ICONHIC2022

Risk and loss mitigation in seismic design

A review of current methods and future directions

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ROSE Centre for Training and Research on Reduction of Seismic Risk

Overview

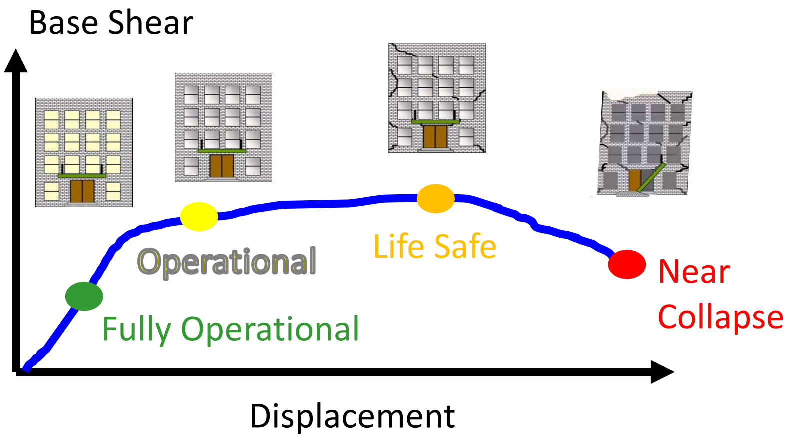
- Background
- Seismic design: existing methods and emerging trends
- Reflection: a critical review of these
    - Are we getting what we want (or can get)?
- Potential: Can we do more?
    - If so, how and with whom, and with what?
- Closing Remarks

