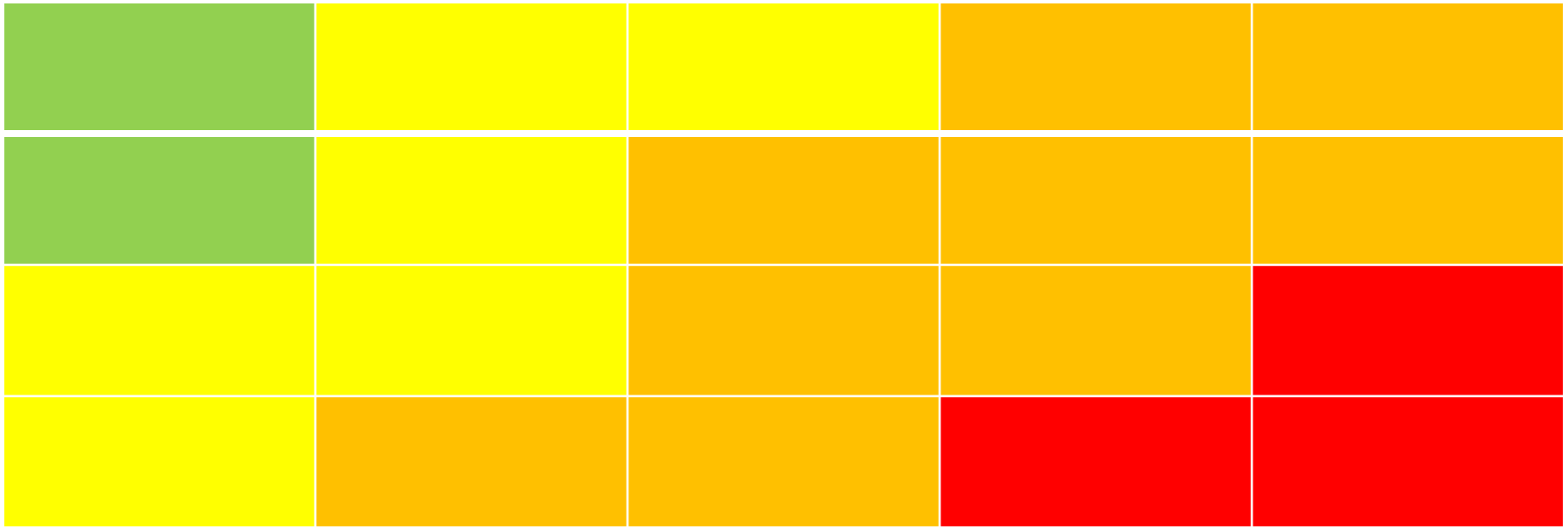
Seismic Risk Mitigation Strategies; Pre Code RC buildings

Sanam Moghimi



Outline

- Thesis Review
- Accomplished Tasks
- Cost Benefit Alternative

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- **Thesis Review**
- Accomplished Tasks
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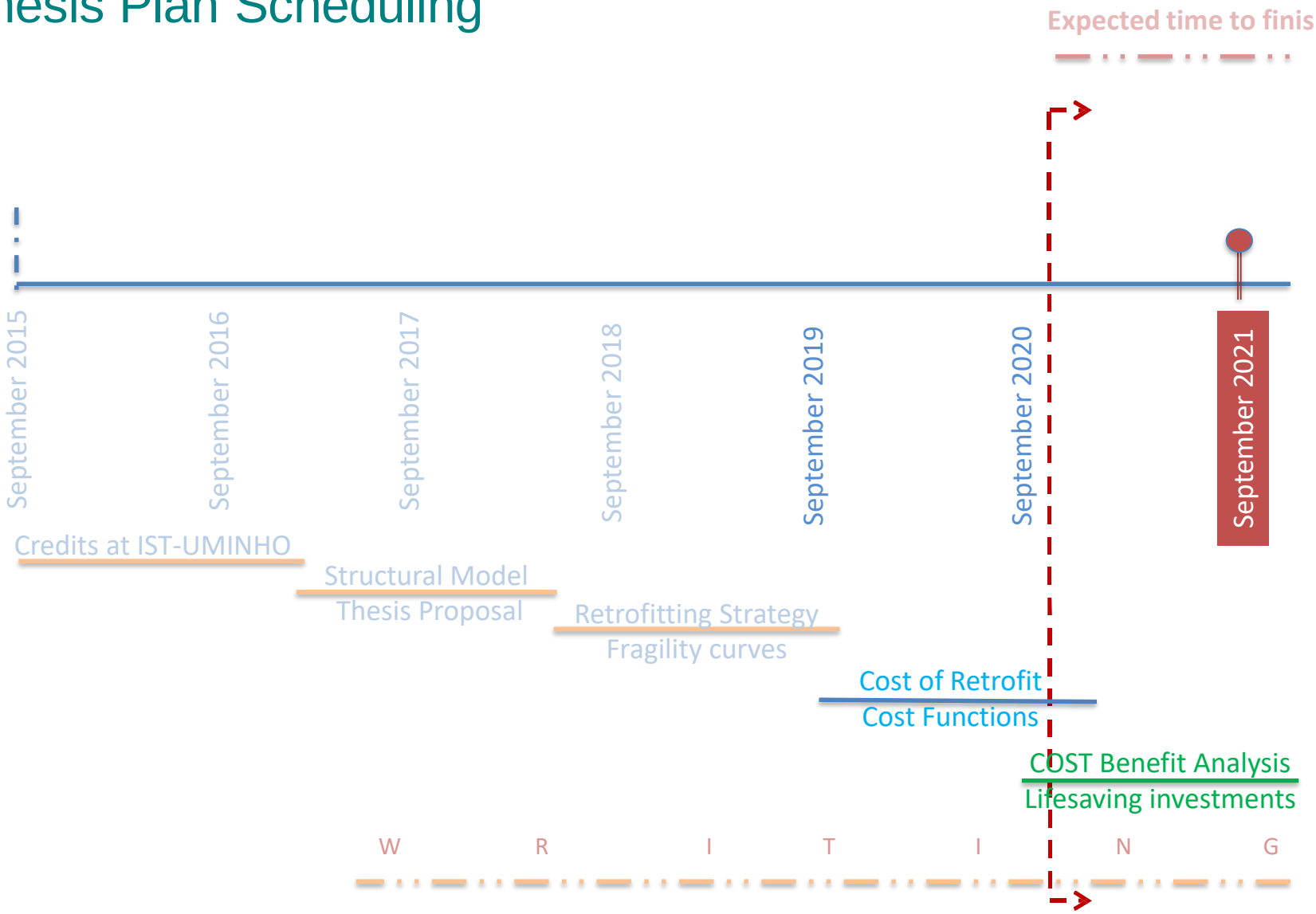
Thesis Plan Scheduling



Risk Assessment Platform

- LNECloss is a seismic scenario risk assessment platform, integrated on a Geographic Information System (GIS), which comprises modules dealing with bedrock input, local soil effects, vulnerability and fragility analysis, human and economic losses

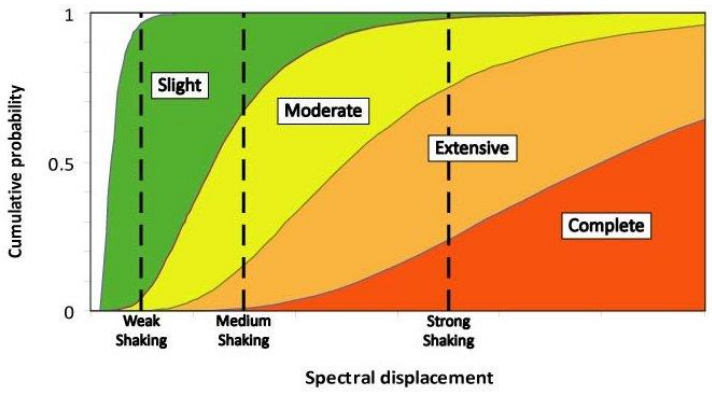
LNECloss Simulator

- Flexible tool
  - easy update
  - modular structure
  - integrated in a GIS

LNECLOSS Limitations

- Fragility curves
  - Implementation is based on HAZUS
  - Simplification of the “actual” damage progression in pre-seismic code buildings

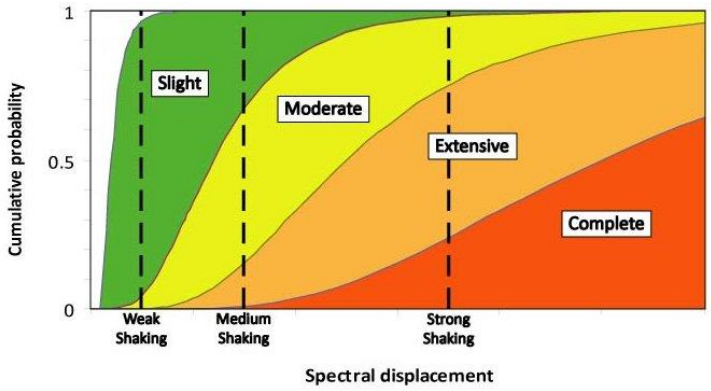
$$P_D\left(D \geq d \mid Sd\right) = \Phi\left[\frac{1}{\beta_d} \ln\left(\frac{Sd}{\langle Sd_d \rangle}\right)\right]$$

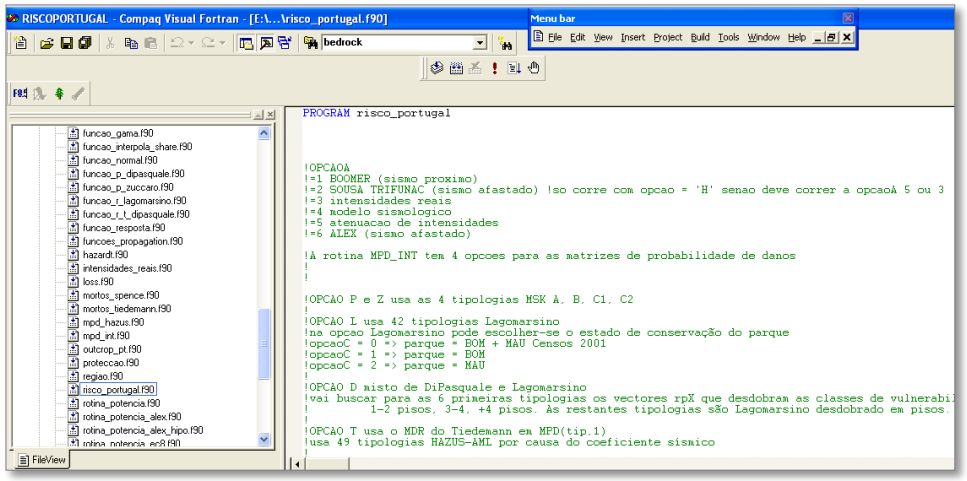


LNECLOSS Limitations

- Fragility curves
  - Implementation is based on HAZUS
  - Simplification of the “actual” damage progression in pre-seismic code buildings
- Mitigation strategies
  - Conceptual assessment of mitigation strategies

