Seismic Risk Mitigation Studies: The Portuguese Experience.

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European Council of Civil Engineers

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Seismic Risk Mitigation Studies. The Portuguese Experience

- **Summary**
  1. Overview on Seismic Risk and Mitigation Strategies Analysis – SRMA
  2. LNECloss a tool for seismic loss estimation

     ANPC (MAL and ERSTA) ; LESSloss … GEM$_1$
  3. The case study of the Metropolitan Area of Lisbon (MAL)
  4. Conclusions regarding the case study
  5. Experimental research in seismic strengthening of buildings in Portugal.

Seismic Risk and Mitigation Analysis (SRMA)

- Seismic Risk and Mitigation Analysis (SRMA) ⇒ Methodology based on Probabilistic Seismic Risk Analysis taken with Mitigation Strategies based on structural earthquake engineering to support the decision to reduce SR.
- Mitigate SR ⇒ Consistent methods to reduce the effects of earthquakes on population, on civil engineering structures and on infra-structures taking into account uncertainties (epistemic and natural)
- SRMA are Interdisciplinary of studies ⇒ interaction of different specialized sub-fields of research;
  - Engineering seismology.
  - Earthquake engineering.
  - Probability seismic risk analysis.
  - Cost benefit analysis.

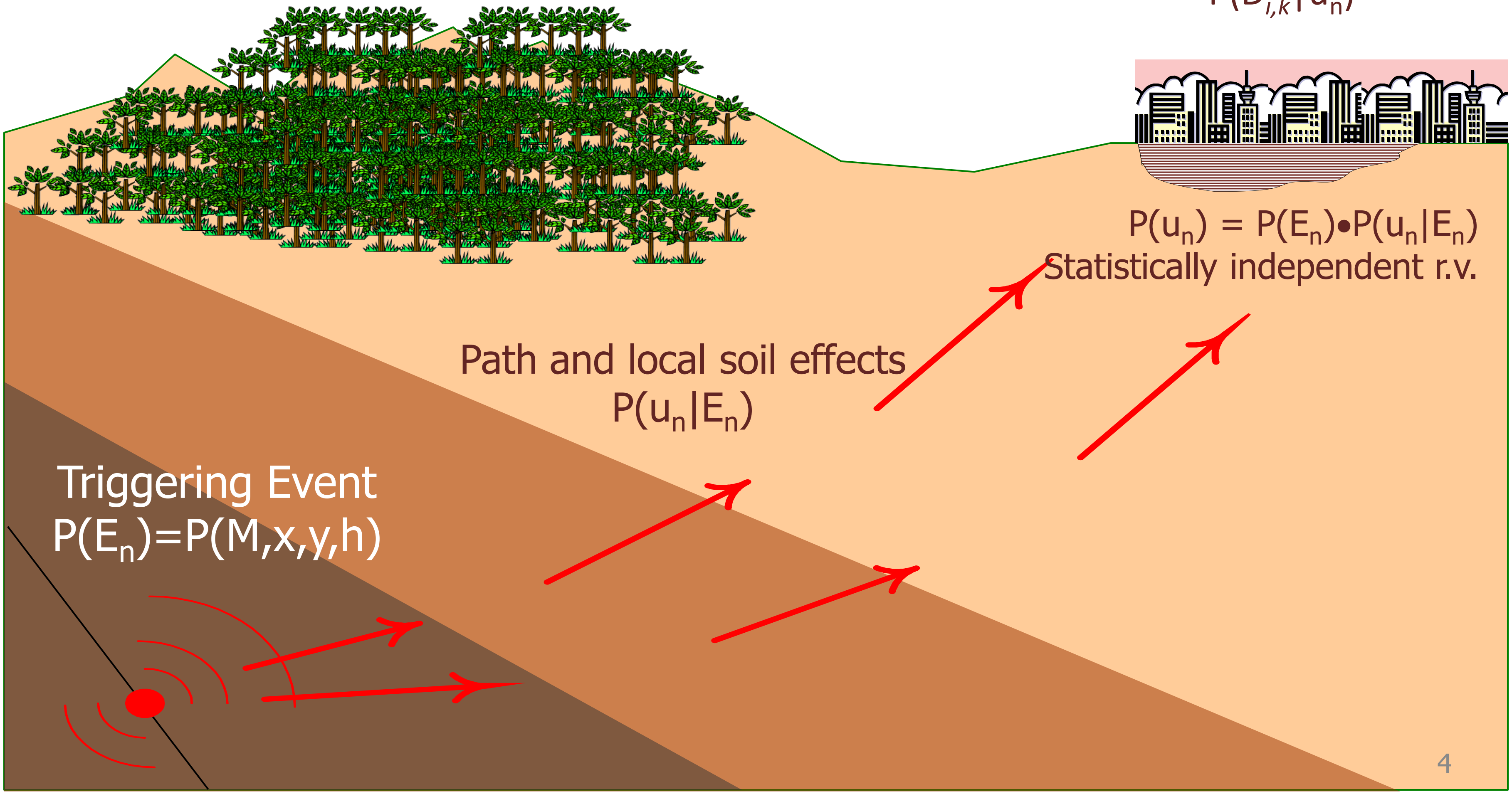
Probabilistic Seismic Risk Analysis

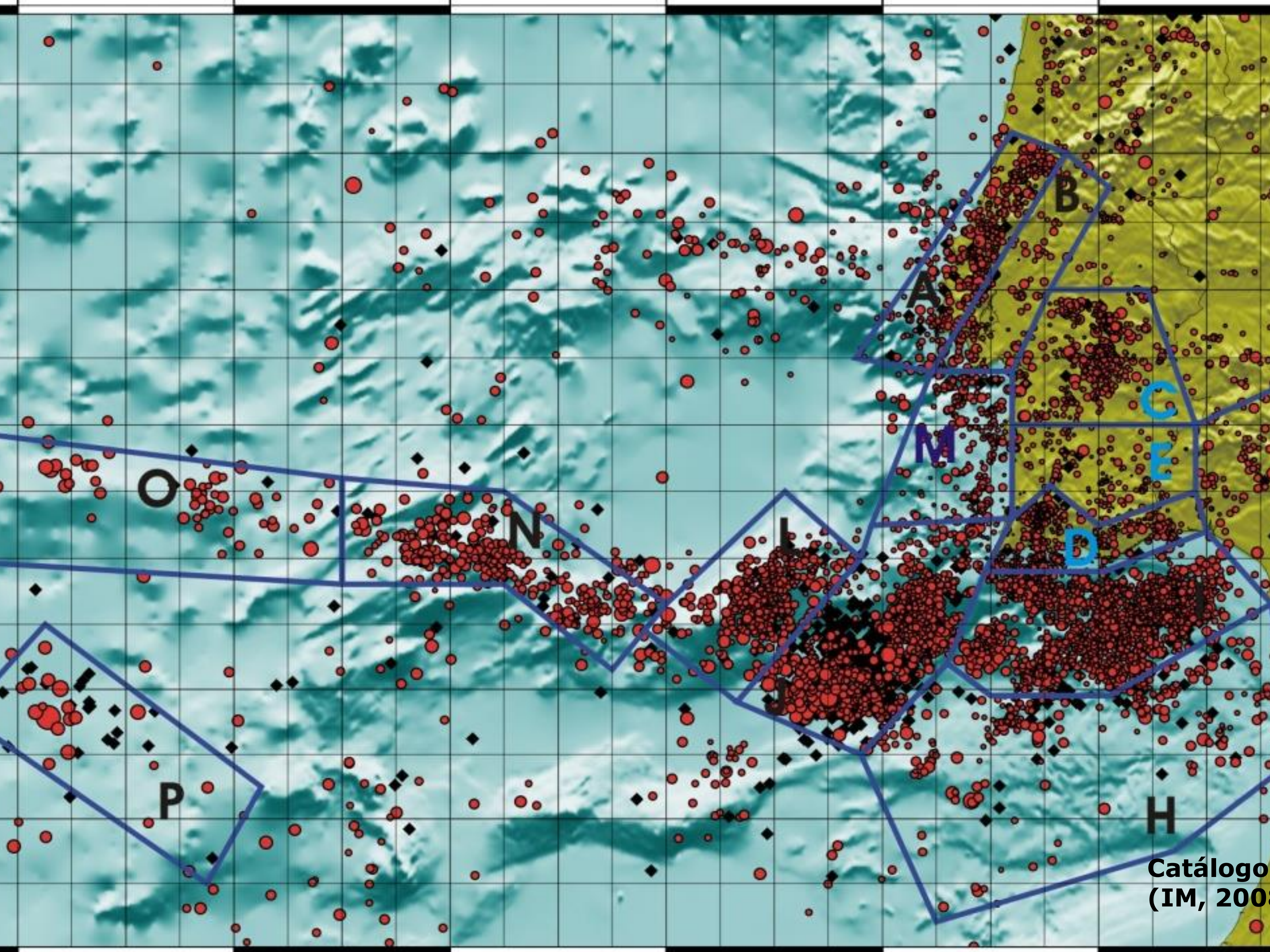
Total Risk Assessment

$E[L]=Risk=\sum_n P(u_n)\bullet\sum_k\sum_i P(D_{i,k}|u_n)\bullet Loss(D_{i,k})\bullet N_{i,k}$

Fragility and Vulnerability per typology *k* and State Damage *i*

$P(D_{i,k}|u_n)$





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Process of Seismic Hazard Disaggregation

