Fragility Curves for Reinforced Concrete Pre-Seismic Code Portuguese Building Stock

Sanam Moghimi

Outline

- Background
- LNECLOSS overview
- Determination of fragility curves
- Future developments

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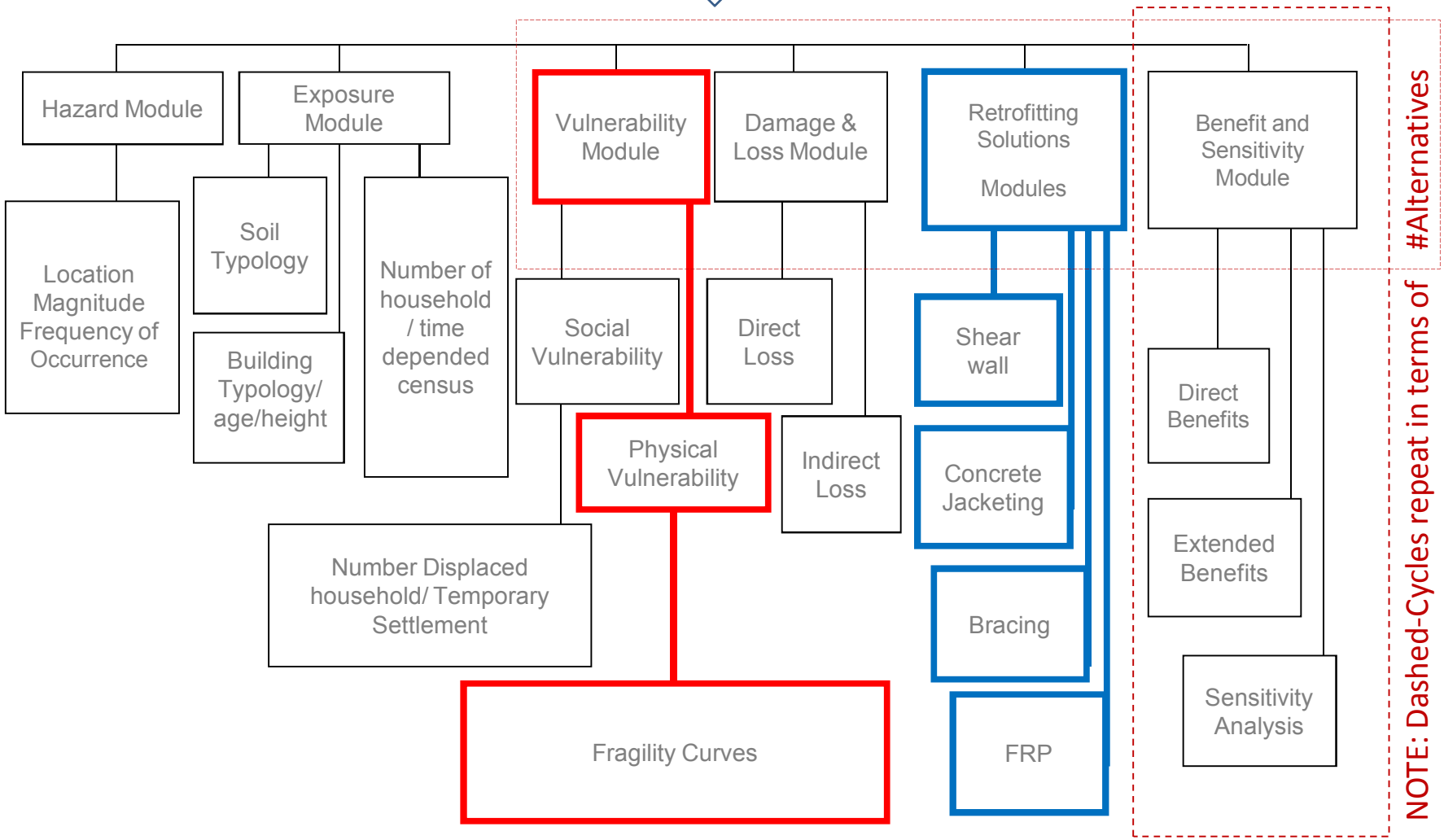
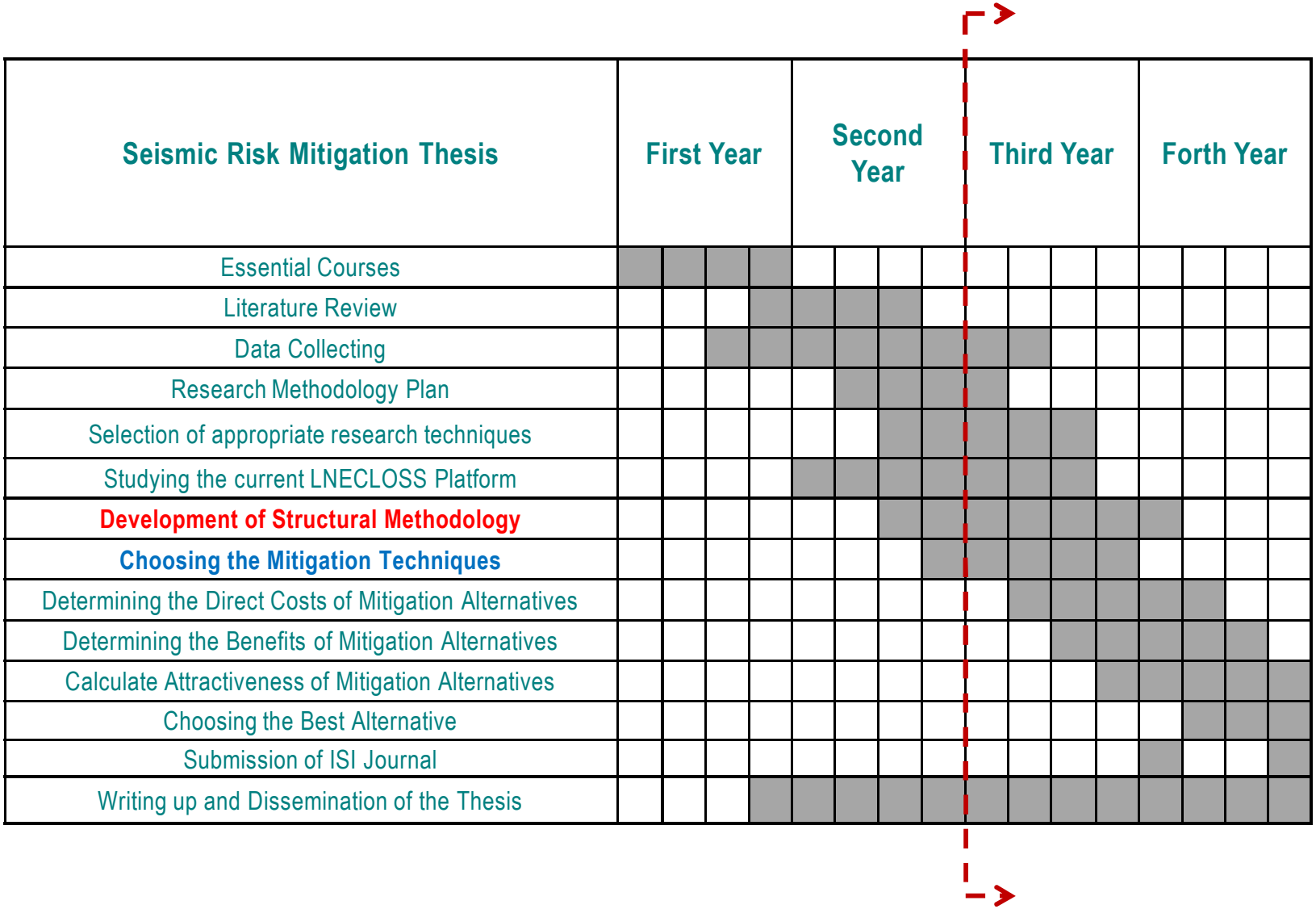
Thesis Framework; Cost Effectiveness Analysis