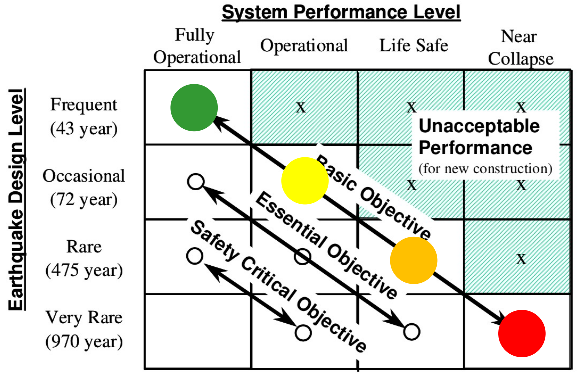
Introduction

- In risk management, 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



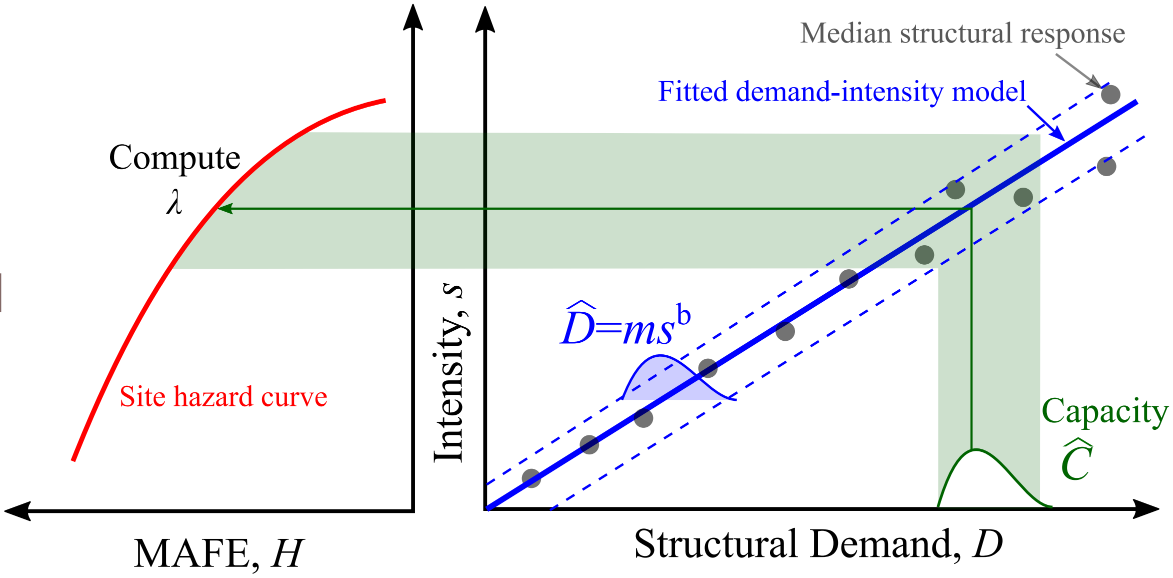


From SEAOC Vision 2000 document

Introduction

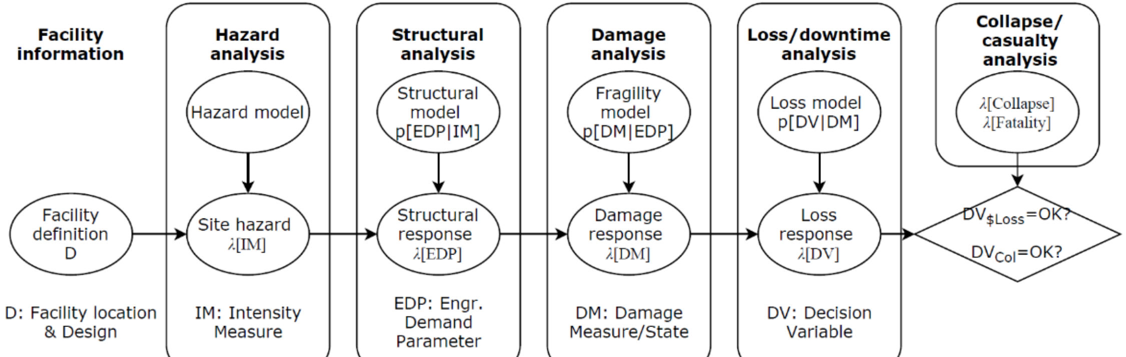
- In recent years, a more probabilistic approach is being favoured
- This is arguably more comprehensive as it considers uncertainty in seismic hazards and structural response

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



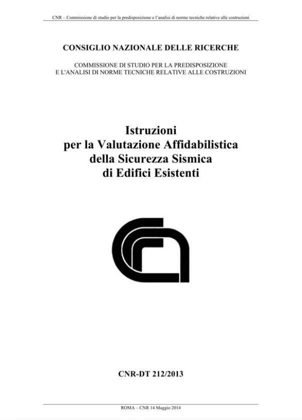
Introduction

- This modernised approach quantifies the building 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



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 version of 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

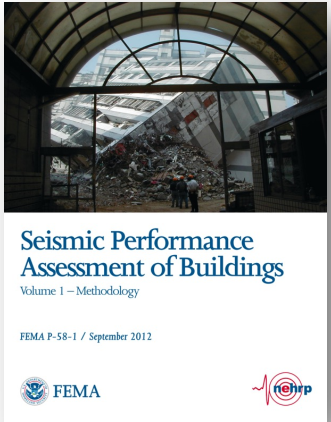
CONSIGLIO NAZIONALE DELLE RICERCHE

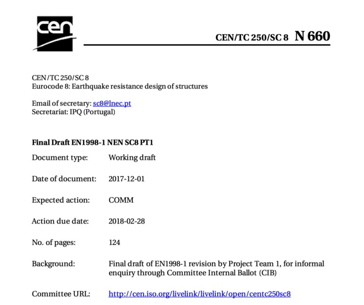
COMMISSIONE DI STUDIO PER LA PREDISPOSIZIONE
E L'ANALISI DI NORME TECNICHE RELATIVE ALLE COSTRUZIONI

Istruzioni
per la Valutazione Affidabilistica
della Sicurezza Sismica
di Edifici Esistenti

CNR-DT 212/2013

ROMA – CNR 14 Maggio 2014




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

Objective

- Review current code-based approaches and risk-targeted design methods in the literature
- Discuss how these methods may be considered in future approaches to building performance evaluation, integrating novel elements of collapse risk and economic loss limitation
- Possible synergies in engineering and the insurance and risk industries
- How they may benefit from further dialogue and collaboration towards a more resilient society?

