Seismic Risk OF PreCode RC Buildings Retrofitted with Jacketing

RC Building of up to 4 Storeys in Metropolitan Area of Lisbon

Sanam Moghimi

Outline

- Background
- LNECLOSS+
- Retrofitting Solutions
- Scenarios of Earthquake
- Risk Mitigation
- Future Development

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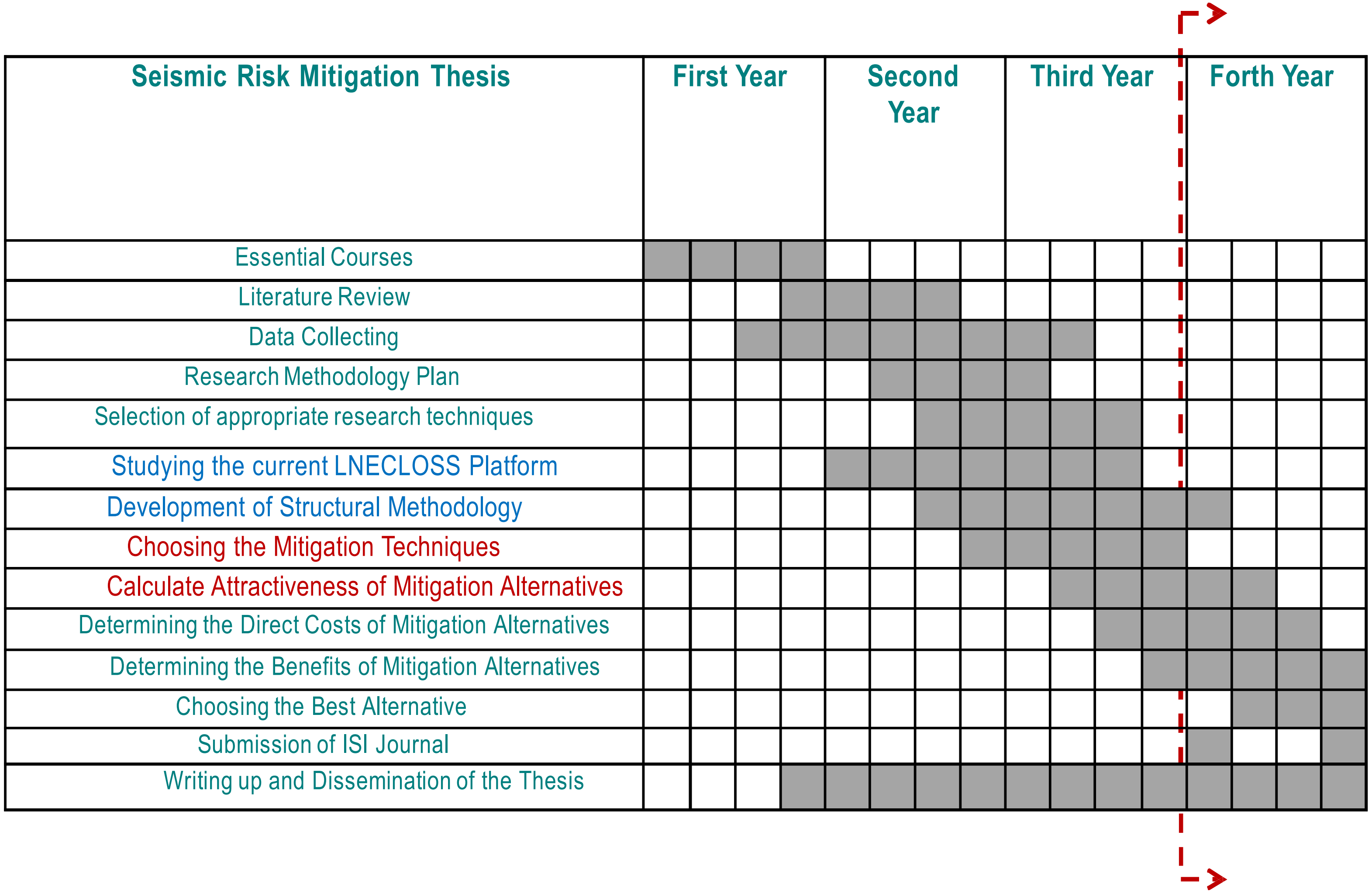
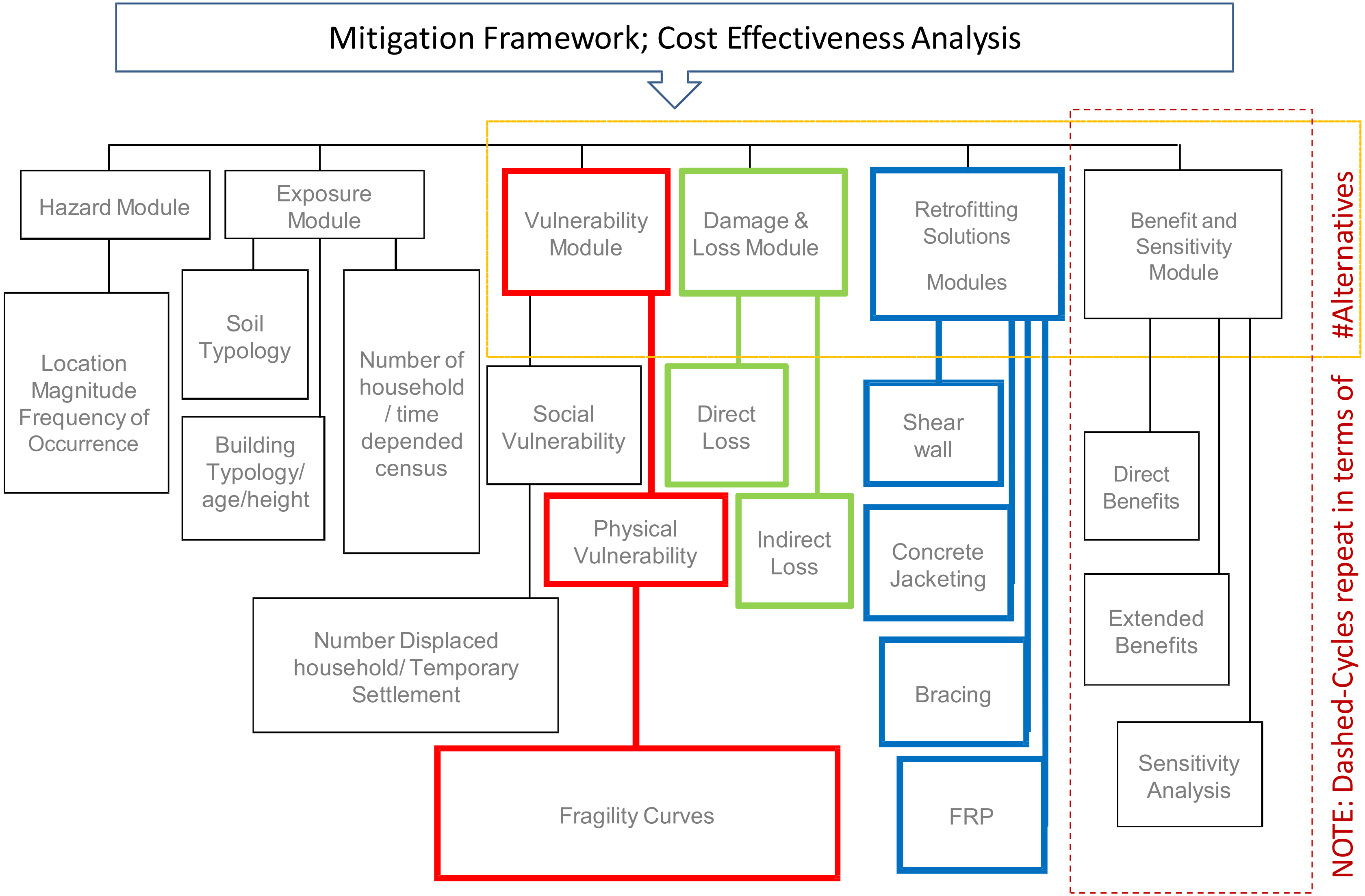
Thesis Plan Scheduling




Mitigation Framework; Cost Effectiveness Analysis
Hazard Module
Exposure Module
Vulnerability Module
Damage & Loss Module
Retrofitting Solutions Modules
Benefit and Sensitivity Module
Location Magnitude Frequency of Occurrence
Soil Typology
Building Typology/ age/height
Number of household / time depended census
Social Vulnerability
Direct Loss
Indirect Loss
Physical Vulnerability
Number Displaced household/ Temporary Settlement
Fragility Curves
Shear wall
Concrete Jacketing
Bracing
FRP
Direct Benefits
Extended Benefits
Sensitivity Analysis
NOTE: Dashed-Cycles repeat in terms of #Alternatives

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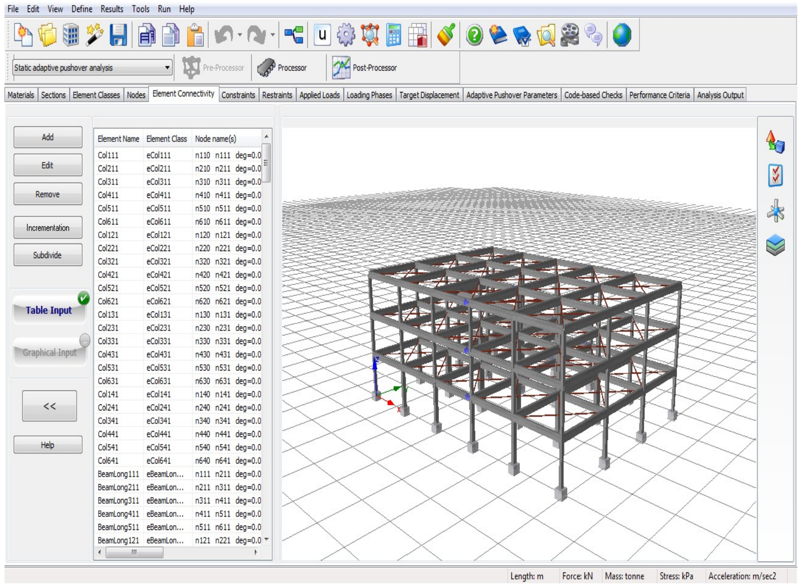
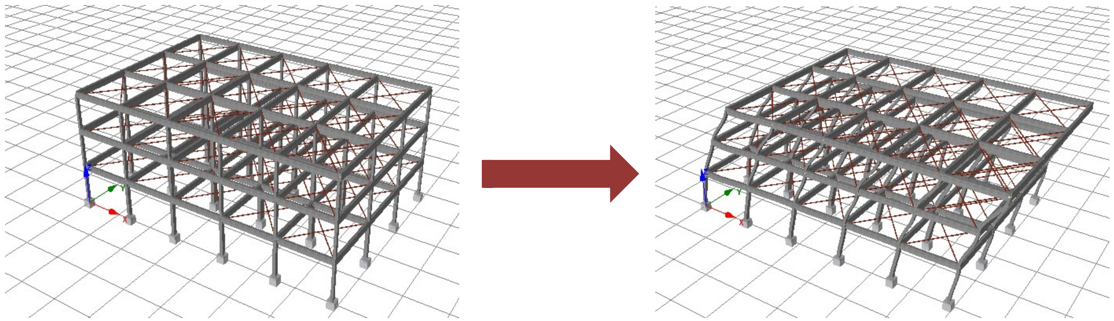
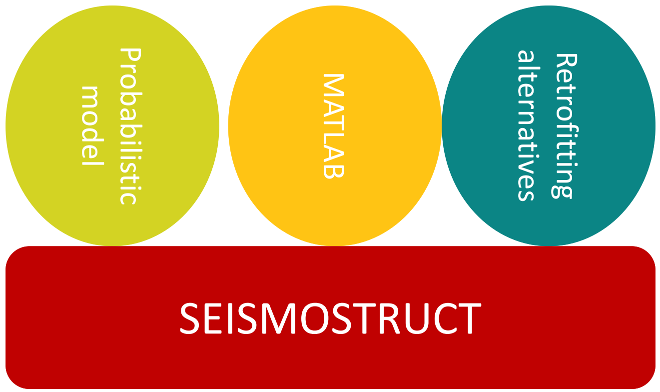
LNECLOSS+

- Numerical Modelling VS Expert Opinion
  - Seismostruct FEA program
  - 500 buildings
  - Two directions of earthquake (X,Y)
  - Adaptive pushover analysis