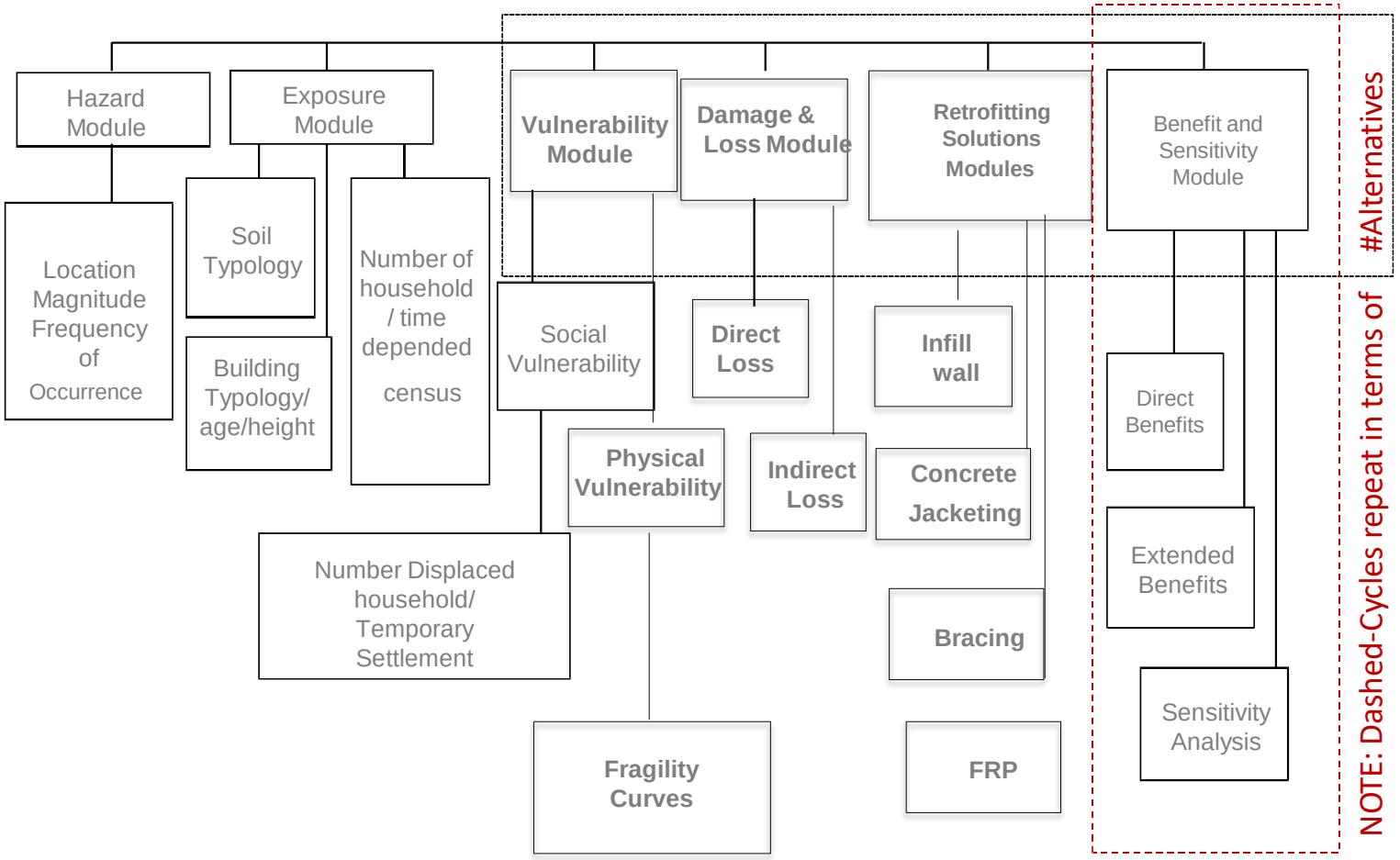
$$P_D\left(D \geq d \mid Sd\right) = \Phi\left[\frac{1}{\beta_d}\ln\left(\frac{Sd}{\langle Sd_d \rangle}\right)\right]$$





# Streng	Masonry	RC	Improvement of force capacity		Improvement of ductile capacity.
			λ	γ	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%

Mitigation Framework; Cost Effectiveness Analysis



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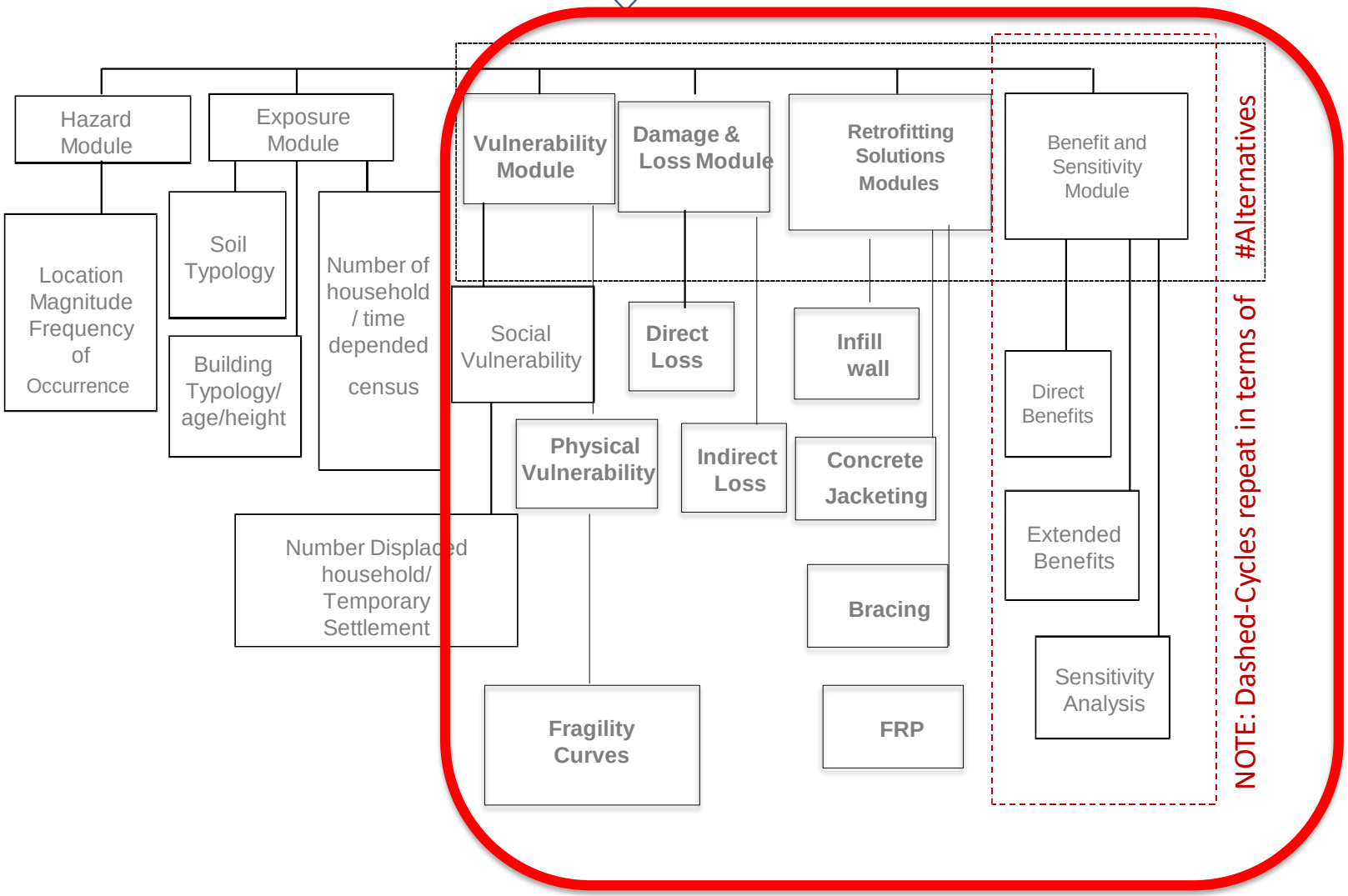
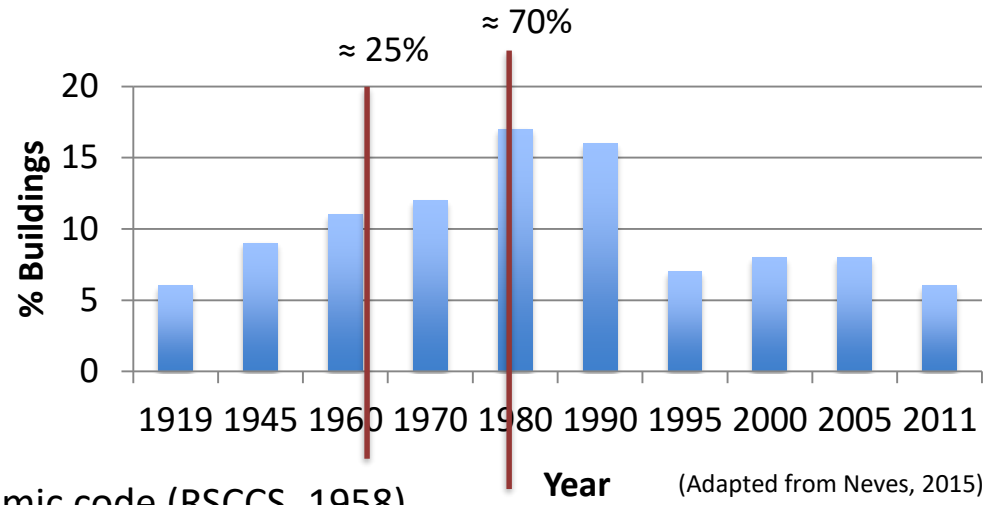


Case Study Building Stock

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

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



(Adapted from Neves, 2015)

1st Seismic code (RSCCS, 1958)

Seismic code in force (RSA, 1983)

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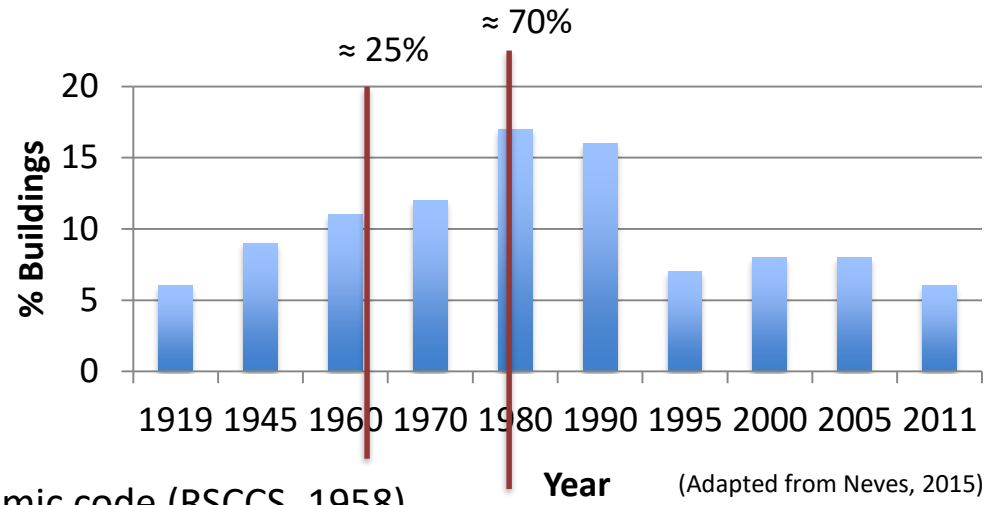


Vulnerability and inventory definition

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

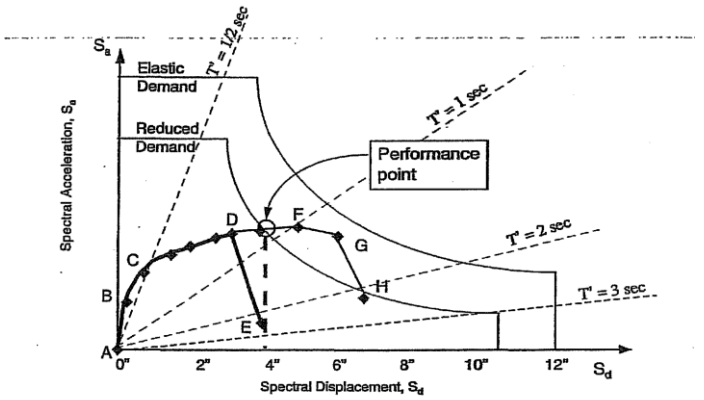
Variables of material and geometry properties