Critical Review

- **Some of notable methods 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)

Shahnazaryan D, O'Reilly GJ. Integrating expected loss and collapse risk in performance-based seismic design of structures. Bulletin of Earthquake Engineering 2021; 19(2): 987–1025. DOI: 10.1007/s10518-020-01003-x.

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	RTDF	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

Accounting for non-linearity (NL)

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

	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)
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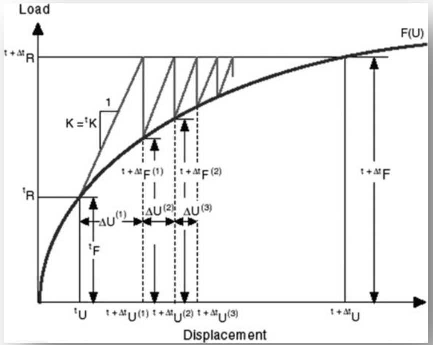
PBEE	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes



Relative difficulty and directness (DD)

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

	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
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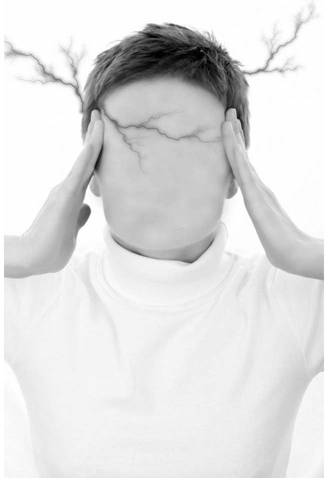
PBEE	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes



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?

	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
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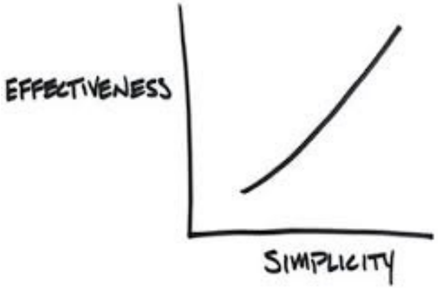
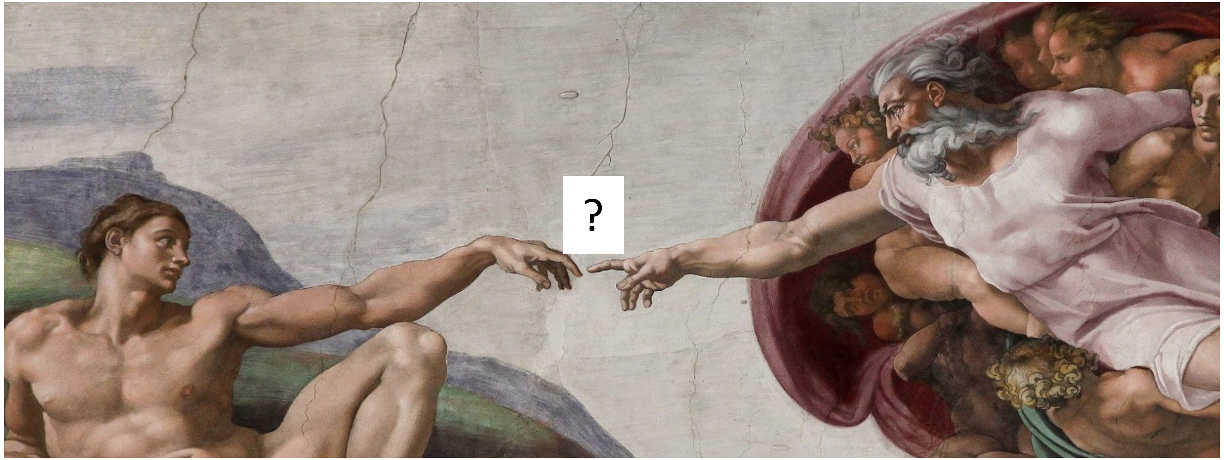