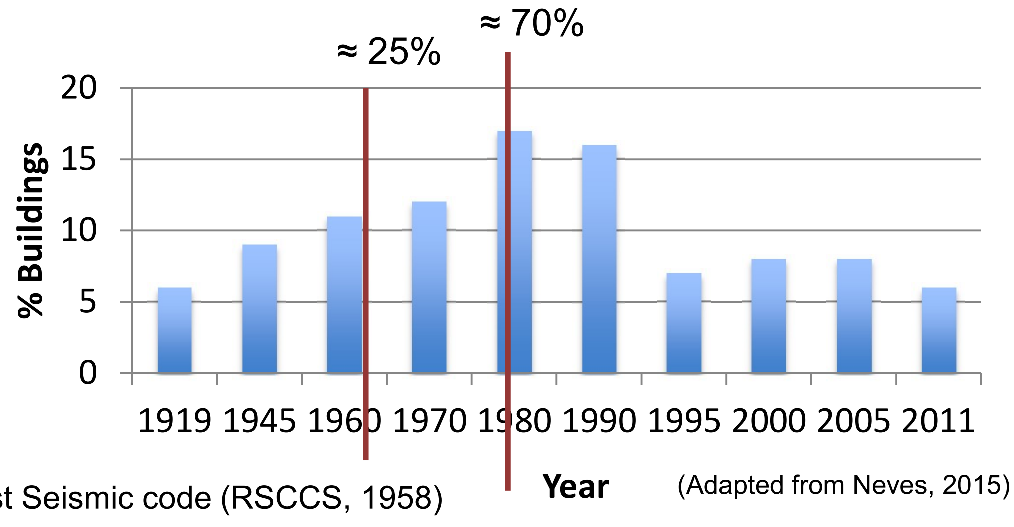
- Capacity Functions
  - Seismostruct FEA program
  - 500 buildings
  - Two directions of earthquake (X,Y)
- Cost Functions



Case Study Building Stock

- **Censos 2011:**
  97% of building stock < 5 storeys

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



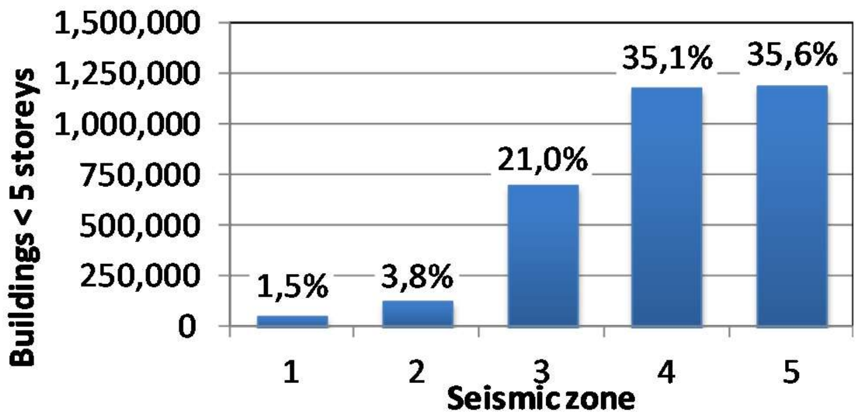
Vulnerability and inventory definition

- 7 vulnerability classes x 7 nº floors

Vulnerability classes
Adobe + rubble stone + others
Masonry before 1960
Masonry 1961-85
Masonry 1986-01
RC before 1960
RC 1961-85
RC 1986-01

RC before 1960
RC 1961-85

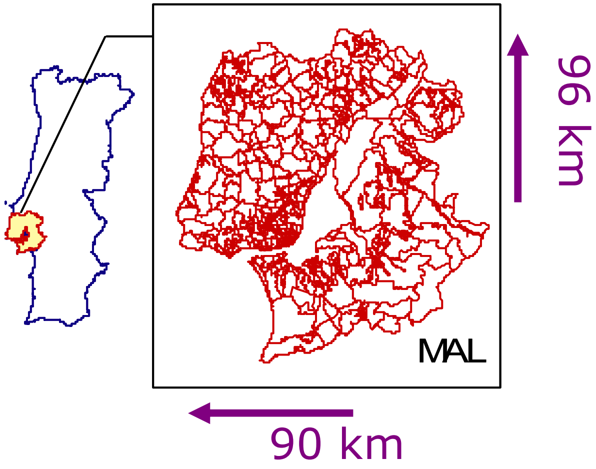
Up to 4 storey Building

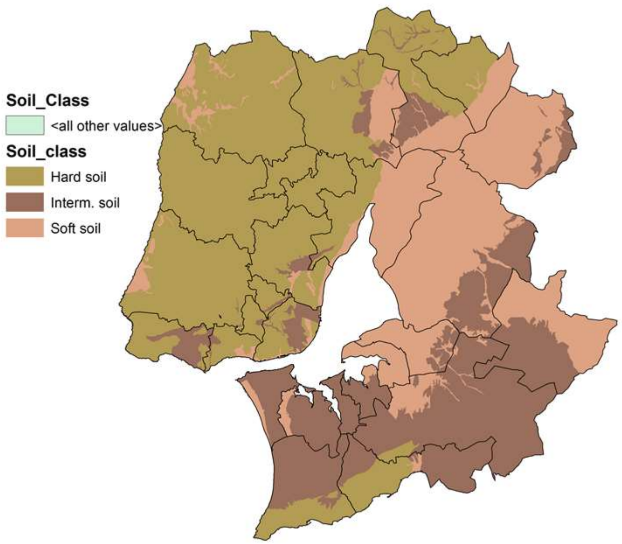


Case Study Area

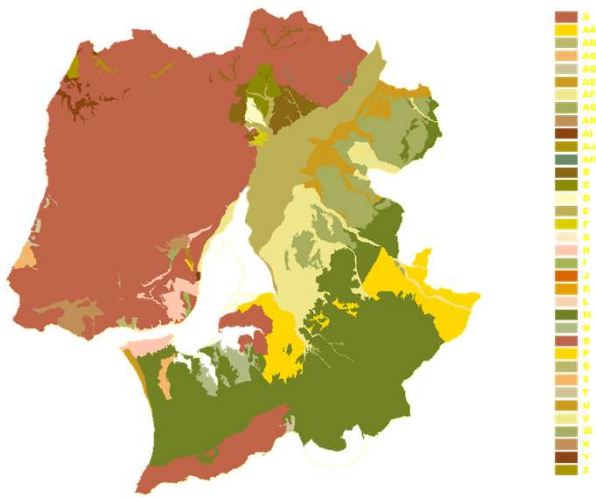
- Metropolitan Area of Lisbon - MAL

Ground type	Stratigraphic profile	v_s [m/s]
A	Rock and hard soil	> 350
B	Intermediate soil	200-350
C	Soft soil	< 200





3 soil classes



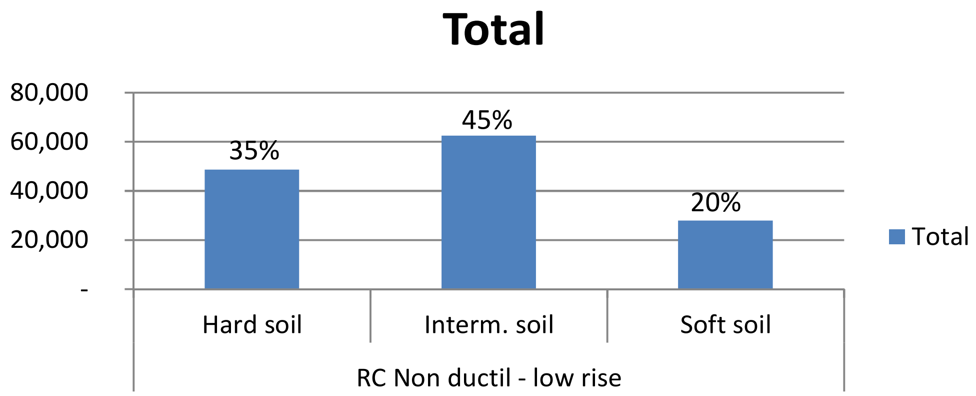
37 soil profiles

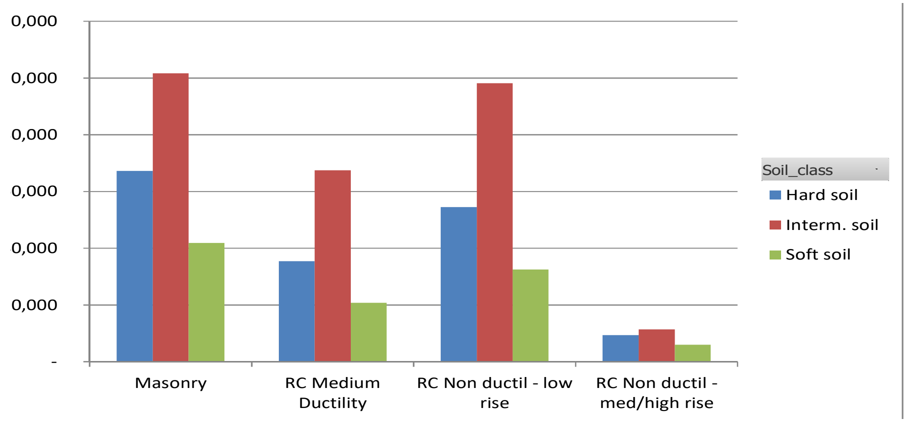
Case study: RC Portuguese pre-seismic code building stock up to 4 storey

Variables of material and geometry properties

Existing buildings

Variáveis	Média	CV (%)	A	B	Referência
G (kN/m^2)	8	12.5	6	10	Sousa *et al.*, 2016
N° pisos	1/2/3/4	28/42/15/15	-	-	Censos, 2011
H_1	3.2	10	2.5	5	
H_n	2.8	6	2.5	4	Silva *et al.*, 2014
$L_{X/Y}$ (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





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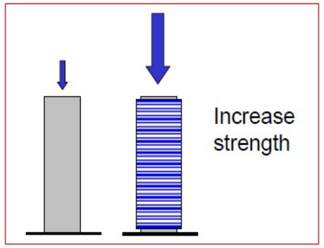
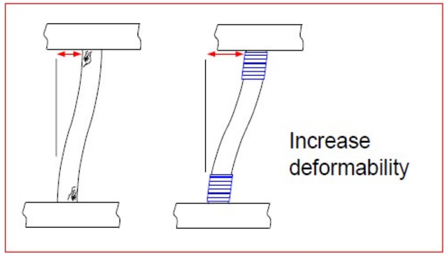
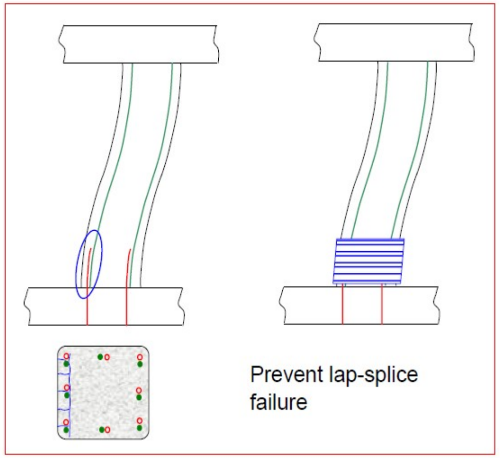
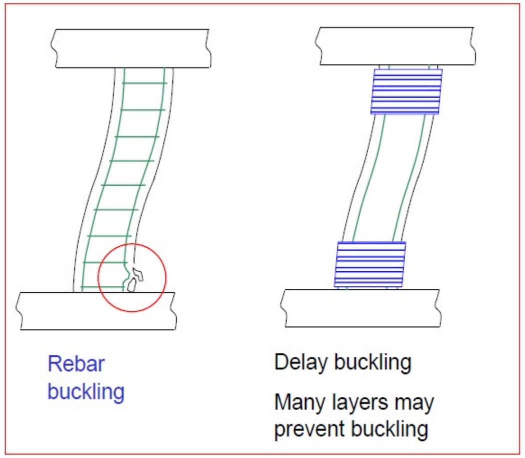
Retrofit Solution

Steel/FRP Jacketing
Considering Confinement





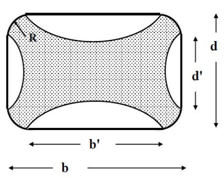




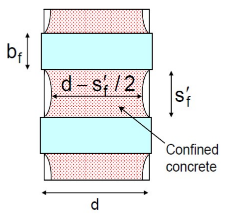
T. TRIANTAFILLOU

Effectiveness Confinement

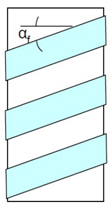
$$\alpha_f = \alpha_n \times \alpha_s \times \alpha_a \le 1$$



$$\alpha_n = \frac{A_e}{A_g} = 1 - \frac{b'^2 + d'^2}{3A_g\left(1 - \frac{A_s}{A_g}\right)}$$



$$\alpha_s = \frac{\left(1 - \frac{s'_f}{2d}\right)^2}{1 - \frac{A_s}{A_g}}$$



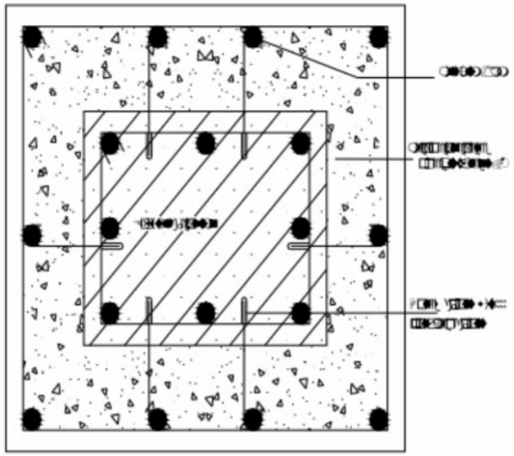
$$\alpha_a = \frac{1}{1 + (\tan\alpha_f)^2}$$

