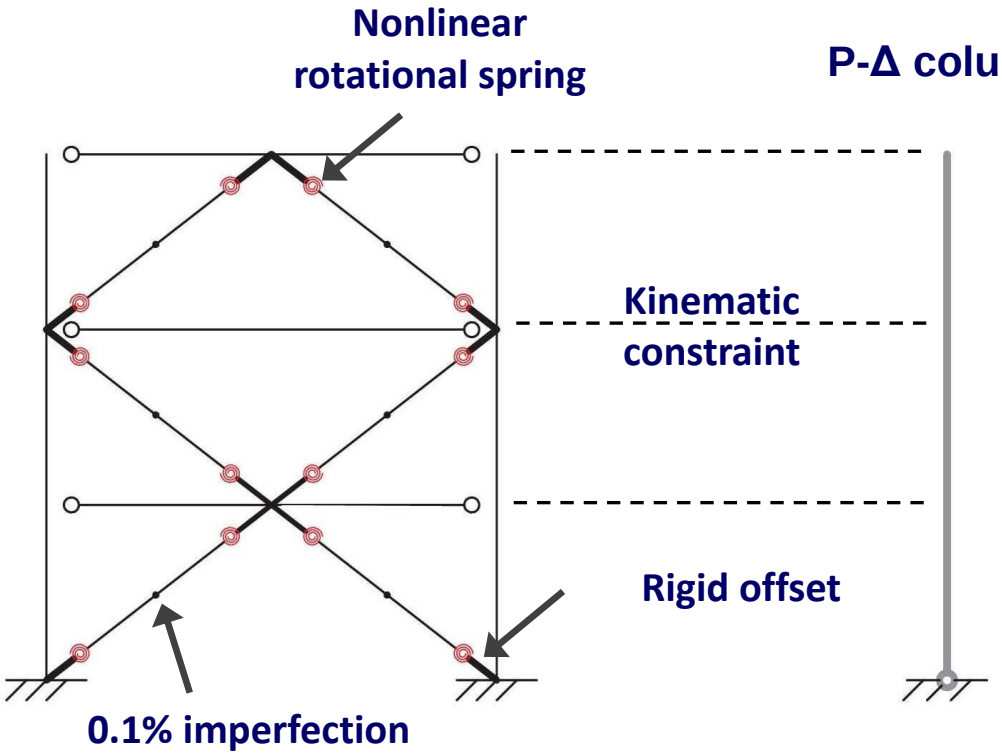
Design and member sizing

Longitudinal Elevation



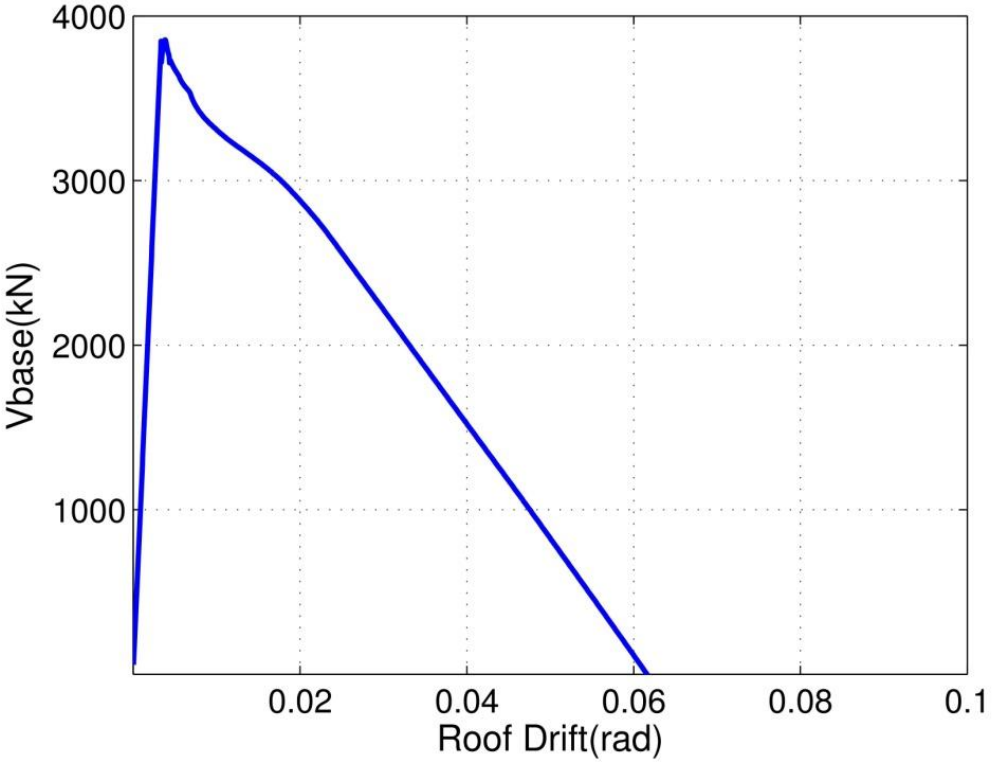
Braced frame model

2D OpenSees model



- Add a geometric imperfection to allow compression buckling
- Fully represent gusset plate offset and connection properties

