# On the Efficient Risk Assessment of Bridge Structures


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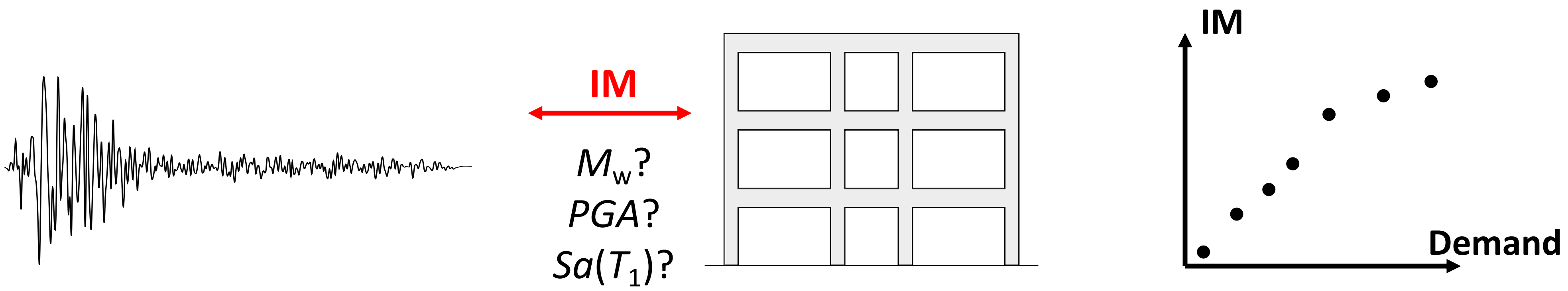
# Intensity measures – what do we mean?

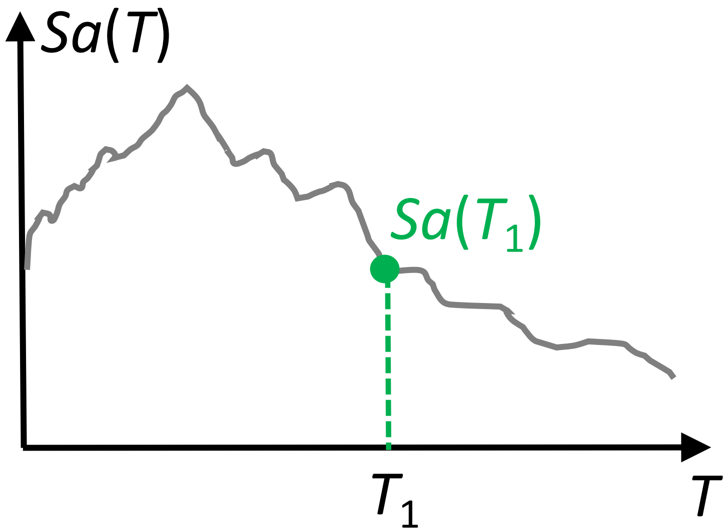
- An intensity measure (IM) is the interface variable that connects seismological and engineering aspects of seismic assessment

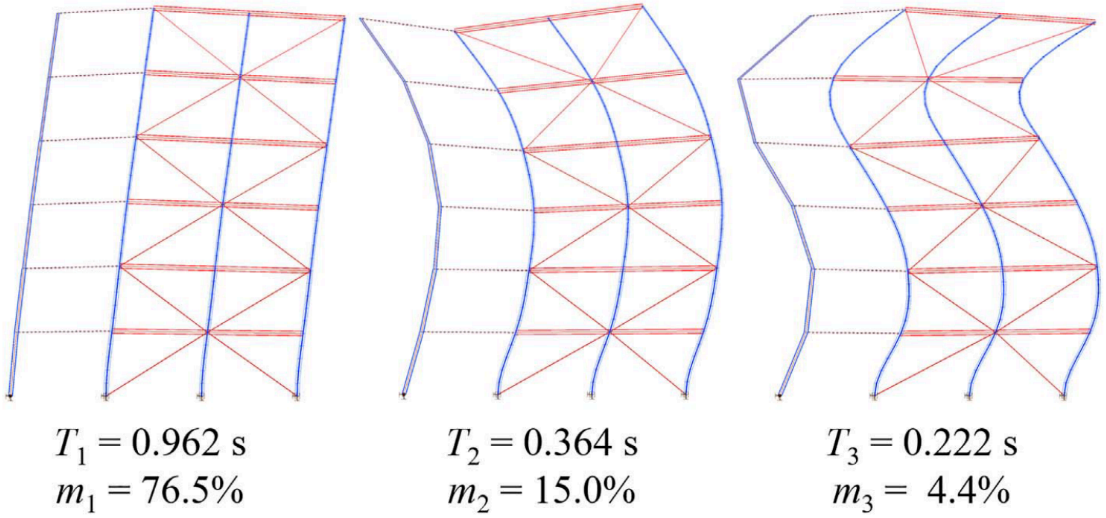



- Seismologists use ground motion prediction equations (GMPEs) and probabilistic seismic hazard analysis (PSHA) to evaluate the rate of exceedance of an IM at a specific site
- Engineers, on the other hand, use the IM to examine the subsequent response of structures and to evaluate their performance

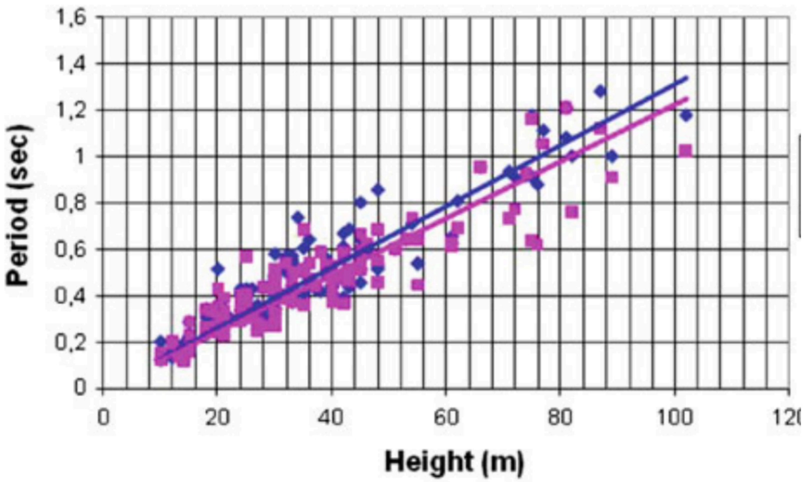
# Intensity measures – buildings

- The most classic example of an IM for buildings is the spectral acceleration at the first mode period $Sa(T_1)$