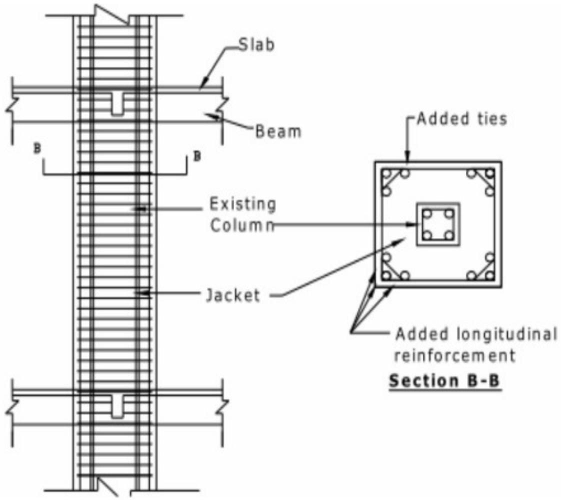
Confinement factor varies: 1.50 , 2.00

results in 2 scenario of Retrofit Solution

Retrofit Solution

Technique for Column Jacketing





Properties of Jacket

(Shri. Pravin B. Waghmare, 2011)

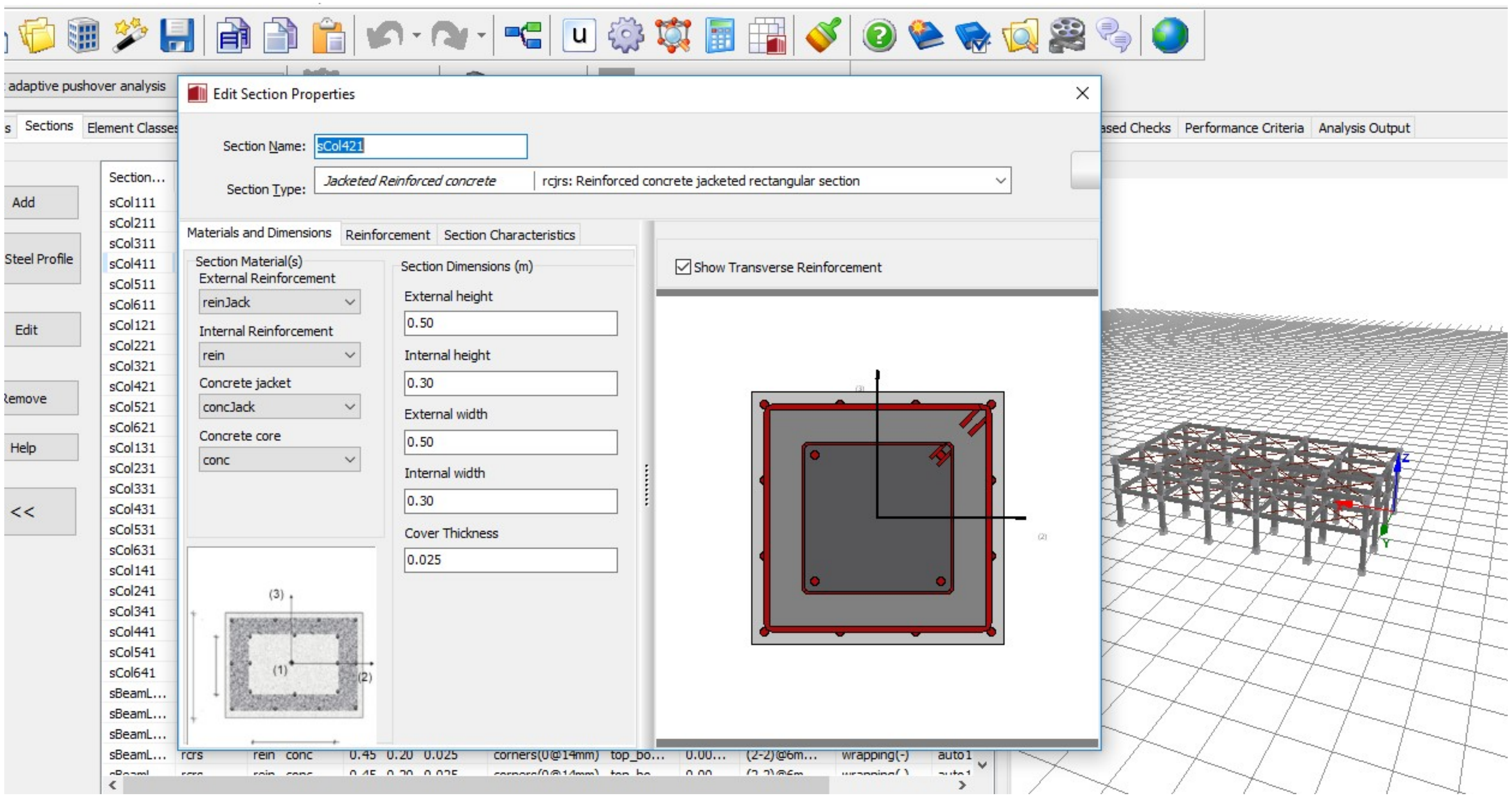
Properties of jackets	• Match with the concrete of the existing structure. • Compressive strength greater than that of the existing structures by 5 N/mm^2 or at least equal to that of the existing structure.
Minimum width of jacket	• 10 cm for concrete cast-in-place and 4 cm for shotcrete. • If possible, four-sided jacket should be used. • A monolithic behaviour of the composite column should be assured. • Narrow gap should be provided to prevent any possible increase in flexural capacity.
Minimum area of longitudinal reinforcement	• $3Af_y$, where, A is the area of contact in cm^2 and f_y is in kg/cm^2 • Spacing should not exceed six times of the width of the new elements (the jacket in the case) up to the limit of 60 cm. • Percentage of steel in the jacket with respect to the jacket area should be limited between 0.015and 0.04. • At least, 12 mm bar should be used at every corner for a four sided jacket.
Minimum area of transverse reinforcement	• Designed and spaced as per earthquake design practice. • Minimum bar diameter used for ties is not less than 10 mm or 1/3 of the diameter of the biggest longitudinal bar. • The ties should have 135-degree hooks with 10bar diameter anchorage.

Percentage of steel in the jacket between 0.015and 0.04 of jacket Area

Minimum width of jacket 10 cm for concrete cast-in-place

Jacketing factor varies: 2R, 3R

results in 2 scenario of Retrofit Solution



New Concrete C30/35
New Steel A400

Capacity Curve of Retrofit Scenarios

Capacity Curves

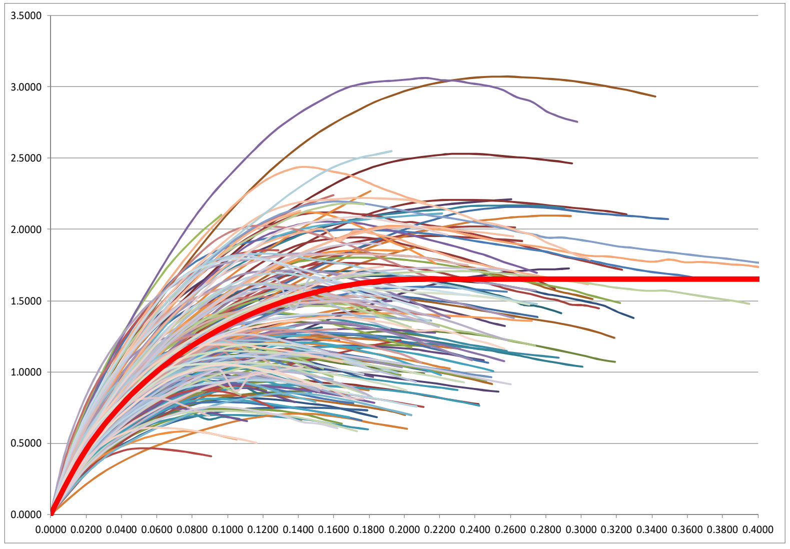
$$S(x,i) := \mathrm{if}\left(x \le Dy_i, \mathrm{if}\left(Dy = 0, 0, x \cdot \frac{Ay_i}{Dy_i}\right), \mathrm{if}\left(x \le Du_i, c_i \cdot \sin\left(\mathrm{acos}\left(\frac{x - Du_i}{a_i}\right)\right) + d_i, Au_i\right)\right)$$

Least Mean Square Root

[Ay,Dy], [Au,Du]

$Ay = Cs\,\gamma / \alpha$ $Dy = Ay\,Te^2 / (2\pi)^2$

$Au = \lambda\,Ay$ $Du = \lambda\,\mu\,Dy$

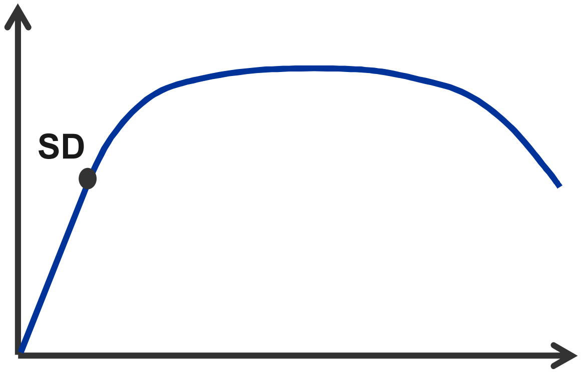


$$P_D\left(D \ge d \,|\, Sd\right) = \Phi\left[\frac{1}{\beta_d}\ln\left(\frac{Sd}{\overline{Sd}_d}\right)\right]$$

$$\overline{Sd}_d = \delta_d \cdot \alpha_2 \cdot h$$

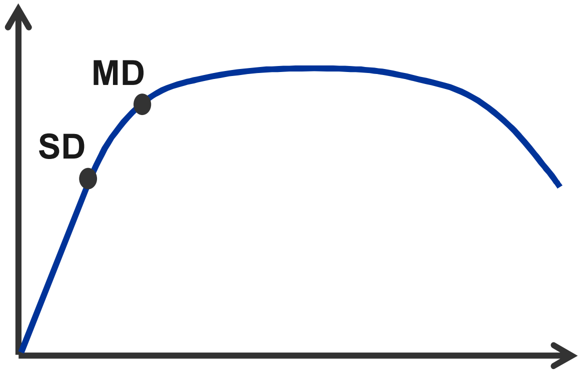
Defining the Limit States

- Limit States Maximum global drift
  - **Slight Damage (SD)**
    - The structure is only slightly damaged and economic to repair
    - 50% of Maximum Base Shear is achieved



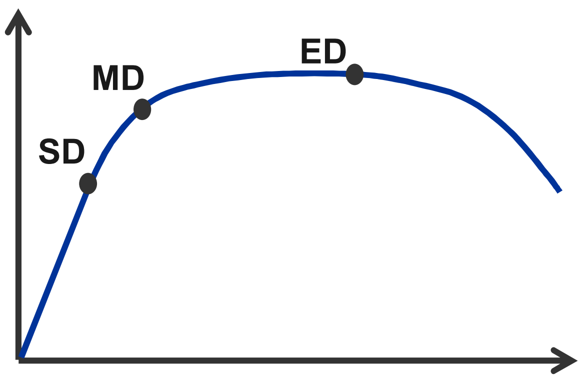
Defining the Limit States

- Limit States
  - **Slight Damage (SD)**
    - The structure is only slightly damaged and economic to repair
    - 50% of Maximum Base Shear is achieved
  - **Moderate Damage (MD)**
    - The structure is moderately damaged
    - 75% of Maximum Base Shear is achieved



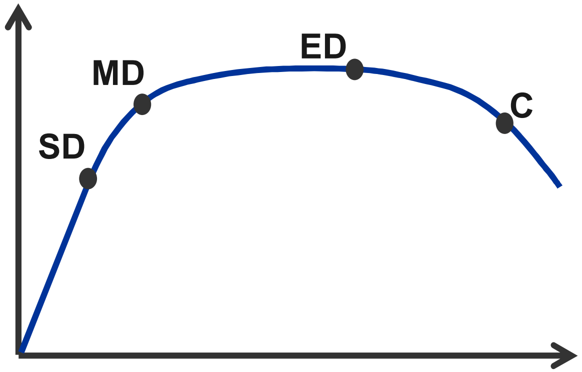
Defining the Limit States

- Limit States
  - **Extensive Damage (ED)**
    - The structure is significantly damaged
    - 100% (Maximum) Base Shear is achieved

