Current and contemporary seismic design methods: a comparative review

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Scuola Universitaria Superiore Pavia

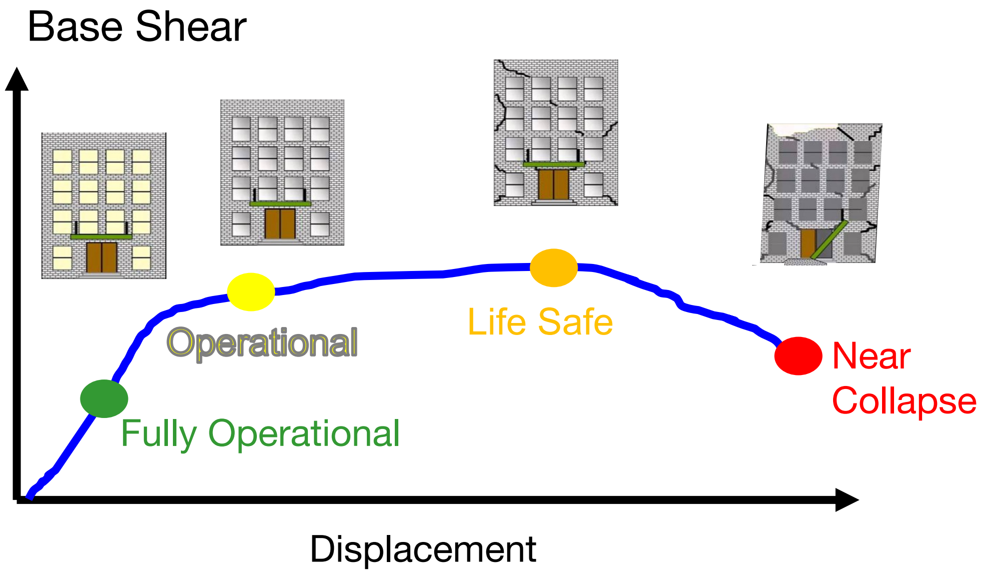
ROSE
Centre for Training and Research on Reduction of Seismic Risk

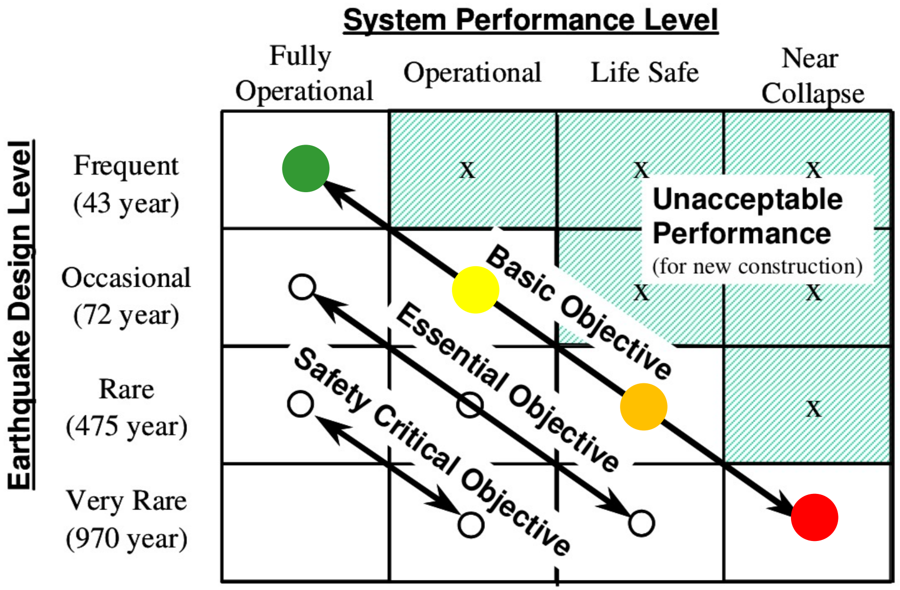
Introduction

- In earthquake engineering, we need to be able to communicate with the decision-makers, building owners and stakeholders
- We strive towards acceptable levels of safety and loss
- This must be quantifiable through risk communication and also insurance terminology
- We need appropriate tools to tackle the issue

Introduction

- Seismic performance has traditionally looked at the idea of defining limit states and linking them to returns periods of shaking
- This is the basis of many modern building codes around the world



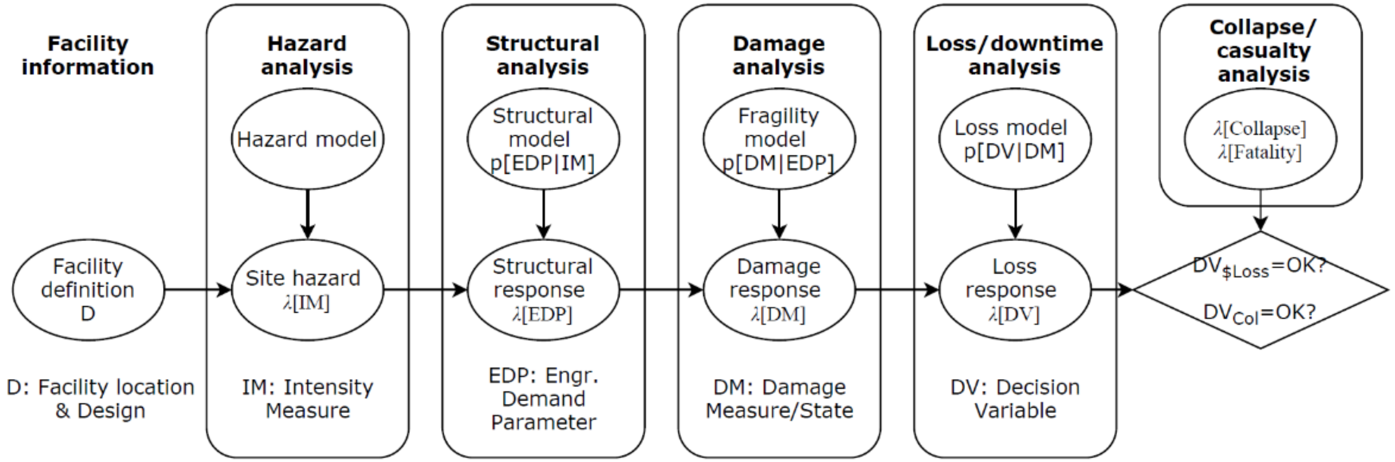


From SEAOC Vision 2000 document

Introduction

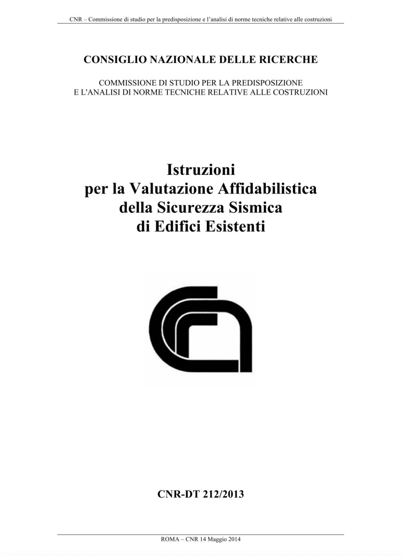
- In recent years, a more probabilistic approach is being favoured and quantifies the performance in a ***risk*** sense
- Its definition of “failure” is flexible, allowing consistent consideration across all pertinent limit states
- It also utilises performance metrics that are useful in other fields:
    - Average annual risk of collapse (or fatality)
    - Average annual loss (direct of indirect?)
    - Downtime