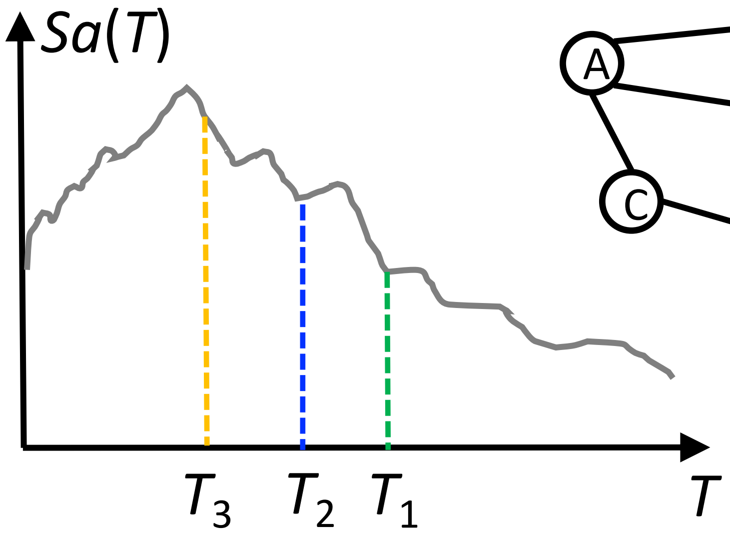



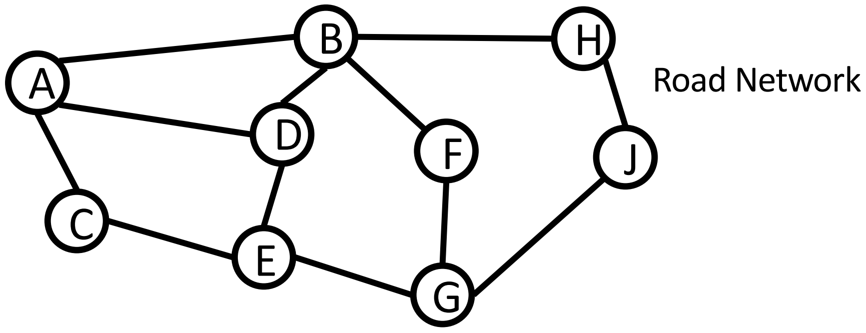

- The assessment of buildings is relatively straightforward:
  - Carried out on individual buildings (usually!)
  - Buildings tend to be first-mode dominated
  - Periods can be estimated reasonably well empirically



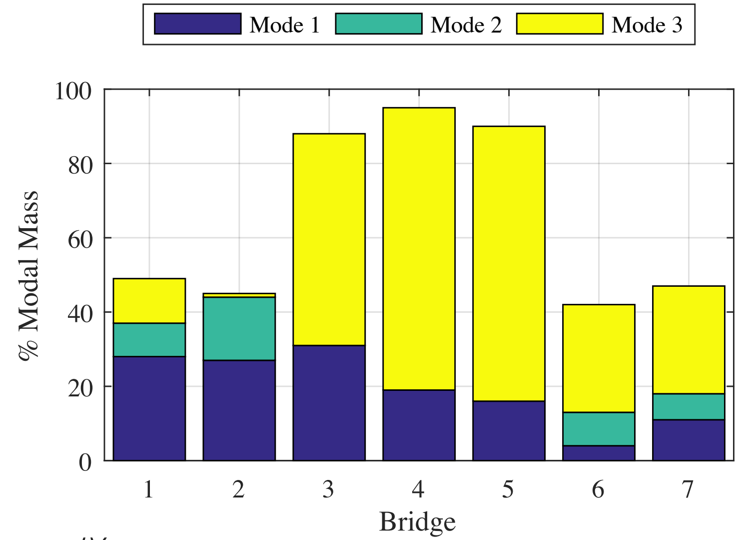
# Intensity measures – bridges

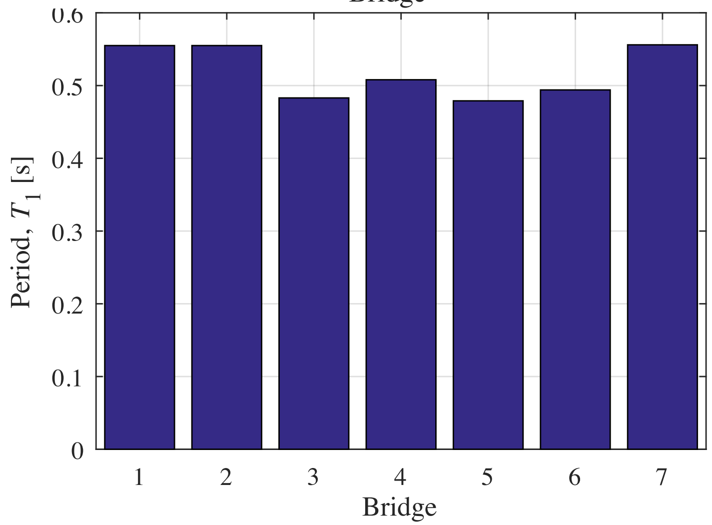
- When switching the conversation to bridges, most of these “conveniences” no longer hold