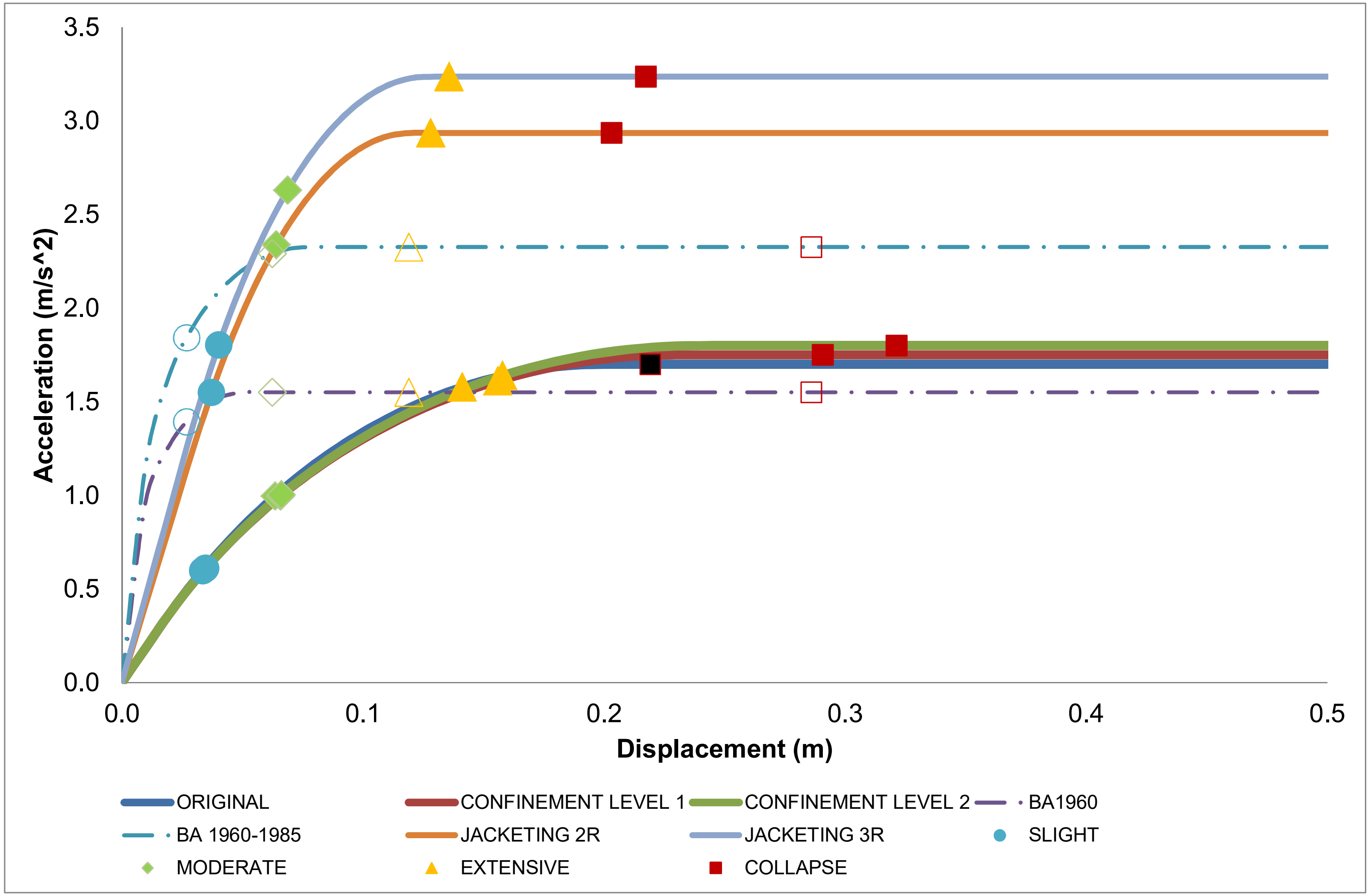


Defining the Limit States

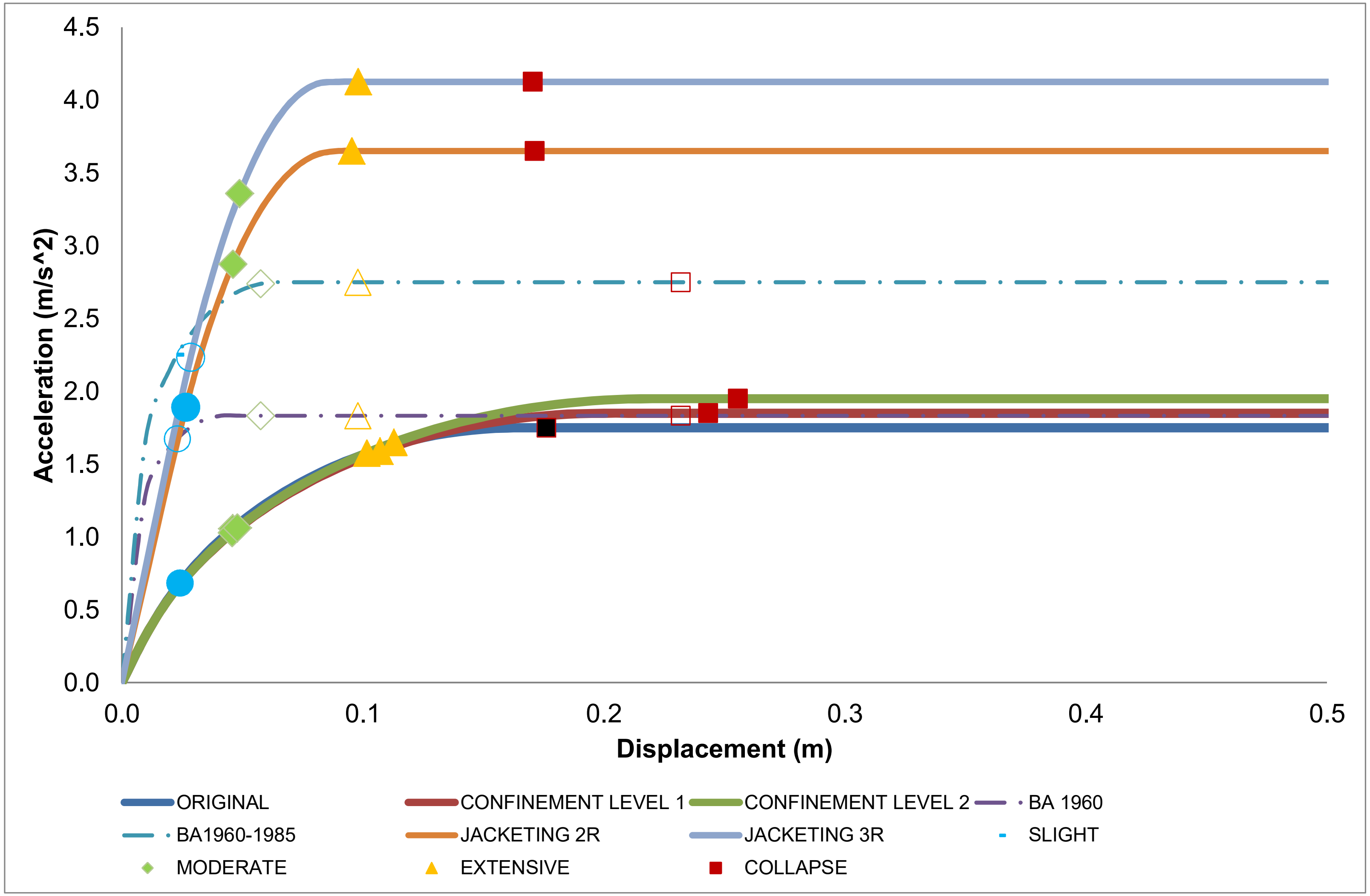
- Limit States
  - **Extensive Damage (ED)**
    - The structure is significantly damaged
    - 100% (Maximum) Base Shear is achieved
  - **Collapse (C)**
    - The structure is completely damaged
    - 80% of Max Base Shear is achieved