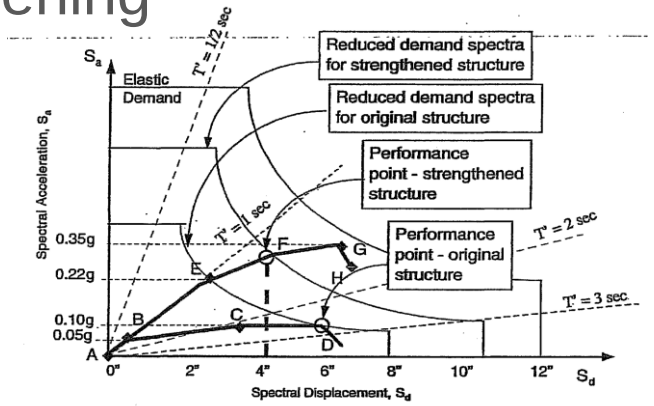
Existing buildings

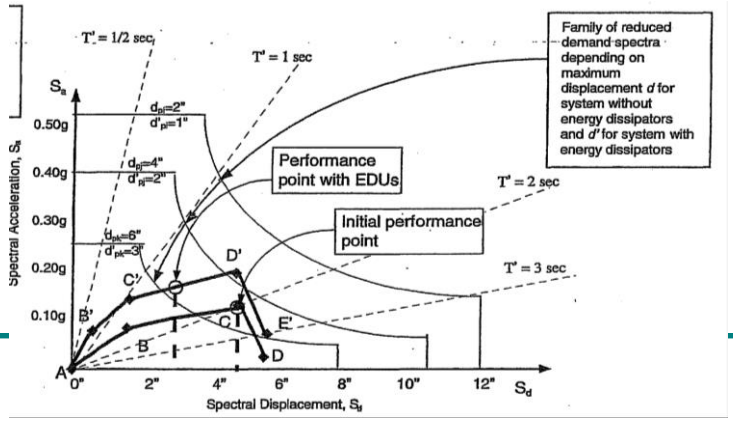
Variáveis	Média	CV (%)	A	B	Referência
G (kN/m^2)	8	12.5	6	10	Sousa *et al*., 2016
N° pisos	1/2/3/4	28/42/15/15	-	-	Censos, 2011
H_1	3.2	10	2.5	5	Silva *et al*., 2014
H_n	2.8	6	2.5	4	
$L_{X/Y}$ (m)	4.4	16	2.5	6.5	Furtado *et al*., 2015
h_{laje} (m)	0.23	24	0.1	0.35	
f_{cm} (MPa)	23.8	49	5.0	80.0	Silva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

Seismic risk mitigation strategies

- Enhancing deformation capacity
  - FRP and steel jacketing
- System strengthening and stiffening
  - RC jacketing
  - Bracing
  - Reinforcing infill walls
- Reducing earthquake demand
  - Base isolation
  - Energy dissipation







Seismic risk mitigation strategies

- **Enhancing deformation capacity**
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- **System strengthening and stiffening**
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  - Bracing
  - Reinforcing infill walls
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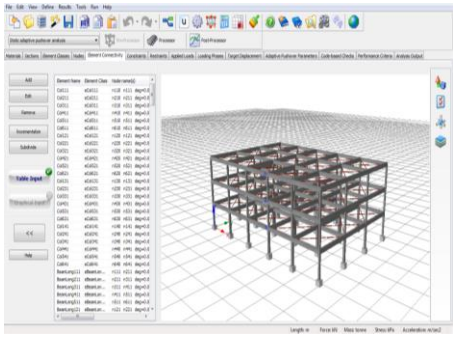
What I’ve done

- Seismostruct modeling 200 buildings in each direction of X and Y

- Pushover analysis and Fragility curves



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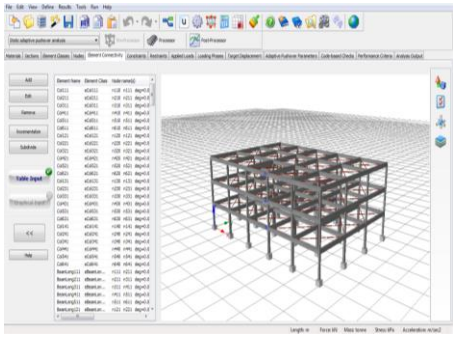
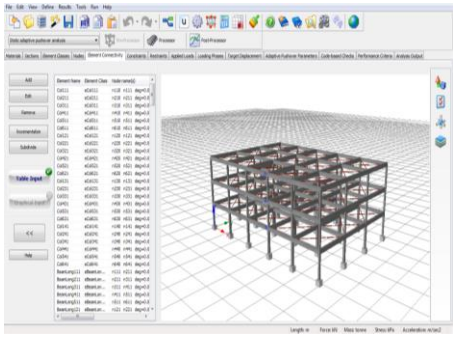


- Seismostruct modeling 200 buildings in each direction of X and Y
- Pushover analysis and Fragility curves
- Comparison of results with original LNECLOSS
  - Retrofitting solution :
    - ❑ RC Jacketing 2 level of reinforcement
    - ❑ Steel Jacketing 2 level of Confinement
    - ❑ FRP 2 level of reinforcement
    - ❑ Bracing 3 level of reinforcement
    - ❑ Infill Walls with shotcreet

What I’ve done



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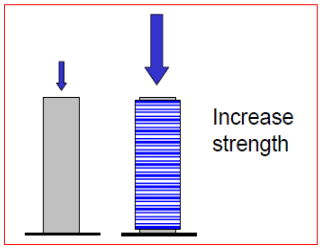
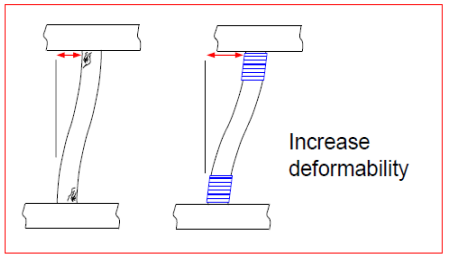
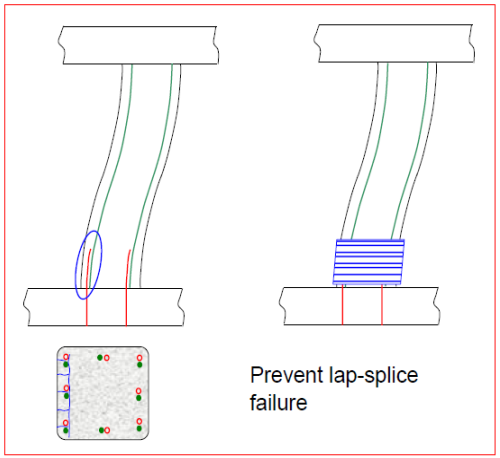
    - ❑ FRP 2 level of reinforcement
    - ❑ Bracing 3 level of reinforcement
    - ❑ **Infill Walls with shotcreet**

Retrofit Solution

Steel/FRP Jacketing
Considering Confinement







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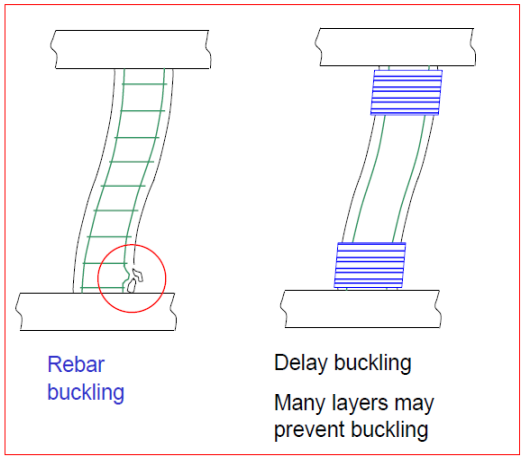
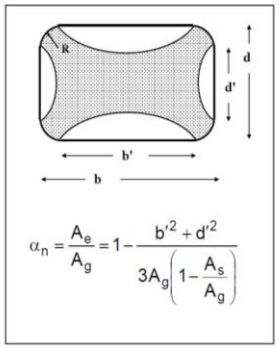
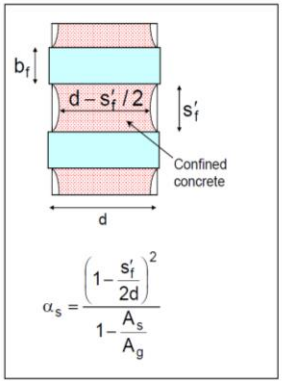


Effectiveness Confinement

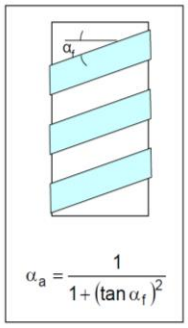
$$\alpha_f = \alpha_n \times \alpha_s \times \alpha_a \le 1$$



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



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



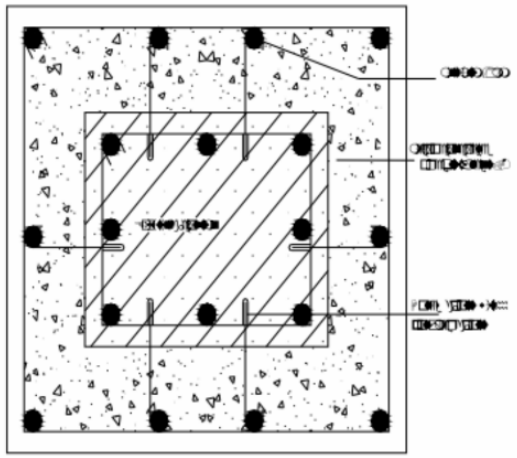
$$\alpha_a = \frac{1}{1 + (\tan\alpha_f)^2}$$

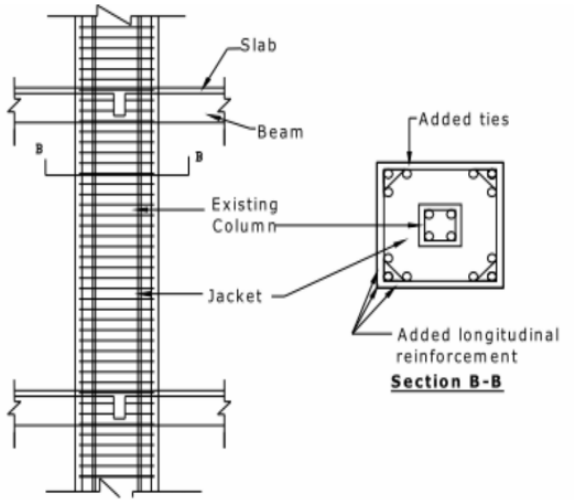
Confinement factor varies: 1.50 , 2.00

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

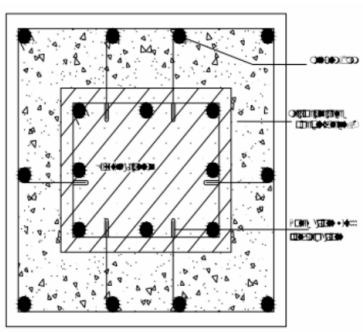
Minimum width of jacket 10 cm for concrete cast-in-place

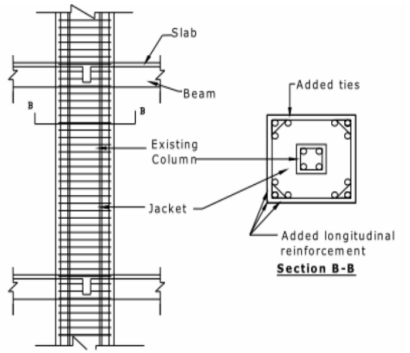
Jacketing factor varies: 2R, 3R

results in 2 scenario of Retrofit Solution

System strengthening and stiffening : RC jacketing of columns

- Overview of strategy
  - New concrete
    - Additional 10 cm thickness
    - C25/30
    - 2,5 cm concrete cover





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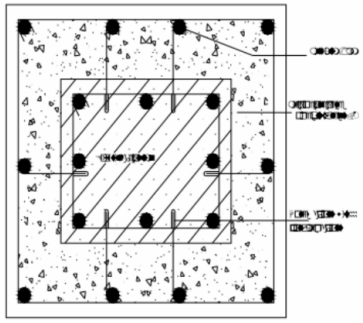
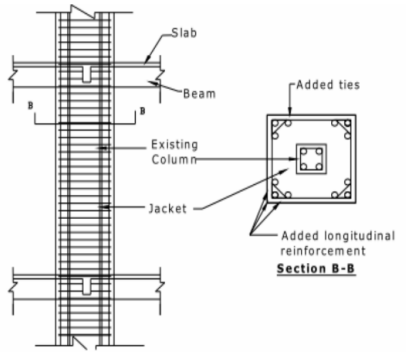