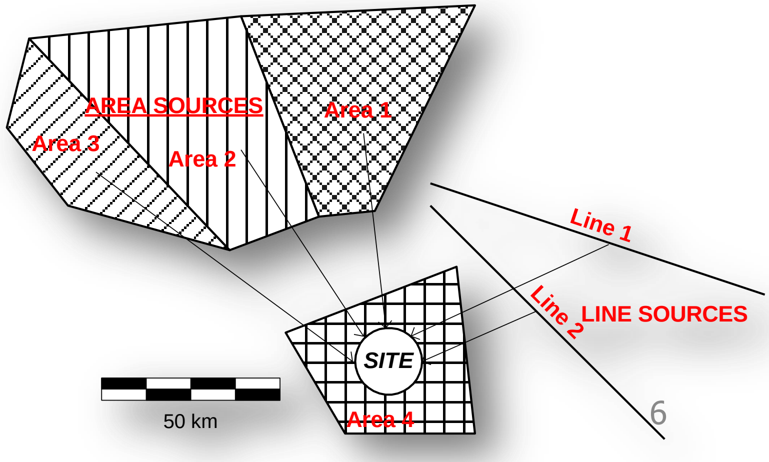
- Seismic Hazard Analysis (PSHA) for given site
  - SHA – To compute the probability of a given intensity level of being exceed in a given time interval (generally one year) based on probabilistic methods.
    - Source energy - Events occur at random in *space*, *time* and *magnitude*
    - Attenuation process - For a given event, site intensities are also *random processes* .

$$P(U>u)_k = \int_R \int_{mo_k}^{mu_k} P(U>u \mid m,R) \cdot f_M(m)_k \cdot f_R(R)_k \cdot dm \cdot dR$$

$$\omega_k = \nu_k \cdot P(U>u)_k$$ Annual mean rate of occurrence of *u*

$$P(U>u) = 1 - e^{\left(-\sum_{k=1}^{n} \omega_k\right)}$$ *n* independent Poisson processes

$$RP(U>u) = \frac{1}{1 - e^{\left(-\sum_{i=1}^{n} \omega_i\right)}}$$ Return Period



Process of Seismic Hazard Disaggregation

- Seismic Hazard Disaggregation
  - Which are the modal value (or values) of the of the *pdf* corresponding to the *CDF:* $P(U \leq u) = 1 - P(U > u)$.
  - Likelihood function of the of independent variables *m,x,y* given an event $U > u_i$. occurred in site.

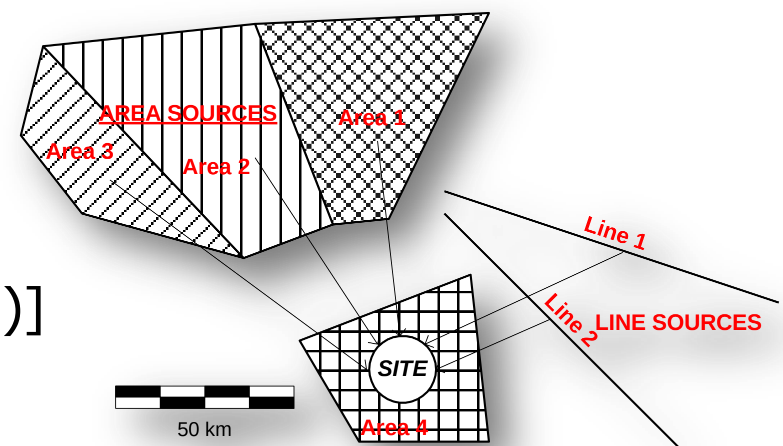
$$\ell(m,x,y|U > u_i) = \sum_{k}^{n} f_S(x,y) \cdot f_M(m)_k \cdot P(U > u_i \mid m, R_i)_k$$

$f_S(x,y)$ spatial distribution of the relative the frequency of events in all seismic zones

  - The values for which *m*, *x* and *y* gives maximum defines the modal event.

$$\tilde{E}_i = \langle \tilde{m}_i, \tilde{x}_i, \tilde{y}_i | U > u_i \rangle = max[\ell(m,x,y|U > u_i)]$$

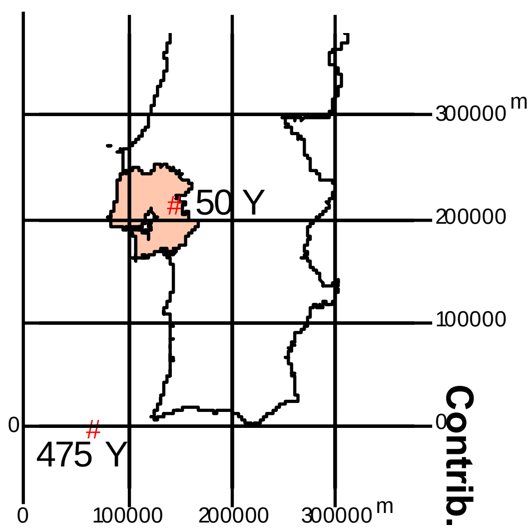
  - For each return period it is possible to define a modal event



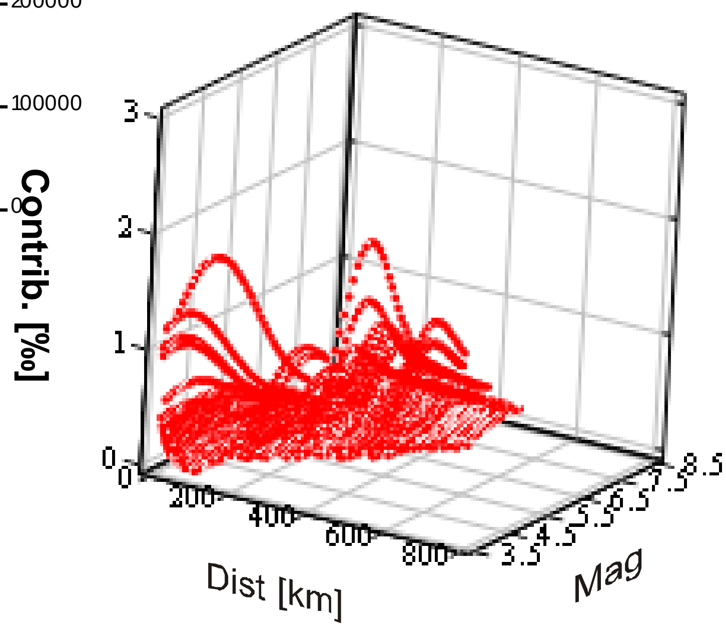
Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Seismic input definition

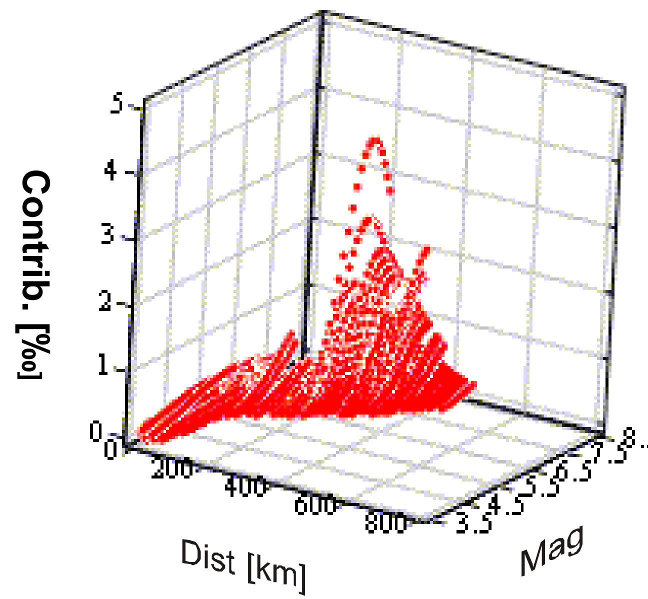
- Earthquake scenario based on PSHA disaggregation