Takeaways…

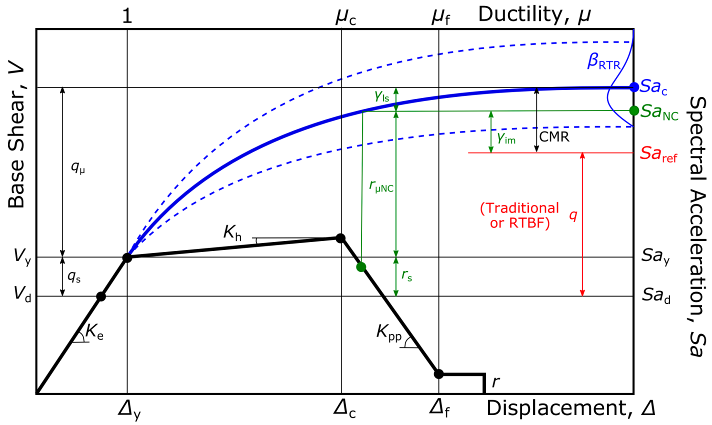
- Progress is being made…
- We are getting away from just structural performance
  - i.e. forces and displacements
- ….and can now talk in terms in risk (at least academically)

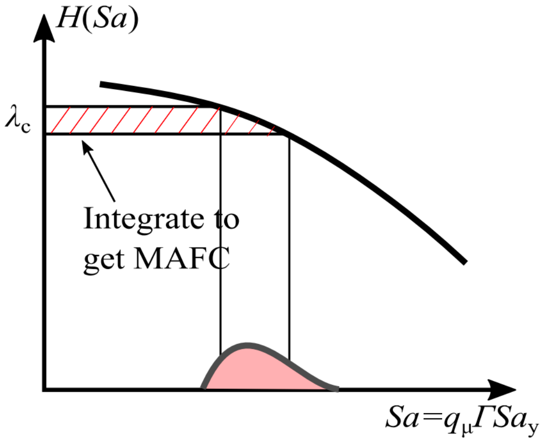
Insurance
Industry
etc.

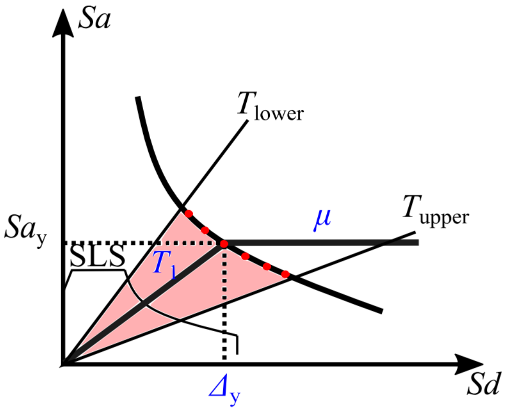


Academia
Engineers
Etc.

Collapse risk as a design variable?