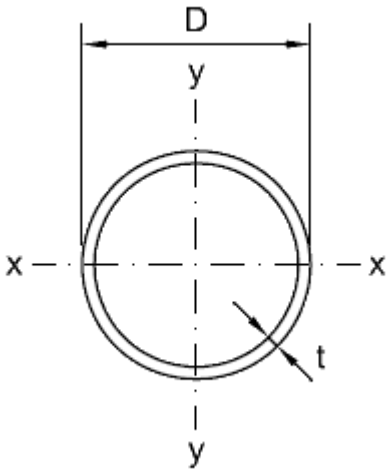


  - 2 different RC jacketing solutions
    - Jacketing 2 : 2% ratio of reinforcement area (wrt new Ac)
    - Jacketing 3 : 3% ratio of reinforcement area (wrt new Ac)

    - Applied by shotcreet or cast in place

Retrofit Solution

- Bracing retrofitting strategy
  - 3 different braces were considered
    - Steel members with circular hollow sections (CHS)
    - Steel S275



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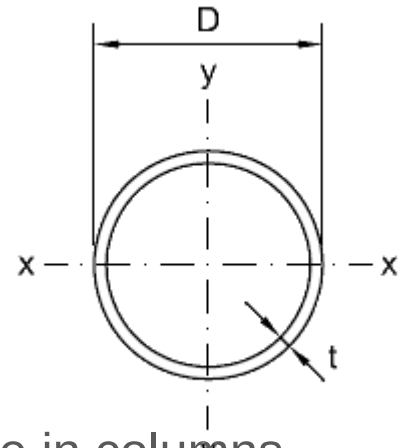
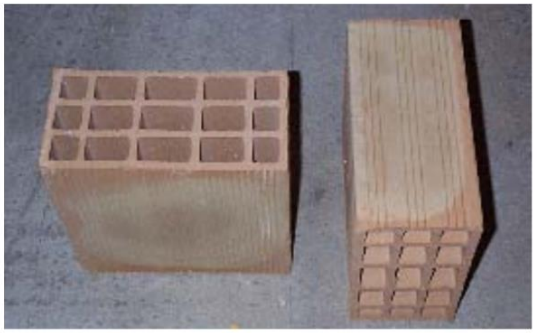
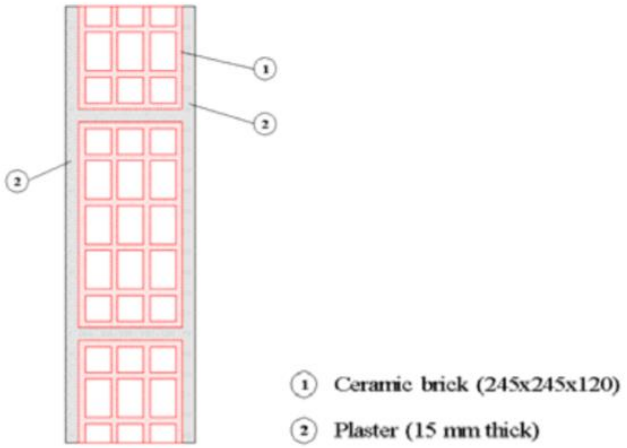


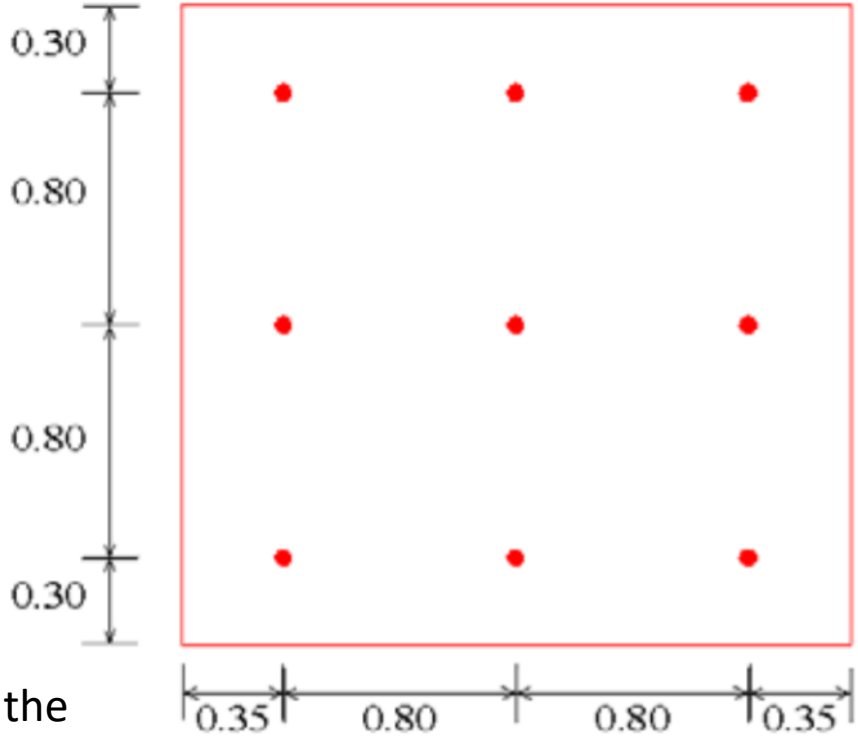
  - Bracing 3 : Designed so that the resulting axial force in columns equals the columns axial resistance
    - D = 76 mm ; t = 4 mm
  - Bracing 2 : Designed to a axial force value equal to 66% of Bracing 3 design force
    - D = 60 mm ; t = 3.2 mm
  - Bracing 1 : Designed to a axial force value equal to 33% of Bracing 3 design force
    - D = 34 mm ; t = 3.2 mm

Structural InfillWall



properties of the infills were calibrated based on the ICONS experimental test, and are similar to the ones used in Portugal.





A light connection
(clamps) between the shotcrete layer and the masonry walls was provided in nine points