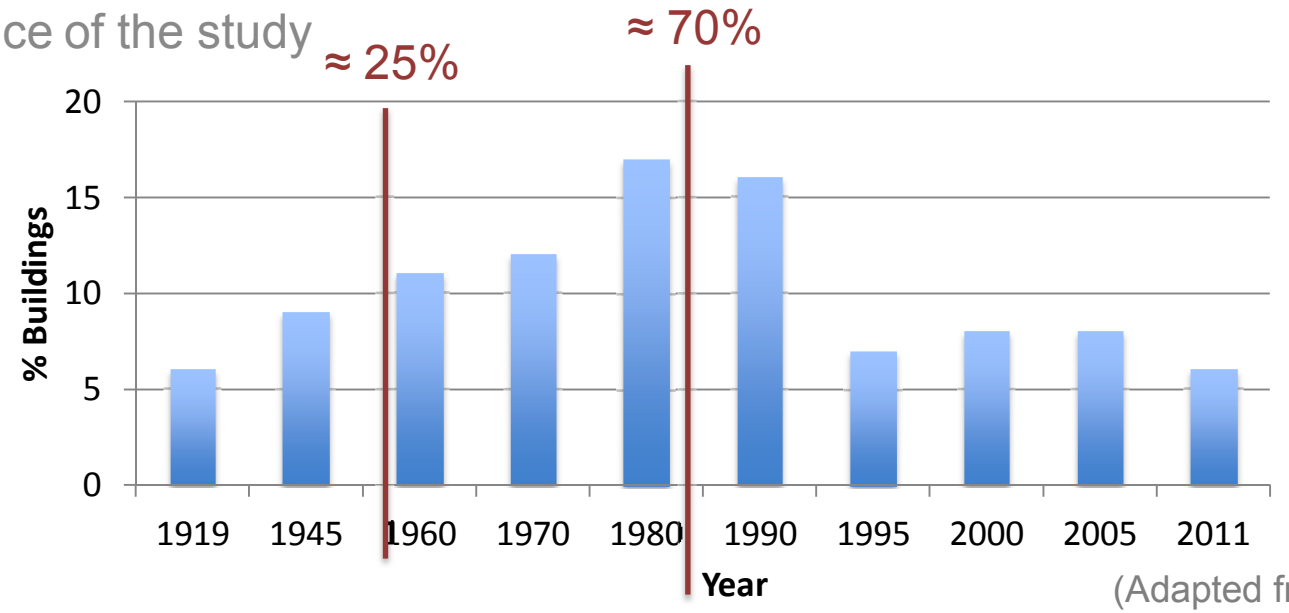


Thesis Plan Scheduling



Background

•Significance of the study



(Adapted from Neves, 2015)

1st Seismic code (RSCCS, 1958)

Seismic code in force (RSA, 1983)

≈ 70 % of building stock was not designed against earthquakes and is potentially vulnerable to seismic actions

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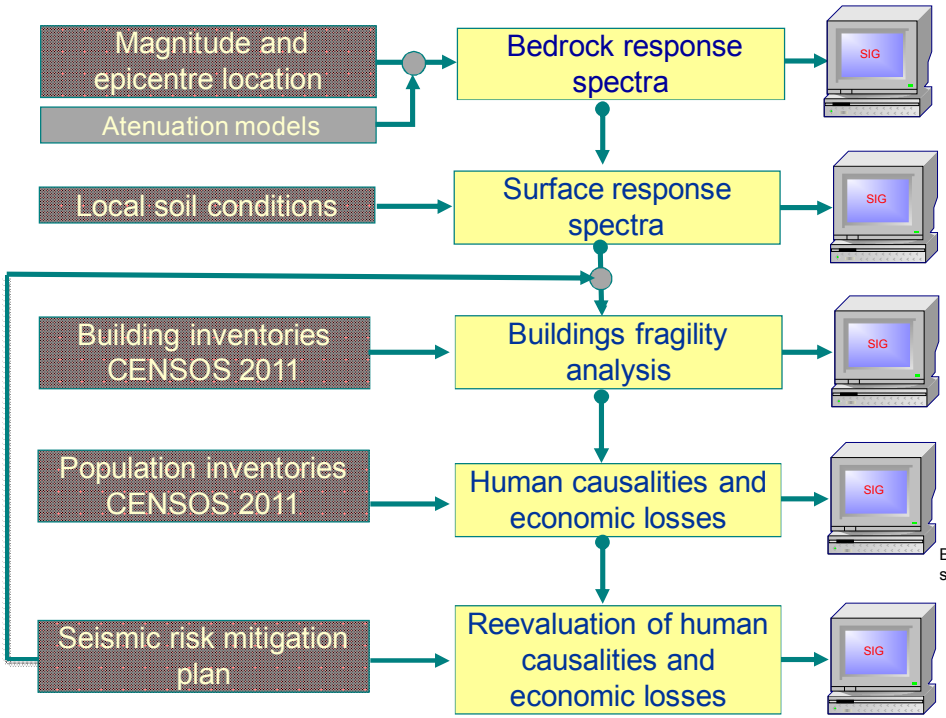
LNECLOSS overview