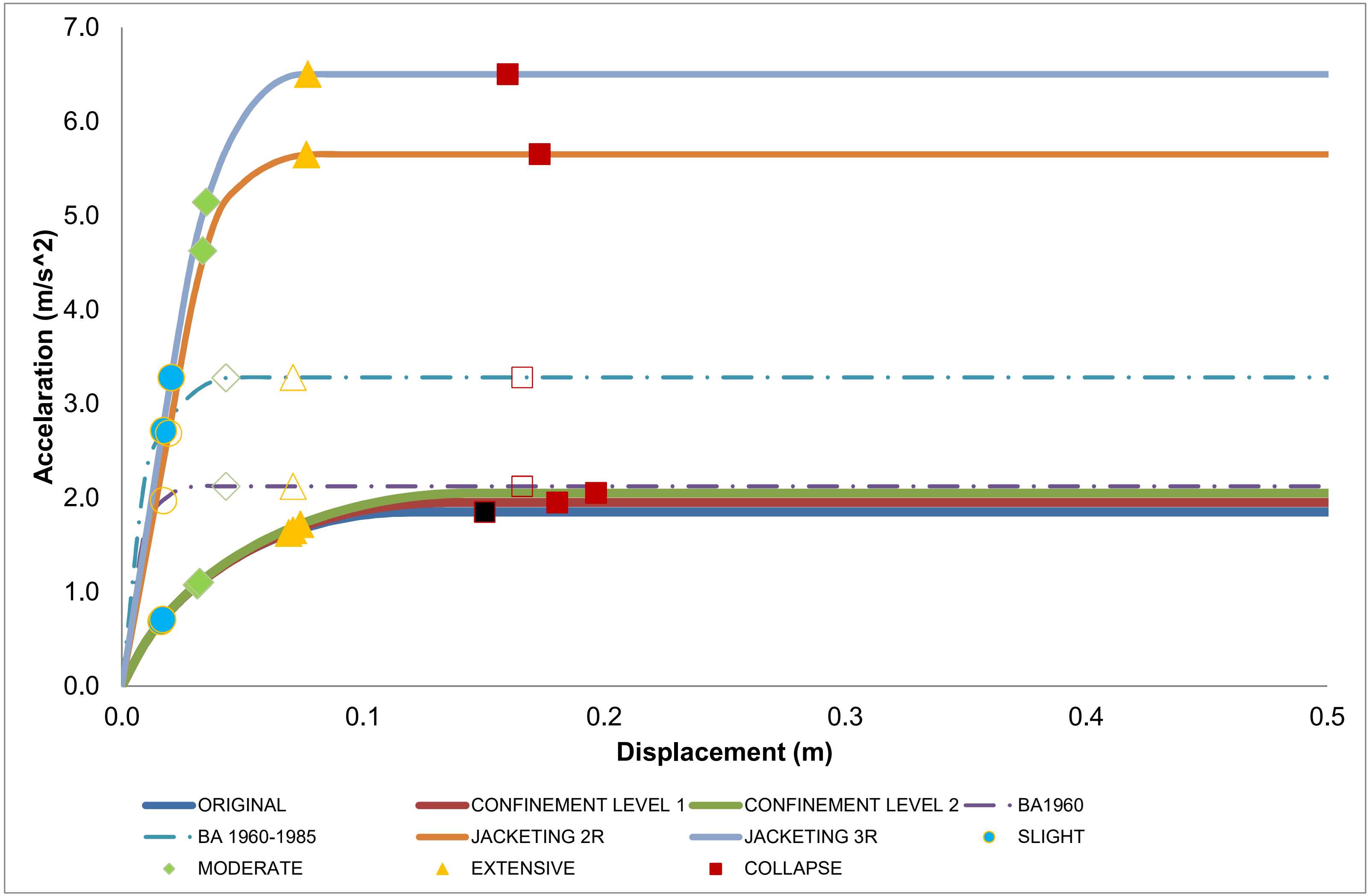
Capacity Curves – 4storeys buildings



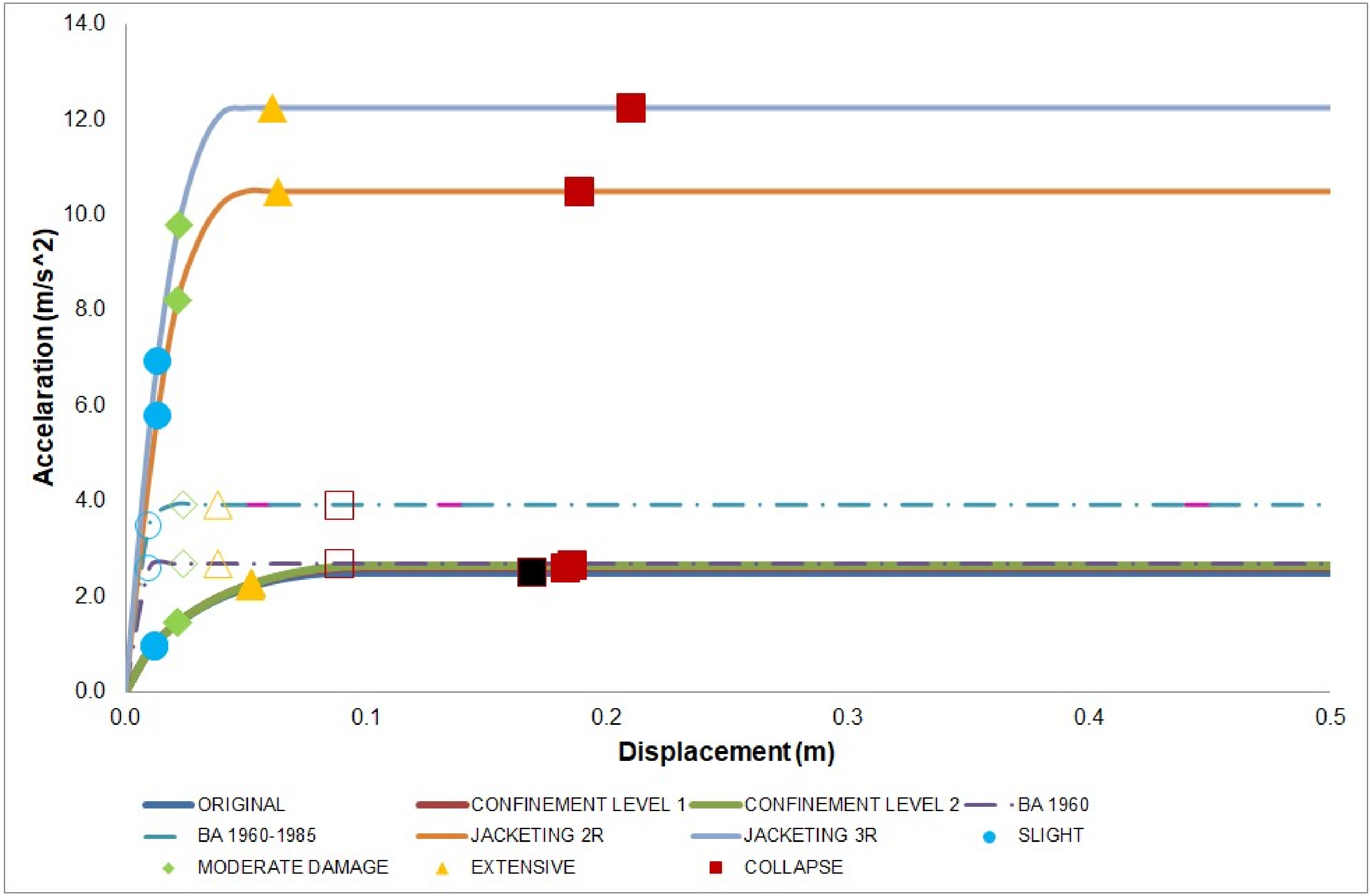
Capacity Curves – 3storeys buildings



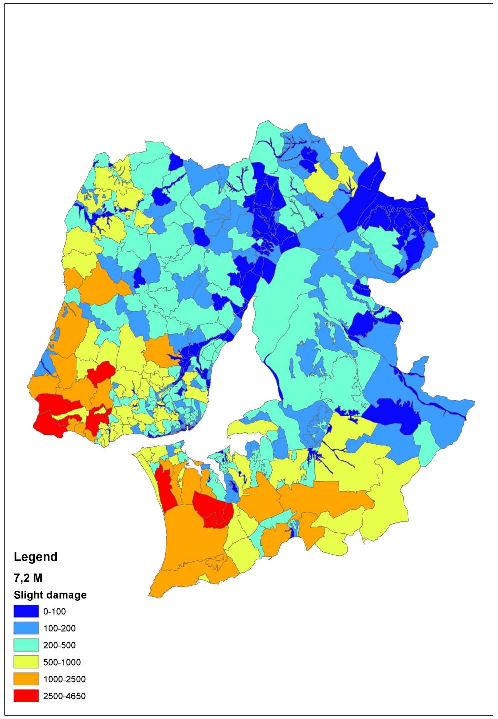
Capacity Curves – 2storeys buildings

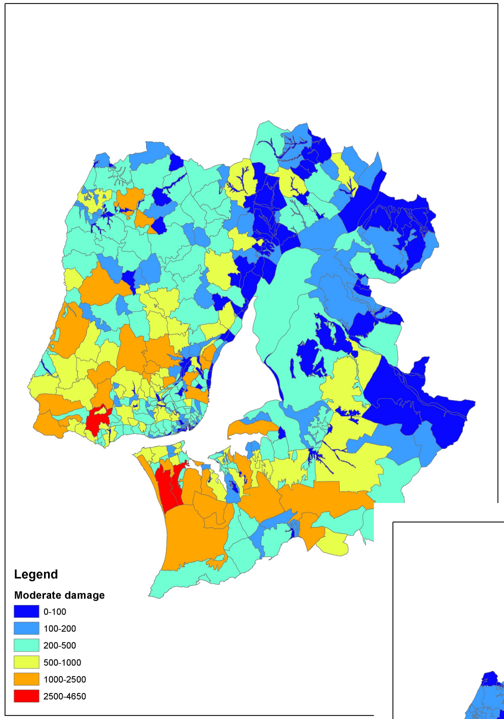


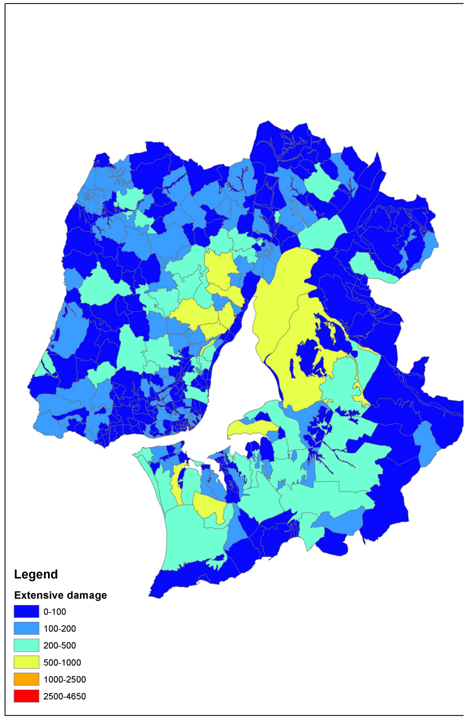
Capacity Curves – 1storey buildings

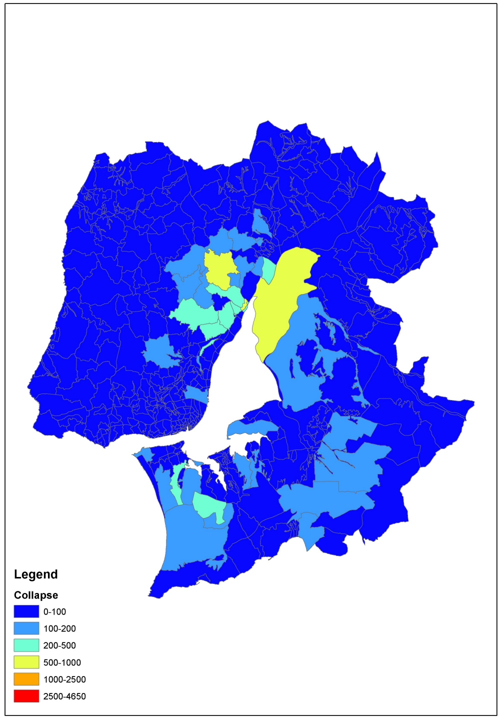


Limit States for No Confinement 7.2M Vale inf Tejo









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Hazard: Seismic input Identification

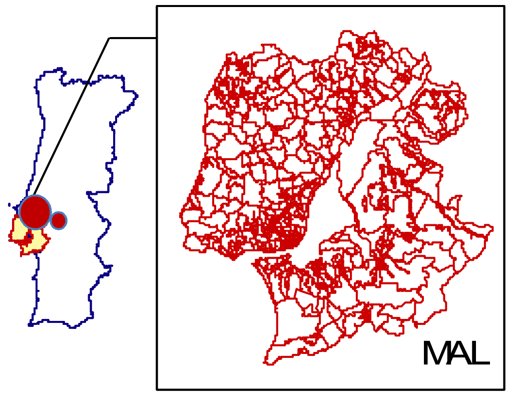
Scenario of Earthquake

Inland			
Name	**M**	**X**	**Y**
Vale inf Tejo	6	124743.00	220791.00
Vale inf Tejo	6,9	124743.00	220791.00
Vale inf Tejo	7,2	124743.00	220791.00
Benavento	6.9	140348.00	220658.00
offshore			
Name	**M**	**X**	**Y**
1755 Earthquake	8.5	-10814.0	-6607.0

Return period

Inland		Offshore	
Return Period	**M**	**Return Period**	**M**
40	5.5	100	7
100	6	300	7.5
200	6.5	475	7.7
475	6.7	600	8
975	6.9	975	8.2
1300	7	2800	8.5
5000	7.2	5000	8.7

Sc1_1	8,5M 1755
Sc2_1	6M Vale inf Tejo
Sc2_2	7,2M Vale inf Tejo
Sc2_5	6,9M Benavente
Sc2_6	6,9M Vale inf Tejo



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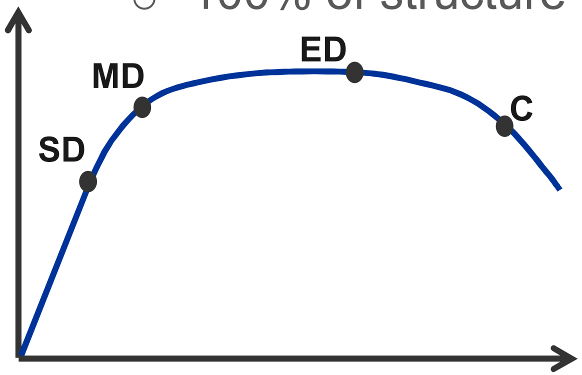
Defining the Loss Area

- **Slight Damage (SD)**
  - 2% of structure is slightly damaged
- **Moderate (MD)**
  - 10% of structure is damaged
- **Extensive Damage (ED)**
  - 50% of structure is significantly damaged
- **Collapse (C)**
  - 100% of structure is completely damaged

Damage states	Loss Ratio
Slight	2%
Moderate	10%
Extensive	50%
Collapse	100%



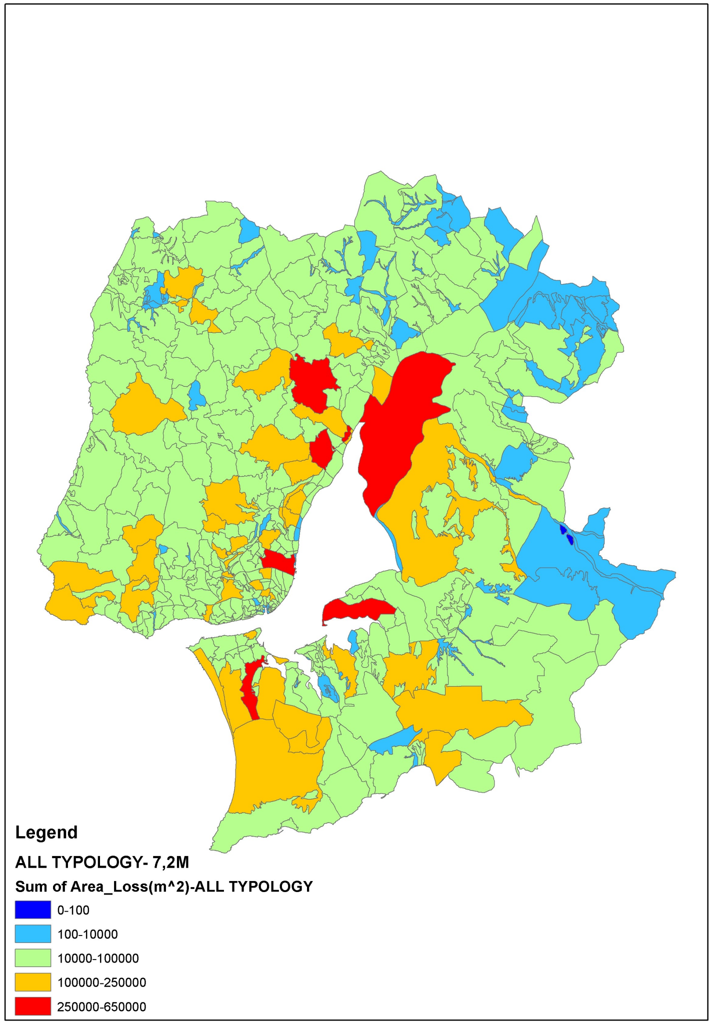
Vulnerability Classification

Vulnerability Classification	Sum of Area_total_m2
Masonry	67,414,361
RC Medium Ductility	66,564,130
RC Non ductil - low rise	64,408,564
RC Non ductil - med/high rise	36,580,119
Grand Total	234,967,173