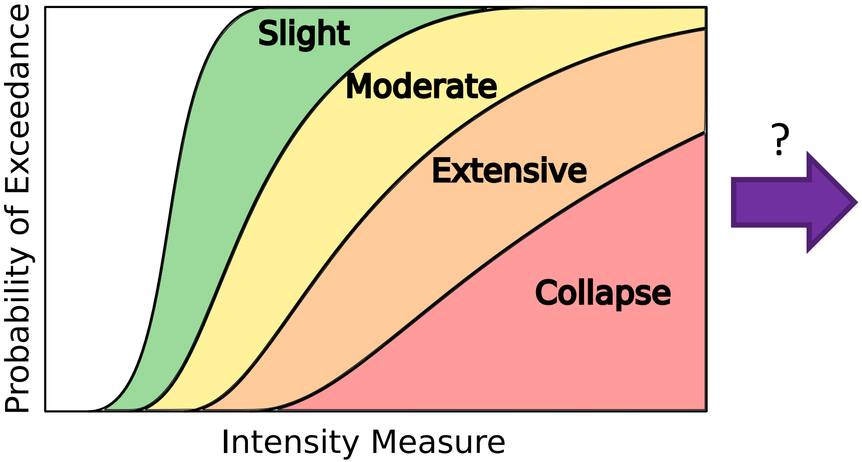


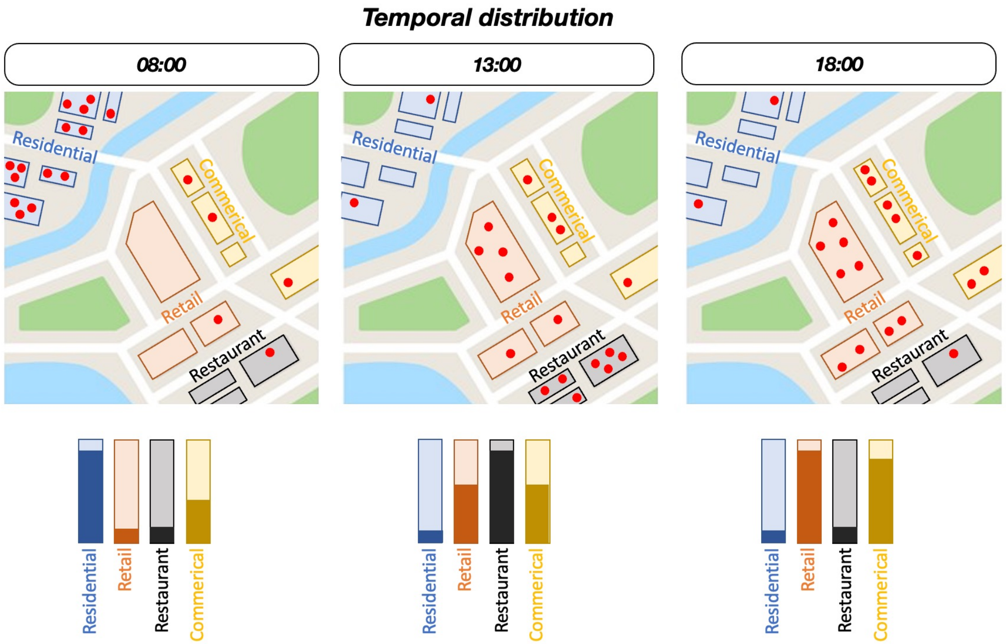




- If we know a structural behaviour, we can estimate its collapse fragility function
- Integrate the collapse fragility function with the hazard curve to obtain the collapse risk
- The procedure is applied multiple times to identify a design collapse surface
- Can we do better?

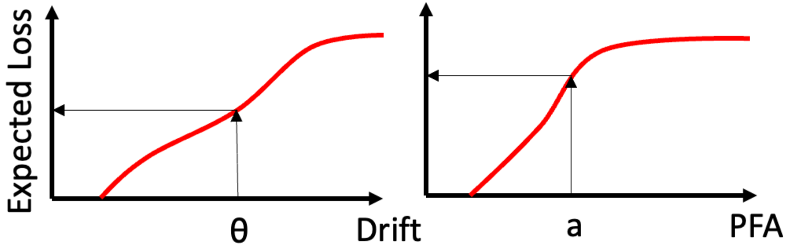
Collapse fatalities as a design variable?