Application architecture

- LNECloss Simulator

  Platform for seismic loss estimation

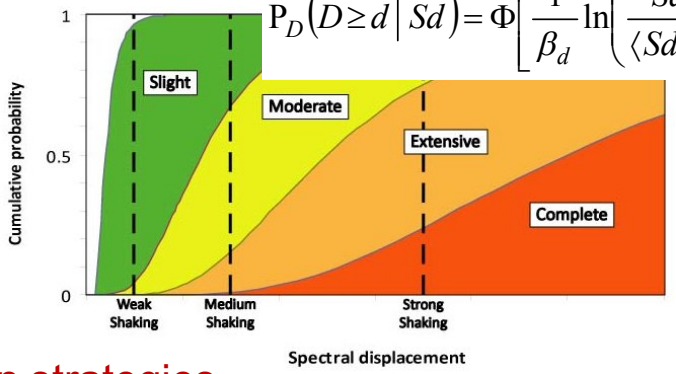
  Developed in a scientific programming language and integrated in a GIS



Limitations

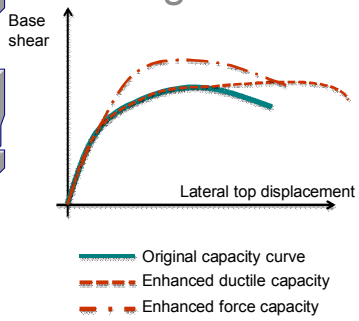
- Fragility curves
  - Implementation is based on HAZUS and Expert opinion
  - Simplification of the "actual" damage progression in pre-seismic code buildings

$$P_D\left(D \geq d \mid Sd\right) = \Phi\left[\frac{1}{\beta_d} \ln\left(\frac{Sd}{\langle Sd_d \rangle}\right)\right]$$



- Mitigation strategies

  Conceptual assessment of mitigation strategies



# Streng	Masonry	RC	Improvement of force capacity λ	Improvement of force capacity γ	Improvement of ductile capacity. δ_d
1	✓	✓	-	25%	25%
2	✓	✓	-	50%	25%
3	✓	✓	-	75%	25%
4	✓	✓	75%	75%	25%
5	✓	✓	-	25%	50%
6	✓	✓	-	50%	50%
7	✓	✓	-	75%	50%
8	✓	✓	75%	75%	50%
9		✓	-	25%	75%

Contribution to LNECLOSS Development
Mitigation Framework Modules (LNECLOSS+)