50 years RP

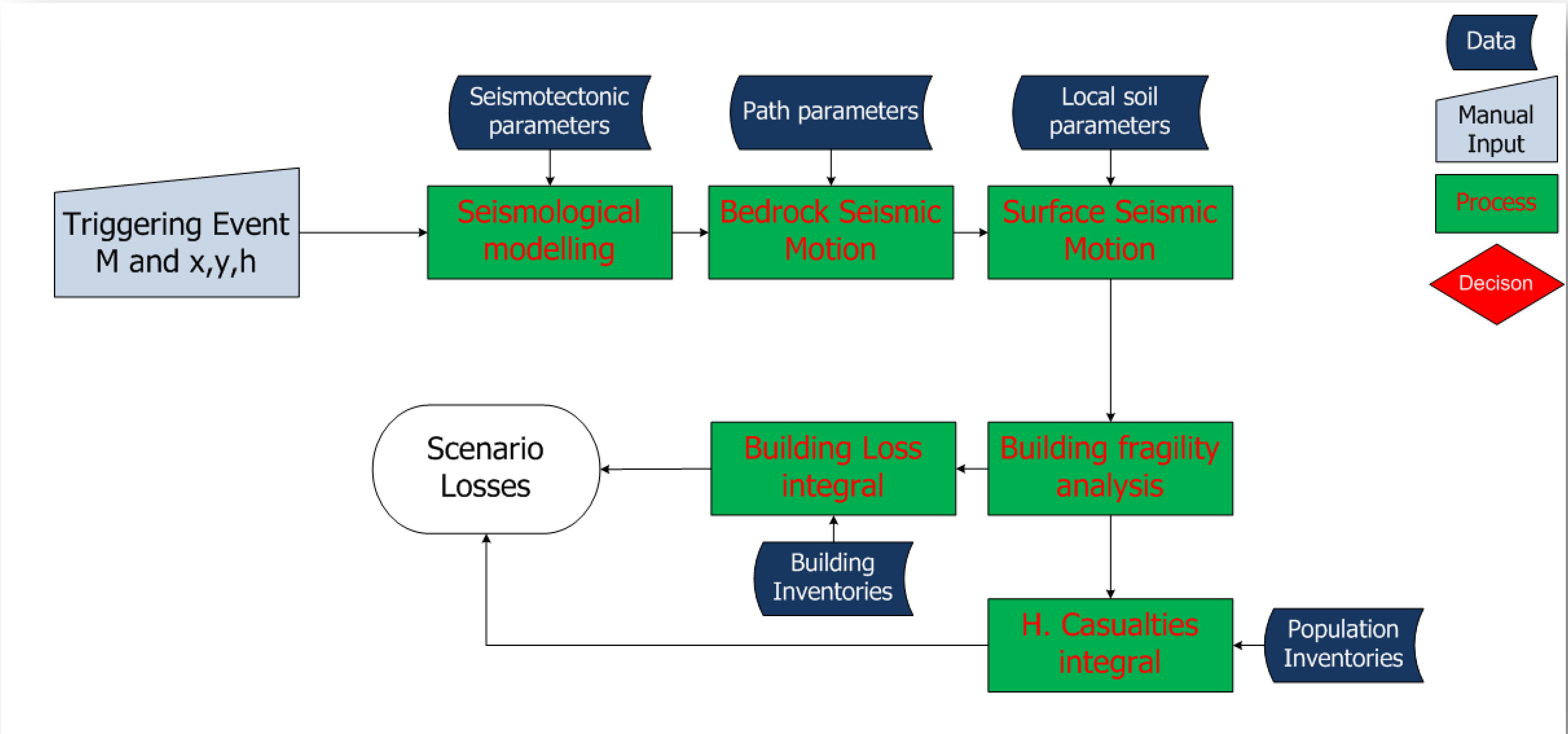


475 years RP



LNECloss - Seismic Loss Scenario Simulator

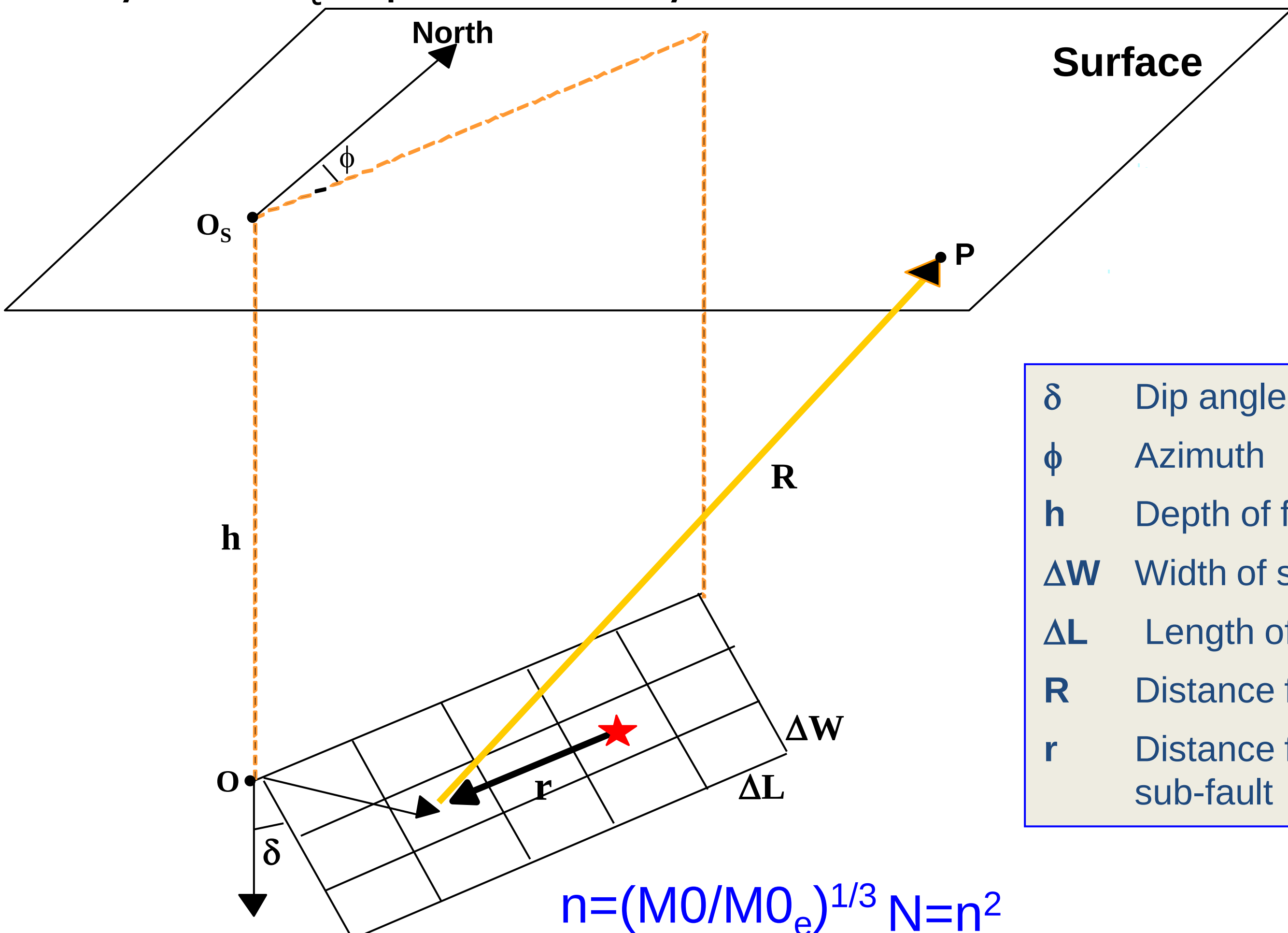
- Seismic loss assessment for a deterministic scenario



LNECloss - Seismic Scenario simulator

Bedrock seismic motion

Finite fault modeling: Fault plane divided in sub-faults considered point sources. Contributions synthesized at the local site taking into account delay time D_t rupture velocity and focal distance.



$D_t = r / Vr + R/\beta$

δ	Dip angle
ϕ	Azimuth
h	Depth of fault plane
ΔW	Width of sub-fault
ΔL	Length of sub-fault
R	Distance from sub-fault to site
r	Distance from hypocenter to the sub-fault

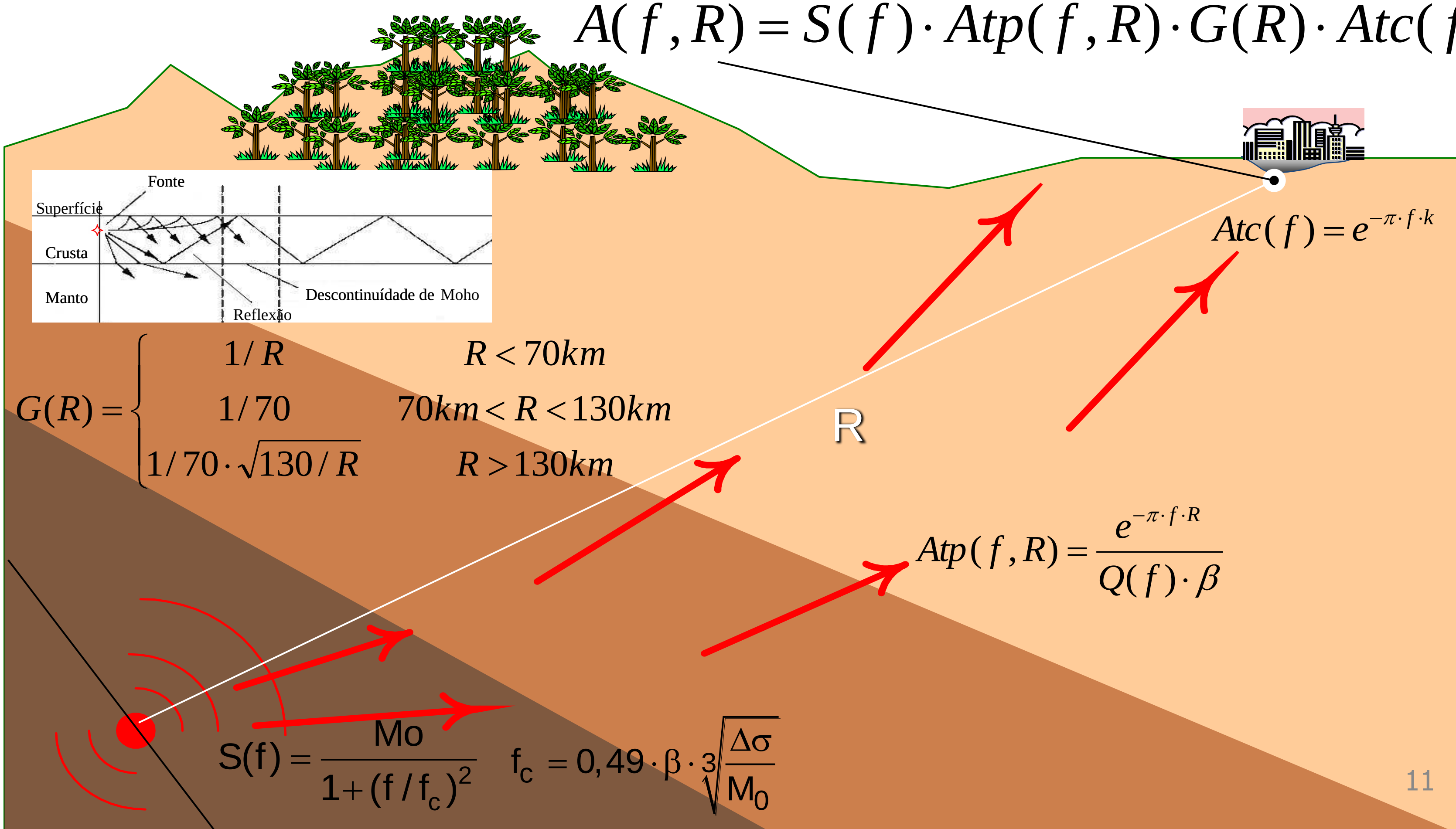
$n = (M0/M0_e)^{1/3}$ $N = n^2$

LNECloss – Seismic Scenario simulator

Seismological modelling module

Seismological model for synthetic motions at bedrock level;
Boore (1983; 2003) – point source
Gail Atkinson et. al. (1998; 2002) – finite fault model source
A. Carvalho (2006) – stochastic finite fault model source