$$\lambda_f = \int_0^{+\infty} P[f|IM = s]|dH(s)|$$



Introduction

- Popular within academic research or specialised reports rather than widespread code implementation for practitioners to use
- Mainly due to the probabilistic nature of the framework and its computationally expensive implementation in certain situations
- Some examples:
    - CNR-DT 212/2013
    - FEMA P-58 - 2012
    - New Eurocode 8 (Annex F)
- If we use these methods and performance metrics, what are the limits or targets ?



CNR – Commissione di studio per la predisposizione e l'analisi di norme tecniche relative alle costruzioni

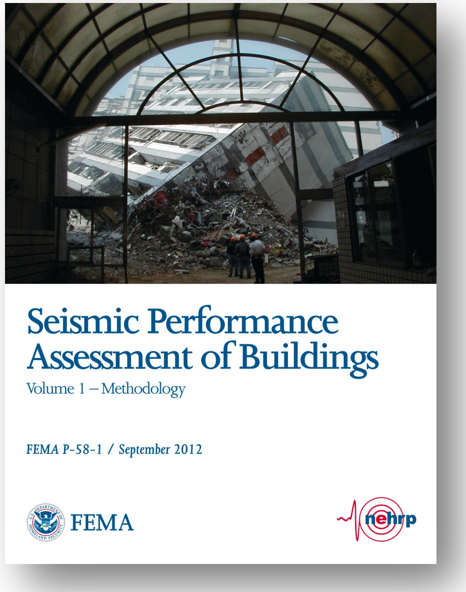
CONSIGLIO NAZIONALE DELLE RICERCHE

COMMISSIONE DI STUDIO PER LA PREDISPOSIZIONE
E L'ANALISI DI NORME TECNICHE RELATIVE ALLE COSTRUZIONI

Istruzioni
per la Valutazione Affidabilistica
della Sicurezza Sismica
di Edifici Esistenti

CNR-DT 212/2013

ROMA – CNR 14 Maggio 2014



Seismic Performance
Assessment of Buildings
Volume 1 – Methodology

FEMA P-58-1 / September 2012

CEN/TC 250/SC 8 N 660

CEN/TC 250/SC 8
Eurocode 8: Earthquake resistance design of structures

Email of secretary: sc8@lnec.pt
Secretariat: IPQ (Portugal)

Final Draft EN1998-1 NEN SC8 PT1

Document type: Working draft

Date of document: 2017-12-01

Expected action: COMM

Action due date: 2018-02-28

No. of pages: 124

Background: Final draft of EN1998-1 revision by Project Team 1, for informal enquiry through Committee Internal Ballot (CIB)

Committee URL: http://cen.iso.org/livelink/livelink/open/centc250sc8

Current design approaches

- Force-based design (FBD) methods
  - Eurocode 8
    - 475 and 95 years for no-collapse and damage limitation
  - New Zealand's NZS1170
    - 500 and 25 years for ultimate and serviceability limit states
  - ASCE 7-16
    - Using a risk-targeted spectrum (see later)

NZS 1170.5:2004
Incorporating Amendment No. 1

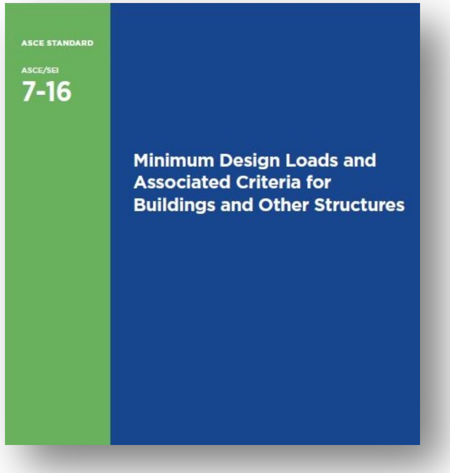
New Zealand Standard

Structural design actions

Part 5: Earthquake actions – New Zealand

STANDARDS NEW ZEALAND
PAEREWA AOTEAROA

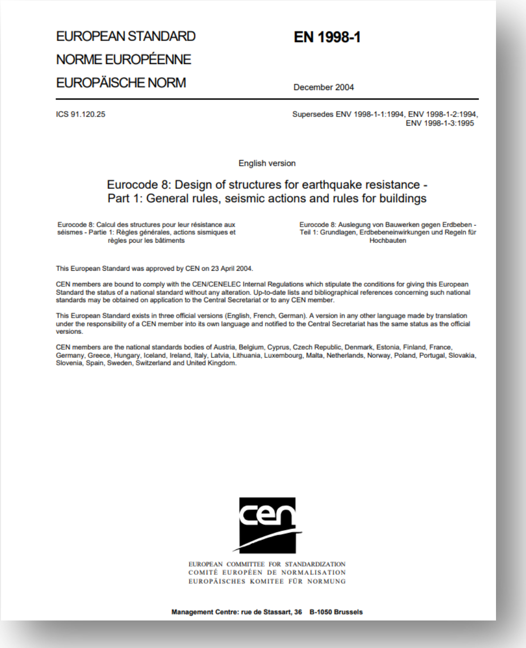
NZS



ASCE STANDARD

ASCE/SEI
7-16

Minimum Design Loads and Associated Criteria for Buildings and Other Structures



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1998-1

December 2004

ICS 91.120.25

Supersedes ENV 1998-1-1:1994, ENV 1998-1-2:1994, ENV 1998-1-3:1995

English version

Eurocode 8: Design of structures for earthquake resistance -
Part 1: General rules, seismic actions and rules for buildings

Eurocode 8: Calcul des structures pour leur résistance aux séismes - Partie 1: Règles générales, actions sismiques et règles pour les bâtiments

Eurocode 8: Auslegung von Bauwerken gegen Erdbeben - Teil 1: Grundlagen, Erdbebeneinwirkungen und Regeln für Hochbauten