Hazard Module

Exposure Module

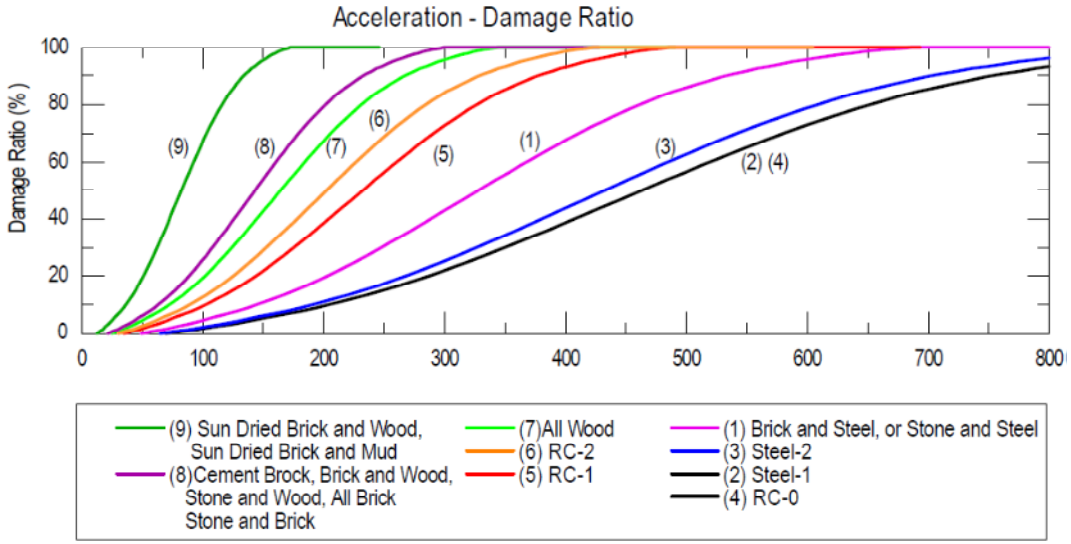
Vulnerability Module

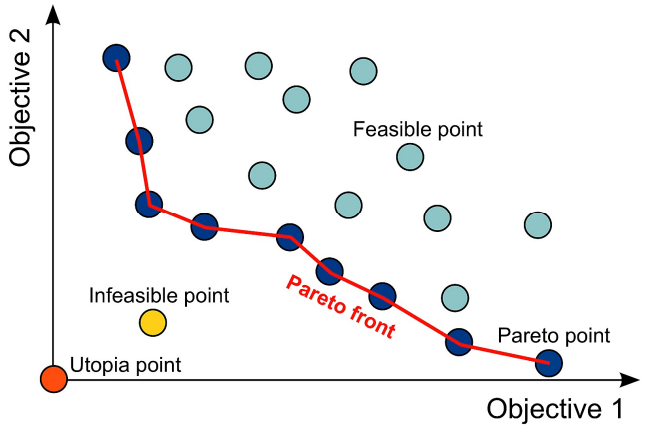
Loss & Damage Module

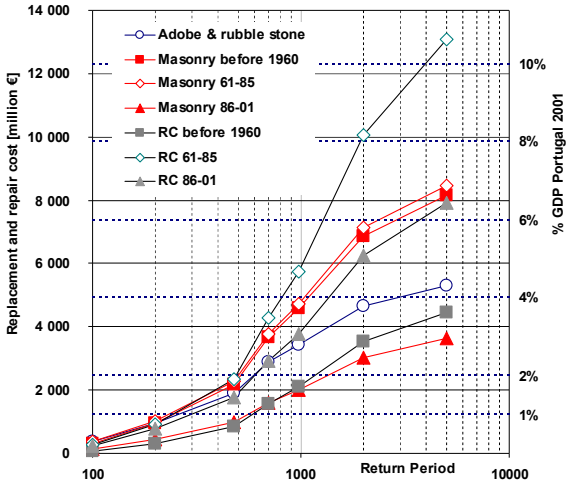
Retrofitting Alternative Module

Benefit & Sensitivity Module

Decision Making Module







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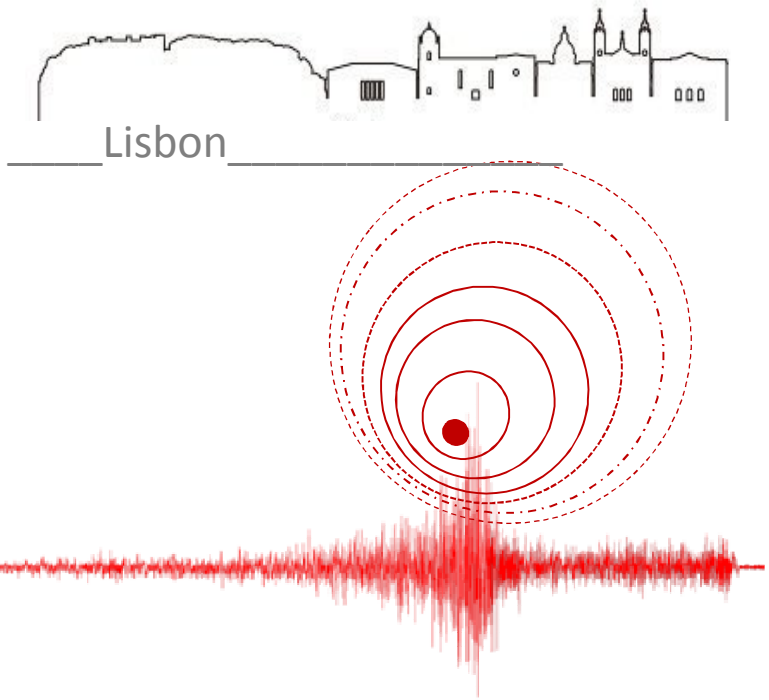
Fragility Curves for Reinforced Concrete Pre-Seismic Code Portuguese Building Stock

Introduction

Fragility curves are plots of the probability of exceedance of a given damage state for a conditional level of seismic action.



Objective

To develop fragility curves and update LNECLOSS in order to be able to perform unbiased cost-effective analyses

Methodology

- Definition of probabilistic models for input random variables
- Generate 500 buildings representative of the building stock
- Perform nonlinear static analyses (pushover)

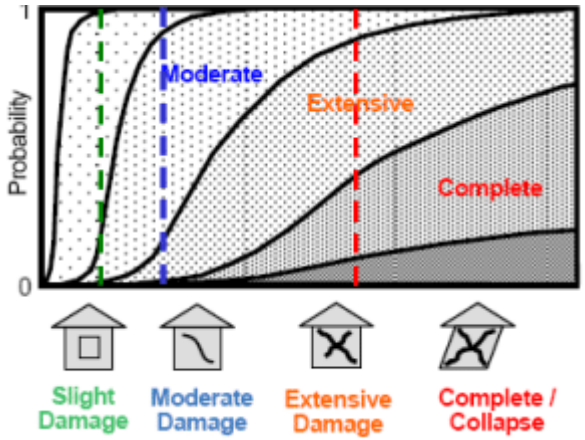
Fragility Curves for Reinforced Concrete Pre-Seismic Code Portuguese Building Stock

Methodology

•Evaluate results considering two performance objectives:

- No-(local-)collapse: This implies that the structure is significantly damaged but retains its full vertical load-bearing capacity and sufficient residual lateral strength and stiffness to protect life even during strong aftershocks.
  - Shear Failure Ultimate Limit State
  - Plastic Hinge Ultimate Limit State
- Damage limitation: The structure itself has no permanent drifts; its elements have no permanent deformations, retain fully their strength and stiffness, and do not need repair. Serviceability Limit State (Yield Rotation of Column)

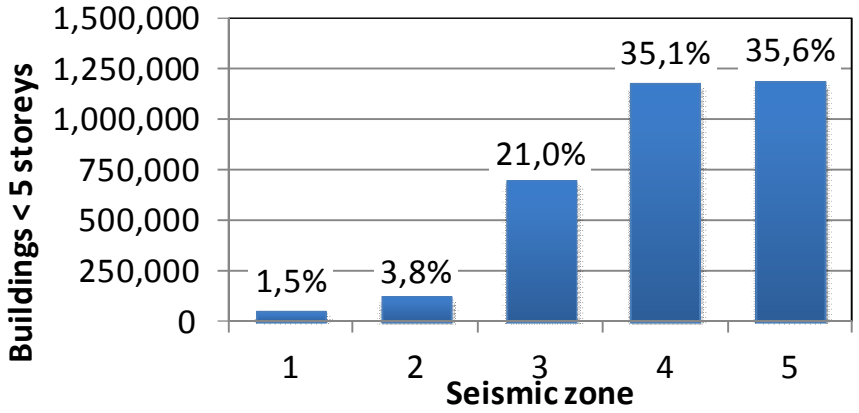
• Determine frequencies of Limit State being exceeded: Plot fragility curves



Case study: RC Portuguese pre-seismic code building stock up to 4storey

Building stock

- **Censos 2011:**
  97% of building stock < 5 storey
  65% of buildings are Reinforced Concrete
  70% of buildings are pre-seismic code



Random variables of material and geometry properties for existing buildings

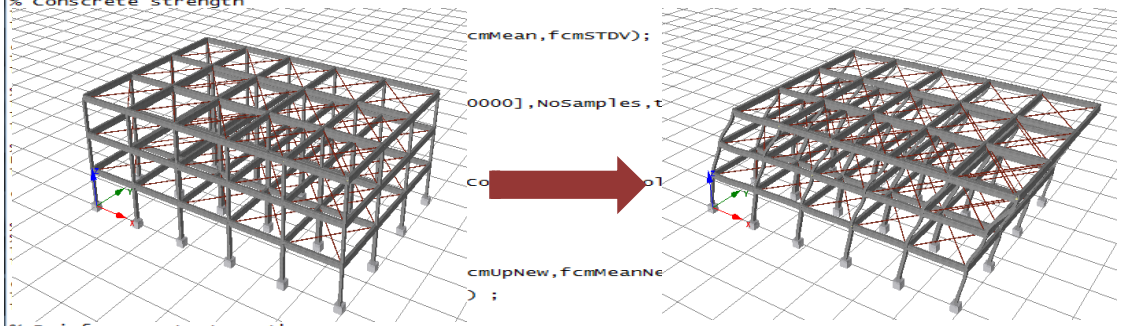
Variables	Mean value	CV (%)	A	B	Reference
G (kN/m^2)	8	12.5	6	10	Sousa *et al.*, 2016
# storey	1/2/3/4	28/42/15/15	-	-	Censos, 2011
H_1	3.2	10	2.5	5	Silva *et al.*, 2014
H_n	2.8	6	2.5	4	
$L_{X/Y}$ (m)	4.4	16	2.5	6.5	Furtado *et al.*, 2015
h_{laje} (m)	0.23	24	0.1	0.35	
f_{cm} (MPa)	23.8	49	5.0	80.0	Silva *et al.*, 2014
f_{yk} (MPa)	235/400/500	25/50/25	-	-	Silva *et al.*, 2014
ρ_l (%)	1	40	0.3	3.5	Furtado *et al.*, 2015 Sousa *et al.*, 2016