**Which bridge period?**

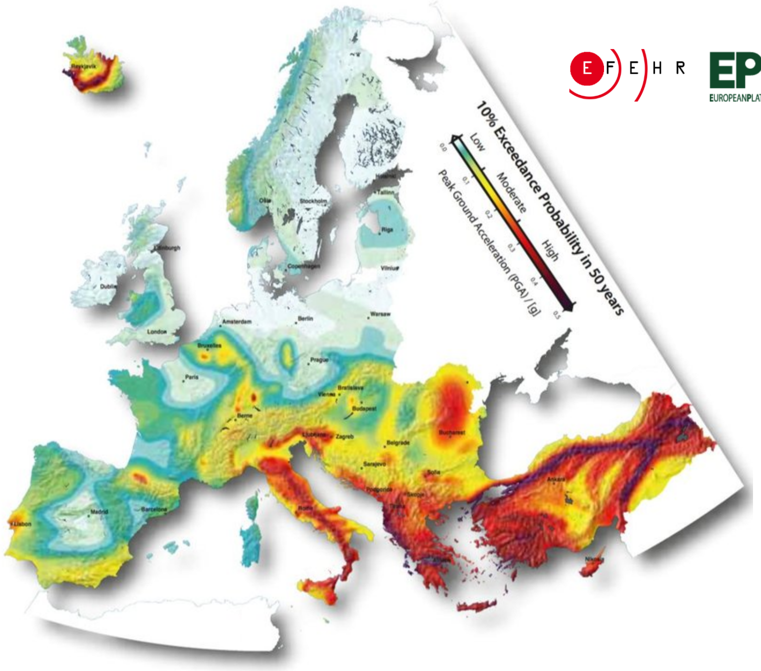


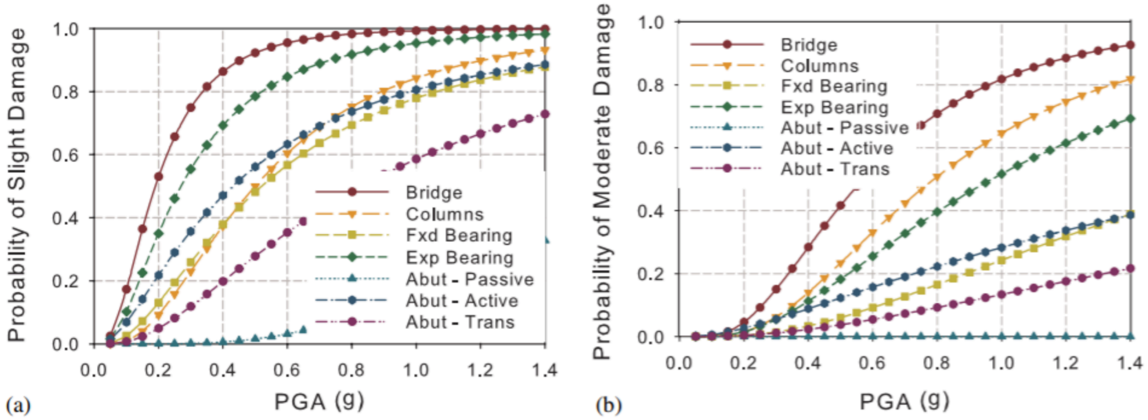




- The assessment of bridges in a similar fashion is not so straightforward:
  - Most bridges have multi-modal response
  - Usually interested in entire bridge networks
  - Periods not so easy to estimate (some expressions do exist)

# How are things currently done for bridges?

- In the past, peak ground acceleration (PGA) has been used.
  - Easy to define
  - Independent of bridge modal properties
  - Most hazard models will map PGA making it convenient for regional assessment
- So what? What is so bad about PGA?
  - It is poor predictor of building response
  - For bridges, it is not bad and comparable to others (see Monteiro *et al.* (2017))

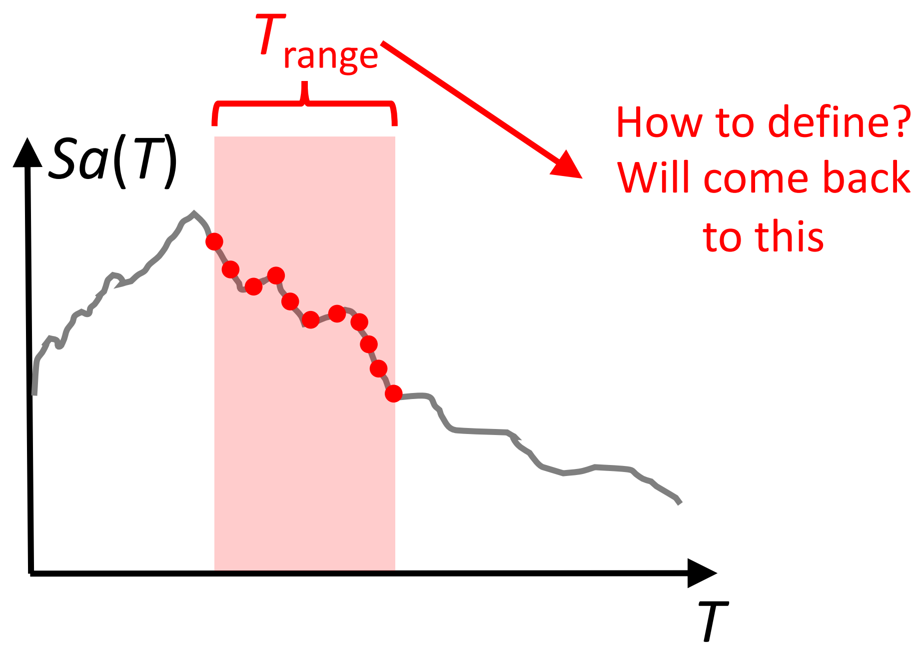



Nielson & DesRoches (2007)