This European Standard was approved by CEN on 23 April 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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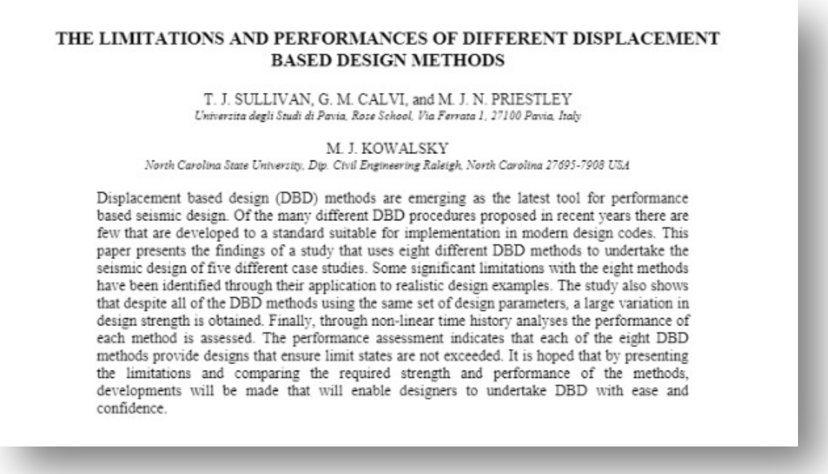
EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Current design approaches

- FBD – not reasonable to quantify expected ductility and spectral demand reduction via unique behaviour factors
- Priestley et al. (2007) proposed using ductility- and typology-dependent spectral reduction approach
- This was the so-called displacement-based design (DBD) approach
- FBD and DBD solutions may be refined to be more in line with risk-targeted objectives



THE LIMITATIONS AND PERFORMANCES OF DIFFERENT DISPLACEMENT BASED DESIGN METHODS

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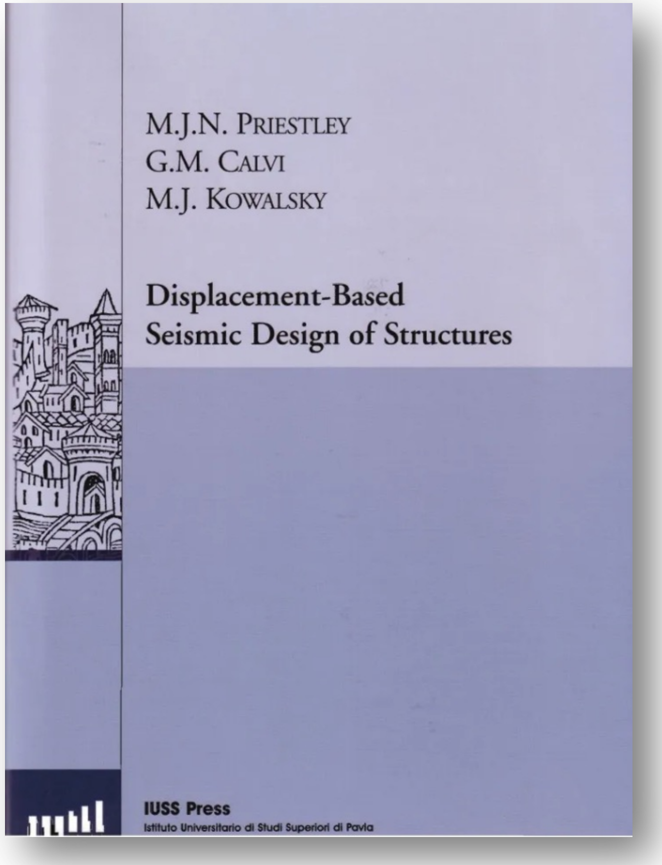
Displacement based design (DBD) methods are emerging as the latest tool for performance based seismic design. Of the many different DBD procedures proposed in recent years there are few that are developed to a standard suitable for implementation in modern design codes. This paper presents the findings of a study that uses eight different DBD methods to undertake the seismic design of five different case studies. Some significant limitations with the eight methods have been identified through their application to realistic design examples. The study also shows that despite all of the DBD methods using the same set of design parameters, a large variation in design strength is obtained. Finally, through non-linear time history analyses the performance of each method is assessed. The performance assessment indicates that each of the eight DBD methods provide designs that ensure limit states are not exceeded. It is hoped that by presenting the limitations and comparing the required strength and performance of the methods, developments will be made that will enable designers to undertake DBD with ease and confidence.



M.J.N. Priestley
G.M. Calvi
M.J. Kowalsky

Displacement-Based
Seismic Design of Structures

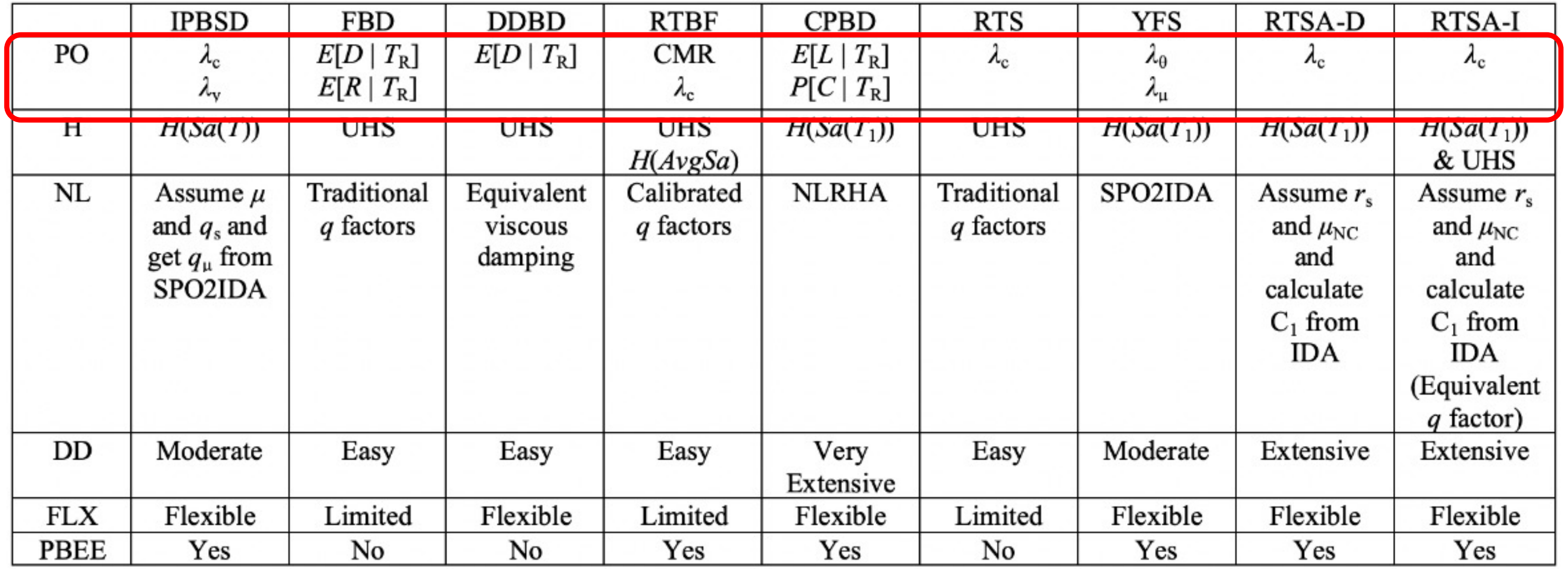
IUSS Press
Istituto Universitario di Studi Superiori di Pavia

