CONSTRUCT

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FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

# Assessing the seismic performance of existing reinforced concrete buildings: from standard-based methods to full probabilistic approaches (and back again to standard-based methods!)

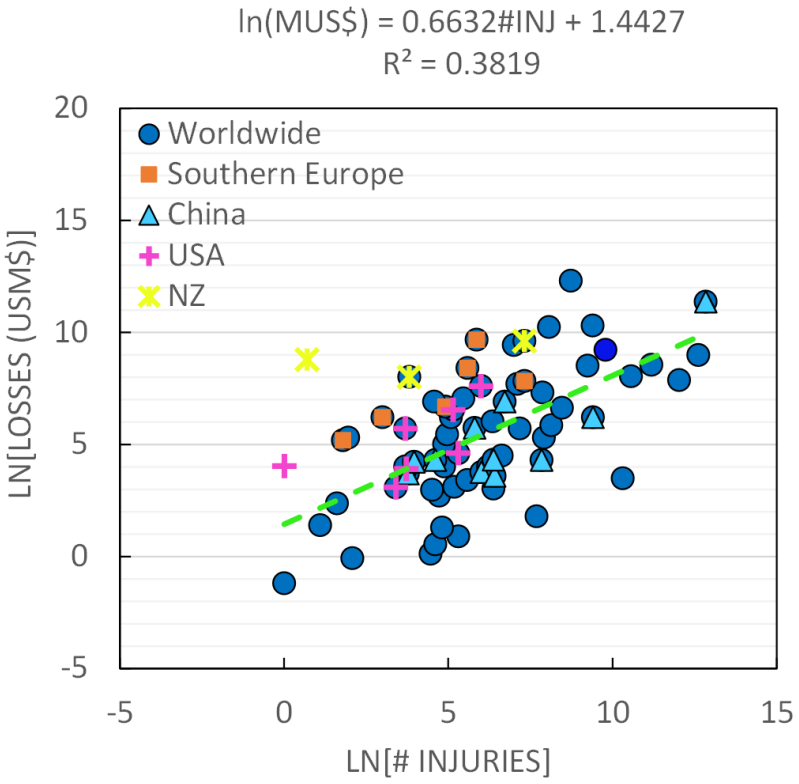
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# Assessing the seismic performance of existing reinforced concrete buildings

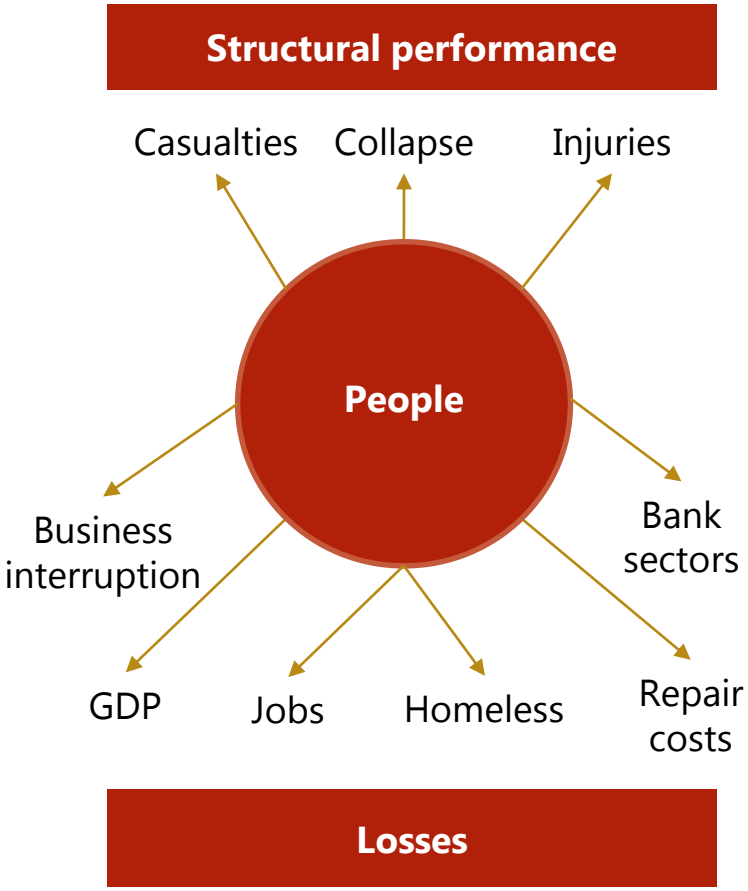
- The earthquakes of the 1990's are a landmark in the evolution of Earthquake Engineering.
- In these events, the number of building collapses was low, but there were extensive losses and a considerable number of post-EQ demolitions.
- After these events, communities realized that designing structures to avoid **collapse** or accounting for **life-safety** conditions may be **insufficient** for modern society.
- We need to ask: **What is "Life Safety" in modern societies?** Are life safety and irreparable buildings acceptable?