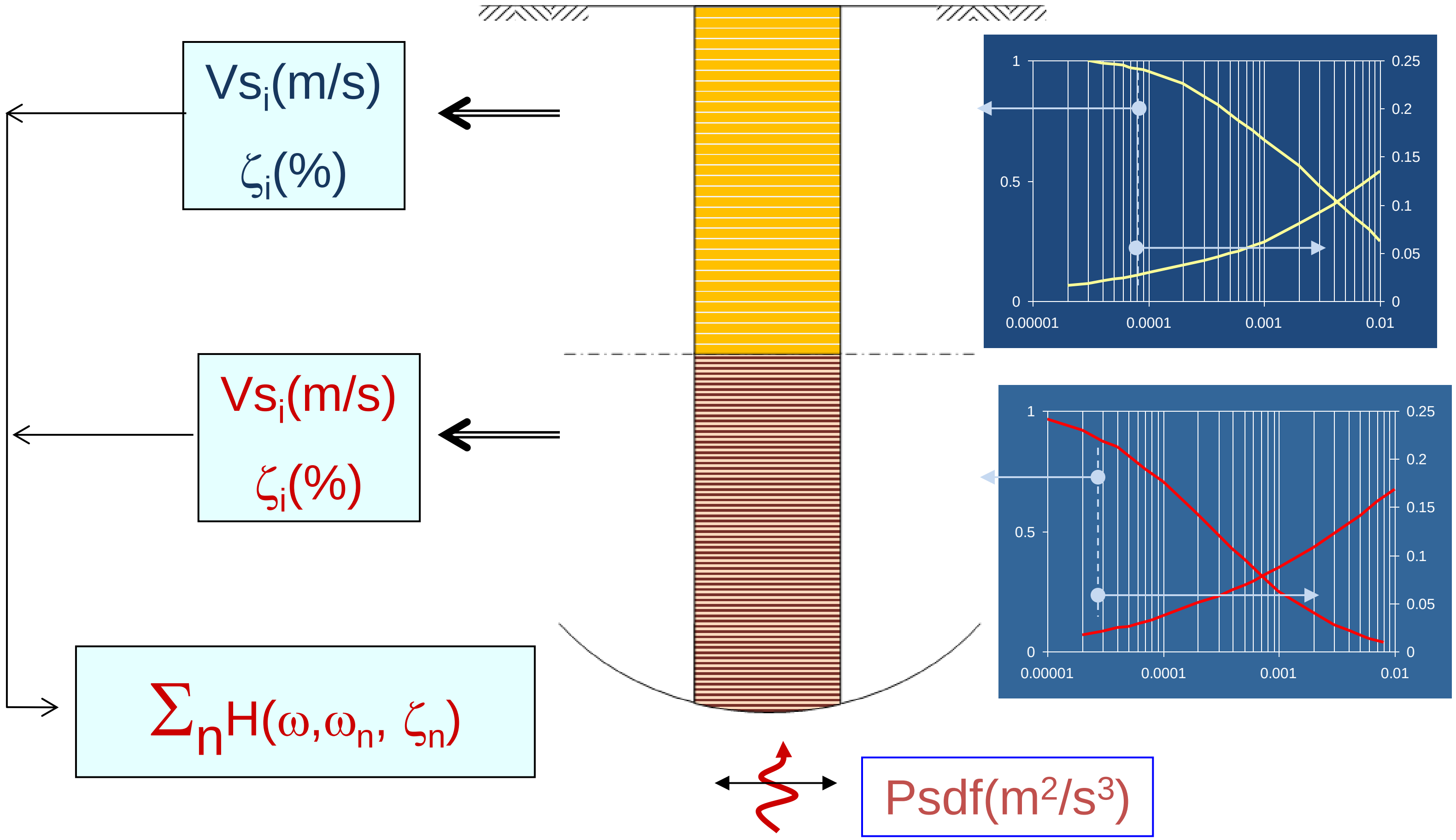
$$A(f,R) = S(f)\cdot Atp(f,R)\cdot G(R)\cdot Atc(f)$$



LNECloss - Seismic Scenario simulator

Modelling of soil site effects

Motions at surface by inelastic modelling of site soil conditions
SHAKE – Deterministic analisys in frequency domain
Bilé Serra (1998) – Stochastic analysis

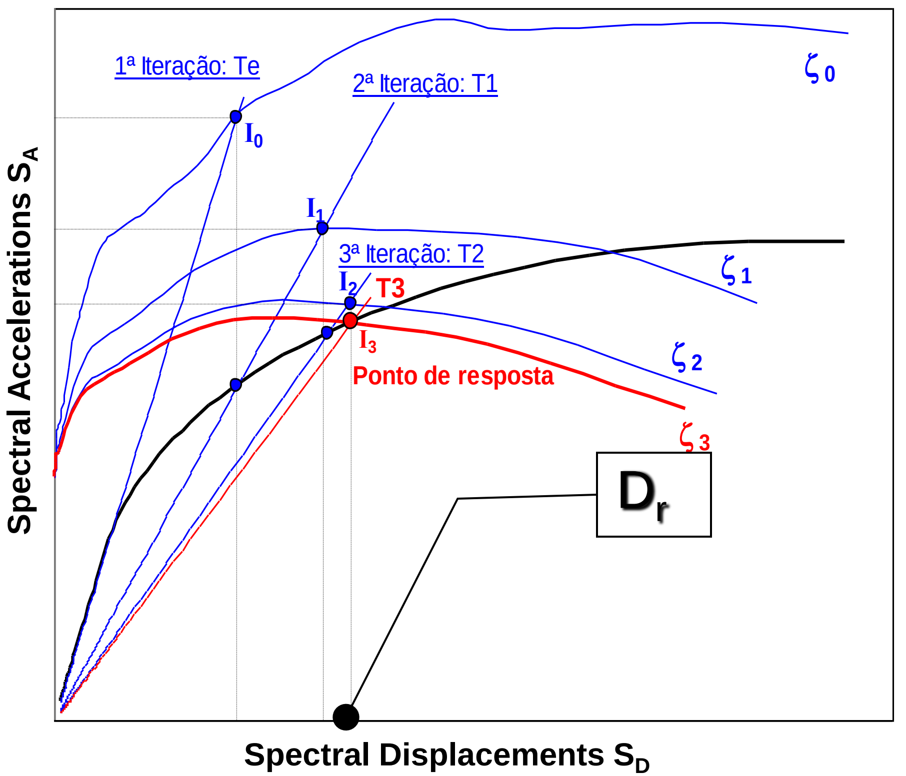


LNECloss - Seismic Scenario simulator

Fragility analysis of building typologies

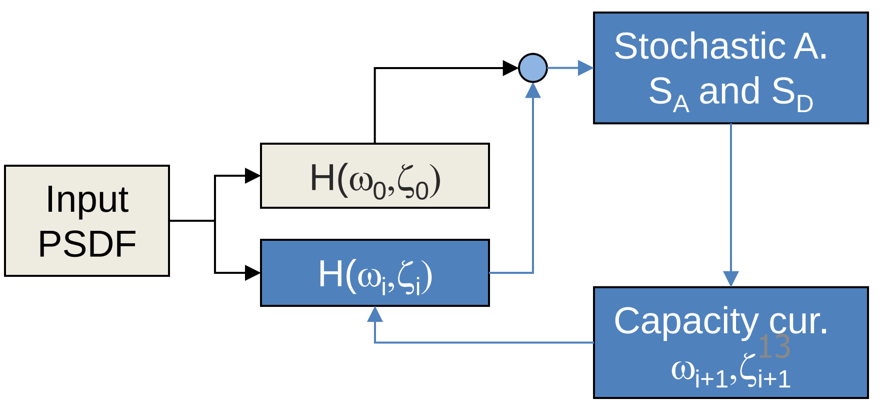
FEMA & NIBS methodology (HAZUS99) - Vulnerability

1. Evaluation of building responses through a capacity curve non linear FxD ⇒ $S_A x S_D$ Displacement Based Assessment - Response Spectra (Er) & iterative computation of the ⇒ Performance Point D_r



LNECloss alternative equivalent scheme

1. Definition of input motion ⇒ Power spectral density function (PSDF)
2. Performance Point D_r computed through an iterative linear stochastic analysis. Advantages:
   - Explicit time duration consideration
   - Non stationary strong ground motions
   - etc ... etc ...