# Average spectral acceleration – a better solution?

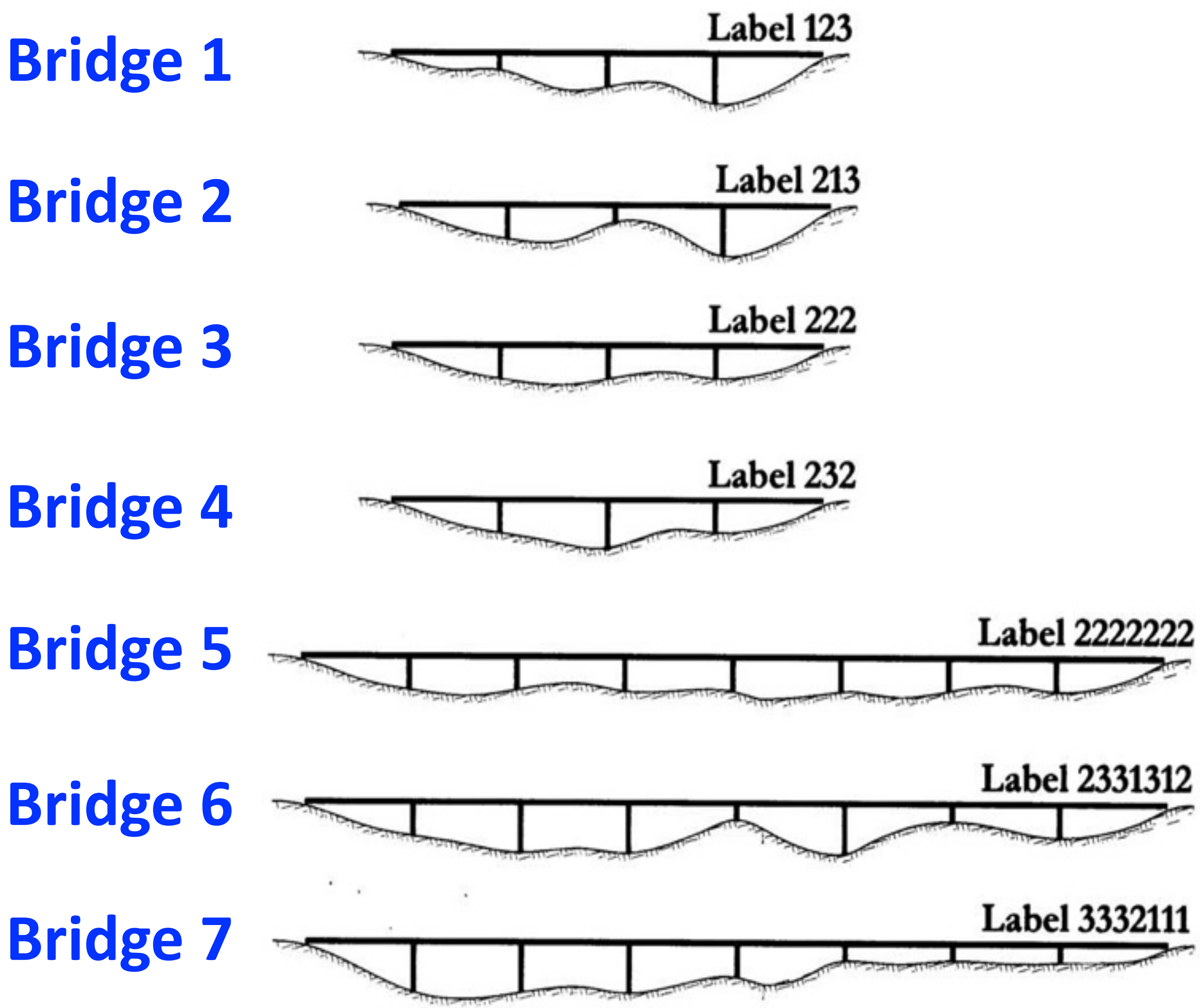
- PGA is not ideal, so can we do better?
  - Average spectral acceleration (AvgSa) has been developed recently for the assessment of buildings, showing many added benefits
- Benefits:
  - Simple in its definition
  - Relatively independent of modal properties (!)
  - Lower GMPE dispersion by definition
- Shown not to be the best predictor for any one EDP but the best “overall” predictor that suits different needs (i.e. EDPs, limit states etc.)




$$AvgSa = \left[\prod_{i=1}^{N} Sa(T_i)\right]^{1/N} \quad for\ T_i \in [T_{lower}, T_{upper}]$$