Assessment via the static approach



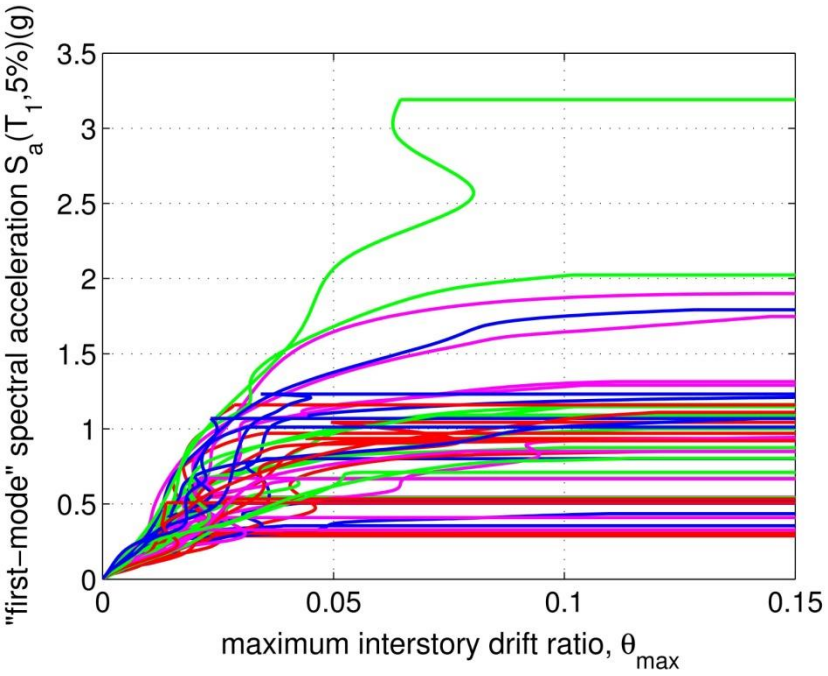
- Yield drift: $\theta_y = 0.0033$
- Ultimate drift: $\theta_u = 0.0160$
- Ultimate ductility:
  $\mu_T = 0.0160/0.0033 =$ **4.83**

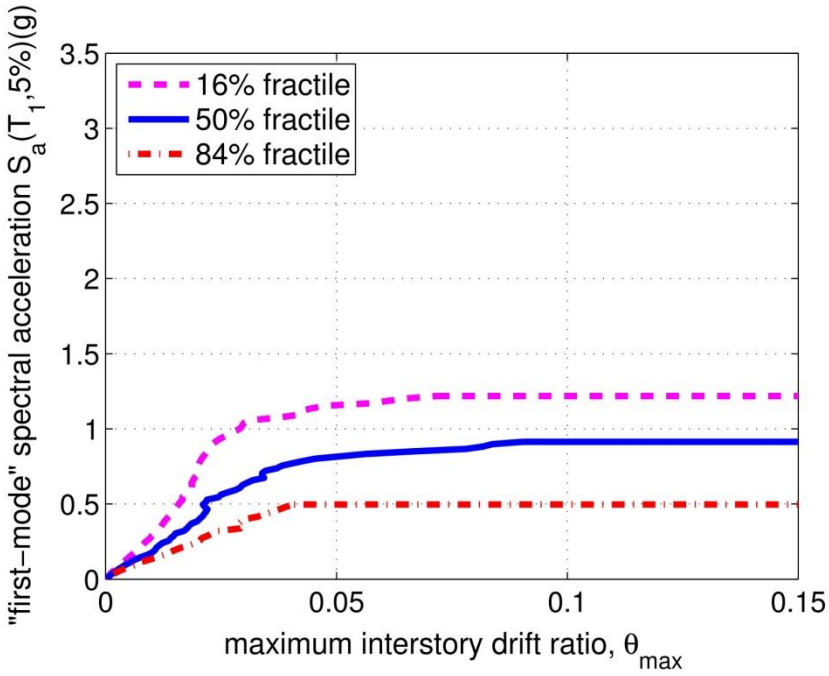
- Max base shear:
  $V_{base} = 3847$kN
- Design base shear:
  $V_{design} = 2736.60$ kN
- Overstrength:
  $\Omega = 3847/2736.60 =$ **1.41**

- Estimated $q = \mu_T \cdot \Omega =$ **6.79**

Nonlinear dynamic analysis (1)

IM = Sa(T_1)