Critical Review

- Some of the more notable methods available are examined:
    - FBD – force-based design implemented in Eurocode 8 (and others)
    - DDBD – displacement-based design advocated by Priestley et al. (2007)
    - RTBF – risk-targeted behaviour factors by Kennedy and Short (1994) and Cornell (1996)
    - CPBD – conceptual performance-based design by Krawinkler et al. (2006)
    - RTS – risk-targeted spectra by Luco et al. (2007)
    - YFS – yield frequency spectra by Vamvatsikos and Aschheim (2016)
    - RTSA – risk-targeted seismic action by Žižmond and Dolšek (2019)
    - IPBSD – integrated performance-based seismic design by Shahnazaryan and O’Reilly (2021)

Performance objectives (PO)

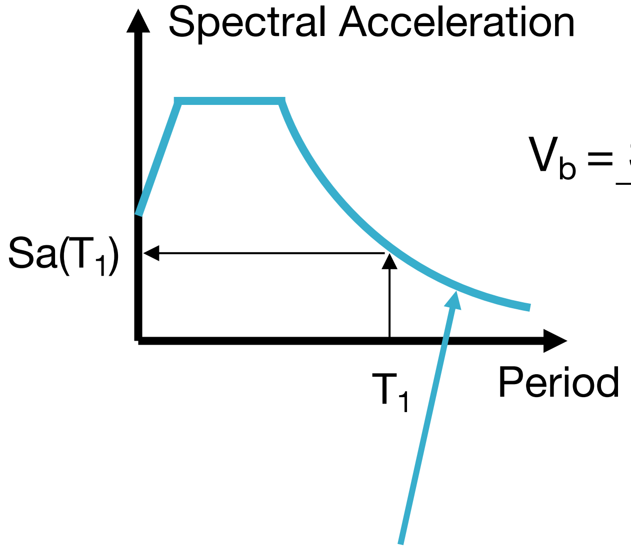
- Primary quantity that each design method targets, limits or bases itself upon
  - Classic methods focus on a specific structural response at a given return period
  - More recent methods are integrating risk aspects like annual probability or economic loss



	IPBSD	FBD	DDBD	RTBF	CPBD	RTS	YFS	RTSA-D	RTSA-I
PO	λ_c λ_y	$E[D \mid T_R]$ $E[R \mid T_R]$	$E[D \mid T_R]$	CMR λ_c	$E[L \mid T_R]$ $P[C \mid T_R]$	λ_c	λ_0 λ_μ	λ_c	λ_c
H	$H(Sa(T))$	UHS	UHS	UHS $H(AvgSa)$	$H(Sa(T_1))$	UHS	$H(Sa(T_1))$	$H(Sa(T_1))$	$H(Sa(T_1))$ & UHS
NL	Assume μ and q_s and get q_μ from SPO2IDA	Traditional q factors	Equivalent viscous damping	Calibrated q factors	NLRHA	Traditional q factors	SPO2IDA	Assume r_s and μ_{NC} and calculate C_1 from IDA	Assume r_s and μ_{NC} and calculate C_1 from IDA (Equivalent q factor)
DD	Moderate	Easy	Easy	Easy	Very Extensive	Easy	Moderate	Extensive	Extensive
FLX	Flexible	Limited	Flexible	Limited	Flexible	Limited	Flexible	Flexible	Flexible
PBEE	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes

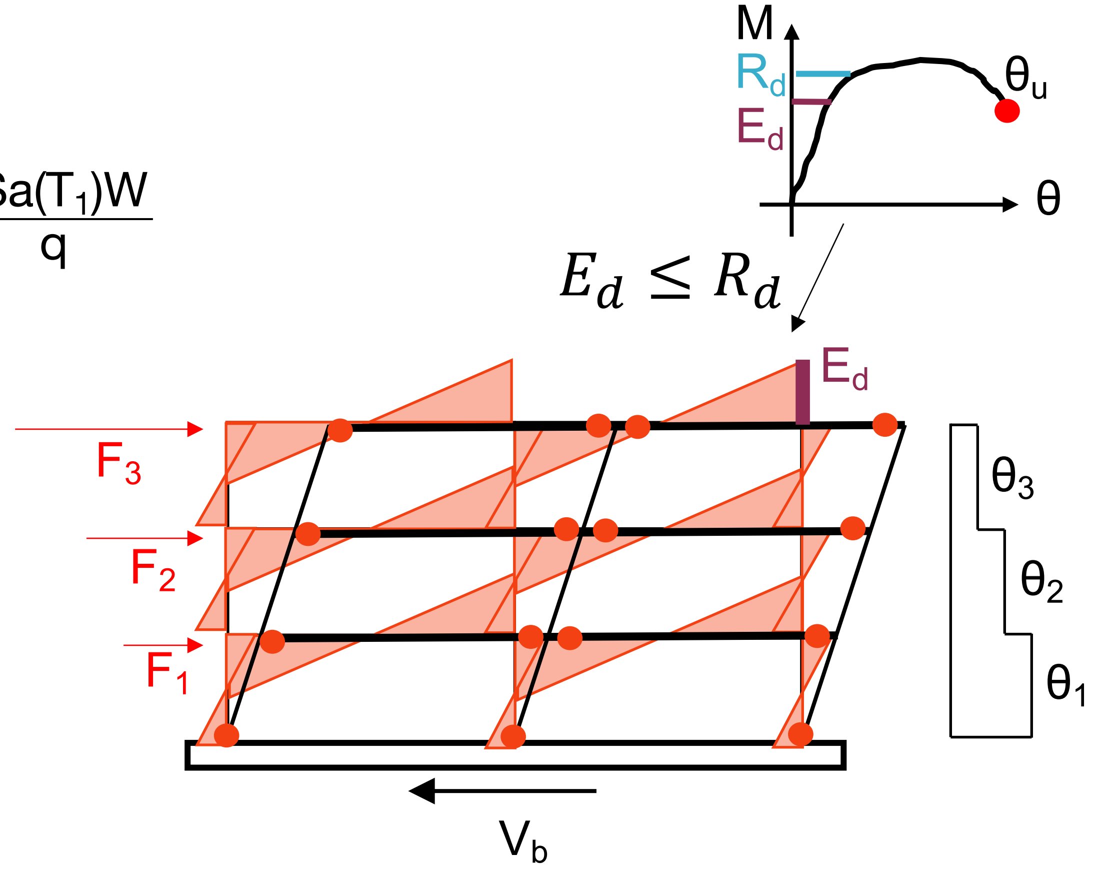
Performance objectives (PO)