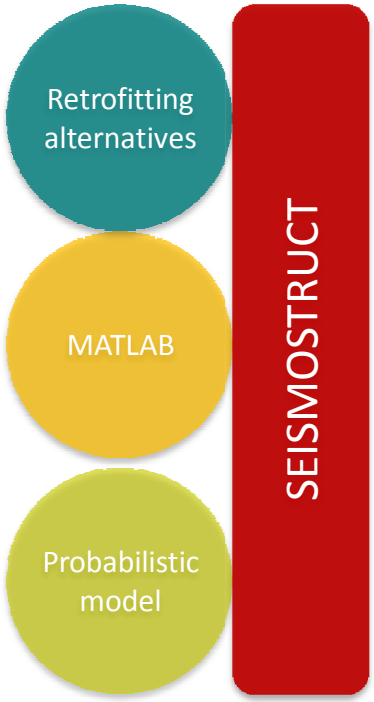
Numerical Modelling

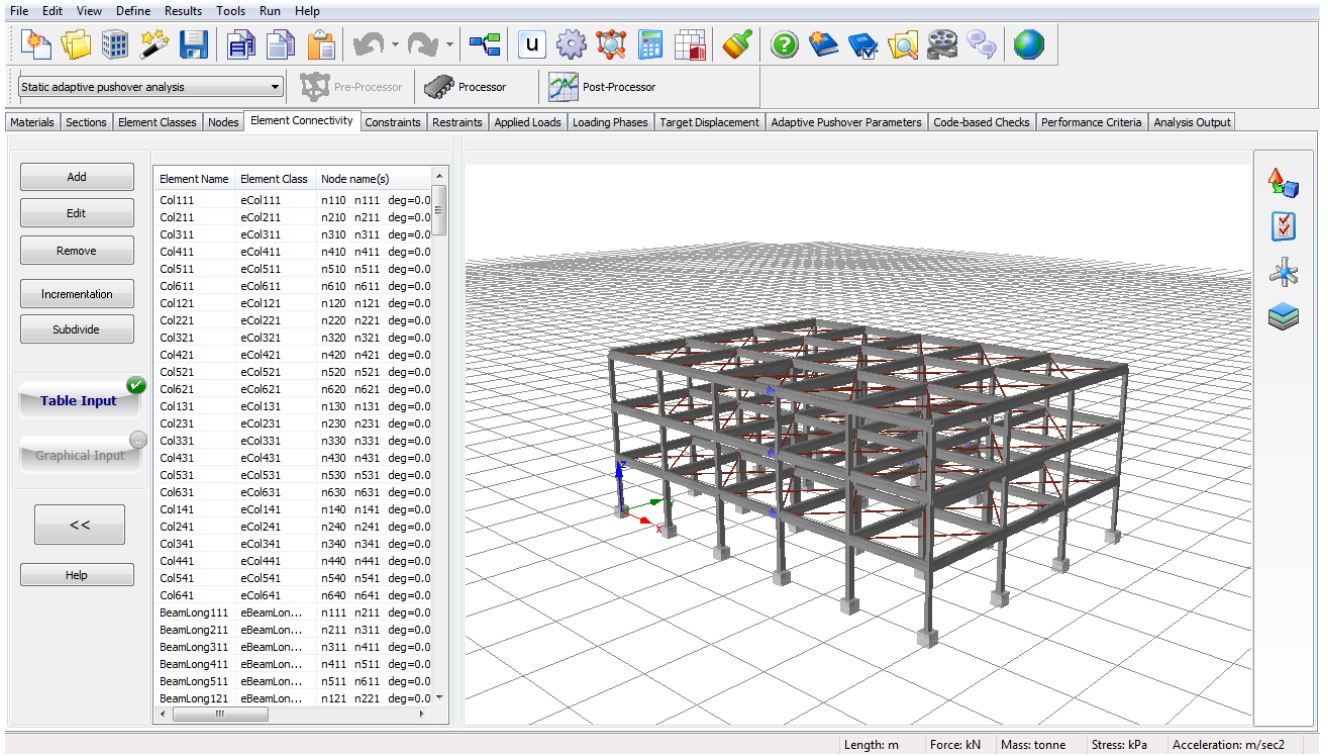
Seismostruct FEA program

- 500 buildings designed only for gravity loads (RSA)
- Two directions of earthquake (X,Y)
- Adaptive pushover analysis

```
for i = 1:NoSamples
    weightGRand(i) = rtnorm (weightGLow,weightGUp,weightGMean,weightGSTDV);
end;
weightQRand = randsample([2 2], NoSamples, true, [0.95 0.05]);
% Conscrete strength
                                                    cmMean,fcmSTDV);
                                                    0000],NoSamples,t
                                                    cmUpNew,fcmMeanNe
                                                    ) ;
% Reinforcement strength
fsykRand = randsample([230000 400000 500000],NoSamples,true,[0.25 0.5 0.25]);
fsydRand = fsykRand ./ GamaRein;
fsymRand = fsykRand .* 1.1 ;
% Long. reinforcement quantity
RhoLongColRand = zeros(NoSamples,1);
for i = 1:NoSamples
```