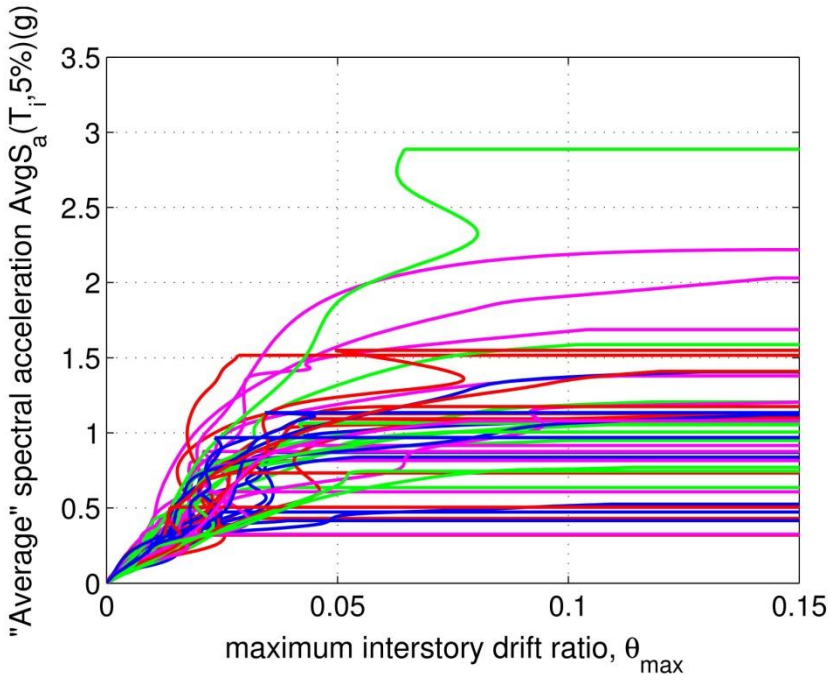


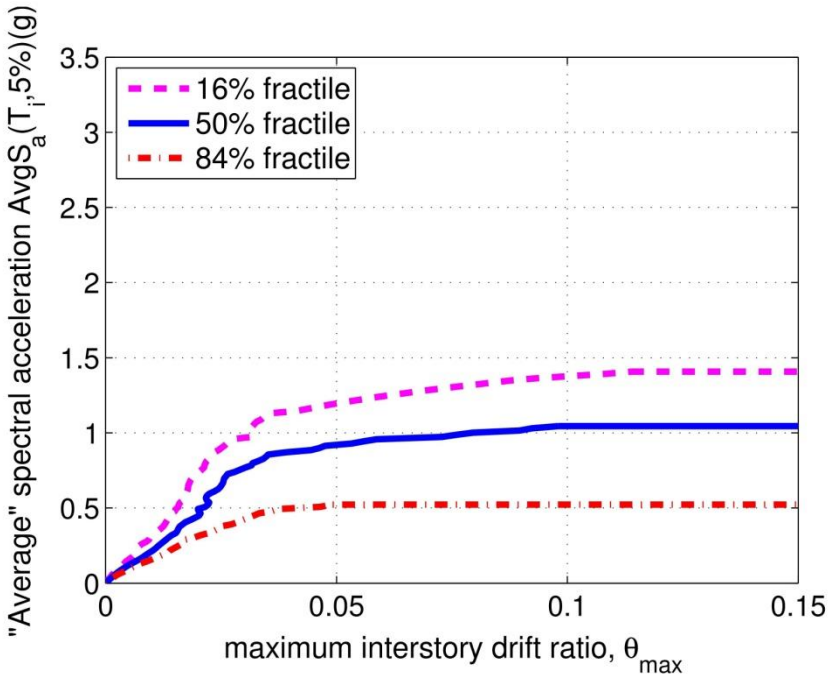
- 44 records
- IDA here, but cloud or MSA work perfectly well

- Median Sa @ collapse: 0.93g

Nonlinear dynamic analysis (2)

IM = AvgSa





- 44 records
- IDA here, but cloud or MSA work perfectly well

- Median Sa @ collapse: 1.06g
- Typically lower dispersions

Comparison of Results

- Sa(T1) results
  - **q ≈ 5.4 – 5.7** (after bias correction)
  - Estimated 97% confidence against collapse @ 1% in 50yrs
  - Design at q = 4 is deemed safe (but conservative)

- AvgSa results:
  - **q ≈ 4.0 – 4.3** (no bias correction needed)
  - Estimated 93% confidence against collapse @ 1% in 50yrs
  - We found less conservatism (but AvgSa results are more reliable!)

Uncomfortable Conclusions

- q-factor estimates differ
  - With building characteristics (e.g., period: tall buildings → lower q)
  - With approach adopted:

    Nonlinear static = **6.8**

    Nonlinear dynamic with Sa(T1) = **5.5**

    Nonlinear dynamic with AvgSa = **4.2**
- We will prefer the latter approach
  - No need for risk-targeted spectra
  - No need for bias correction of q if IM=AvgSA
  - …..but at the cost of a heavier analysis burden

Our thanks go to

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  - http://innoseis.ntua.gr/
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