Source: NOAA data about earthquakes observed worldwide since the beginning of the year 2000.

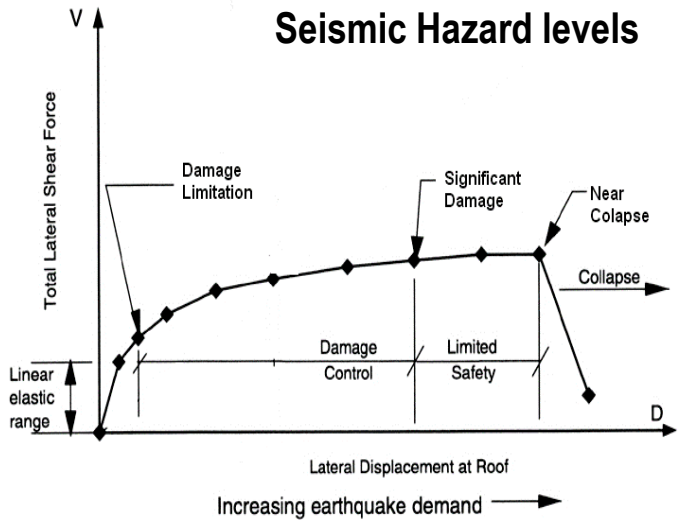
# When Life Safety is not "just" Life Safety…

- In modern cities, people often live in multi-storey/**multi-residential compounds** made of gravity-designed **RC buildings**.
- Mortgage obligations and businesses are usually associated to these buildings
- If extensive damage is observed, buildings may need to be demolished after the earthquake.
- This leads to a significant pressure on bank sectors, stakeholders, insurance companies and, ultimately, on society.
- **A full control of the seismic performance of existing RC buildings** is paramount.



- **Problem Statement: Is it possible to transform the EC8-3 framework into a simplified loss-based methodology where POs⇔LS conditions?**