- Starting first with the classic methods, what are the performance objectives?
- These are typically the expected response at known return periods (T_R): $E[R \mid T_R]$ $E[D \mid T_R]$



$$V_b = \frac{Sa(T_1)W}{q}$$

Response is checked for this return period



$$E_d \leq R_d$$

Make sure our sections have enough “kN”s or “kNm”s resistance

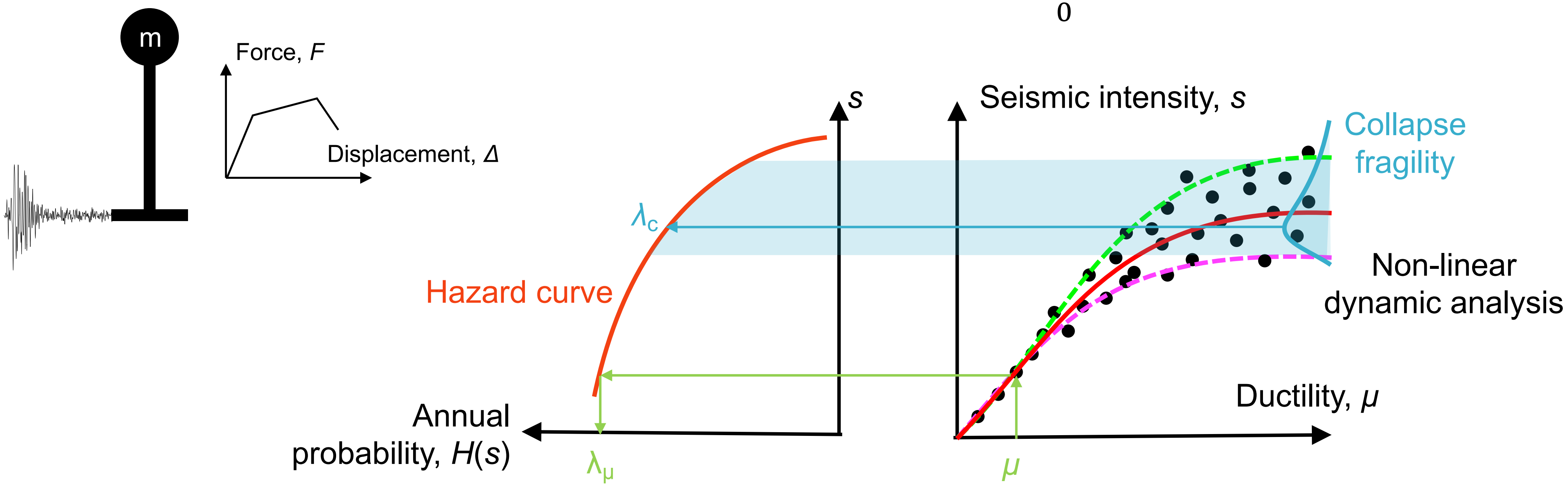
Depending on the type of non-structural element (NSE) and its connectivity, we have:

- Brittle NSEs: $\theta_{max} \leq 0.50\%$
- Ductile NSEs: $\theta_{max} \leq 0.75\%$
- Special or no NSEs: $\theta_{max} \leq 1.00\%$

Performance objectives (PO)

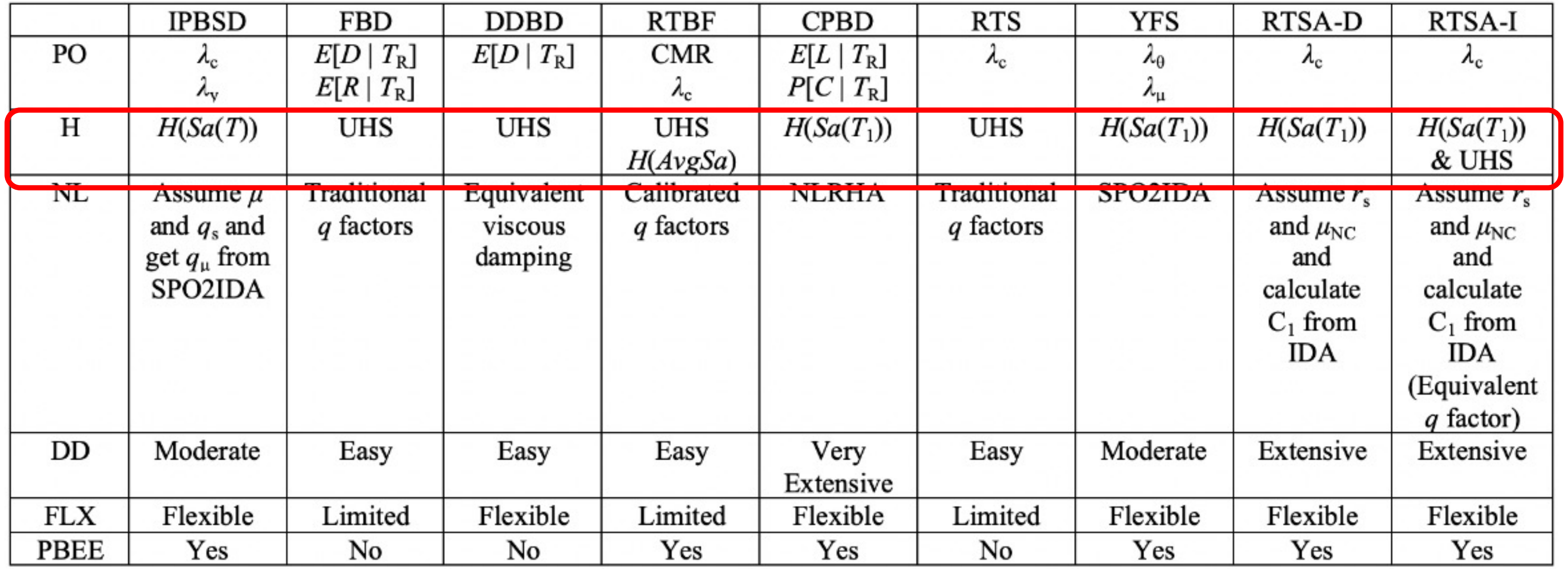
- More novel methods consider the performance across **many intensity levels**
- They integrate with the hazard curve to get the annual probability
- Methods based on this are risk-targeted

$$\lambda_f = \int_{0}^{+\infty} P[f|IM = s]\,|dH(s)|$$



Hazard (H)