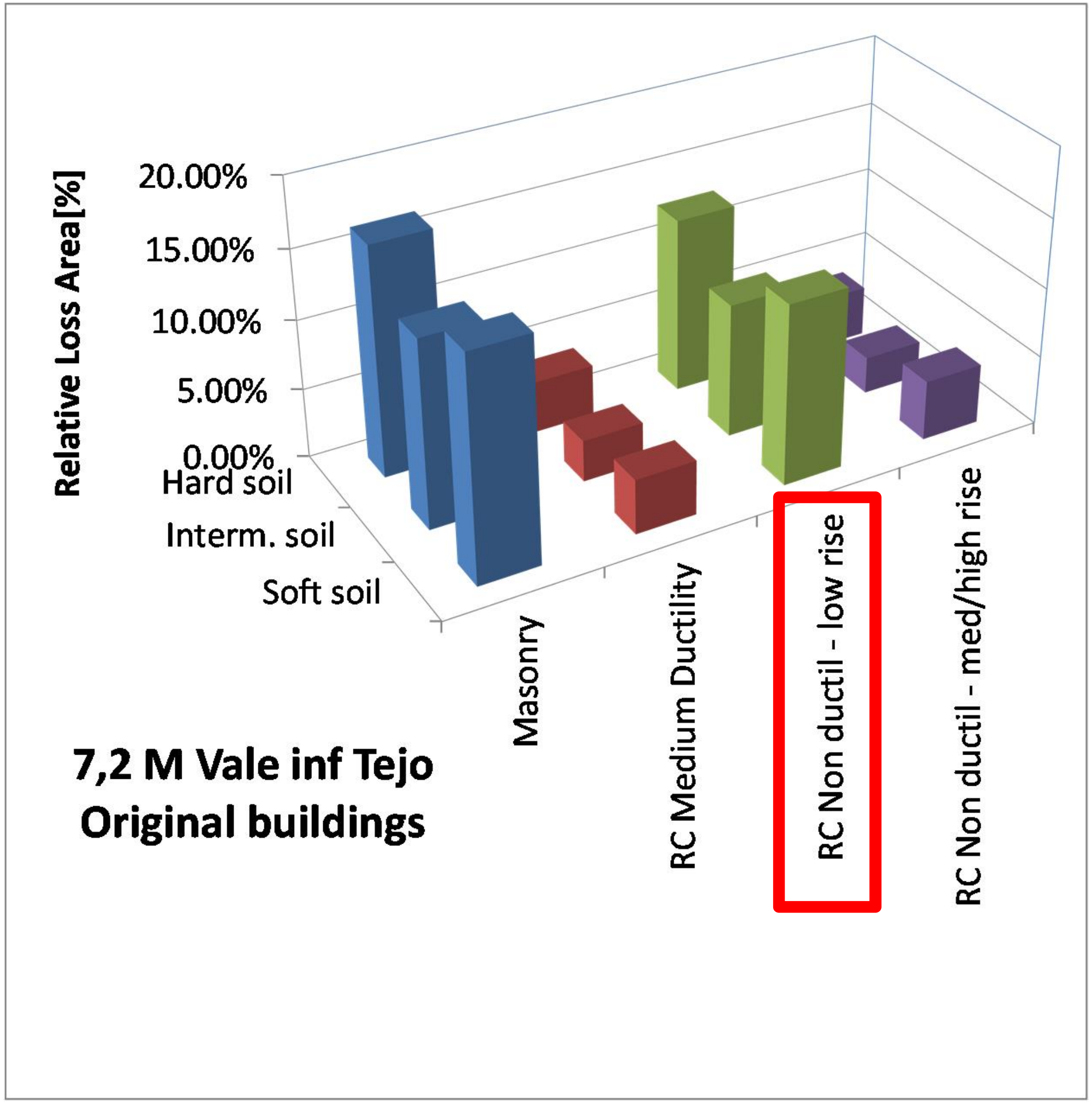
Vulnerability Classification	7,2 M - Lower Vale de Tejo			
	OldLNECLoss			
	Sum of Loss(m^2)			
	Hard soil	Interm. soil	Soft soil	Grand Total
Masonry	493,928	626,298	307,217	1,427,443
RC Medium Ductility	94,772	141,071	66,671	302,513
RC Non ductil - low rise	43,255	81,748	23,711	148,714
RC Non ductil - med/high rise	43,773	38,405	31,871	114,050
Grand Total	675,728	887,522	429,469	1,992,720

Importance of case study: Example of results

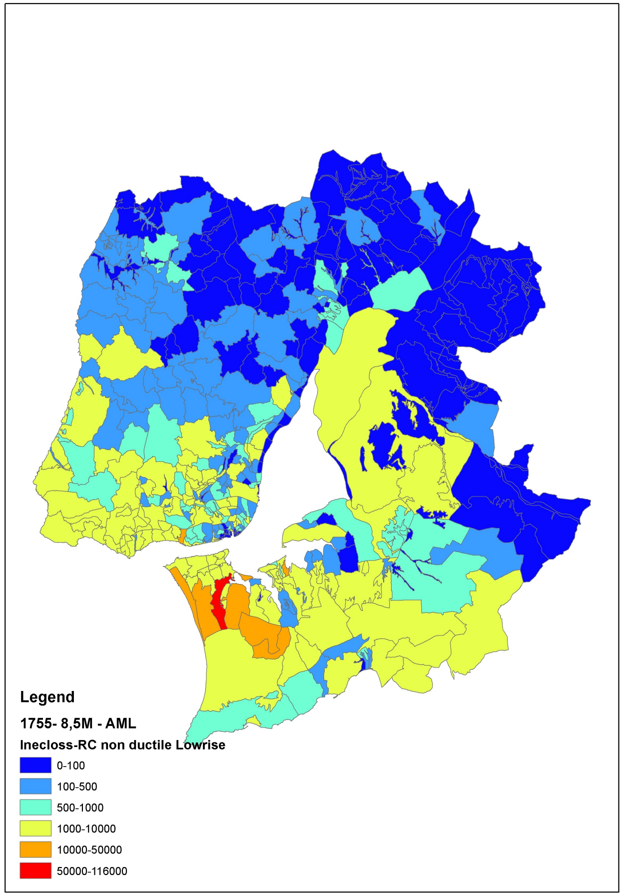
- Total Damaged Area
  - 7,2M Vale inf Tejo
  - No Confinement
    [Original buildings]
  - All typologies



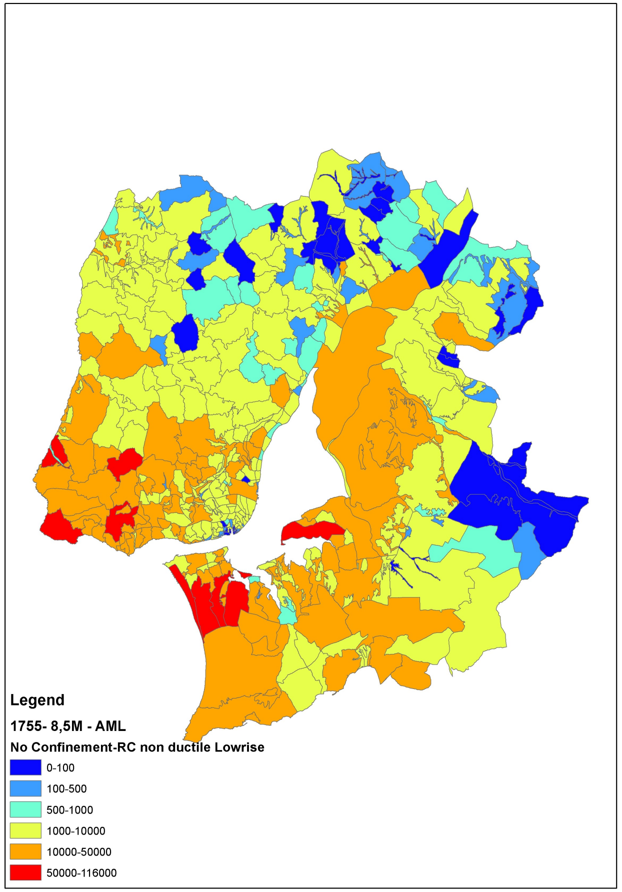
Importance of case study: Example of results



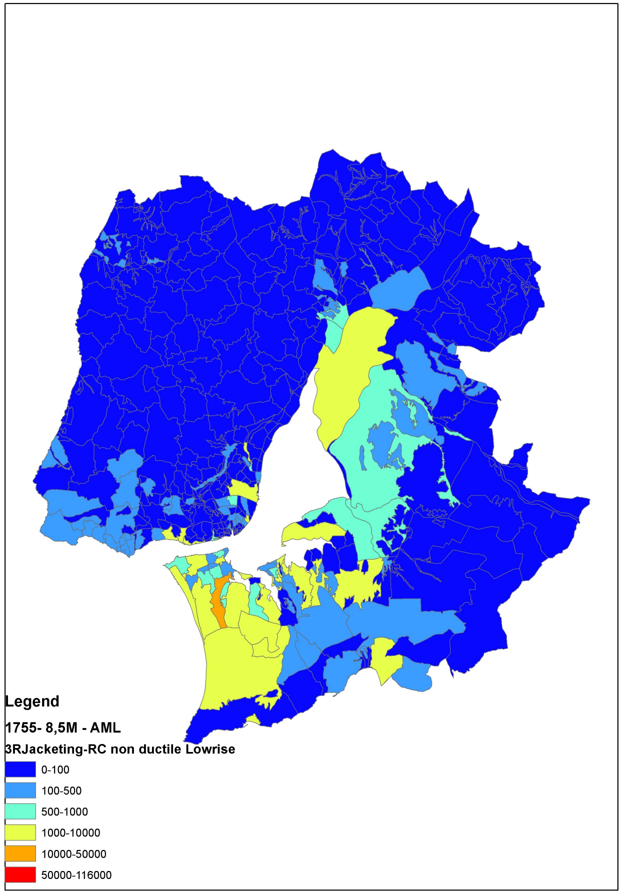
Damaged Area (m^2) for Case Study
8.5M 1755



Old Lnecloss
No confinemnet

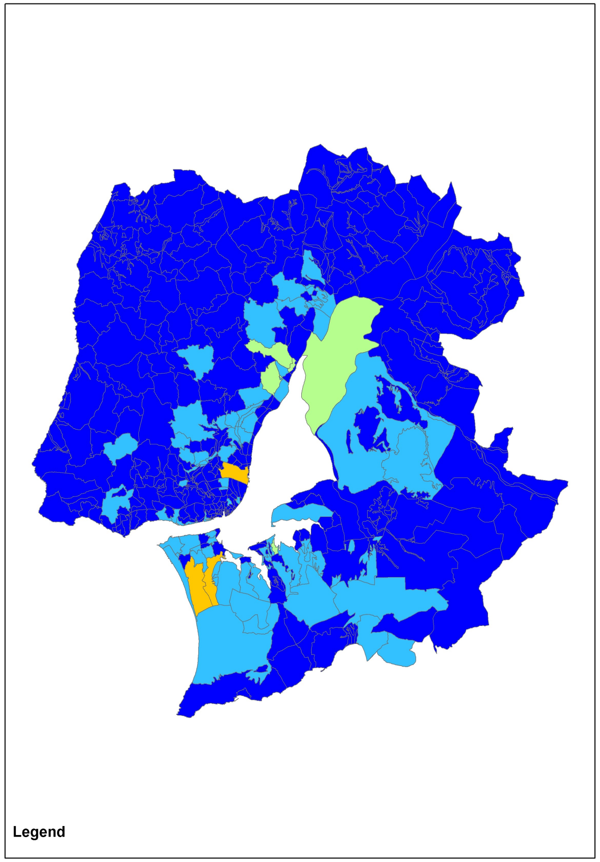


Present study
No Confinement

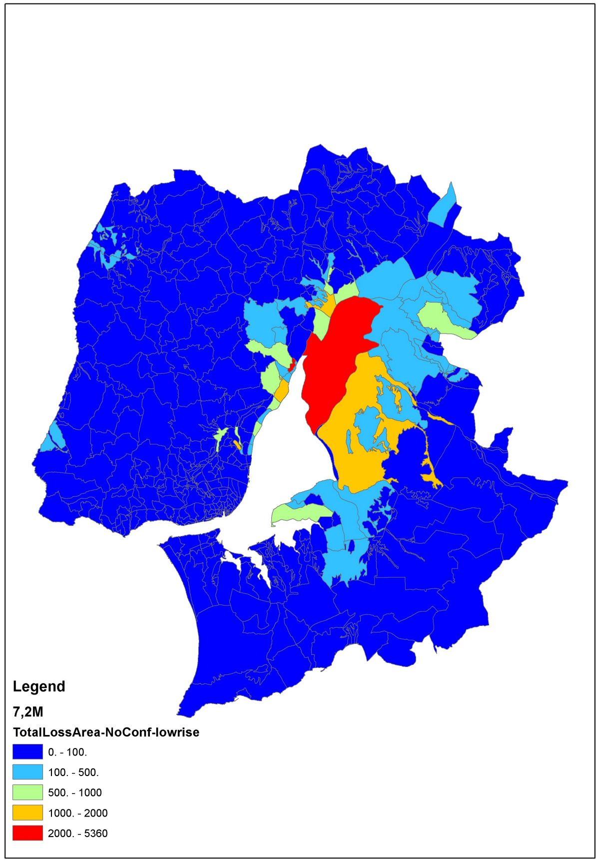


Jacketing 3R

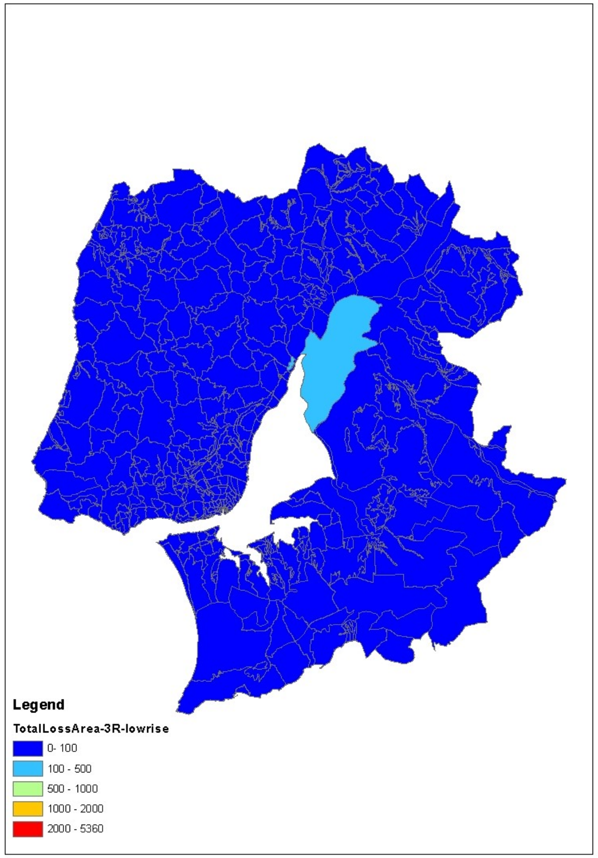
Damaged Area (m^2) for Case Study
6,0M Vale inf Tejo