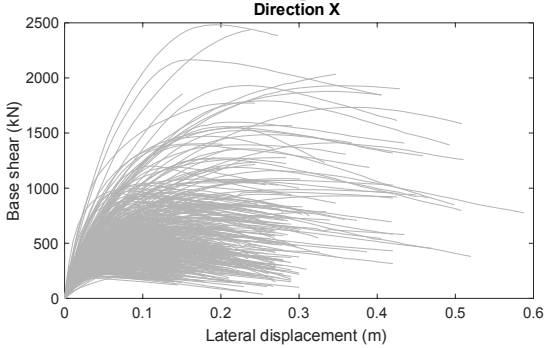


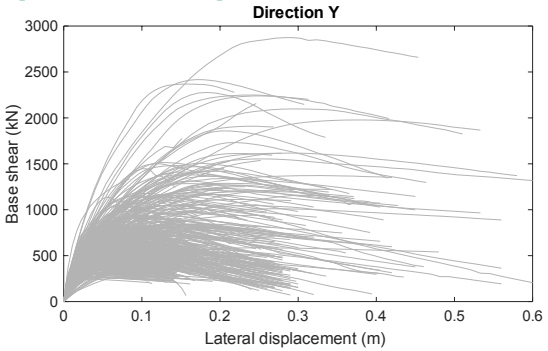


Results of the numerical modelling for the existing buildings

- Global structural behaviour

  High resistance and deformation variability

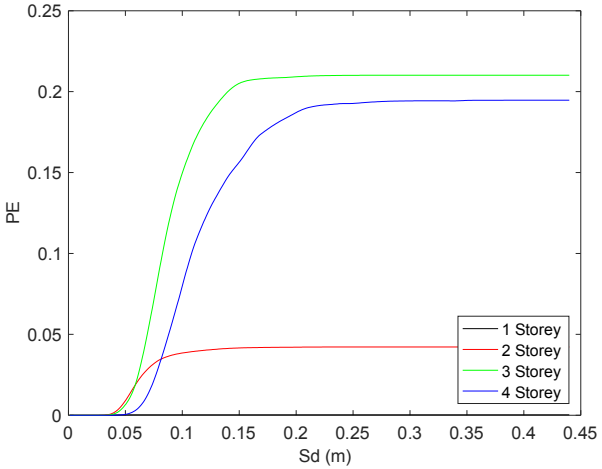




- Fragility curves (Local Limit States-collapse)

Force based Limit State

Shear Failure Ultimate Limit State (EC8-3)

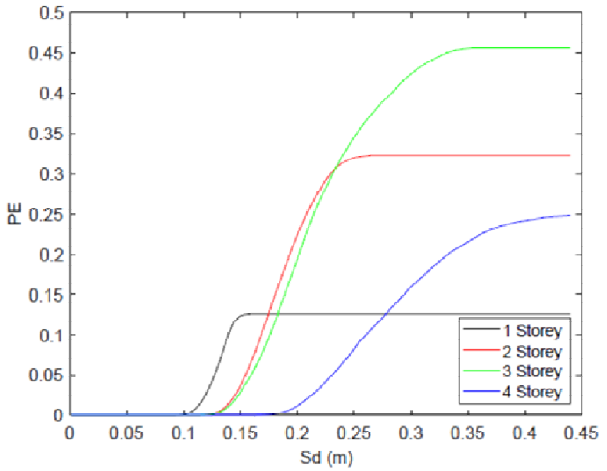


$$V_R = \frac{1}{\gamma_{el}}\left[\left(\frac{h-x}{2L_V}\min(N, 0.55A_c f_c) + \left(1 - 0.05\min\left(5, \mu_\Delta^{pl}\right)\right)\cdot\right.\right.$$
$$\left.\left.\cdot\left[0.16\max(0.5, 100\rho_{tot})\left(1 - 0.16\min\left(5, \frac{L_V}{h}\right)\right)\sqrt{f_c}A_c + V_w\right]\right)\right]$$

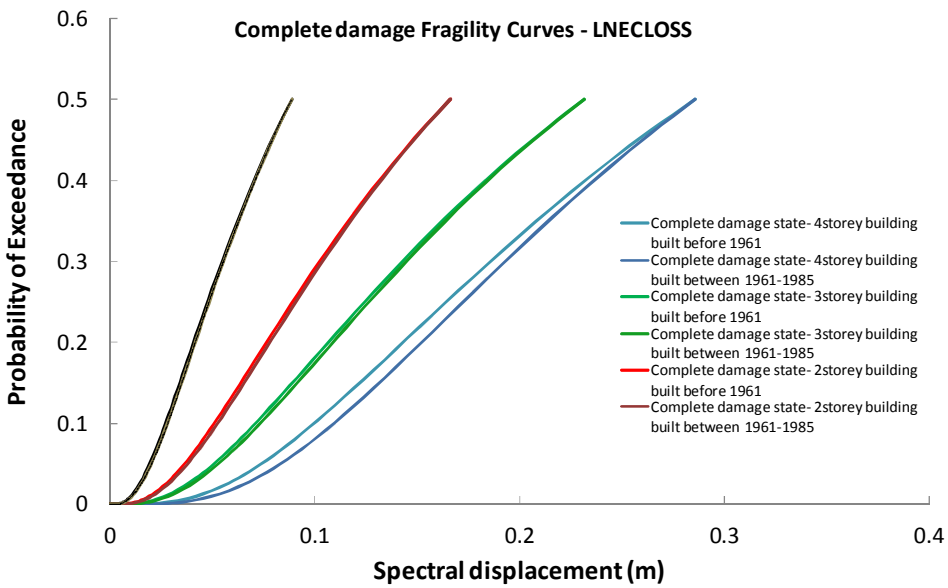
Deformation based Limit State

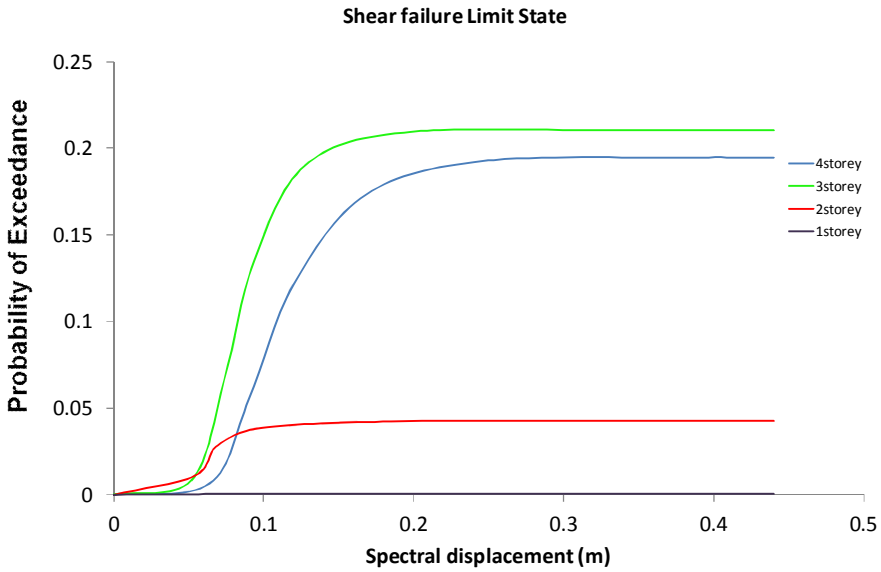
Plastic Hinge Ultimate Limit State (EC8-3)