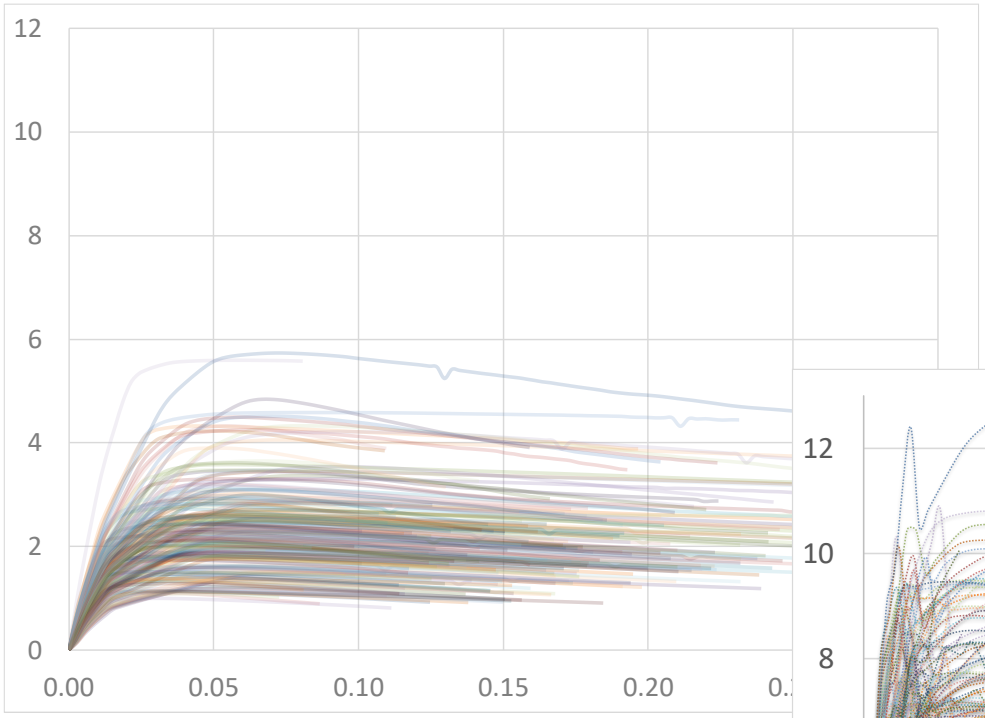
Structural InfillWall





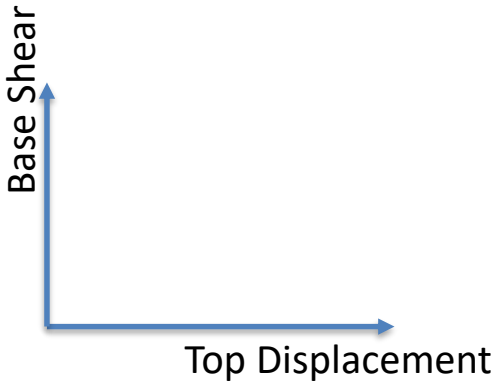



Capacity curves – 1 storey buildings



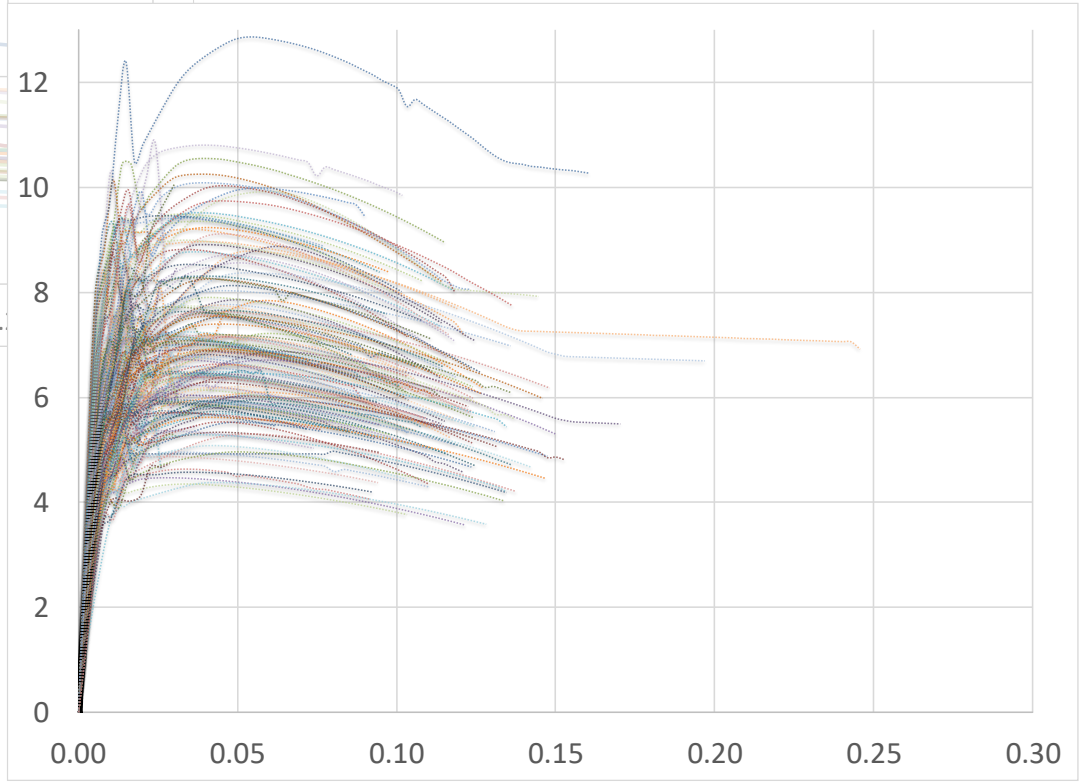
Bracing

Higher Deformation capacity



Infills

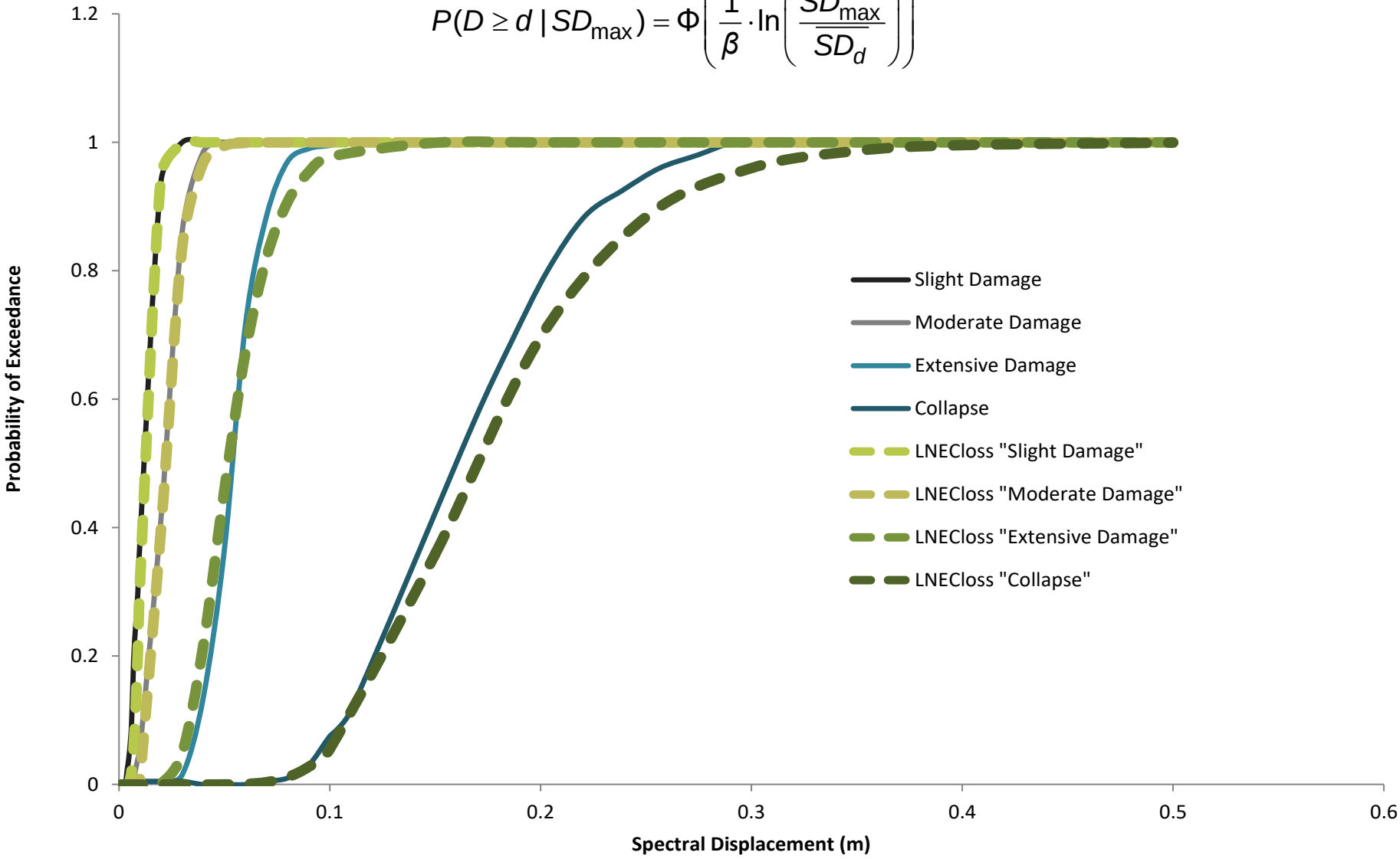
More resistance



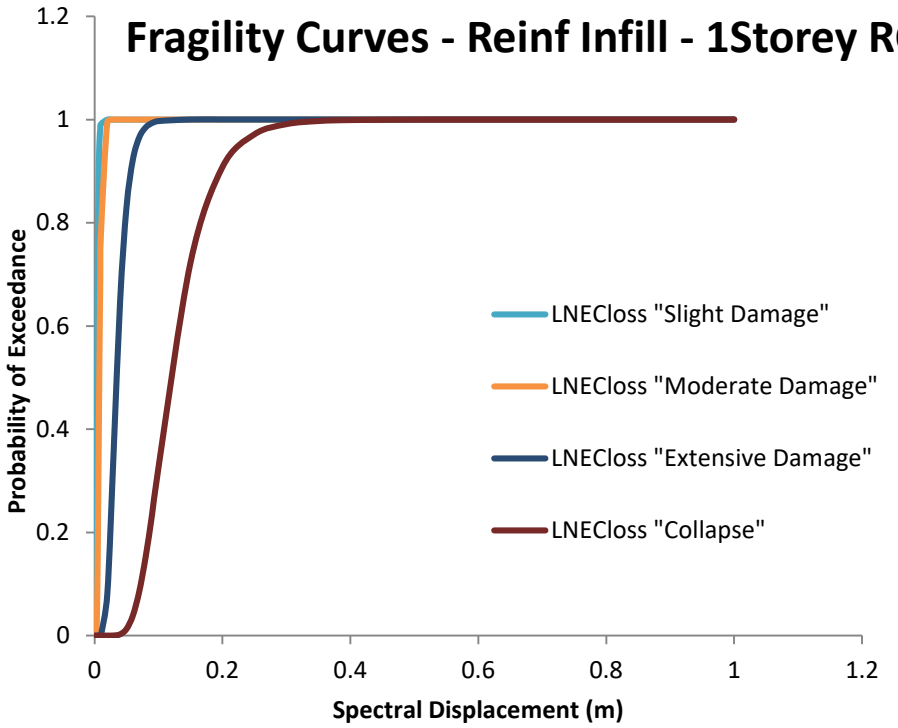
Fragility curves for 1 storey buildings

Using LogN hypothesis vs Numerical Model

$$P(D \geq d \mid SD_{\max}) = \Phi\left(\frac{1}{\beta} \cdot \ln\left(\frac{SD_{\max}}{\overline{SD_d}}\right)\right)$$



Fragility curves for infills strategy



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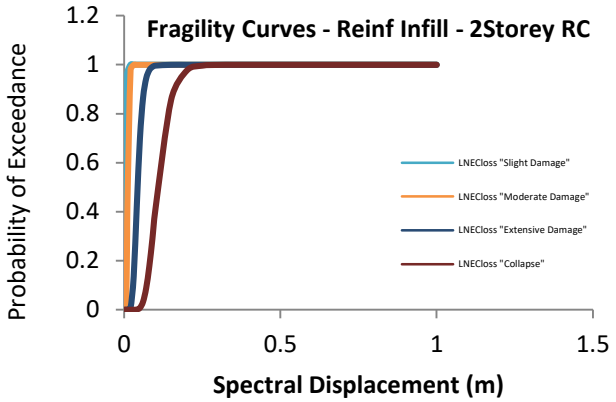
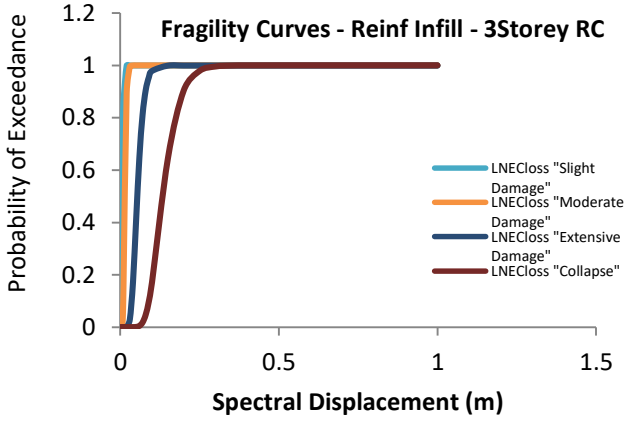
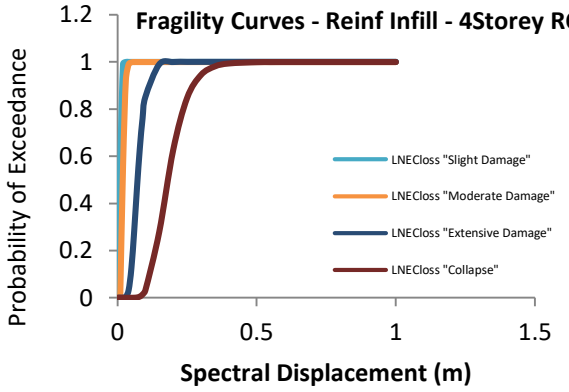
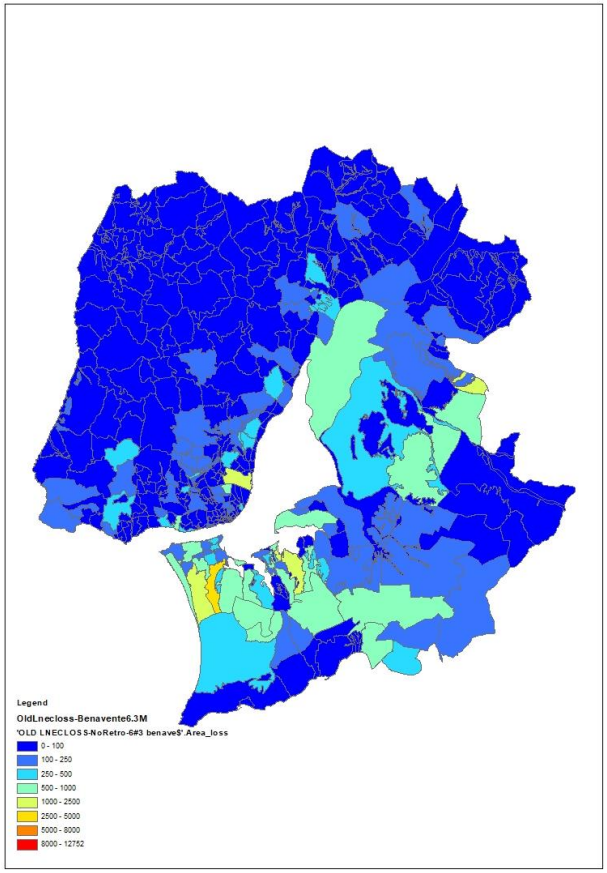