- How seismicity is characterized during design
  - Several of the methods employ uniform hazard spectrum (UHS)
  - Others use a hazard curve associated with an intensity measure, *H*(•)



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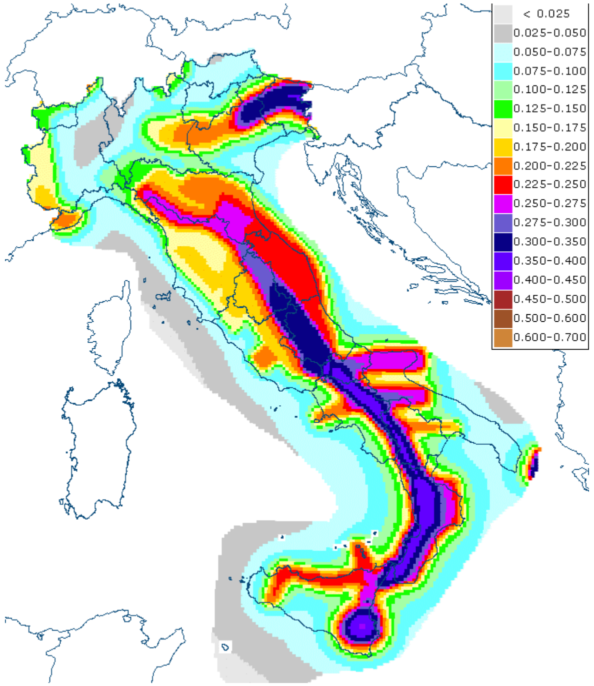
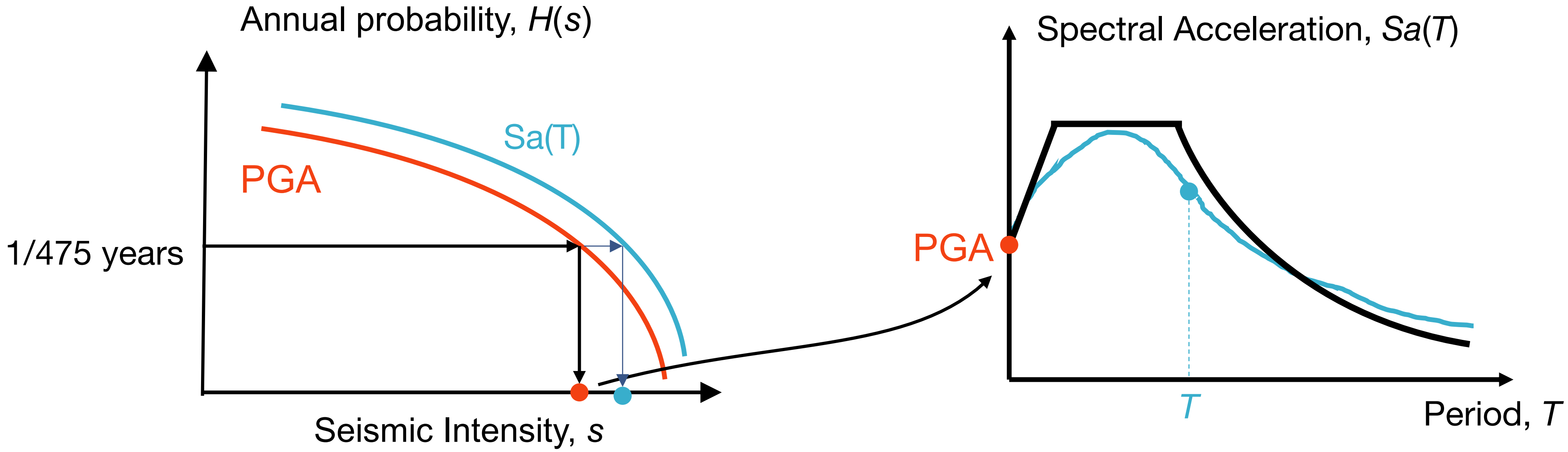


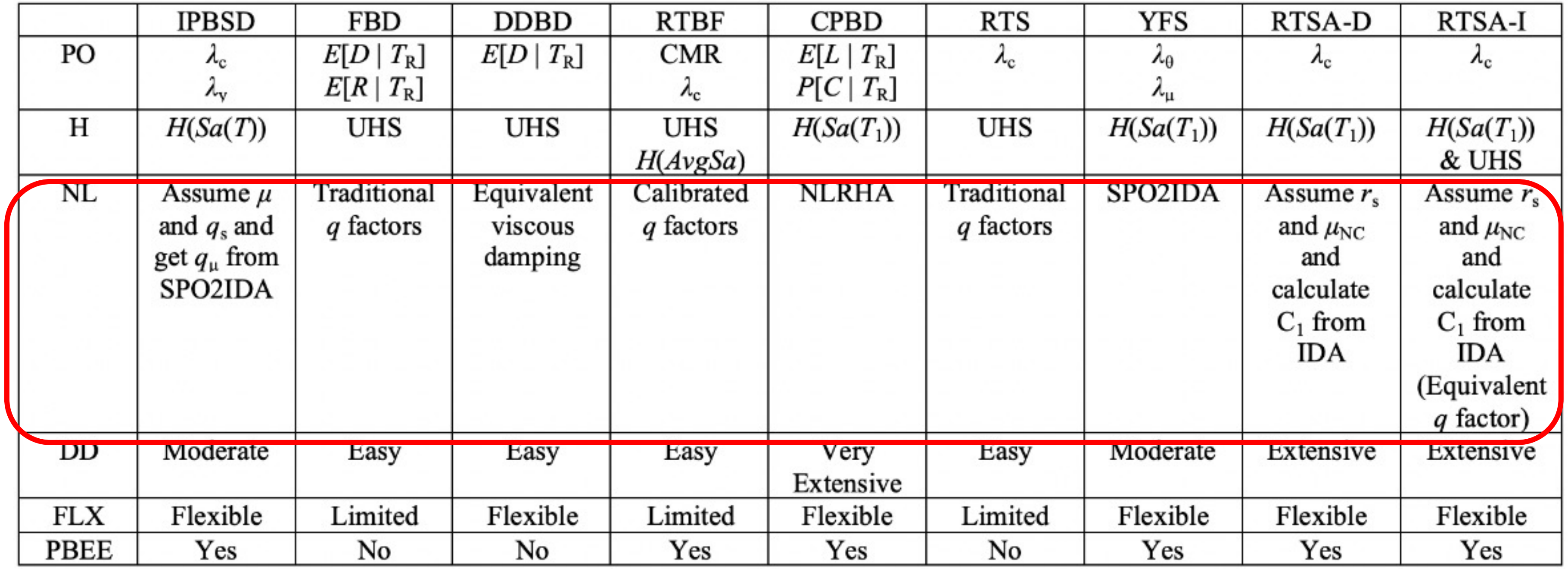
Hazard (H)

- The main difference here is whether we should consider the performance across all intensities via the hazard curve
- Or simply choose a few and check for those
- Are simplified code expressions for UHS actually representative of hazard analysis?