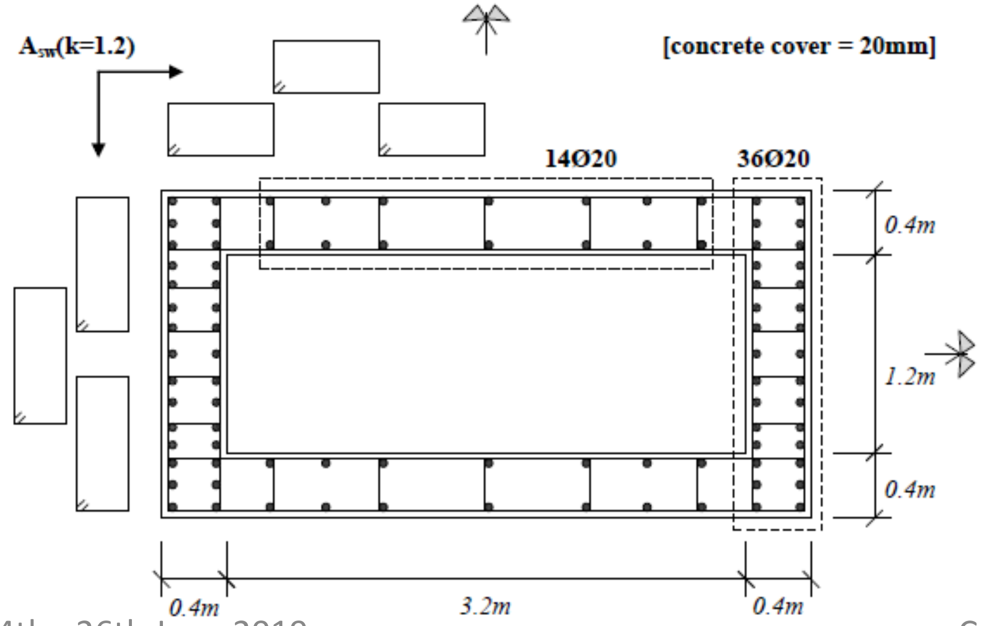
# Case study bridges

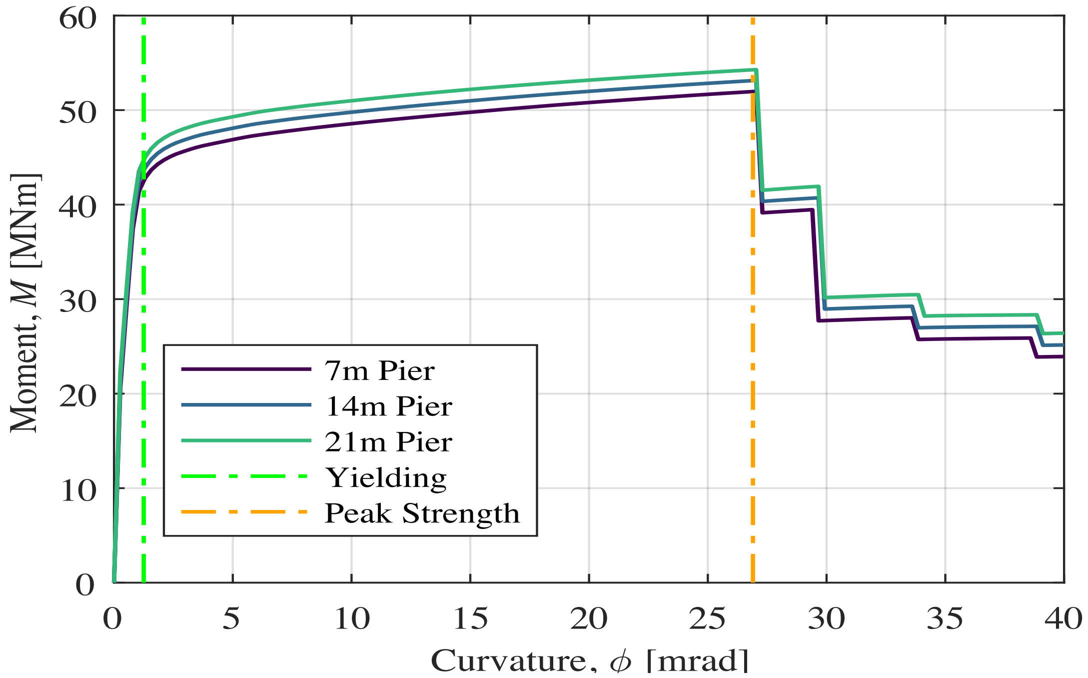
- A number of case study bridge structures previously examined by Pinho *et al.* [14] were utilised
- Bridge structures of two lengths, with viaducts consisting of either four or eight 50m spans
- The label numbers 1, 2, and 3 denote pier heights of 7m, 14m, and 21m, respectively



# Numerical modelling and limit states

- A numerical model of each bridge was built using OpenSees
- Pier elements were modelled using lumped plasticity elements, whose parameters were established from moment-curvature analysis
- To simulate the bar rupture, a MinMax criterion was used to simulate loss of strength beyond a certain strain threshold
- Rupture strain was estimated as 0.10 based on Priestley *et al.* [17] for reinforcement steel used in bridges in Europe.

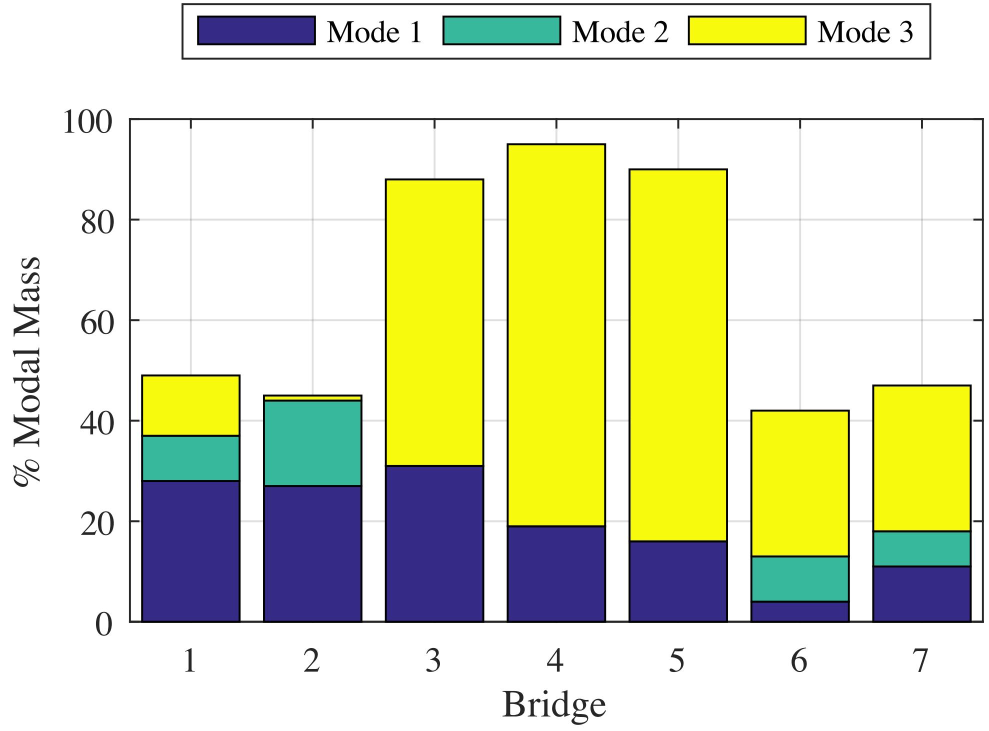


# Modal properties

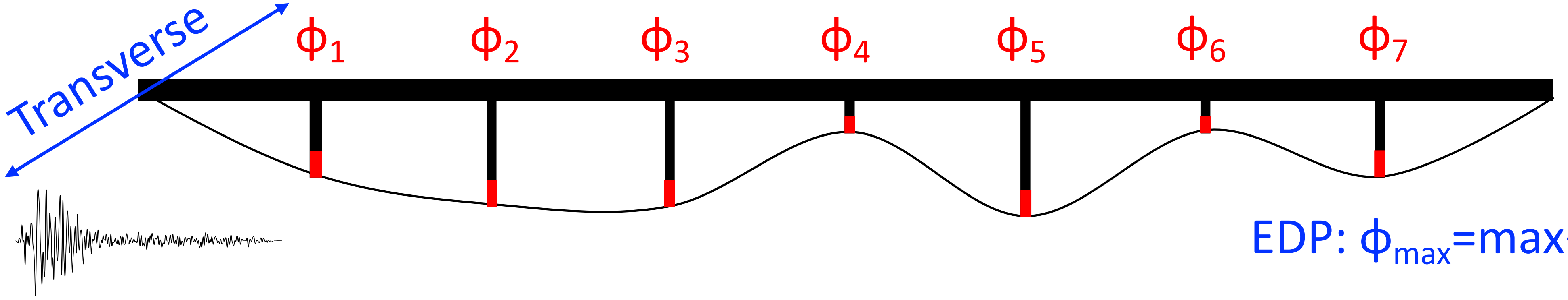
- Unlike building structures, the first mode of response is not always the most dominant in the response
- Modal mass participation tends to be spread across a number of modes
- For some, 3 modes suffice and for others, more are required