$$\theta_{um} = \frac{1}{\gamma_{cl}}0{,}016\cdot(0{,}3^{\nu})\left[\frac{\max(0{,}01;\omega')}{\max(0{,}01;\omega)}f_c\right]^{0{,}225}\left(\frac{L_V}{h}\right)^{0{,}35}25^{\left(\alpha\rho_{sx}\frac{f_{yw}}{f_c}\right)}(1{,}25^{100\rho_d})$$



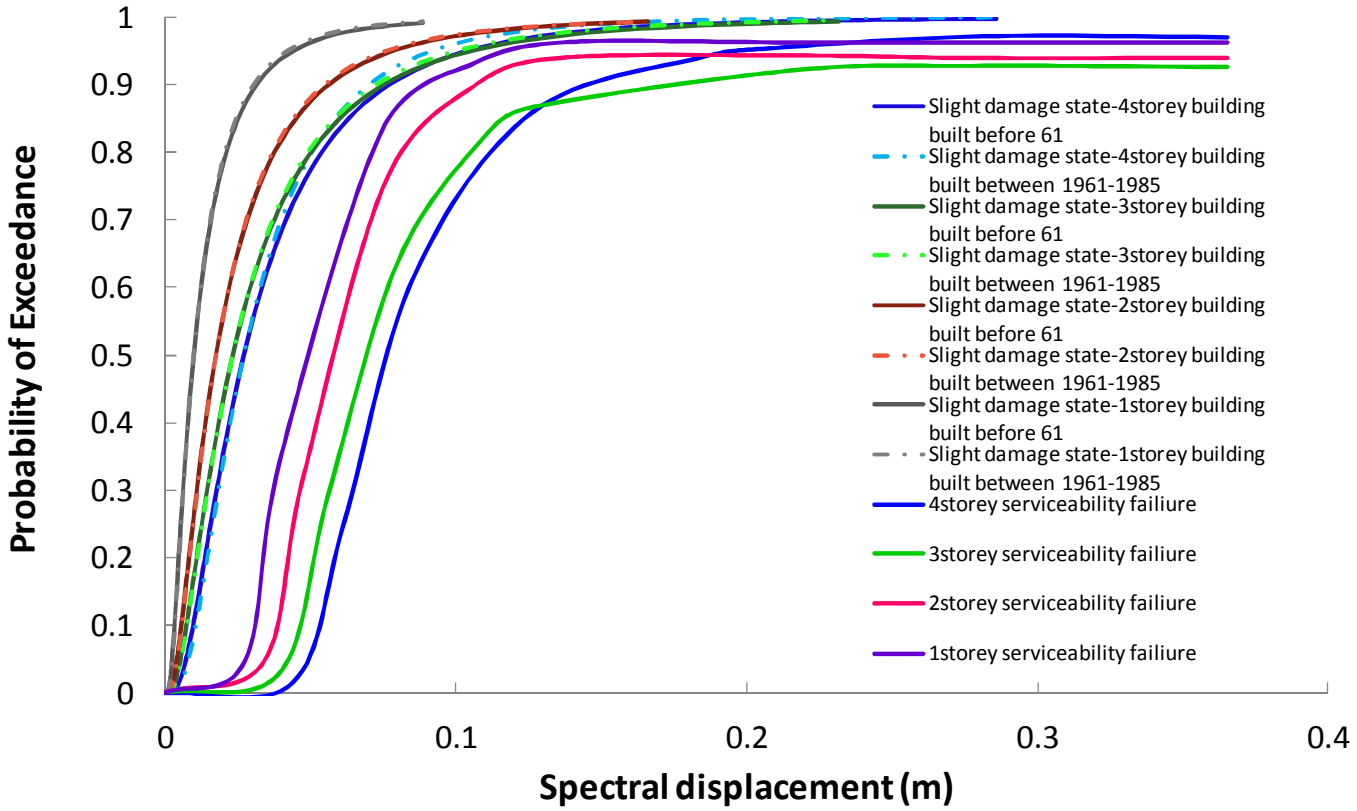
LNECLOSS Complete damage Fragility Curves comparing to Non-Collapse limit state





- Fragility curves for Plastic Hinge mechanism are under development
- Existing pre-seismic code buildings may collapse by shear (brittle) failure of columns (with increasing likelihoods for higher number of storey buildings ≈ 20%)
- For collapses involving large deformations Plastic Hinge (ductile) mechanism will occur

LNECLOSS Slight damage Fragility Curves comparing to Damage limitation limit state (Yield Chord Rotation of Column)