Accounting for non-linearity (NL)

- How ductile structure behaviour is accounted for:
  - Reduce design forces via q-factors?
  - Use some proxy models?



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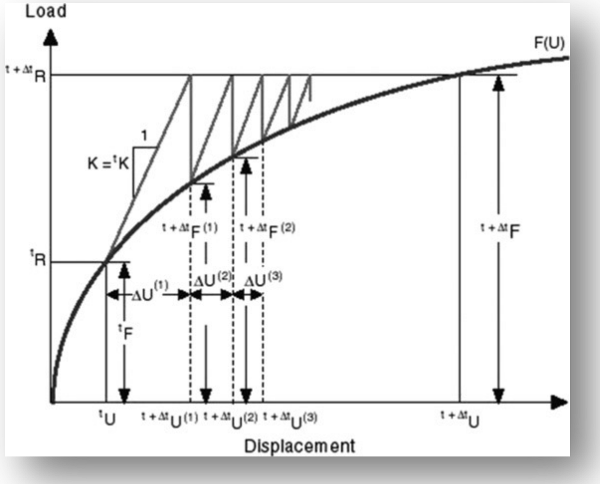
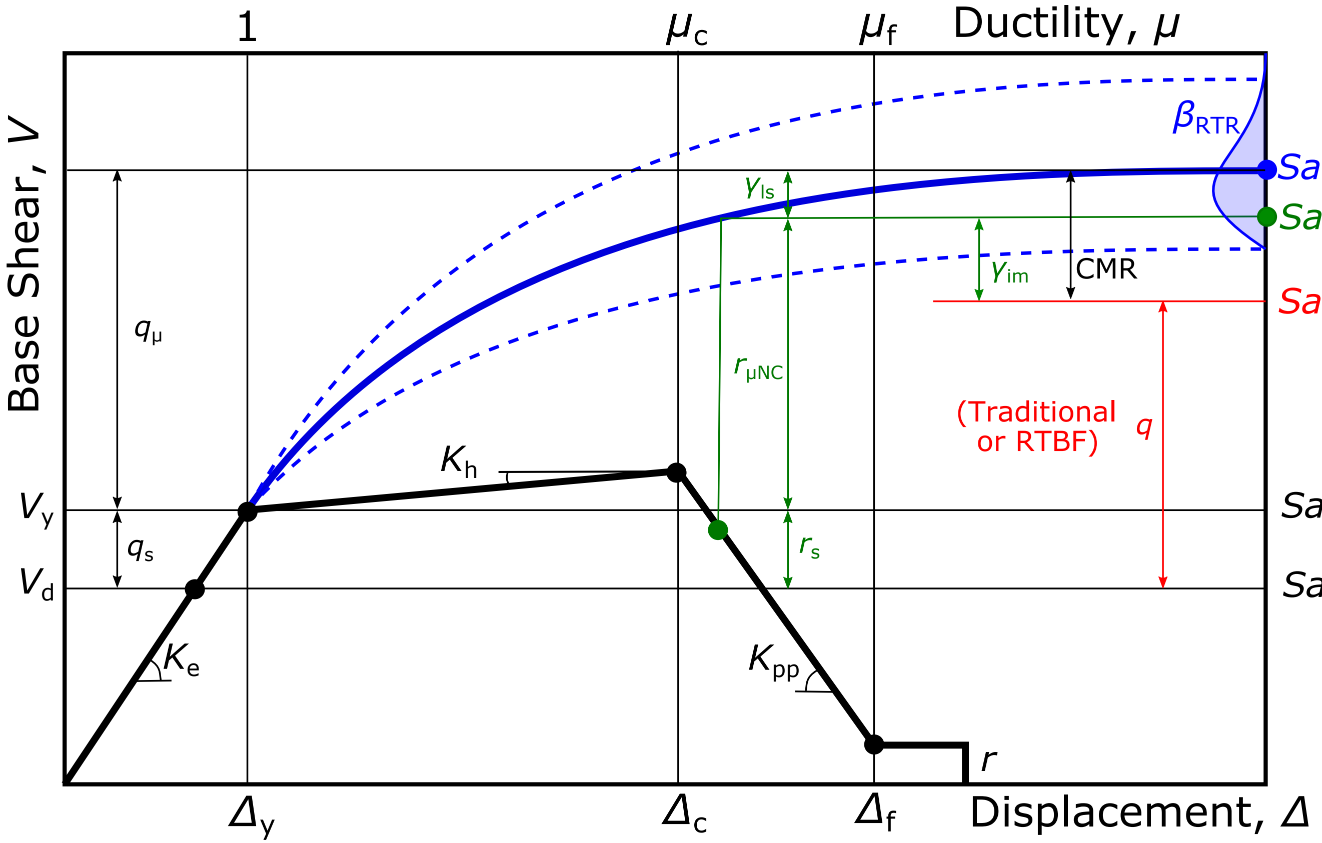