| | Periods | | | Modal Masses | | | |
|---|---|---|---|---|---|---|---|
| Bridge | $T_1$ [s] | $T_2$ [s] | $T_3$ [s] | $\%M_1$ | $\%M_2$ | $\%M_3$ | Sum %M |
| 1 | 0.56 | 0.45 | 0.28 | 28 | 9 | 12 | 48 |
| 2 | 0.56 | 0.47 | 0.25 | 27 | 17 | 1 | 45 |
| 3 | 0.48 | 0.48 | 0.22 | 31 | 0 | 57 | 88 |
| 4 | 0.51 | 0.48 | 0.31 | 19 | 0 | 76 | 95 |
| 5 | 0.48 | 0.48 | 0.23 | 16 | 0 | 74 | 89 |
| 6 | 0.49 | 0.47 | 0.36 | 4 | 9 | 29 | 42 |
| 7 | 0.56 | 0.44 | 0.39 | 11 | 7 | 29 | 47 |



# Incremental dynamic analysis

- To characterise the bridge response, IDA was used:
  - Analyses were conducted in the transverse direction
  - 2% tangent stiffness-proportional Rayleigh damping model was adopted
- To quantify structural demand, an EDP was needed:
  - In buildings, maximum drift along the height or roof drift is a typical EDP
  - In the case of bridges, the damage is typically localised to the pier elements
  - Track the section curvatures in the pier element plastic hinge zones for each ground motion
  - Maximum for all piers chosen as the EDP



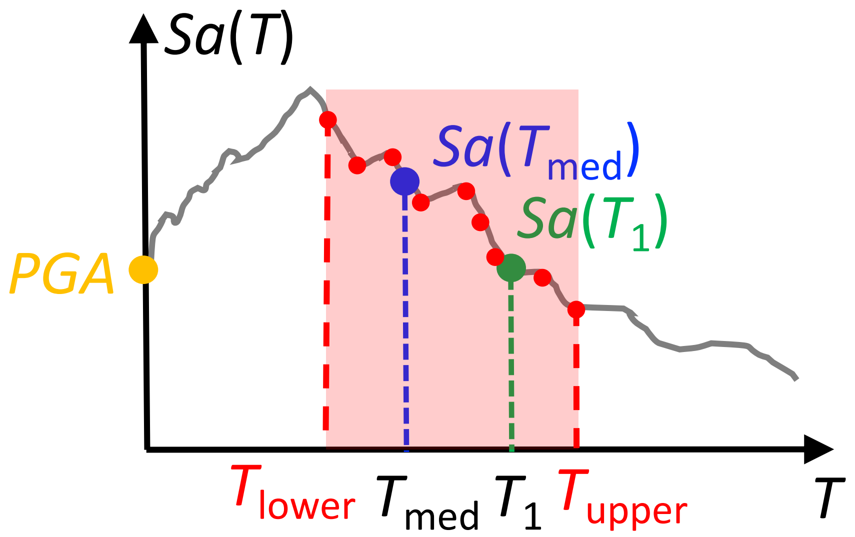

EDP: $\phi_{max}=\max\{\phi_1, \phi_2, \dots \phi_7\}$

# Intensity measures examined

- The IMs considered as part of this study were:
  1. ***PGA***
  2. ***Sa*(*T*$_1$)** for each bridge
  3. ***Sa*(*T*$_{med}$)** at median period of the first three modes for all bridges
  4. ***PGV*** (peak ground velocity)
  5. ***AvgSa*** for ten equally space periods spanning the range of $T_{lower}$ and $T_{upper}$

$T_{lower}=0.5T_{3,16\%}=0.11s$

$T_{upper}=1.5T_{1,84\%}=0.83s$




| Bridge | $T_1$ [s] | $T_2$ [s] | $T_3$ [s] |
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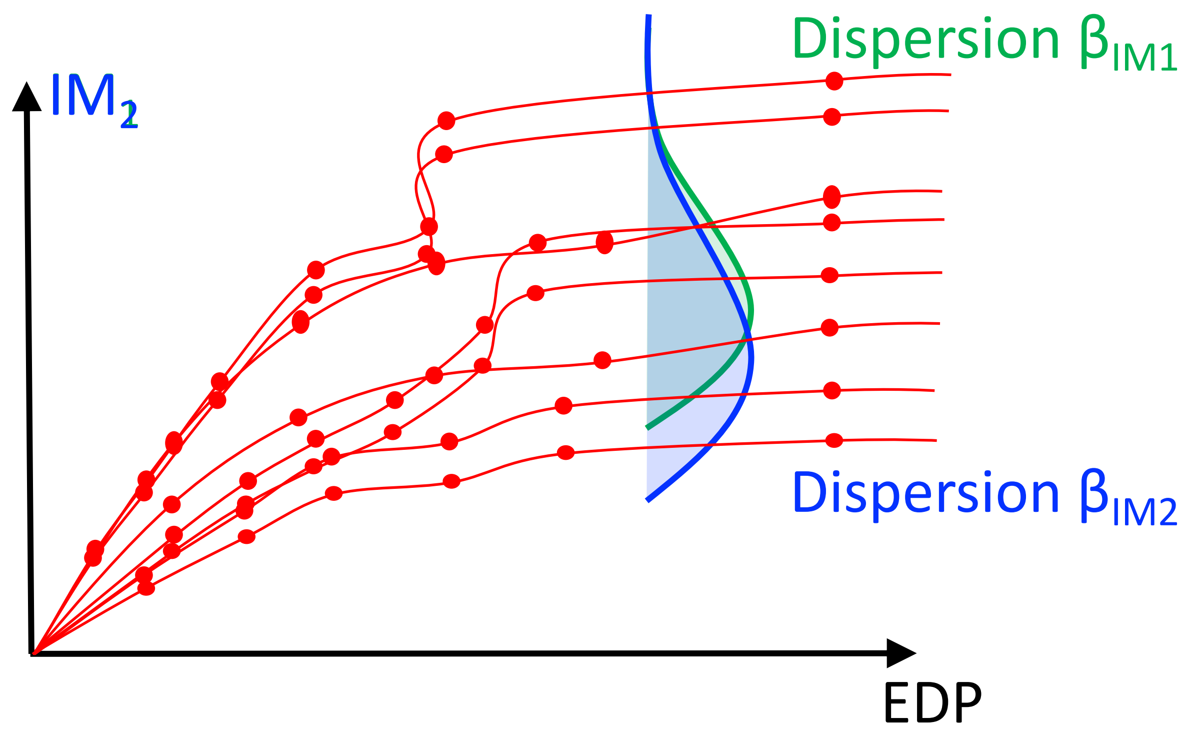
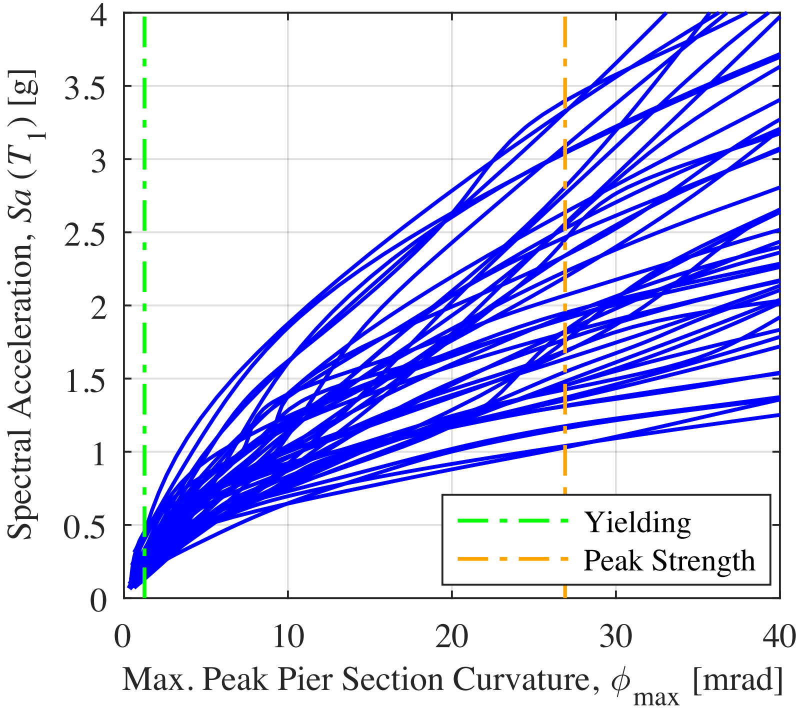
| 6 | 0.49 | 0.47 | 0.36 |
| 7 | 0.56 | 0.44 | 0.39 |