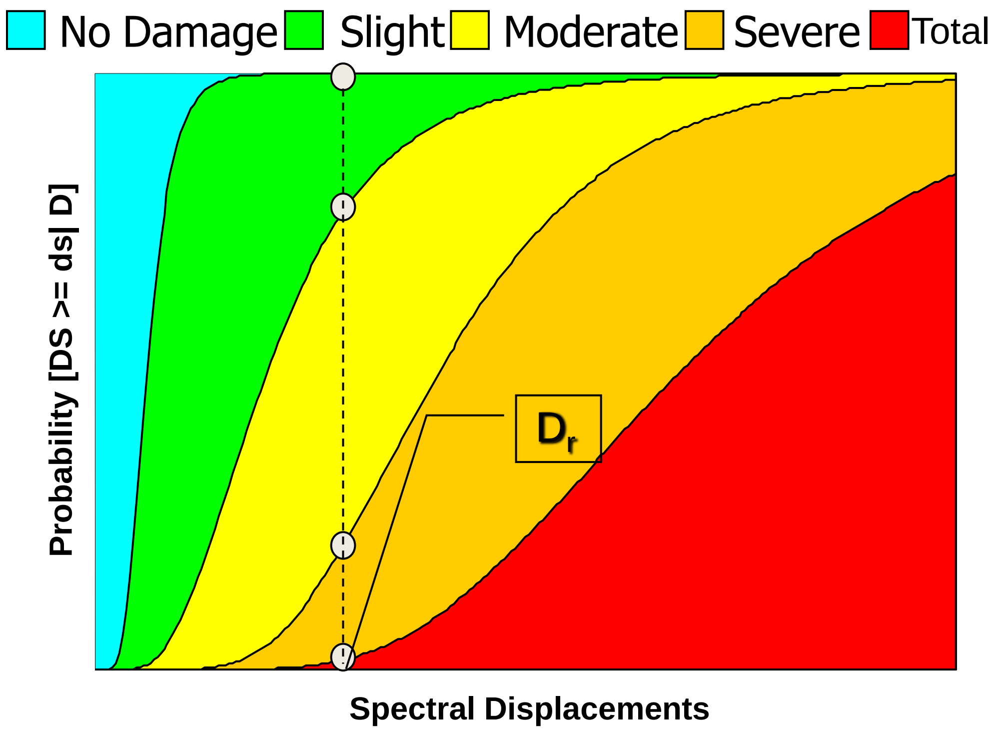


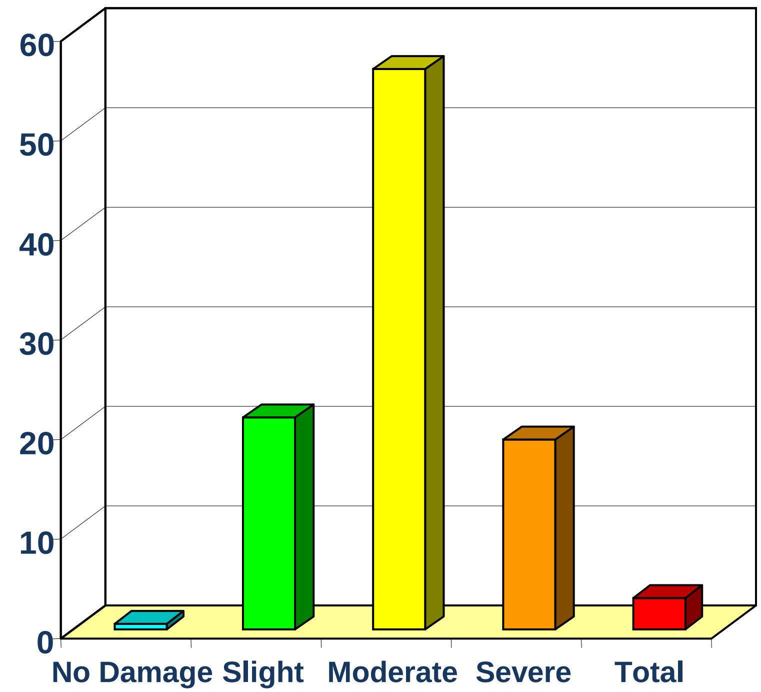
LNECloss - Seismic Scenario simulator

Fragility analysis of building typologies

FEMA & NIBS Methodology (HAZUS99 software) – FRAGILITY

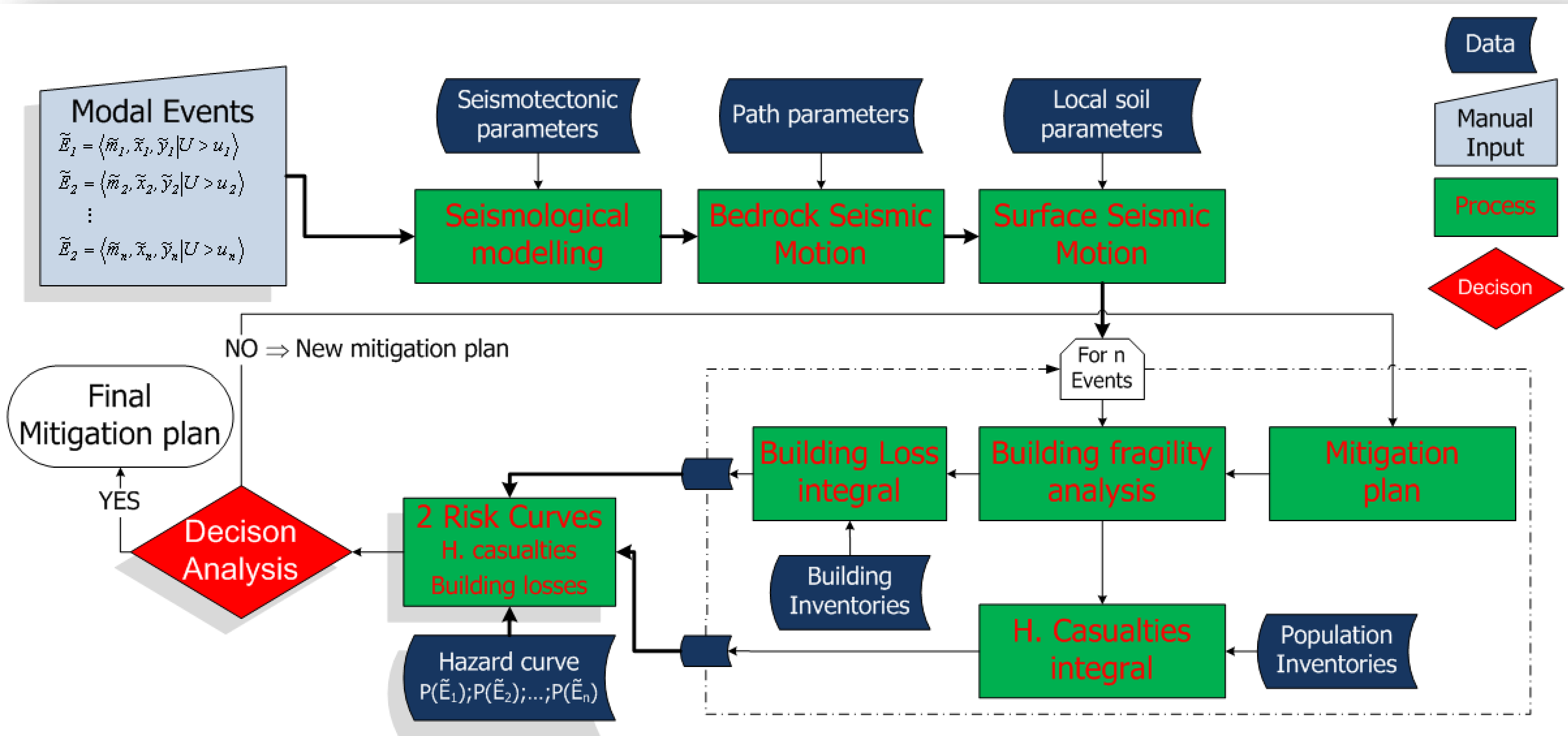
1. Introduction of the Limit Damage States
2. Fragility defined in terms of structural response and not seismic intensity





LNECloss - Seismic Scenario simulator

- Probabilistic Seismic Risk Analysis based on modal events



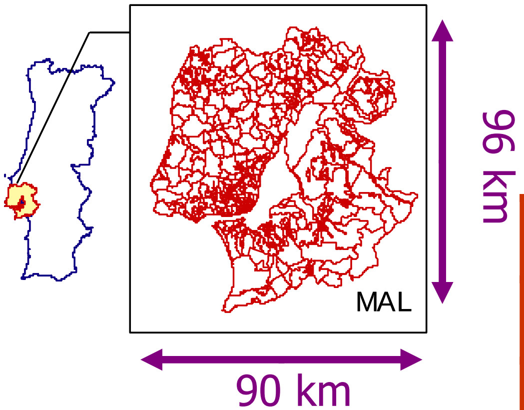
Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Choice of case study area
Metropolitan Area of Lisbon - MAL

3×10^6 inhabitants

Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Case study area: Metropolitan Area of Lisbon - MAL



Global Statistics 2001	
Parishes	277 (7%)
Geotechnical profiles	37
Number of smallest geographic divisions: parishes+ geotechnical profiles	405
Building classes	49
Residential buildings	477 170 (16%)
Dwellings	1 389 236 (29%)
Population	2 841 067 (29%)
2001 GDP	$\cong 55 \times 10^6$ € ($\cong$ 47%)

Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

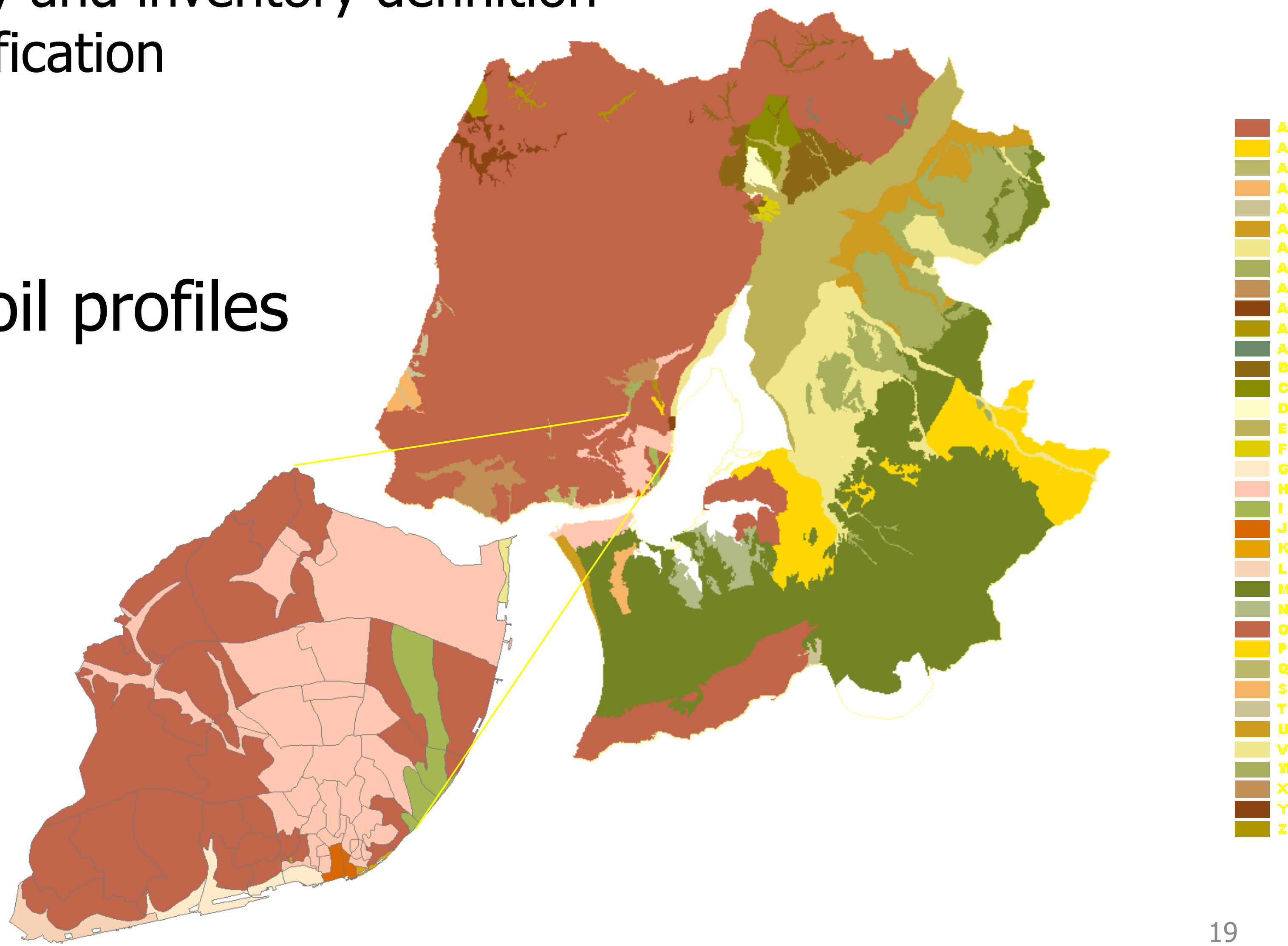
Case study area: Metropolitan Area of Lisbon - MAL

Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Vulnerability and inventory definition

- Soil classification

37 soil profiles



Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Vulnerability and inventory definition

- Soil classification

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

37

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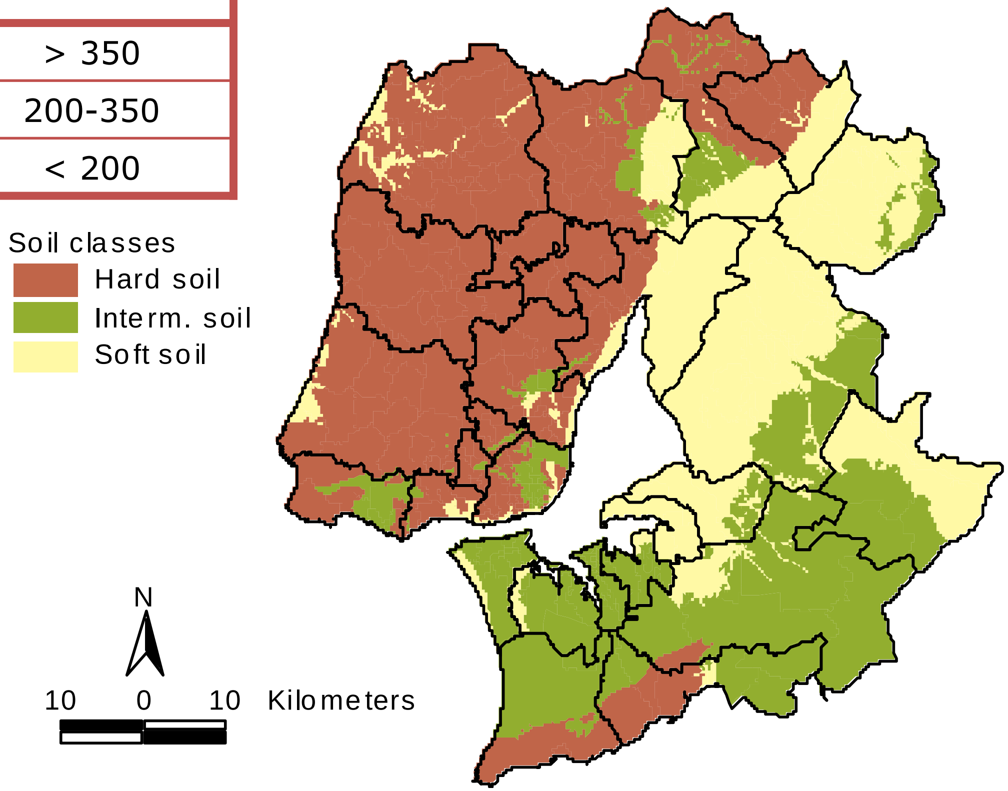
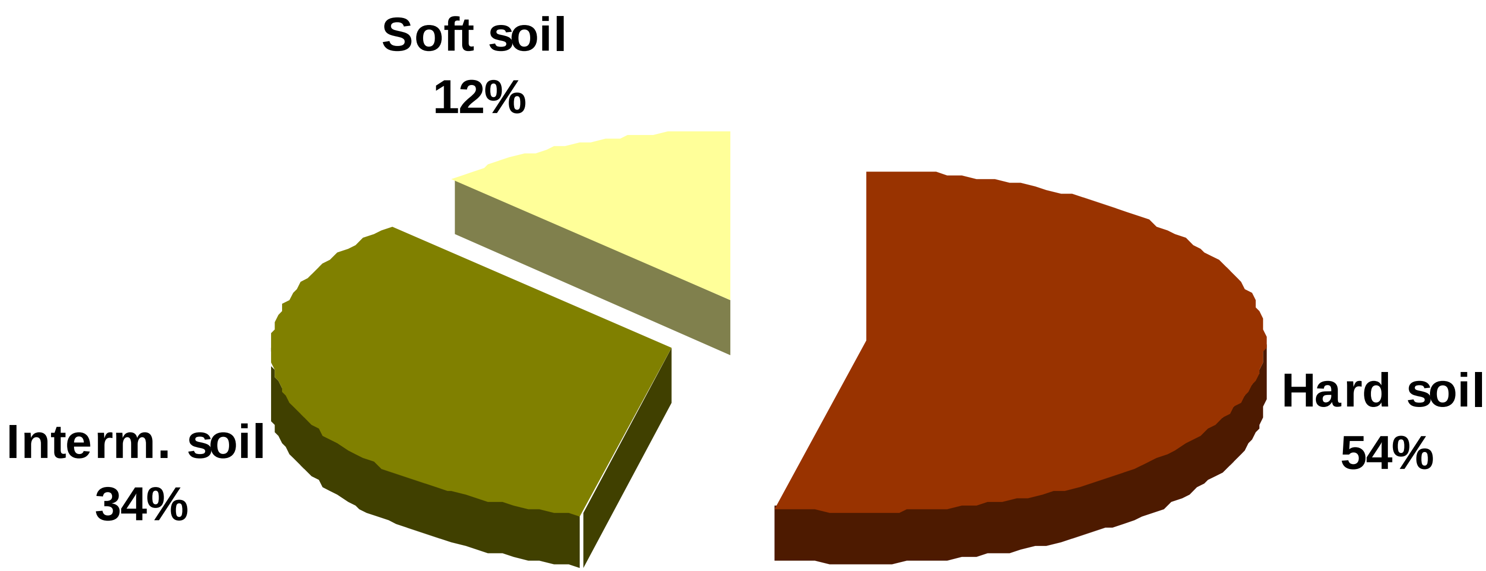


Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Vulnerability and inventory definition

- Exposure analysis by soil classification

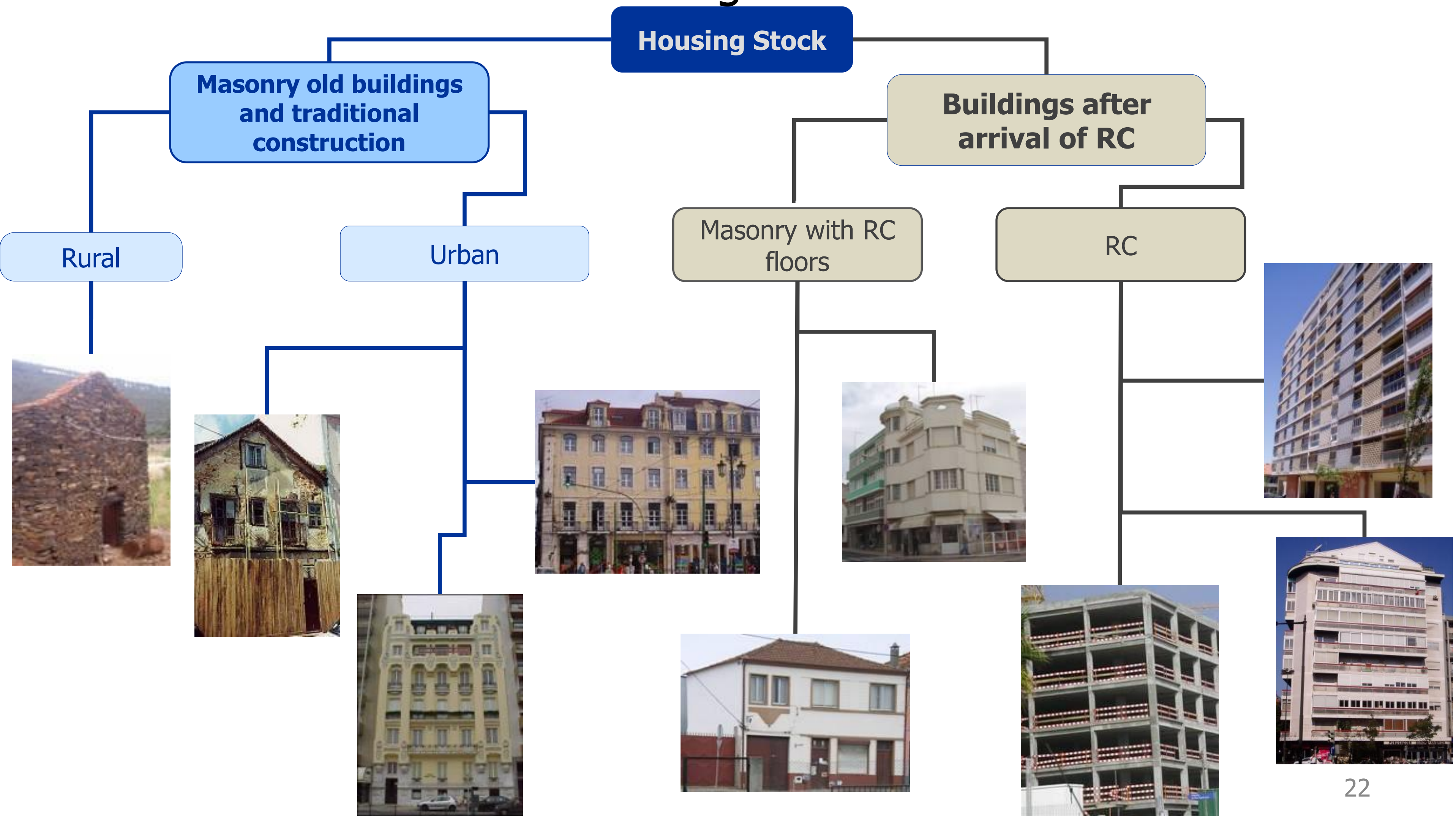
Economic values - Repair and replacement cost of the MAL residential building stock ≅ 134 000·10^6€ (<u>based on official replacement cost/m^2</u>)



Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Vulnerability and inventory definition

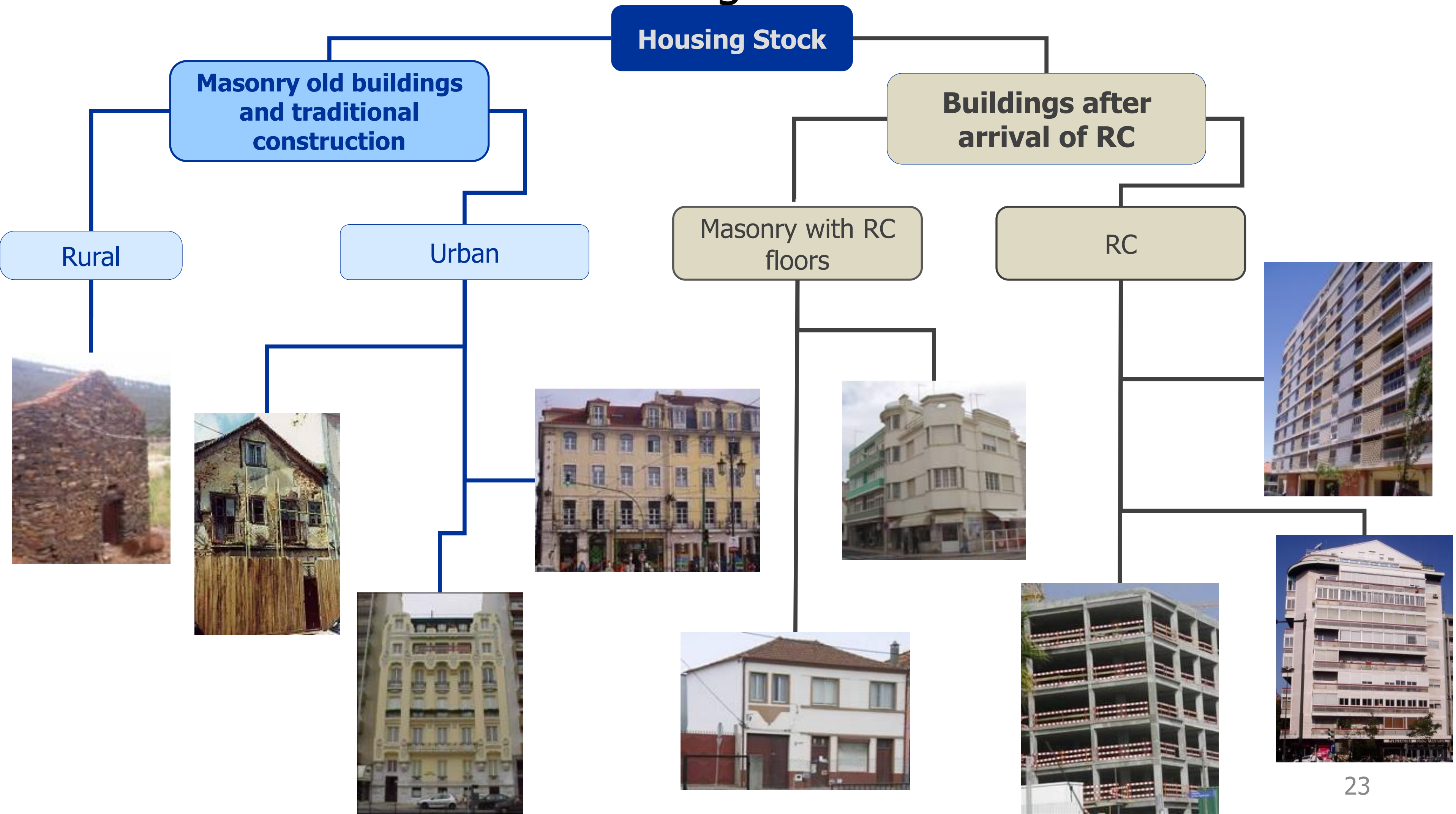
- Characterization of MAL housing stock



Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Vulnerability and inventory definition

- Characterization of MAL housing stock



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Vulnerability and inventory definition

• 7 vulnerability classes x 7 nº floors

CENSOS 315

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LNECloss 49

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

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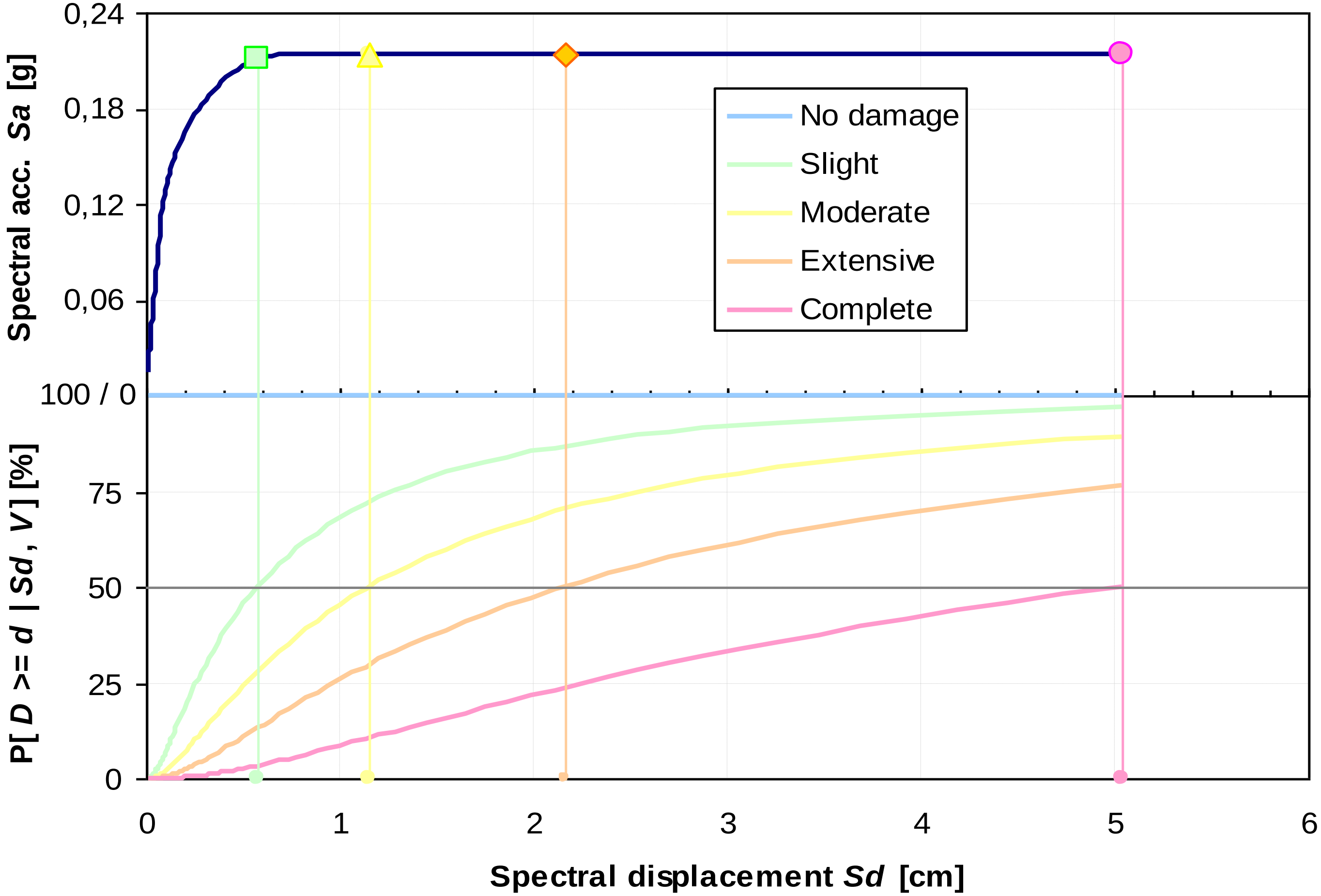
Vulnerability and inventory definition