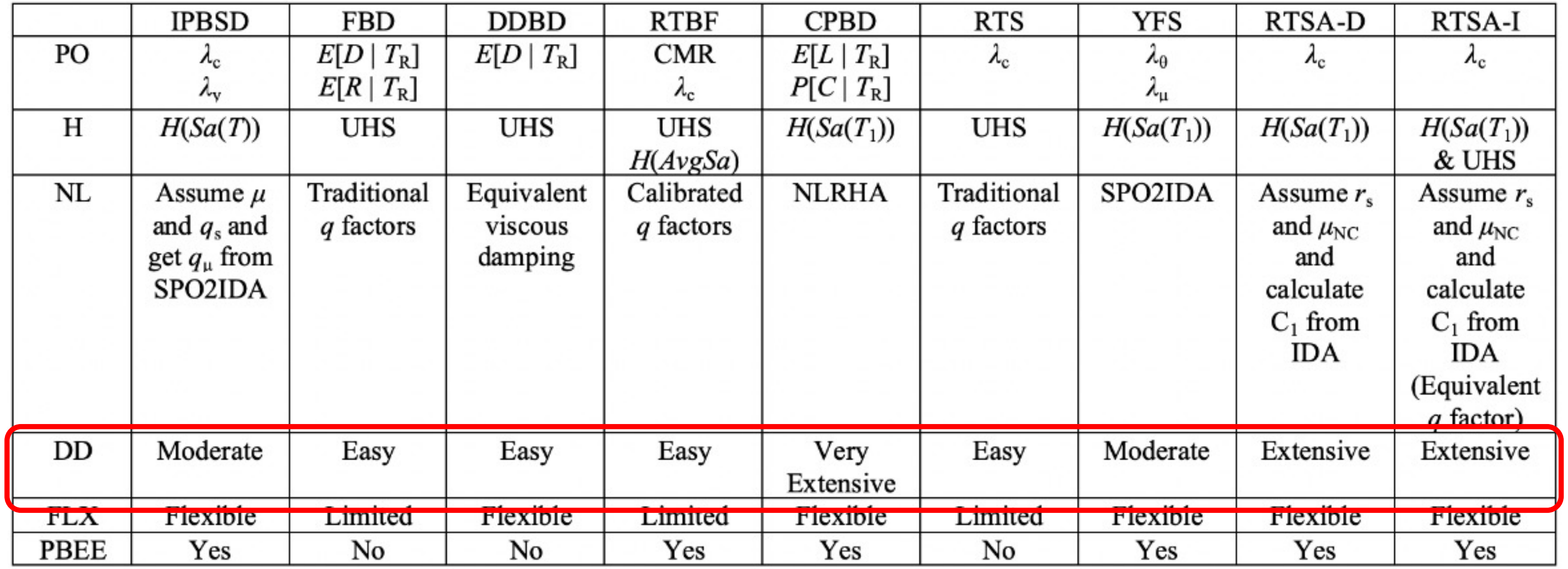
Accounting for non-linearity (NL)

- One of the biggest challenges in simplified seismic design is how to relate the non-linear response of the system to its elastic SDOF equivalent



Relative difficulty and directness (DD)

- How difficult the method is – e.g., NLRHA required?
- How direct the method is – e.g., Multiple iterations required?



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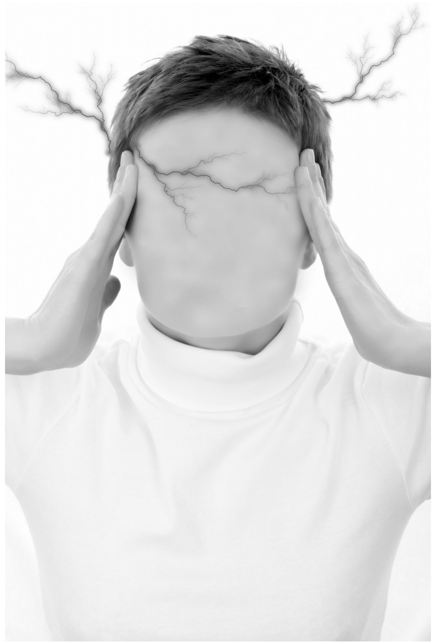
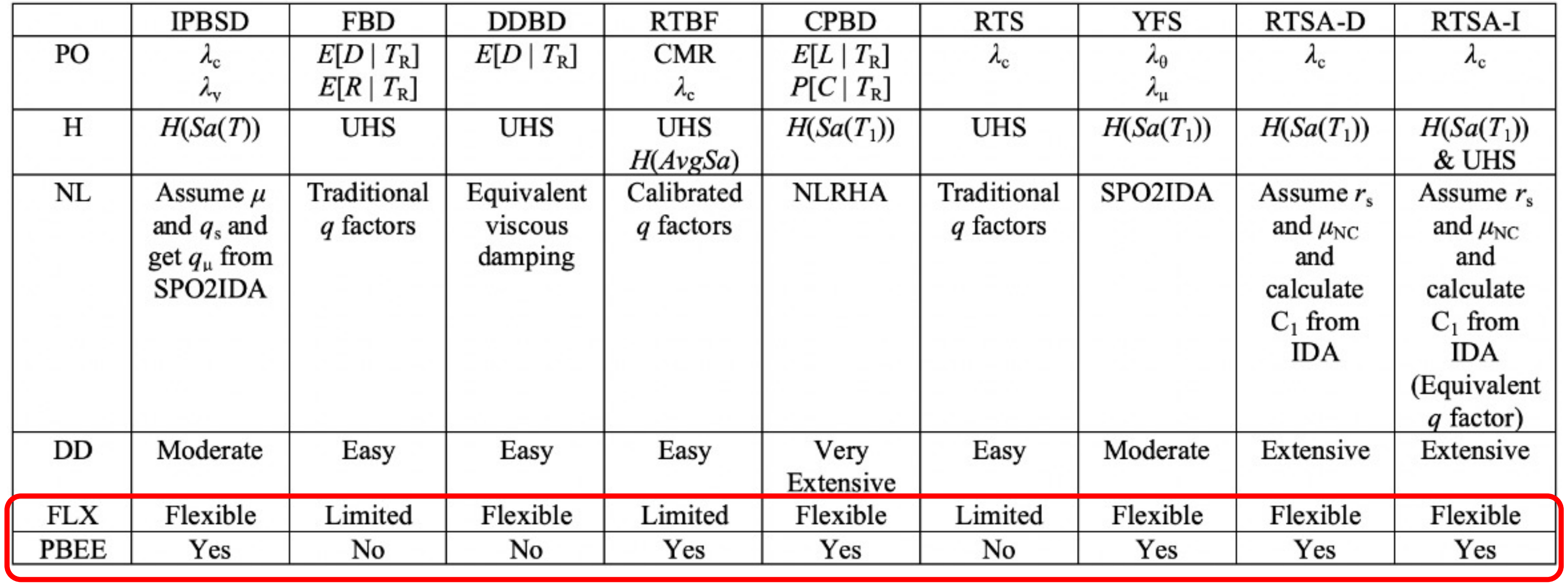


Flexibility and PBEE compliant?

- Flexibility - FLX
  - Ease of tailoring design targets beyond what it has been developed for so far
- PBEE
  - Is the method risk-consistent?



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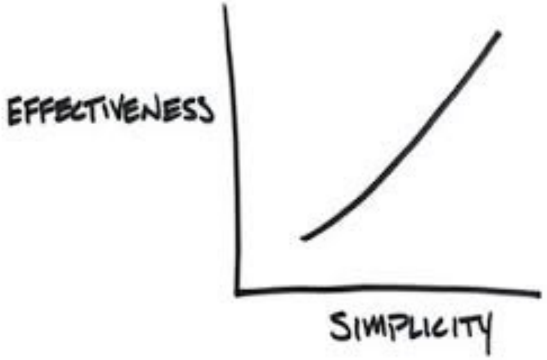

In conclusion…

- This paper presented a review of classic design approaches and methods available in the literature
- Current design methods deal with design without adequately accounting for the probabilistic nature of the problem
- More contemporary risk-based seismic design approaches are available