Old Lnecloss
No confinemnet

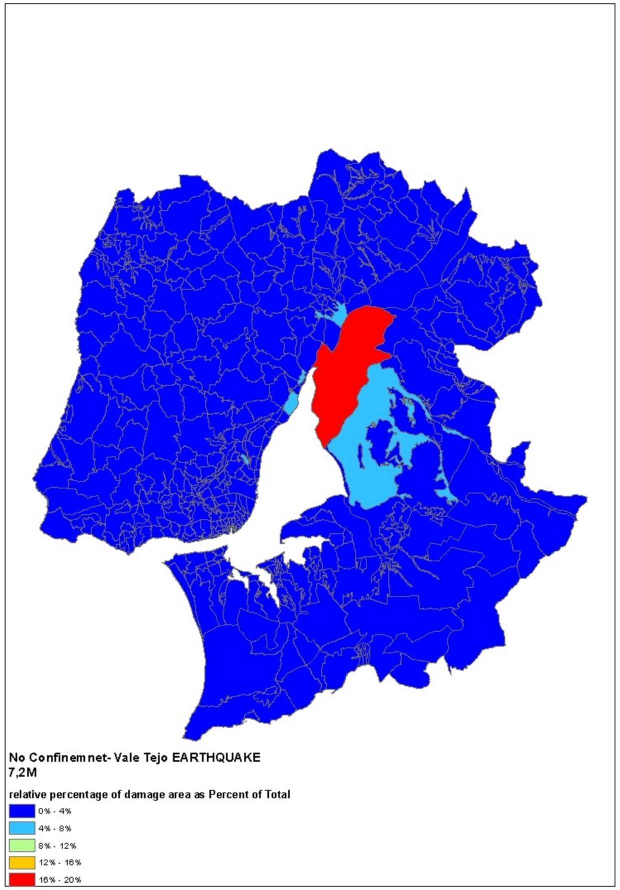


Present study
No Confinement

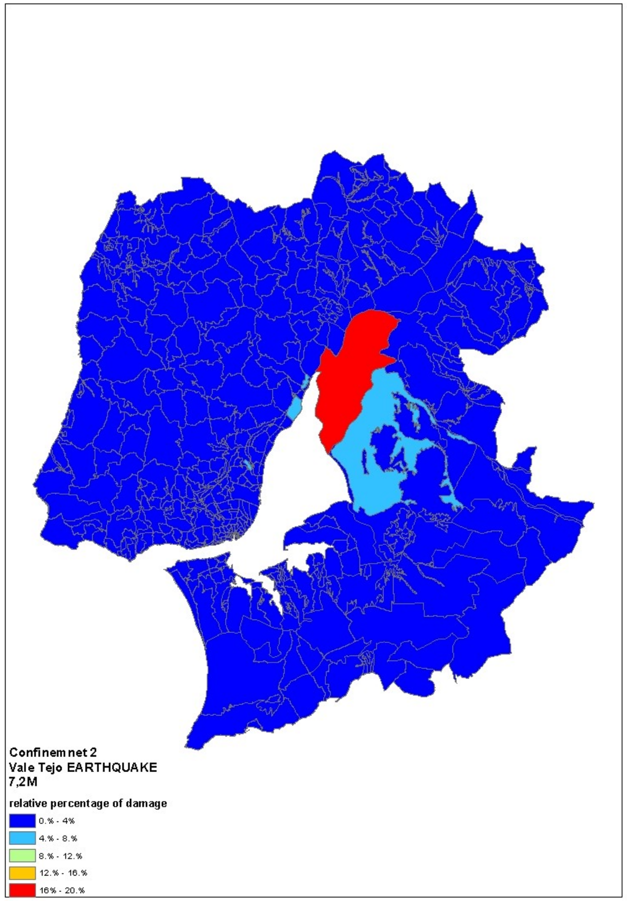


Jacketing 3R

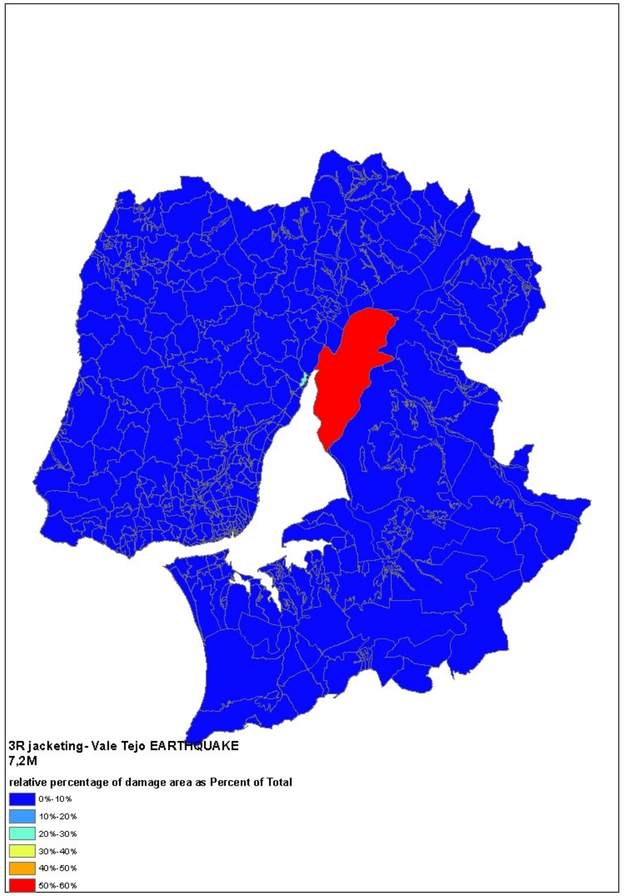
Relative contribution to Damaged Area
Different Retrofit Strategies, 7,2M Vale inf Tejo



No Confinement

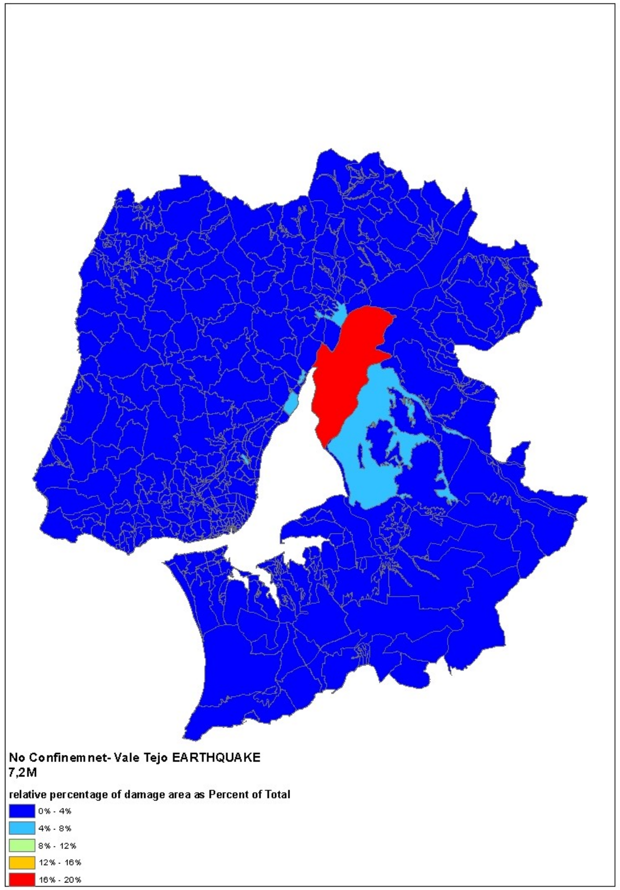


Confinement 2

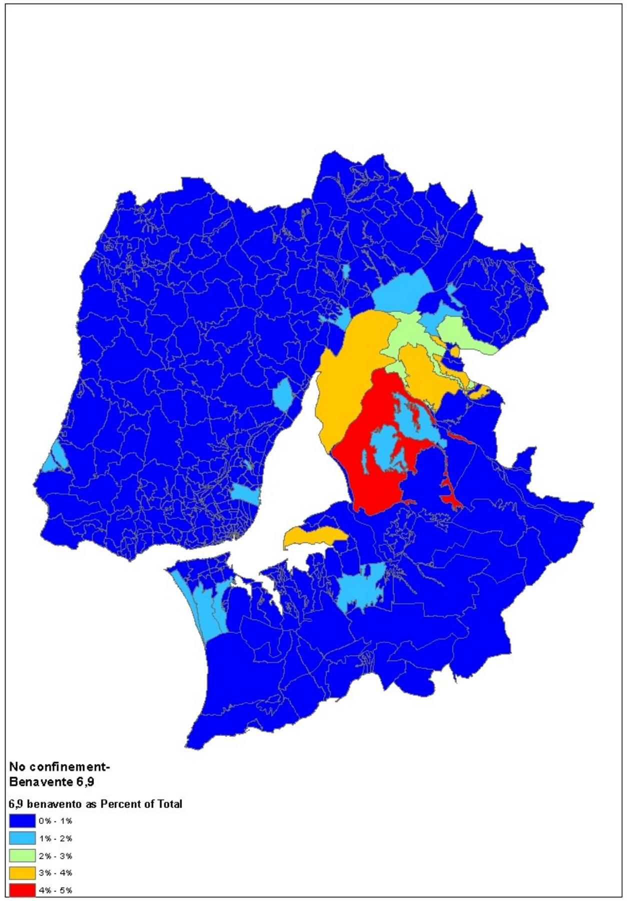


Jacketing 3R

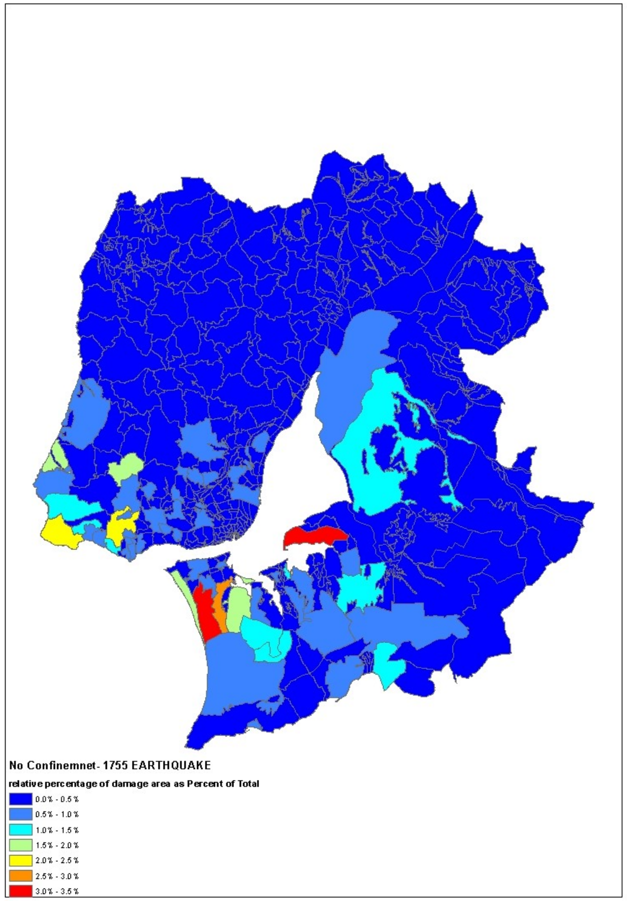
Relative contribution to Damage Area
Different Earthquake Scenarios