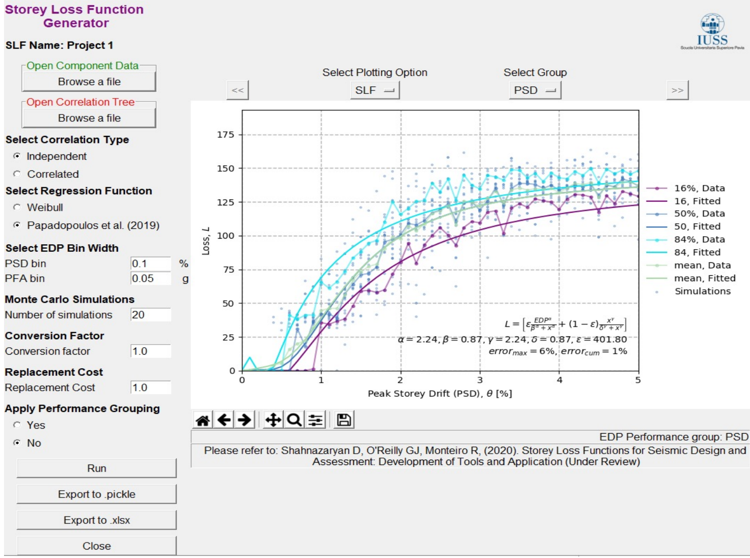


- We can estimate the risk of collapse of a building
- Can we exploit data on population models to extend to fatalities and use this?

Estimating economic losses

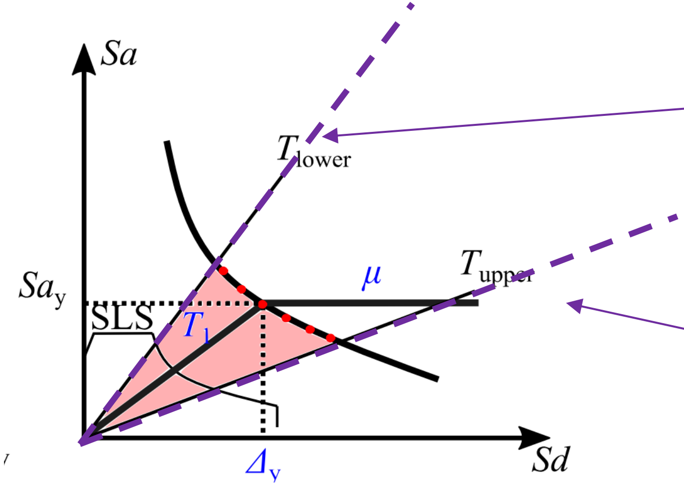


Open-Source object-oriented toolbox developed on Python and available on GitHub
https://github.com/davitshahnazaryan3/SLFGenerator
https://doi.org/10.5281/zenodo.4897799



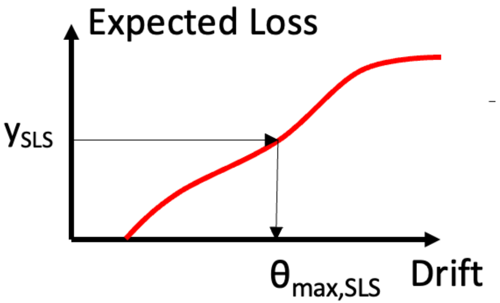
- We know the relationships between demands on structures and expected economic losses
- This will vary storey-by-storey and different buildings will have different functions
- Can we try to standardise these for general use?

Economic loss as a design variable?



Limit the lower period to avoid stiff buildings with acceleration sensitive loss

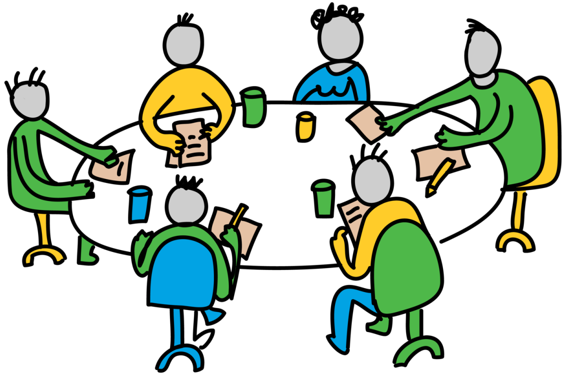
Limit the upper period to avoid flexible buildings with drift sensitive loss



- We know that:
  - flexible buildings gives drift-sensitive loss
  - stiff buildings give acceleration sensitive loss
- There must be some middle ground and **trade-off**
- If we control the period of vibration of a structure we can control the losses better (using storey loss functions)