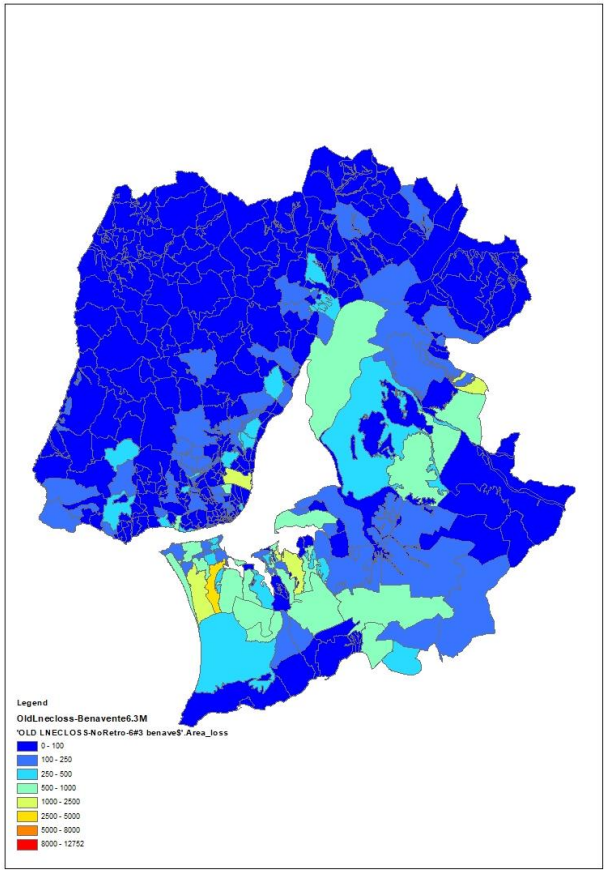
What I’ve done

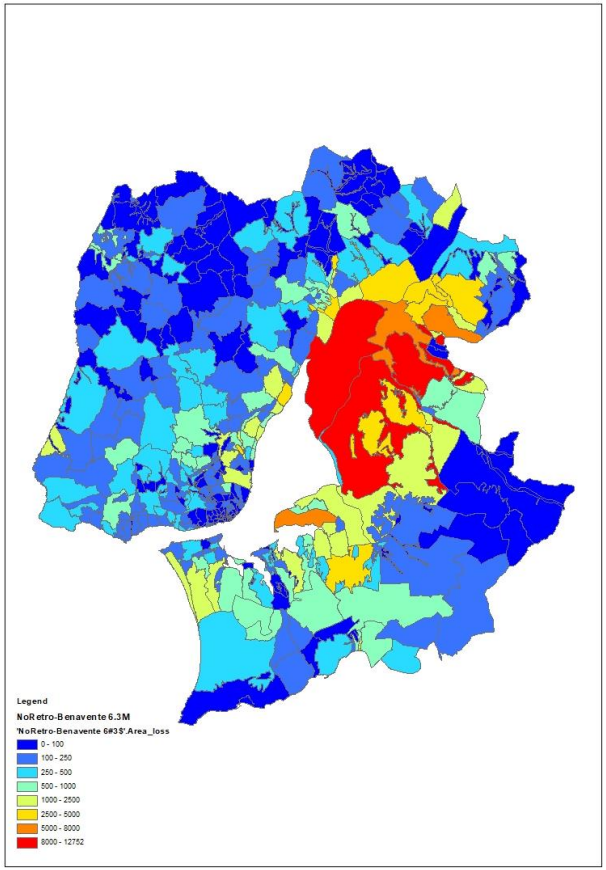
- Comparison of Infill results with original LNECLOSS
  Lossed area : Graphical representation- 6,3M Benavente



What I’ve done

- Comparison of Infill results with original LNECLOSS
  Lossed area : Graphical representation- 6,3M Benavente





What I’ve done

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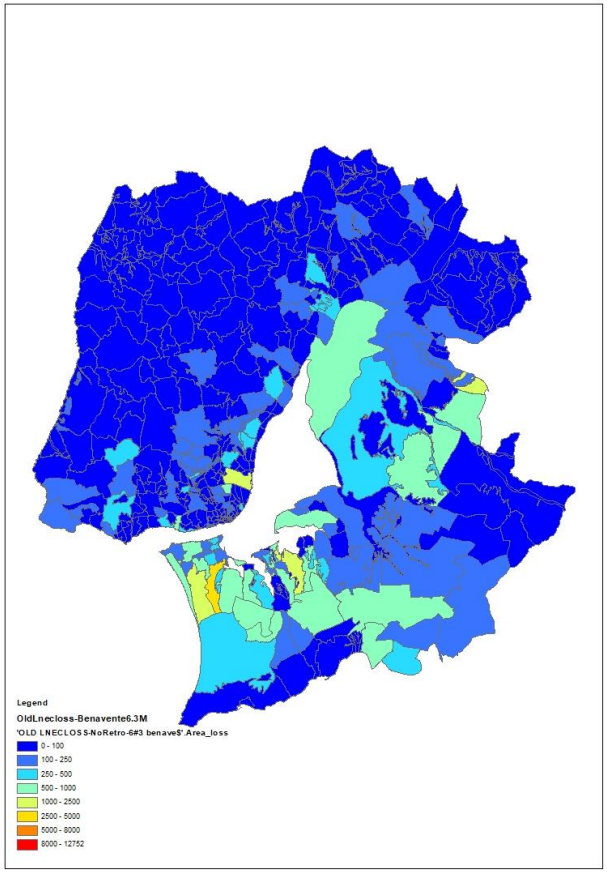
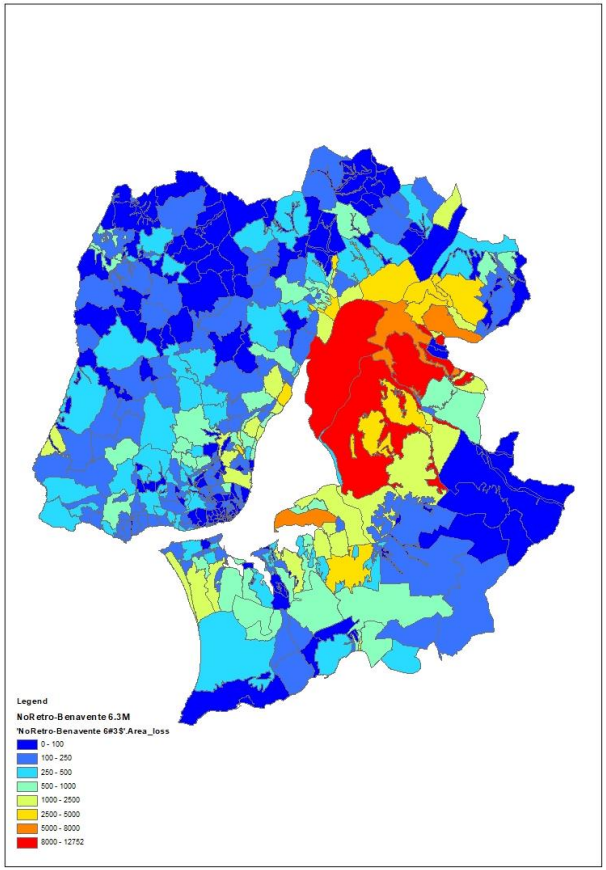
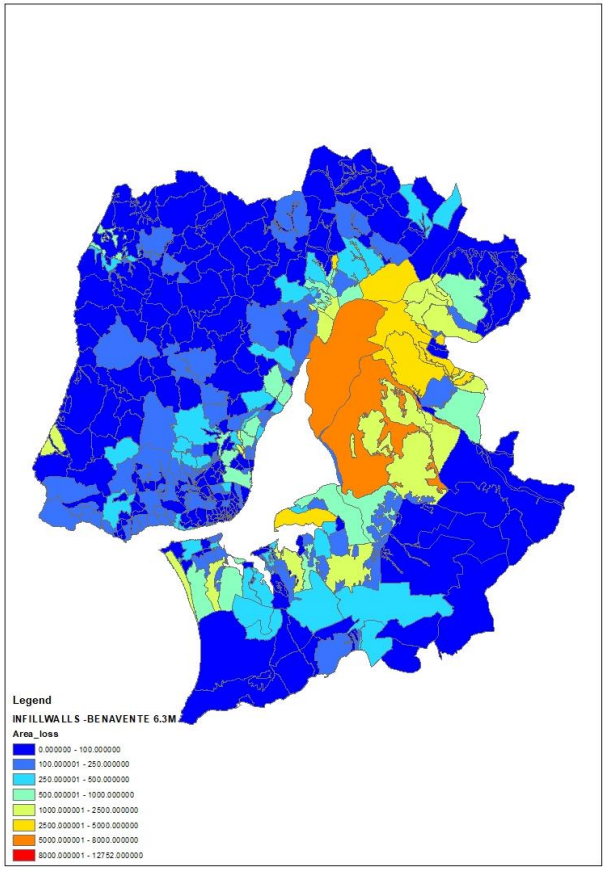
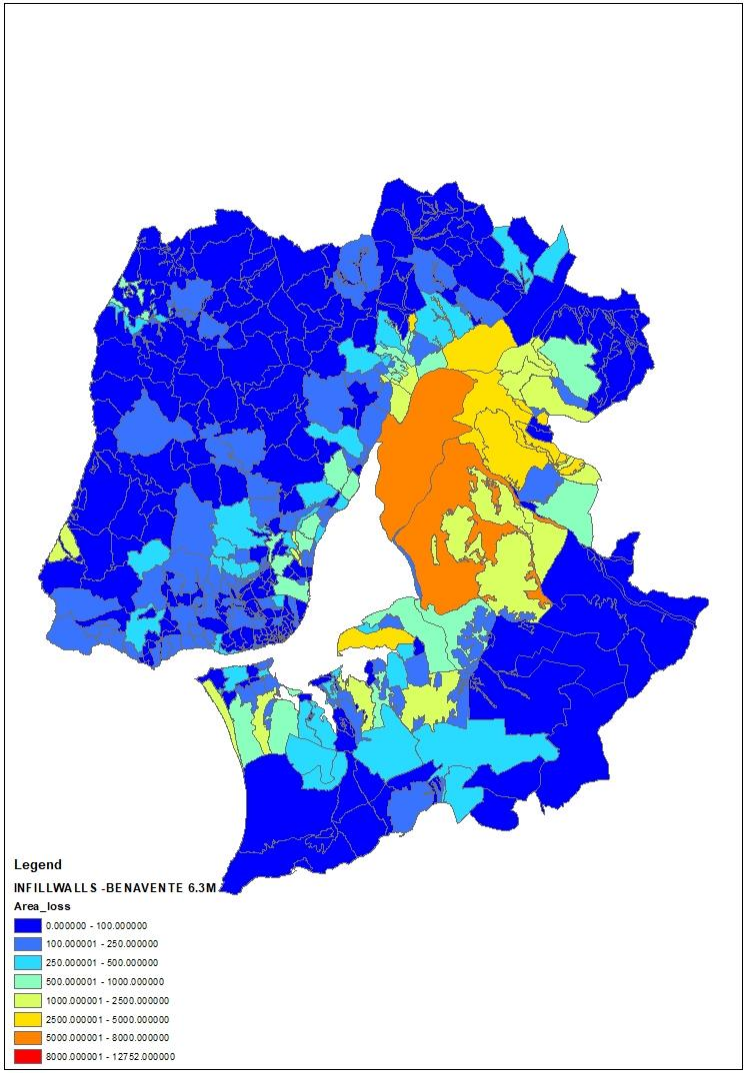