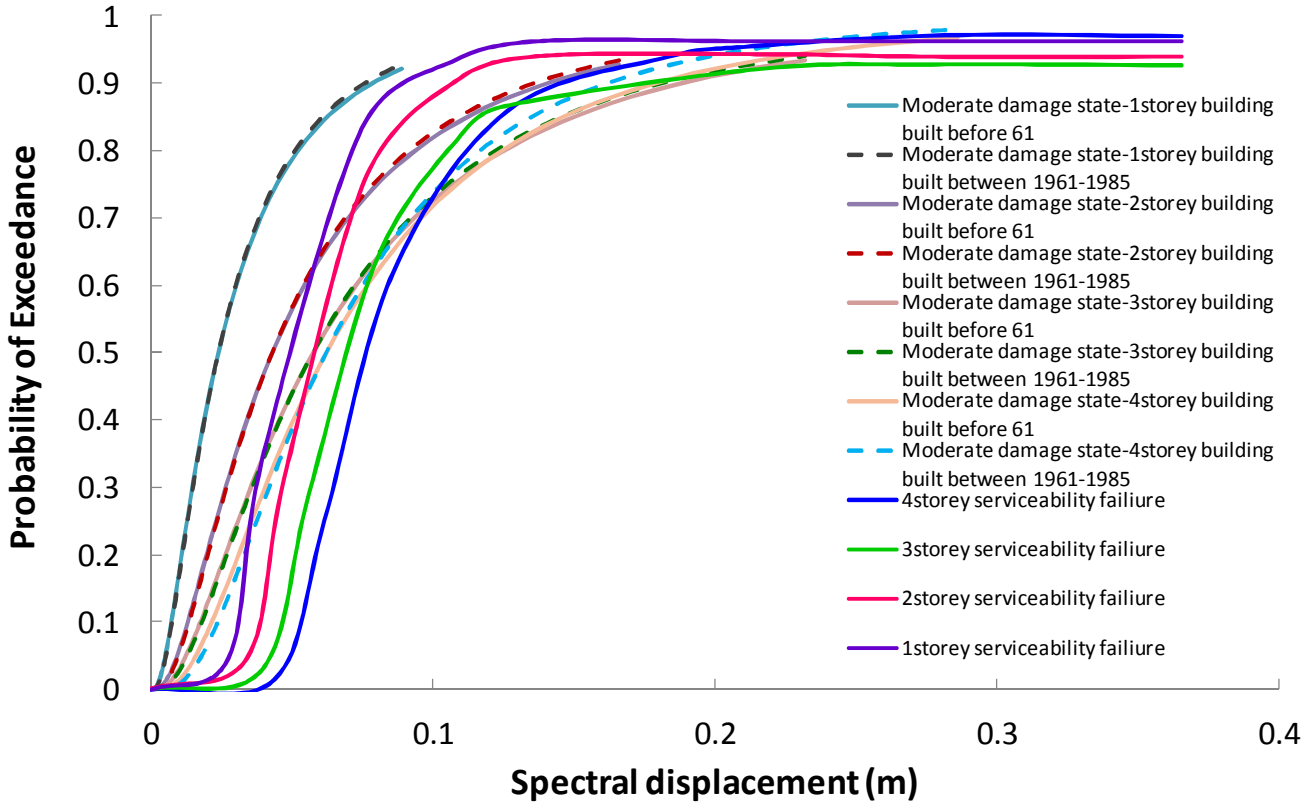


- LNECLOSS fragility curves are in all cases conservative
- By using more accurate fragility curves, the investment needed in retrofit strategies is reduced

- Yield chord rotation of column (EC8-3)

$$\theta_y = \phi_y \frac{L_V + a_V z}{3} + 0{,}00135\left(1 + 1{,}5\frac{h}{L_V}\right) + \frac{\varepsilon_y}{d - d'}\frac{d_b f_y}{6\sqrt{f_c}}$$

LNECLOSS Moderate damage Fragility Curves comparing to Damage limitation limit state (Yield Chord Rotation of Column)



•LNECLOSS fragility curves for moderate damage have a better fit to the new curves

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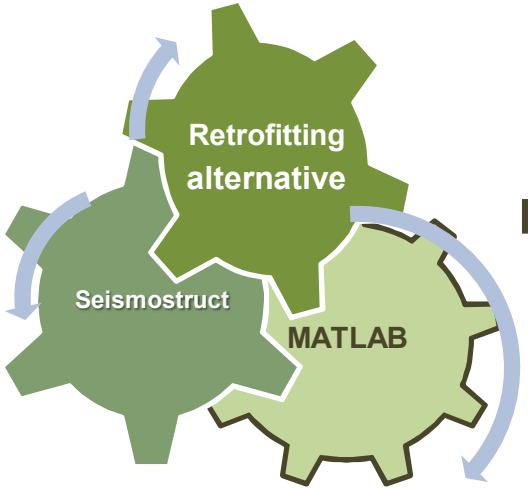
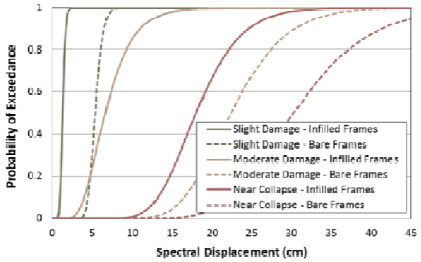
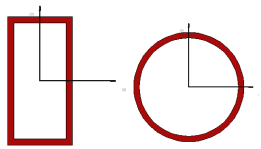
Under development studies

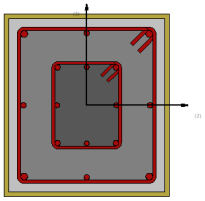


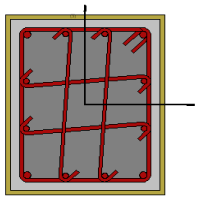
New fragility curves

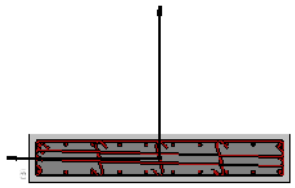


The Retrofitting techniques considered in this study are:







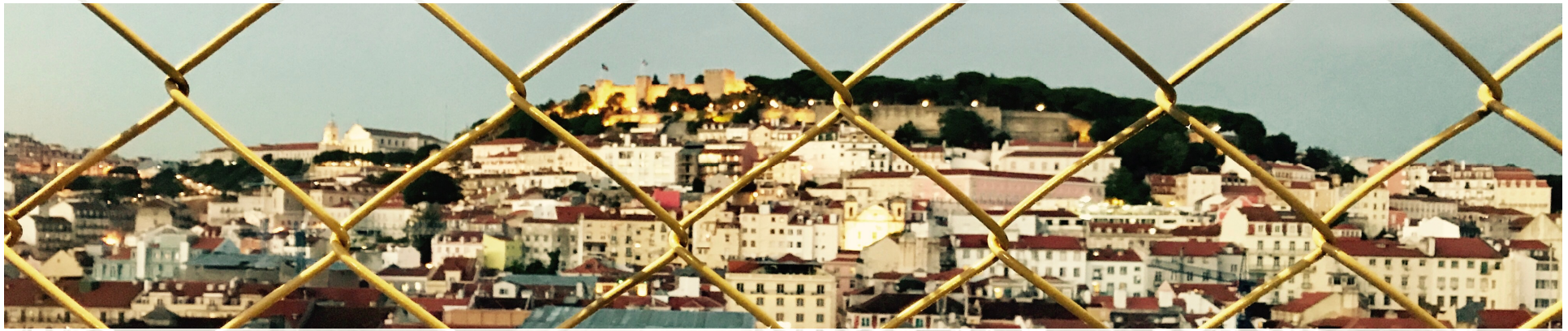


Steel bracings

RC jacketing

FRP sheets

Shear walls



Thank You for Your Attention

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