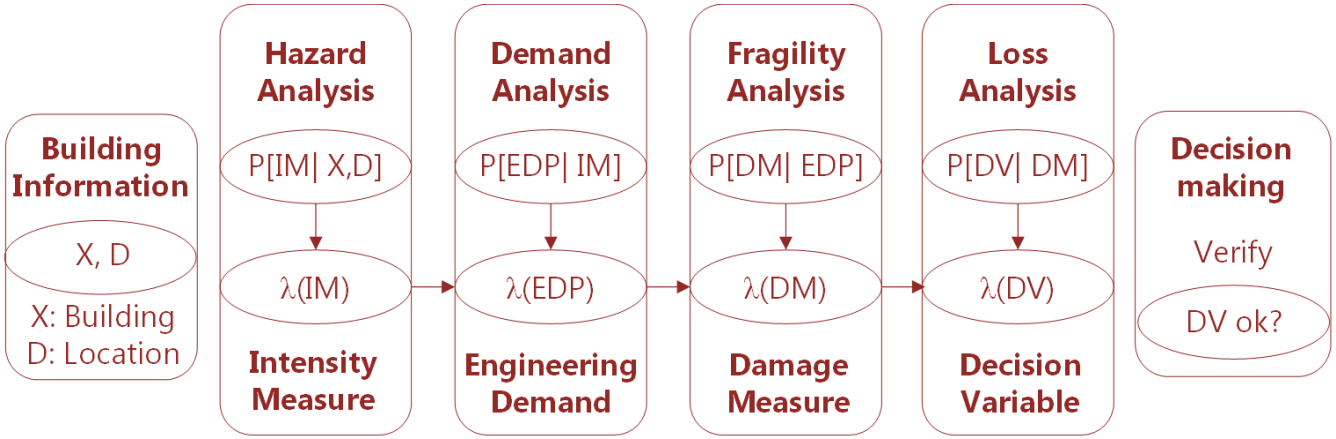
  - The EC8/3 establishes 3 performance objectives, each corresponding to a seismic hazard level.
  - Component-based compliance criteria: chord rotations and shear forces in beams, columns and walls.
  - It does not include all the necessary decision variables




| Performance Objectives | Structural Components | Non-structural Components | Permanent deformations | Reparable structure? |
|---|---|---|---|---|
| Damage Limitation, DL | Light | Econm. repairable | Negligible | Yes |
| Significant Damage, SD | Significant | Damaged | Visible | Uneconomic |
| Near Collapse, NC | Heavy | Collapsed | Large | No |

- **From standard-based methods to full probabilistic approaches: the PEER methodology**

$$\lambda(DV > dv) = \int_{IM} \int_{EDP} \int_{DM} G(DV|DM) \cdot |dG(DM|EDP)| \cdot |dG(EDP|IM)| \cdot |d\lambda(IM)|$$




$$E(L|IM) = \sum_{i=1}^{n} E(L|IM_i) \cdot p(IM_i)$$

$$E(L|IM_i) = E(L|NC \cap R, IM_i) \cdot [1 - p(D|IM_i)] \cdot [1 - p(C|IM_i)] + \\ + p(D|IM_i) \cdot [1 - p(C|IM_i)] + \\ + p(C|IM)$$

Repair

Demolition

Collapse

- # Methodology: Transforming the EC8-3 conditions into loss-based DVs

Single component failure condition from EC8-3:

$$Y_{LS} = \frac{\Theta_{d,LS}}{\Theta_{c,LS}} = 1$$

Notice that this is similar to :

$$Y_{LS} = \frac{EDP_{D,LS}}{EDP_{C,LS}}$$

(Jalayer *et al.* 2007)

Equivalent Loss-based failure condition

$$Y_{LS} = \frac{E(L|IM_{LS})}{\tau_{LS}}$$

**Reparability conditions**

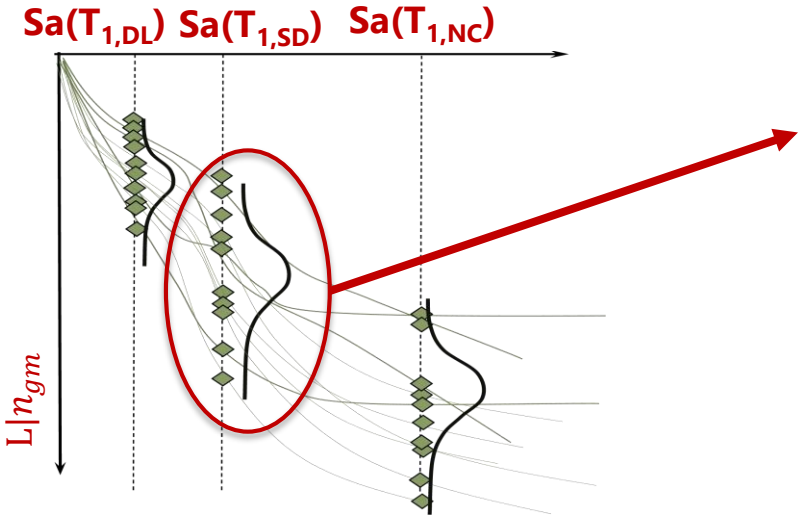
**DL - $\tau_{LS}$=0.10**
**SD - $\tau_{LS}$=0.40**
**NC – IDA……**

$\tau_{LS}$ - defines the Limit State condition by introducing a limit for the repair cost.