Vale de Tejo 7,2M

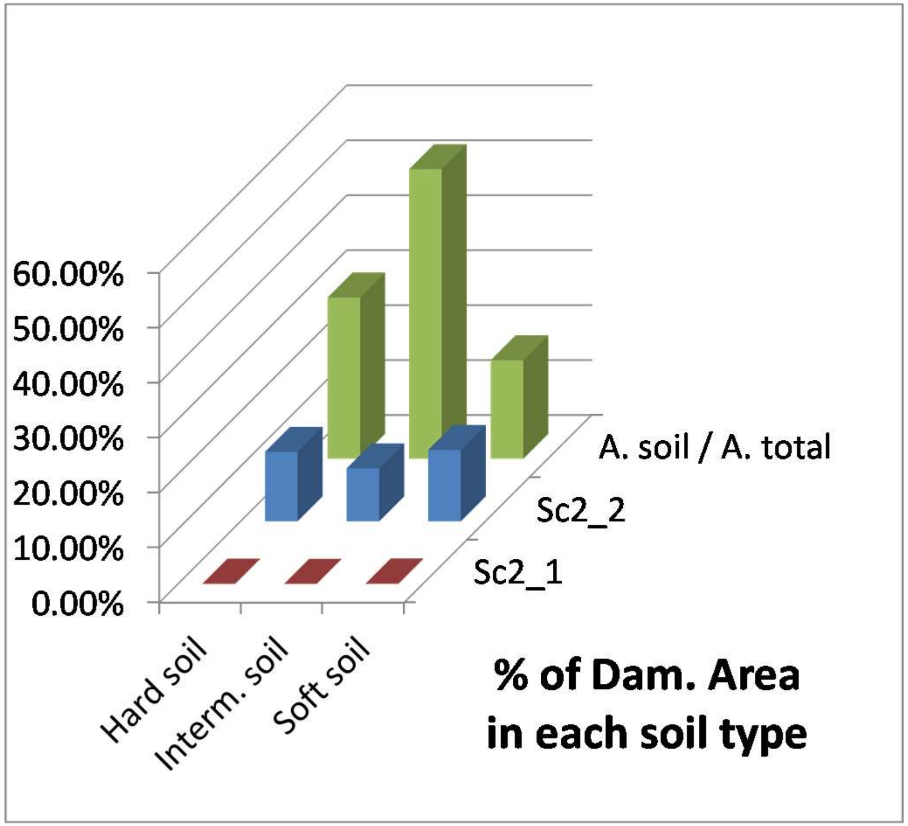


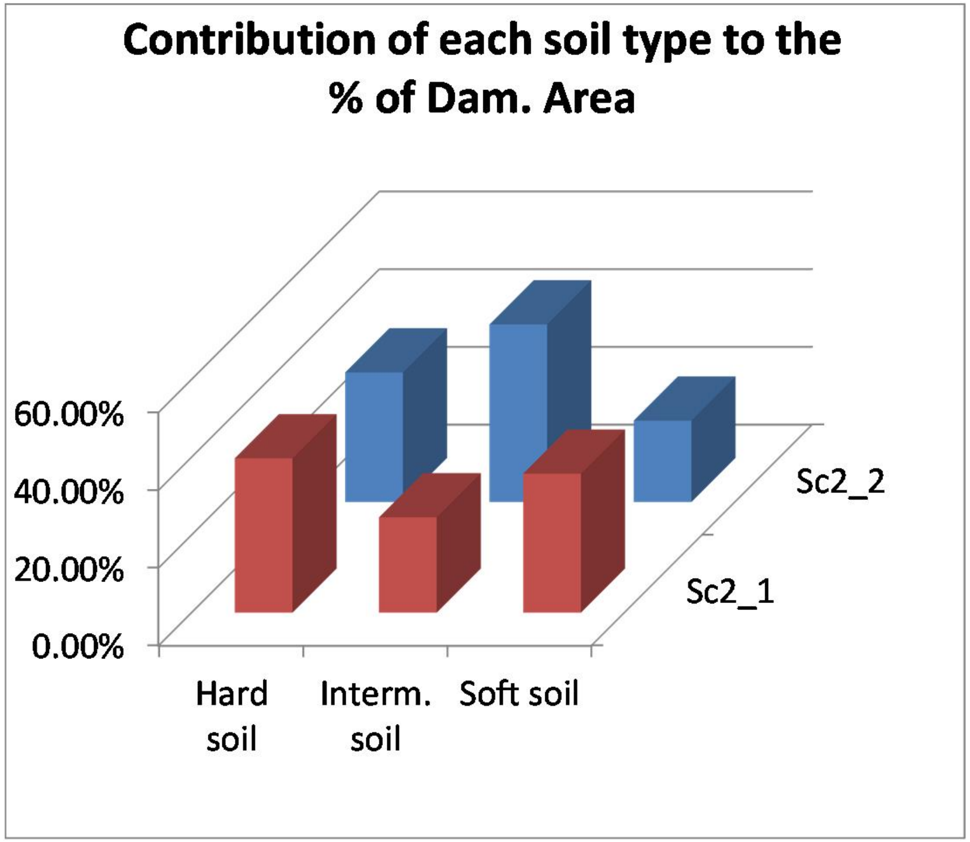
Benavento 6,9M



1755 – 8,5M

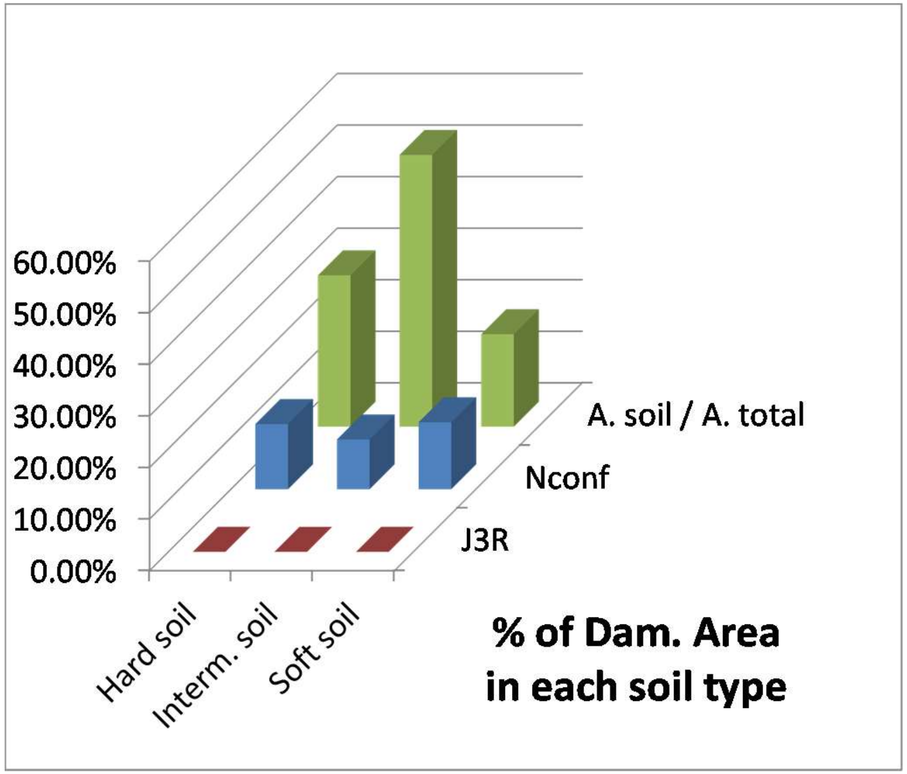
Damaged area vs. Soil type vs. Scenario
6,0M vs. 7,2M Vale inf Tejo for No Confinement

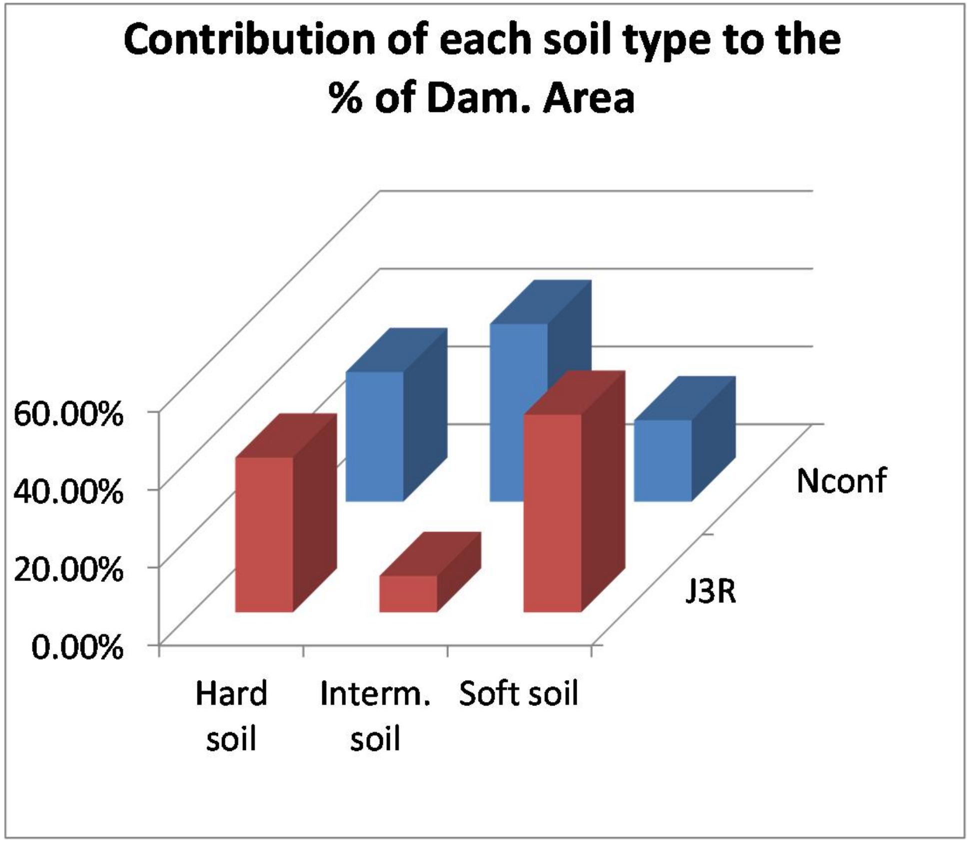




Damaged area vs. Soil type vs. Retrofit Strategy

No Confinement vs. RC Jacketing 3 for 7,2M Vale inf Tejo



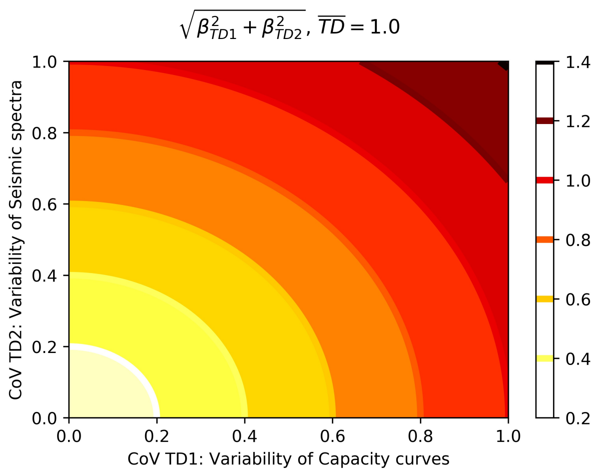


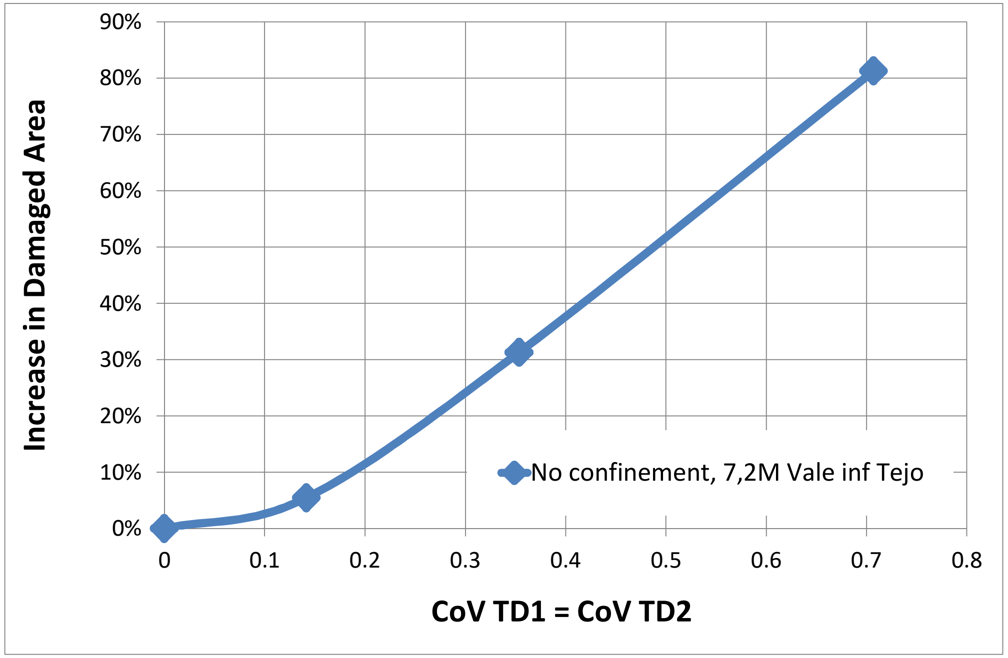
Uncertainty propagation example

- Uncertainty in the determination of Target Displacement
  - Contribution of Capacity Curves variability (TD1)
  - Contribution of Seismic Spectra variability (TD2)

Standard deviation (β) of TD, assuming LOGNORMAL Distributions for both variables:

$$\beta_{TD} = \sqrt{{\beta_{TD1}}^2 + {\beta_{TD2}}^2}$$





Outline

- Background
- LNECLOSS+
- Retrofitting Solutions
- Scenarios of Earthquake
- Risk Mitigation
- **Future Development**

Future Development:

- Review the damage to cost function
  - Repair techniques for each limit states
  - Measuring cost of repair (direct/indirect)
  - To value the loss of properties
- Develop the cost model to related retrofit solutions
- Develop a model for benefits
- Cost benefit algorithm to find the suitable solution

Thank You for Your Attention