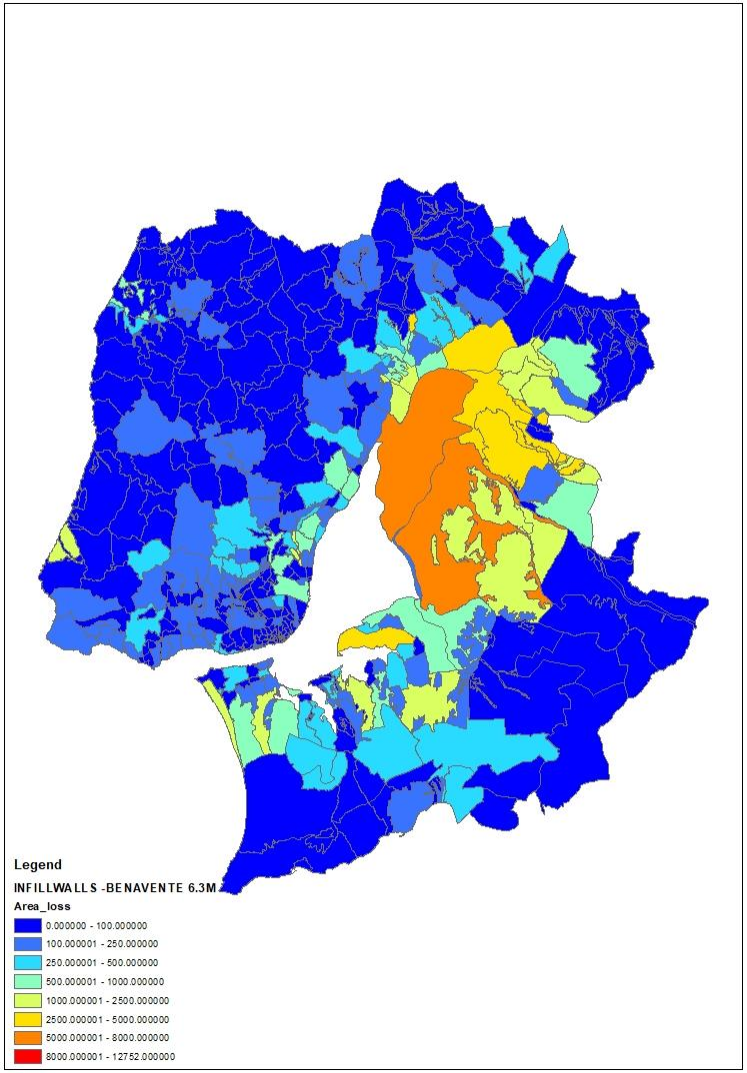




Infill Walls



Infill Walls



Comparison of results with original LNECLOSS

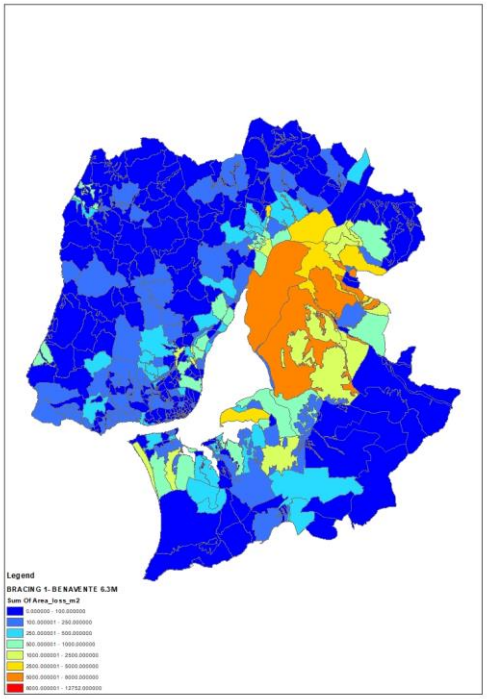
Lossed area : Graphical representation

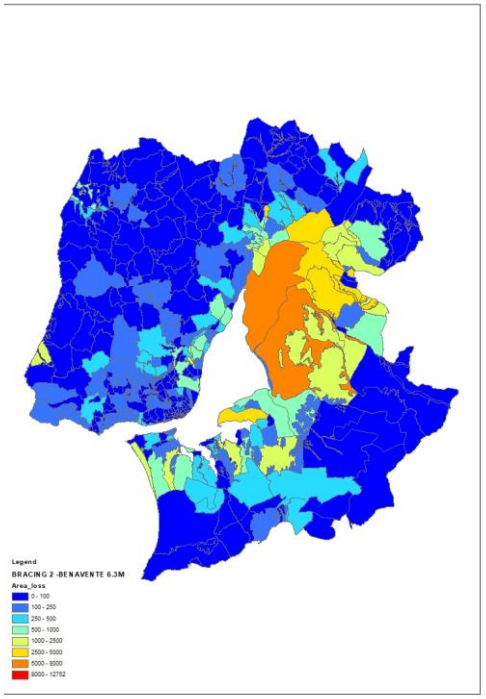
Infill Walls				
Sum of Area_Loss(m^2)	Column Labels			
Row Labels	Hard soil	Interm. soil	Soft soil	Grand Total
Masonry	202878.1804	285694	168025.5	656597.6
RC Medium Ductility	22236.99962	32795.56	41564.55	96597.12
RC Non ductil - low rise	10360.53414	30561.57	12733.48	53655.59
RC Non ductil - med/high rise	7631.965466	7691.428	10111.56	25434.95
Grand Total	243107.6796	356742.5	232435.1	832285.3

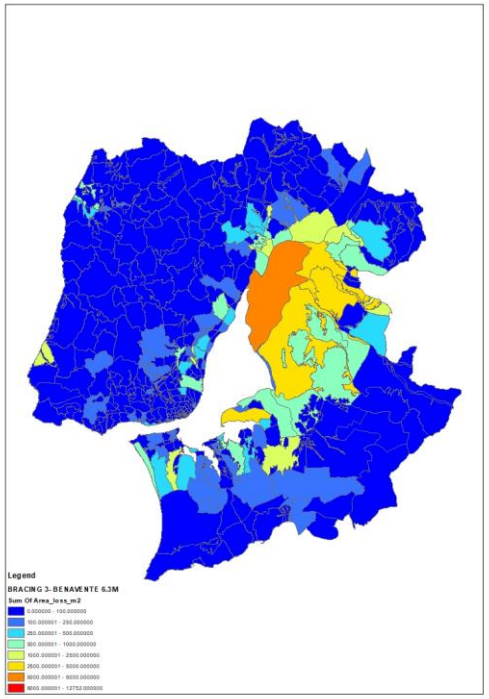
No Retro				
Sum of Area_Loss(m^2)	Column Labels			
Row Labels	Hard soil	Interm. soil	Soft soil	Grand Total
Masonry	202878.1804	285694	168025.5	656597.6
RC Medium Ductility	22236.99962	32795.56	41564.55	96597.12
RC Non ductil - low rise	36584.40222	32218.42	125798.4	194601.2
RC Non ductil - med/high rise	7631.965466	7691.428	10111.56	25434.95
Grand Total	269331.5477	358399.4	345499.9	973230.9

Reduction achieved with mitigation

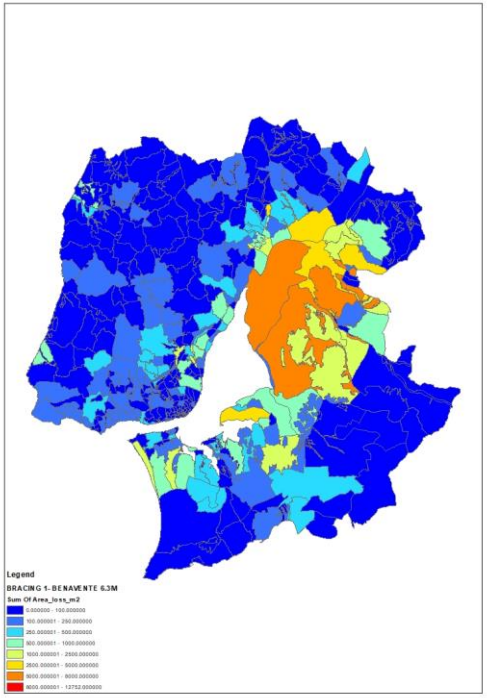
Bracing Level1 VS Level2 VS Level3

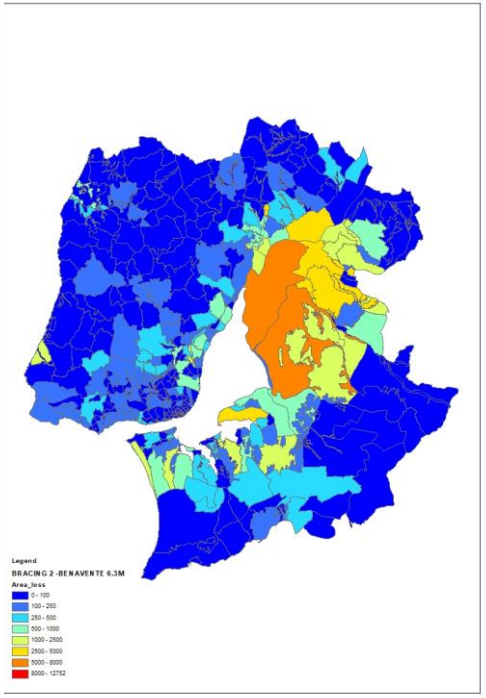


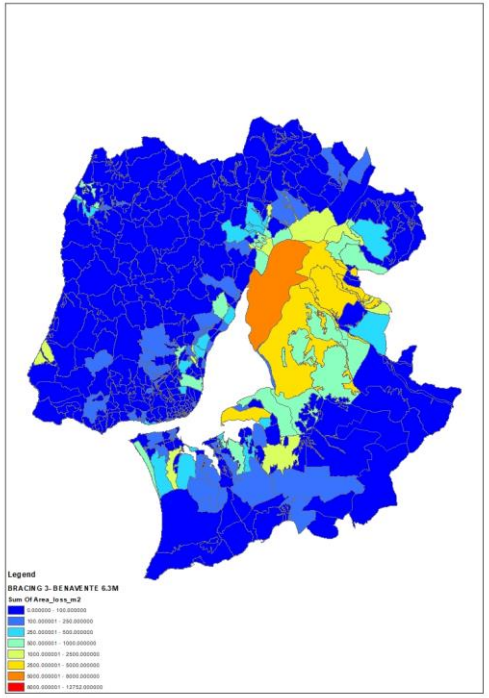




Bracing Level1 VS Level2 VS Level3





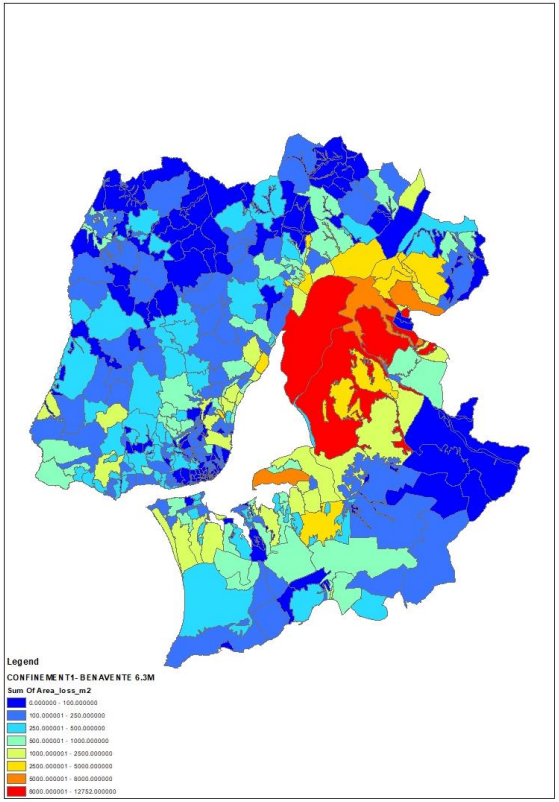


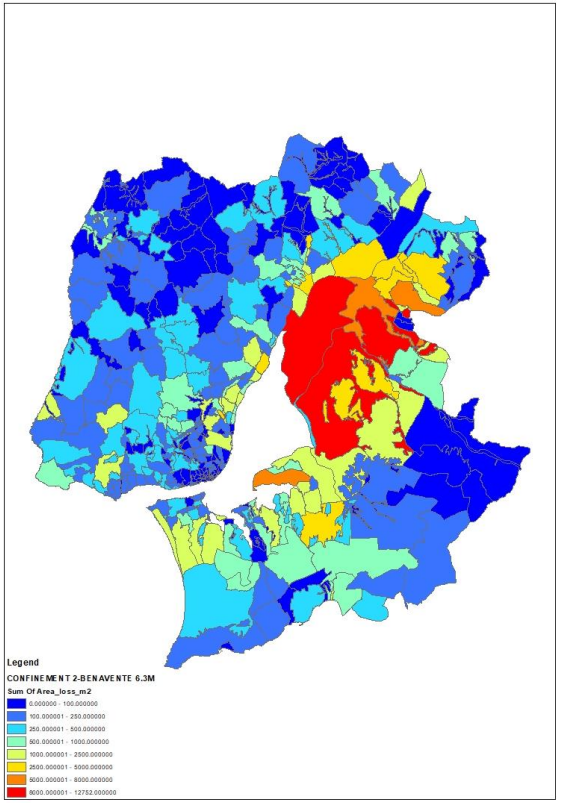
Bracing1				
Sum of Area_Loss(m^2)	Column Labels			
Row Labels	Hard soil	Interm. soil	Soft soil	Grand Total
Masonry	202878.1804	285694	168025.5	656597.6
RC Medium Ductility	22236.99962	32795.56	41564.55	96597.12
RC Non ductil - low rise	18670.54799	19532.8	66373.11	104576.5
RC Non ductil - med/high rise	7631.965466	7691.428	10111.56	25434.95
Grand Total	251417.6935	345713.8	286074.7	883206.2

bracing2			
Column Labels			
Hard soil	Interm. soil	Soft soil	Grand Total
202878.1804	285694	168025.5	656597.6
22236.99962	32795.56	41564.55	96597.12
17379.05655	21680.61	66616.8	105676.5
7631.965466	7691.428	10111.56	25434.95
250126.202	347861.6	286318.4	884306.2