$\tau_{DL} = 0.10$ - since the non-structural components have to be repairable, only a low level of losses can be allowed.

$\tau_{SD} = 0.40$ - since this is the limit above which FEMA P58 indicates that building owners prefer to demolish the building instead of repairing it.

- **Methodology: Dynamic Analysis Case**




$$Y_{LS} = \frac{E(L|IM_{LS})}{\tau_{LS}} = \left(\frac{1}{N_{gm}} \cdot \sum_{n_{gm}}^{N_{gm}} \mathrm{L}|n_{gm}\right) / \tau_{LS} < 1.0$$

Includes information about the collapse case

$$\mathrm{L}|n_{gm} = \begin{cases} 1.0 & collapse \\ E\left[\mathrm{L}|n_{gm}\right] \cdot \left[1 - \Phi\left(\frac{\ln[RIDR] - \ln[0.015]}{0.3}\right)\right] + \Phi\left(\frac{\ln[RIDR] - \ln[0.015]}{0.3}\right) & otherwise \end{cases}$$

Obtained by the sum of all storey losses calculated with storey-based EDP-to-Loss functions.

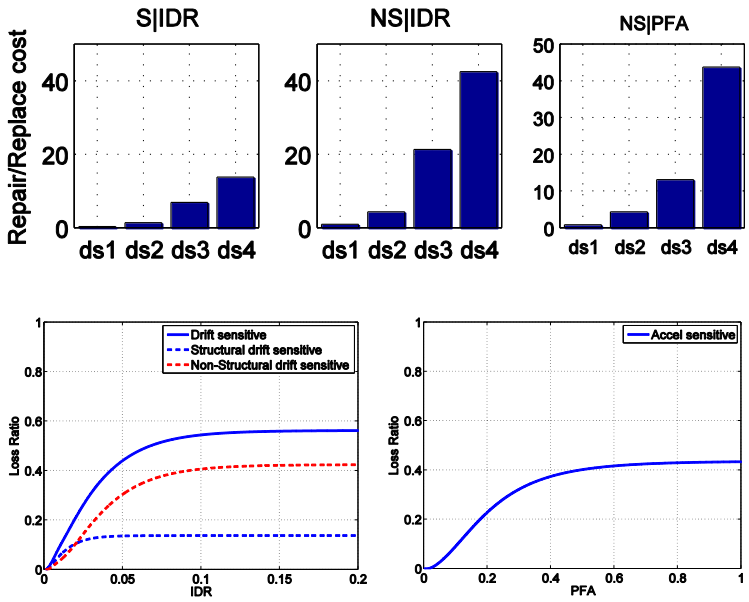
Introduces the excessive residual deformation criteria into the loss assessment condition.

- **Methodology: Deriving new storey-based loss functions compatible with risk mitigation strategies and with the Portuguese built environment**

1. Select the fragility curves for drift-sensitive structural and nonstructural components and for acceleration-sensitive non-structural elements.

2.Calculate the repair needs in each type of component using the consequence models.