# Incremental dynamic analysis - IMs

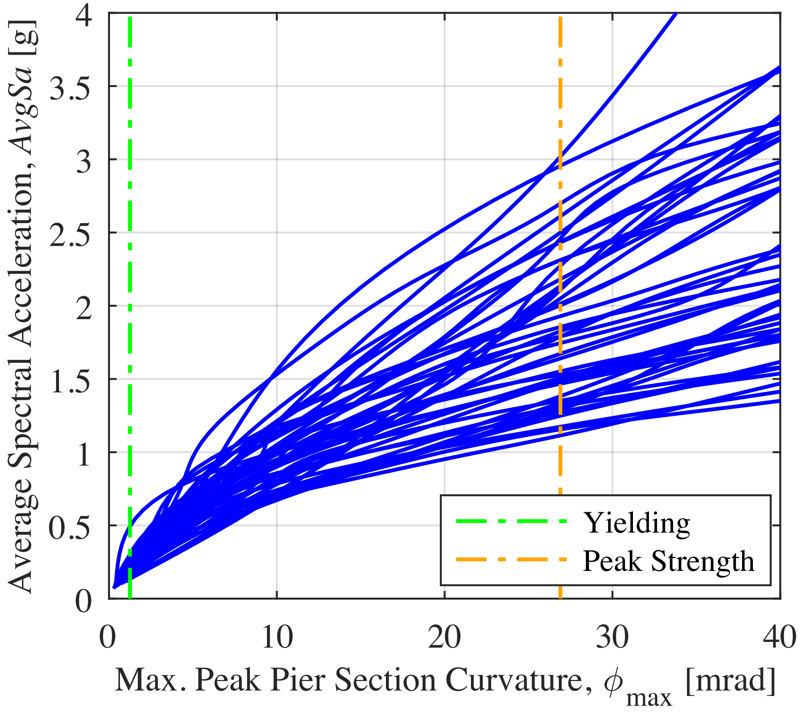
- To use the same set of IDA results for each IM considered, a simple reprocessing for a different definition of ground motion intensity
- This simplified method is not perfect, but for the relative comparison we are looking to make here it is good enough
- Two limit states were examined based on the pier damage:
  - Pier yielding
  - Pier peak strength