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
- There are possible future directions involving collaboration between engineering, financial and risk management sectors
- It is hoped that this kind of discussion could foster further collaboration between sectors and strive towards the common goal of reduced and effectively managed risk



ERIES

ENGINEERING RESEARCH INFRASTRUCTURES FOR EUROPEAN SYNERGIES

RESEARCH GOALS

Advancing frontier knowledge on individual issues that contribute to the broader research theme of:

- Loss-driven design and mitigation approaches
- Risk quantification and prioritisation
- Green and sustainable development

The objective of ERIES is to provide transnational access (TA) to research infrastructures to advance frontier knowledge related to seismic, wind and geotechnical hazards

RESEARCH AREAS (RA)

HAZARDS

- Earthquake
- Wind
- Geotech/SSI

- RA1: Built Environment
- RA2: Critical Infrastructures
- RA3: Industrial Facilities
- RA4: Advanced Technologies

TA User Groups

Total Budget: €11,616,118

Duration: 4 years (01/06/2022 – 31/05/2026)

Project Coordinator

IUSS Scuola Universitaria Superiore Pavia

Research Infrastructures

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ARISTOTLE UNIVERSITY OF THESSALONIKI

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ИЗИИС IZIIS

UNIVERSITÀ DI GENOVA

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Western WindEEE Research Institute

University of BRISTOL

CSTB le futur en construction

European Commission

European Commission

ERIES: Engineering Research Infrastructures for European Synergies (2022-2026)
Funded under the Horizon Europe Framework Programme
Ref: 101058684-HORIZON-INFRA-2021-SERV-01-07

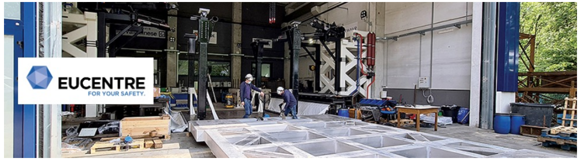
ERIES
ENGINEERING RESEARCH INFRASTRUCTURES FOR EUROPEAN SYNERGIES

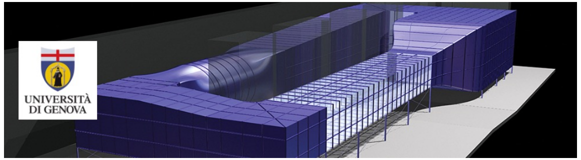
TA User Groups

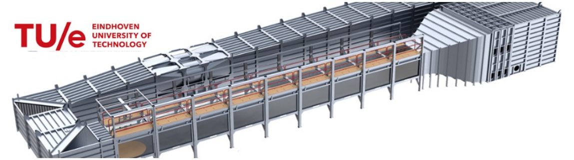
World-class experimental research infrastructures include:

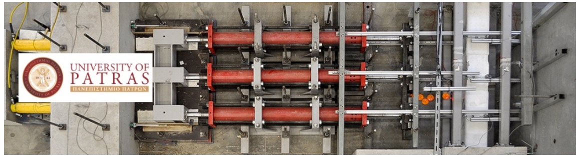
- ➢ Shaking Tables
- ➢ Reaction Walls
- ➢ Soil Pits
- ➢ Wind Tunnels
- ➢ Doppler Lidar Systems
- ➢ Hybrid-Simulation Capabilities (Multi-lab)

- ➢ External user groups prepare project proposals in line with the goals of ERIES
- ➢ They collaborate with ERIES research infrastructures via transnational access
- ➢ This means European* users travel to another country and use the research infrastructures made available as part of ERIES
- ➢ Cost of experimental testing in addition to travel and accommodation of user groups are covered









More information !

www.eries.eu

Applications collected and evaluated at cut-off dates:

- 30 Sept 2022
- 1 Jan 2023 (est.)
- 1 Jun 2023 (est.)
- 1 Nov 2023 (est.)

European Commission

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Ref: 101058684-HORIZON-INFRA-2021-SERV-01-07