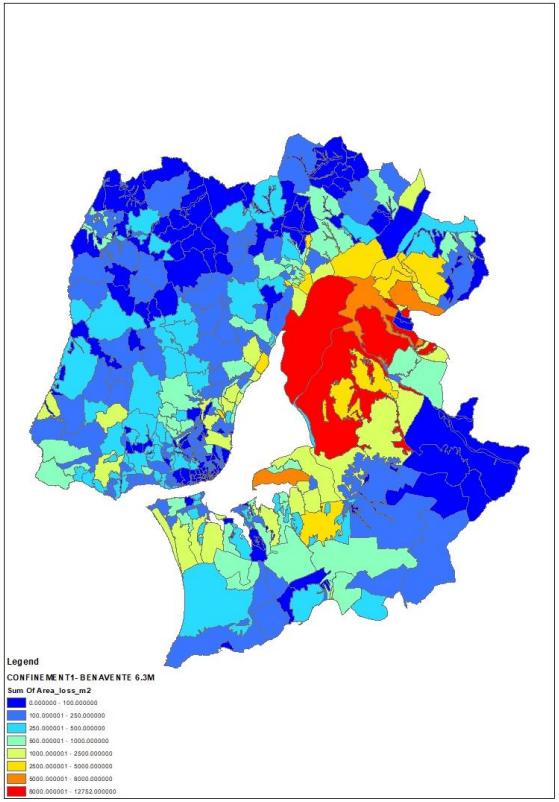
Bracing3			
Column Labels			
Hard soil	Interm. soil	Soft soil	Grand Total
202878.1804	285694	168025.5	656597.6
22236.99962	32795.56	41564.55	96597.12
8538.27045	13170.78	45848.58	67557.63
7631.965466	7691.428	10111.56	25434.95
241285.4159	339351.7	265550.2	846187.3

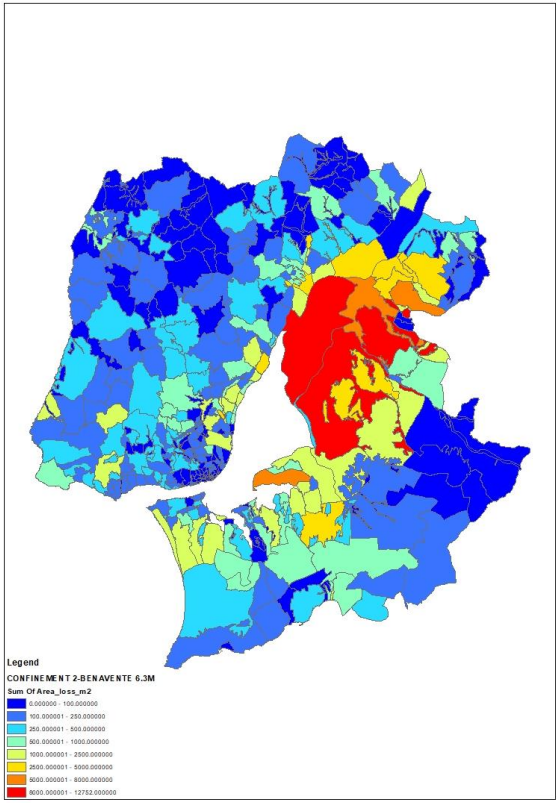
FRP/STEEL JACKETING confinement Level1 VS Level2





FRP/STEEL JACKETING confinement Level1 VS Level2

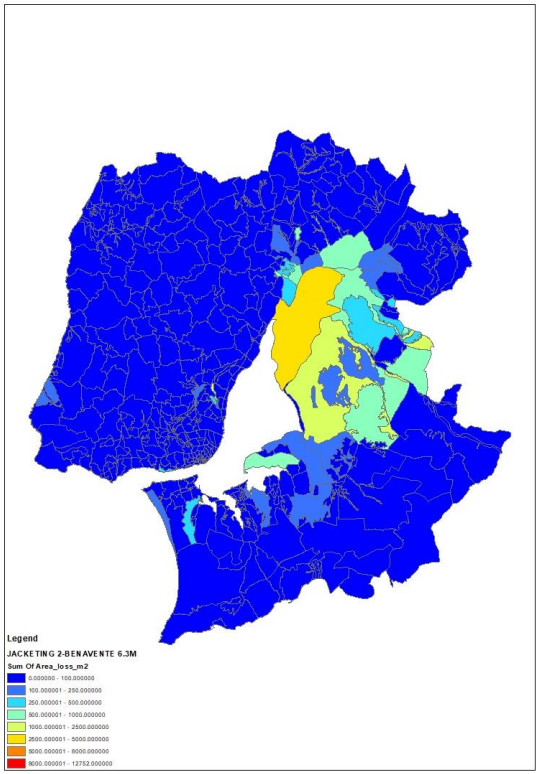


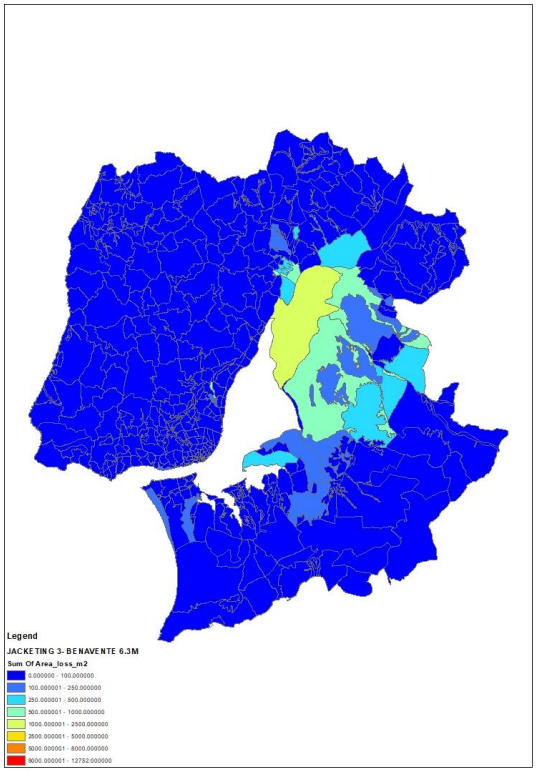


	Confinement 1			
Sum of Area_Loss(m^2)	Column Labels			
Row Labels	Hard soil	Interm. soil	Soft soil	Grand Total
Masonry	202878.2	285694	168025.5	656597.6
RC Medium Ductility	22237	32795.56	41564.55	96597.12
RC Non ductil - low rise	42879.94	36054.89	125971.4	204906.2
RC Non ductil - med/high rise	7631.965	7691.428	10111.56	25434.95
Grand Total	275627.1	362235.8	345673	983535.9

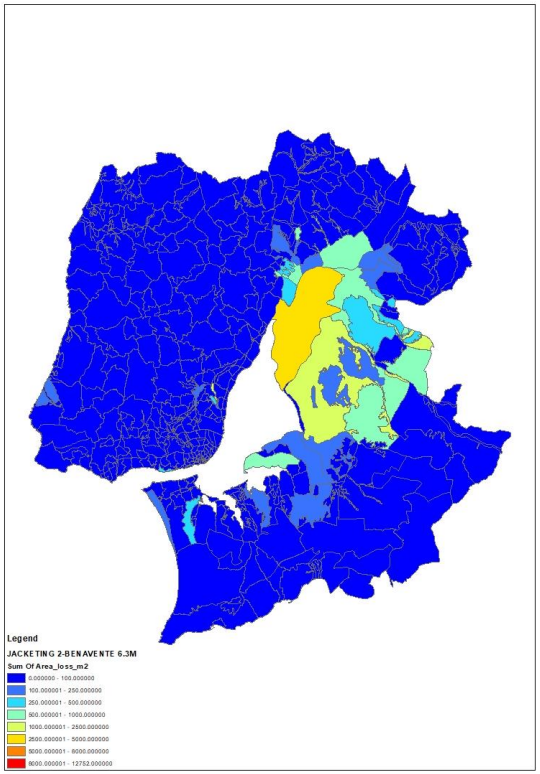
Confinement 2			
Column Labels			
Hard soil	Interm. soil	Soft soil	Grand Total
202878.2	285694	168025.5	656597.6
22237	32795.56	41564.55	96597.12
40614.82	34633.72	122151.4	197400
7631.965	7691.428	10111.56	25434.95
273362	360814.7	341853	976029.7

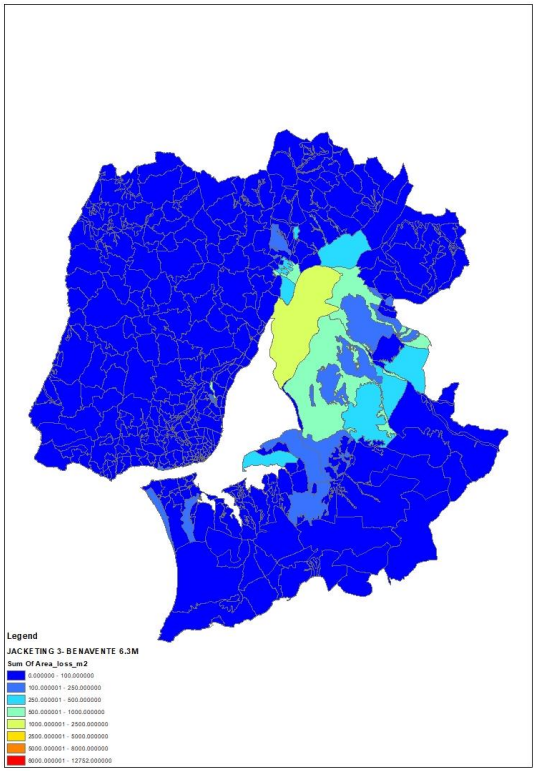
RC jacketing 2R VS 3R





RC jacketing 2R VS 3R





	Jacketing 2R			
Sum of Area_Loss(m^2)	Column Labels			
Row Labels	Hard soil	Interm. soil	Soft soil	Grand Total
Masonry	202878.2	285694	168025.5	656597.6
RC Medium Ductility	22237	32795.56	41564.55	96597.12
RC Non ductil - low rise	386.1703	4387.864	13021.96	17796
RC Non ductil - med/high rise	7631.965	7691.428	10111.56	25434.95
Grand Total	233133.3	330568.8	232723.6	796425.7

Jacketing 3R			
Column Labels			
Hard soil	Interm. soil	Soft soil	Grand Total
202878.2	285694	168025.5	656597.6
22237	32795.56	41564.55	96597.12
133.9558	2561.126	7618.544	10313.63
7631.965	7691.428	10111.56	25434.95
232881.1	328742.1	227320.1	788943.3

Outline

- Thesis Review
- Accomplished Tasks
- **Cost Benefit Alternative**

Cost-Benefit analysis

- Benefits
  - Increased value of the building due to its improved seismic performance (B)
- Costs
  - Costs of implementing mitigation strategy (C_{MS})
  - Damage repair costs (C_{RP})
  - Demolition and reconstruction costs ($C_D + C_{RC}$)
  - Costs of relocation of users (C_{RU})
  - Costs of loss revenue (C_{LR})
  - Costs of fatalities/injuries compensations (C_{FIC})
  - ...

Cost-Benefit analysis

- Cost function

$$C_{TOT} = C_{MS} + C_{RP} + (C_D + C_{RC}) + C_{RU} + C_{LR} + C_{FIC}$$

- In order to compare costs at different times, all values must be adjusted to a reference year prices, multiplying the costs by

$$\frac{1}{(1+r)^{\Delta T}}$$

  - r represents the discount rate [2% to 4%]
  - ΔT is given by T_i - T_r, where T_i represents the year of cost i and T_r represents the reference year

Stay Safe

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