# Incremental dynamic analysis - Results



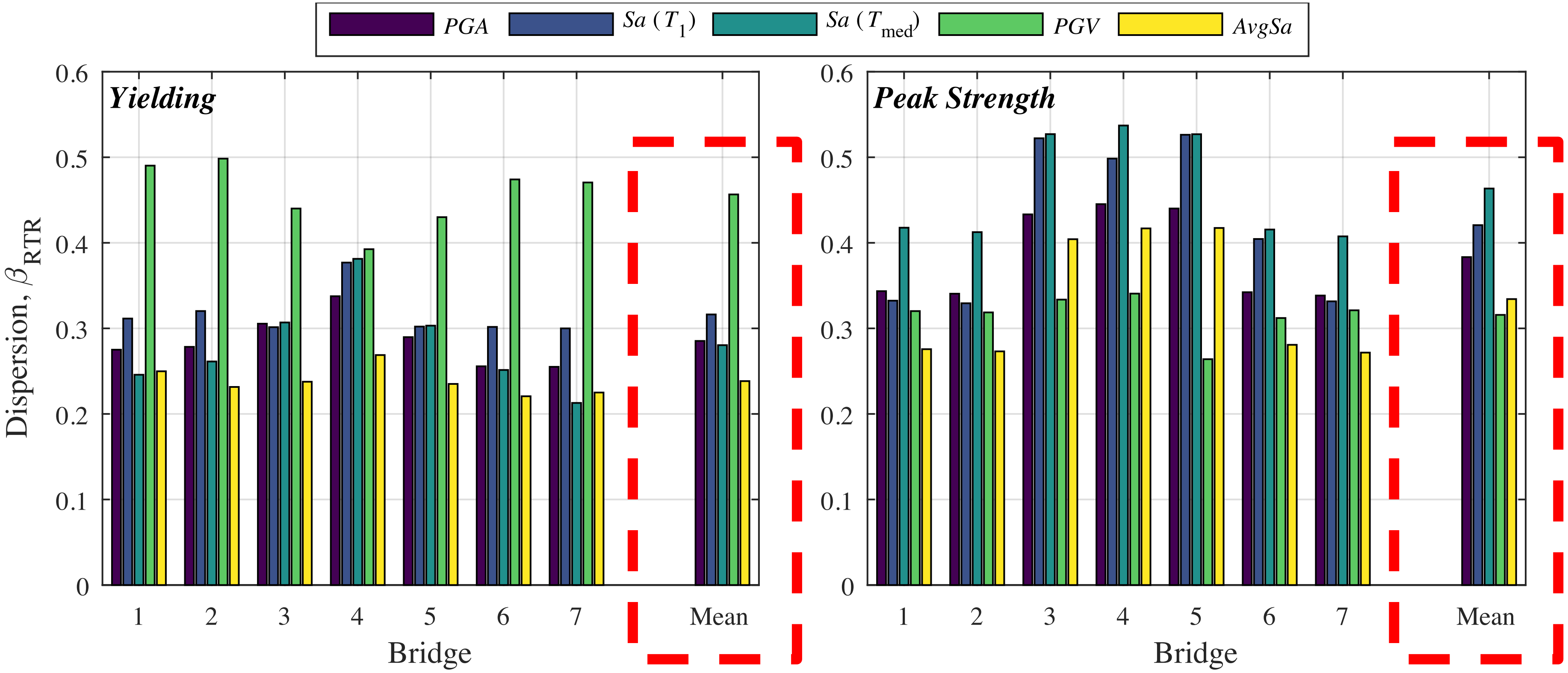

$Sa(T_1)$




$AvgSa$

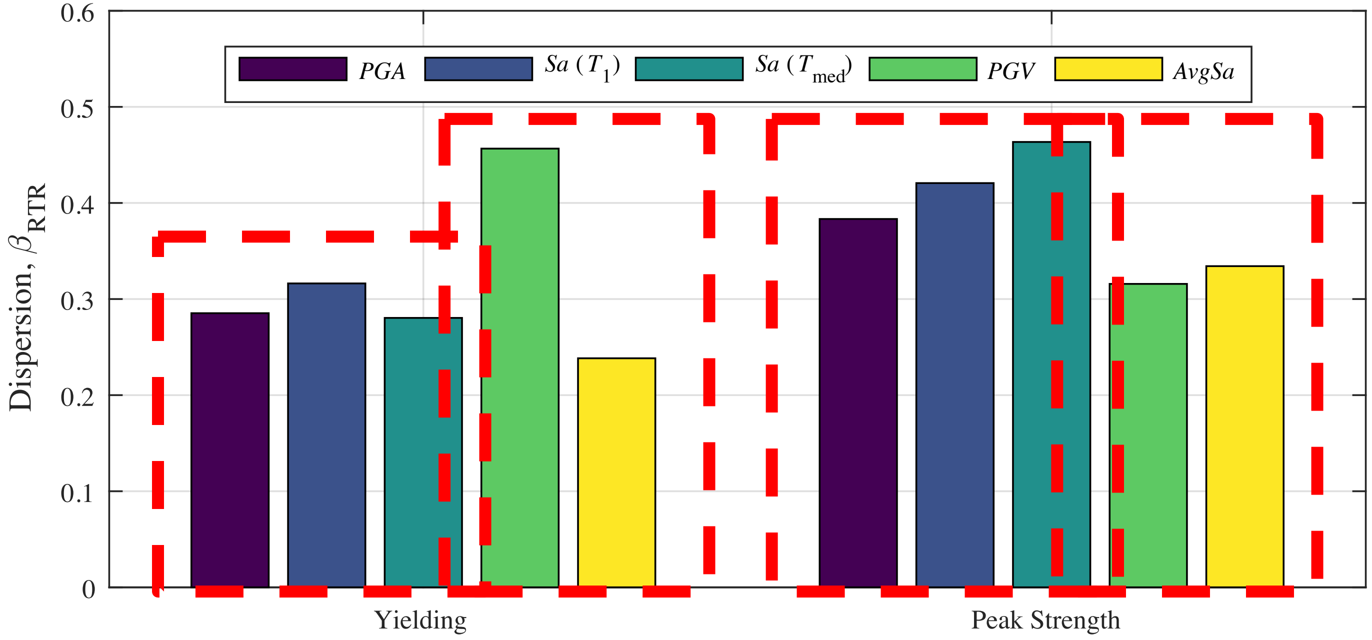
- Considering the intersection of these vertical lines, the dispersion due to record-to-record variability, $\beta_{RTR}$, of each IM could examined

# Limit state dispersion




- Tentatively operating on the premise that lower dispersion implies a more accurate response quantification and, in turn, risk, some initial observations can be made
- Let's look at the mean values for both limit states for a better overall idea

# So which one is best?




- *PGA*, *Sa*($T_1$) and *Sa*($T_{med}$) are fair predictors at both limit states
  - Similar at yielding but *PGA* slightly better at peak strength
- *Sa*($T_1$) and *Sa*($T_{med}$) are poor for regular bridges
  - Modal masses indicate that the 3rd mode is the dominant mode – need to be careful
- *PGV* and *AvgSa* were the best ones overall
  - *PGV* sligthly better than *AvgSa* at peak strength but very inefficient at yielding

# Conclusions

- We need to use an IM when performing risk assessment
- Typical IMs for building relate to the modal properties
- In bridges, this is not so straightforward
  - Multi-modal response
  - First mode of response is not always dominant
  - Typically need to look at a group of bridges
- Has led to the use of PGA and PGV for regional assessment
- AvgSa has proven to be an improved IM for buildings
- The work here shows that it is one of the better performers overall for bridge structures (both regular and irregular) compared to all other IMs examined

- This work was carried within the project INFRA-NAT, which looks to provide accessible tools to stakeholders for the assessment of bridge networks in Italy, North Macedonia and Israel
- Visit the project website:

www.infra-nat.eu

Infra NAT

**Thanks for your attention**