3. Use these curves as storey-based vulnerability functions using appropriate weights.
From Martins et al. (2015):

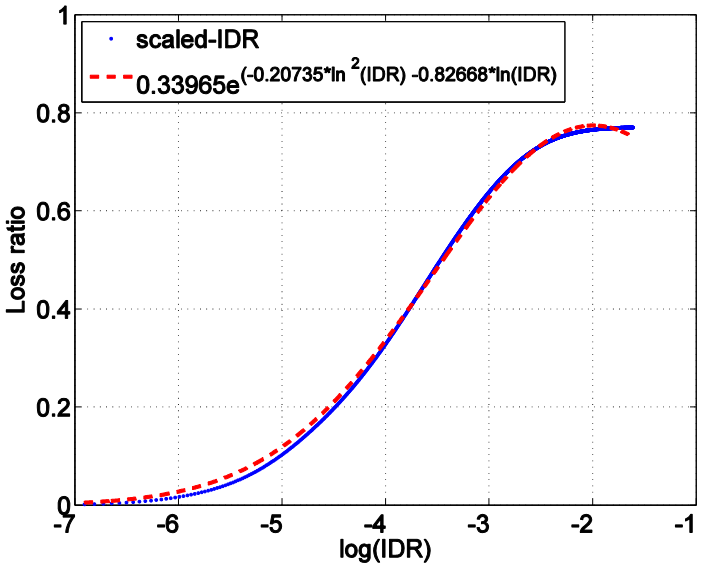


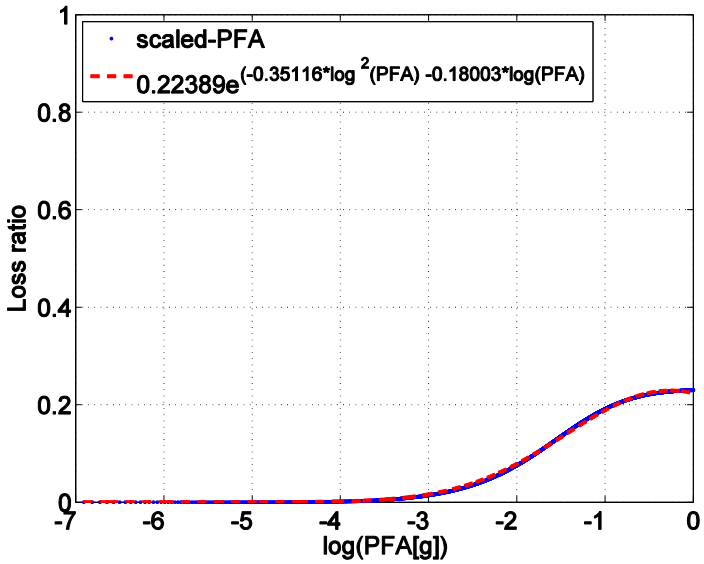

**32% structure,**
**33% infills,**
**15% electric and pumbing systems,**
**12% Windows and interior doors**
**8% para outros elementos**

**32% drift-sensitive structural**
**45% drift-sensitive non-structural**
**23% acceleration-sensitive non-structural**

- **Methodology: Deriving new storey-based loss functions compatible with risk mitigation strategies and with the Portuguese built environment**

4. Using simulations, models correlating the storey drifts and the floor accelerations with the corresponding costs were created for a building within the class CM4 of Hazus (FEMA, 2013). An analytical fit was made to the obtained data.



# **Conclusions:** and back again to standard-based methods!

**(Is it possible to transform the EC8-3 framework into a simplified loss-based methodology where PO's ⇔ LS conditions?)**

- Yes! The simplified method formulated using an intensity-based approach similar to the proposal of EC8-3 defines Loss-based limit states compatible with the POs.
  - The EDP-to-Loss functions avoid the necessity to catalog all the components of the structure, their fragility and the corresponding value.
  - The proposed approach explicitly includes the demolition, excessive residual deformations and the collapse information.
  - It also directly includes information about the damage state/repair needs of structural and non-structural components.
- The proposed Loss-based approach is fully compatible with simplified static methodologies such as the one proposed in FEMA P58.
- Are the component-based limit state conditions representative for existing RC buildings? Can a combination of components represent a system-level metric? To find out soon…