- Capacity curves fragility distributions

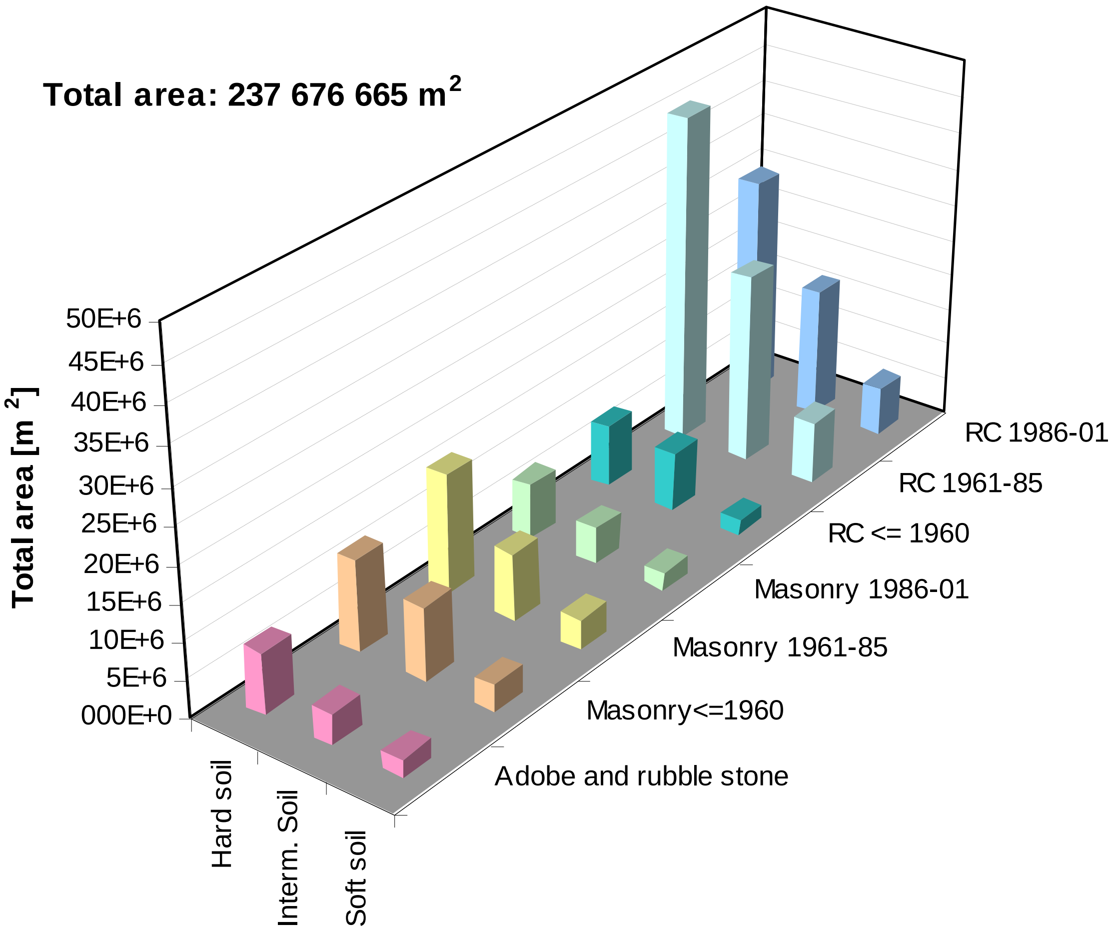
Capacity curves fragility distributions where adopted for 49 Typologies



Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Vulnerability and inventory definition

- Exposure analysis

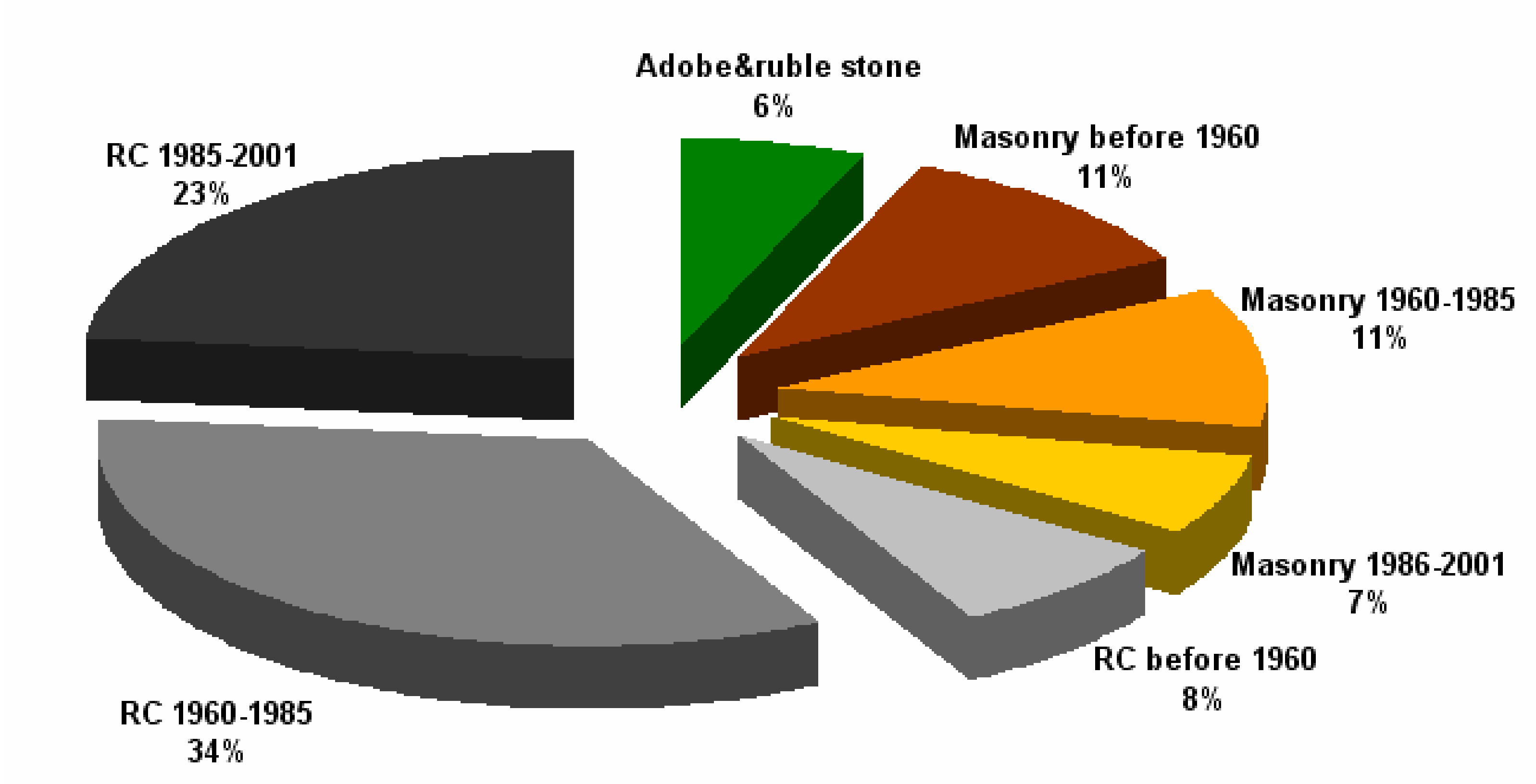


Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Vulnerability and inventory definition

- Exposure analysis

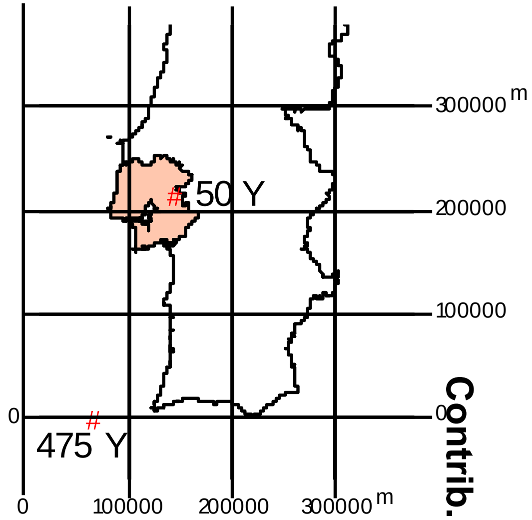
Economic values - Repair and replacement cost of the MAL residential building stock ≅ 134 000·10⁶€ (<u>based on official replacement cost/m²</u>)



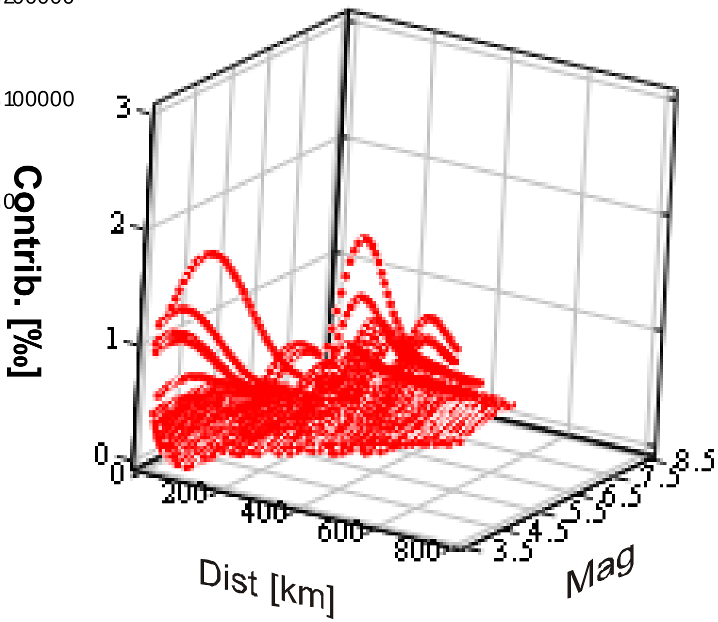
Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Seismic input definition

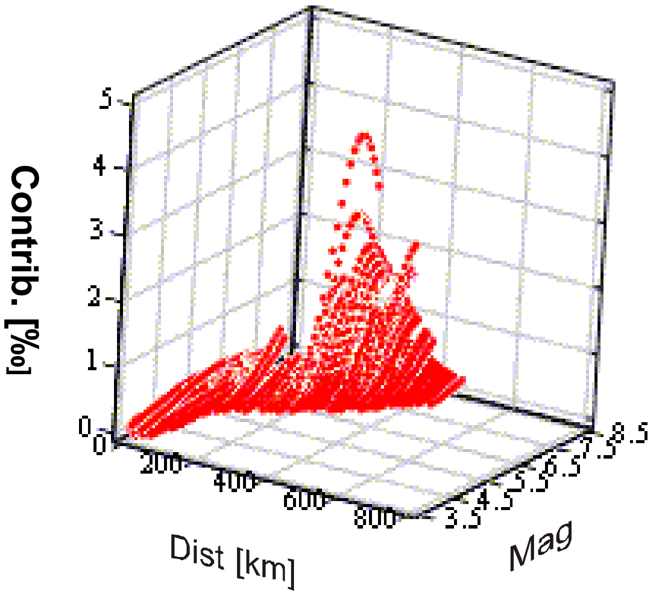
- Earthquake scenario based on PSHA disaggregation



50 years RP



475 years RP



Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Seismic input definition

- Earthquake scenario based on PSHA disaggregation

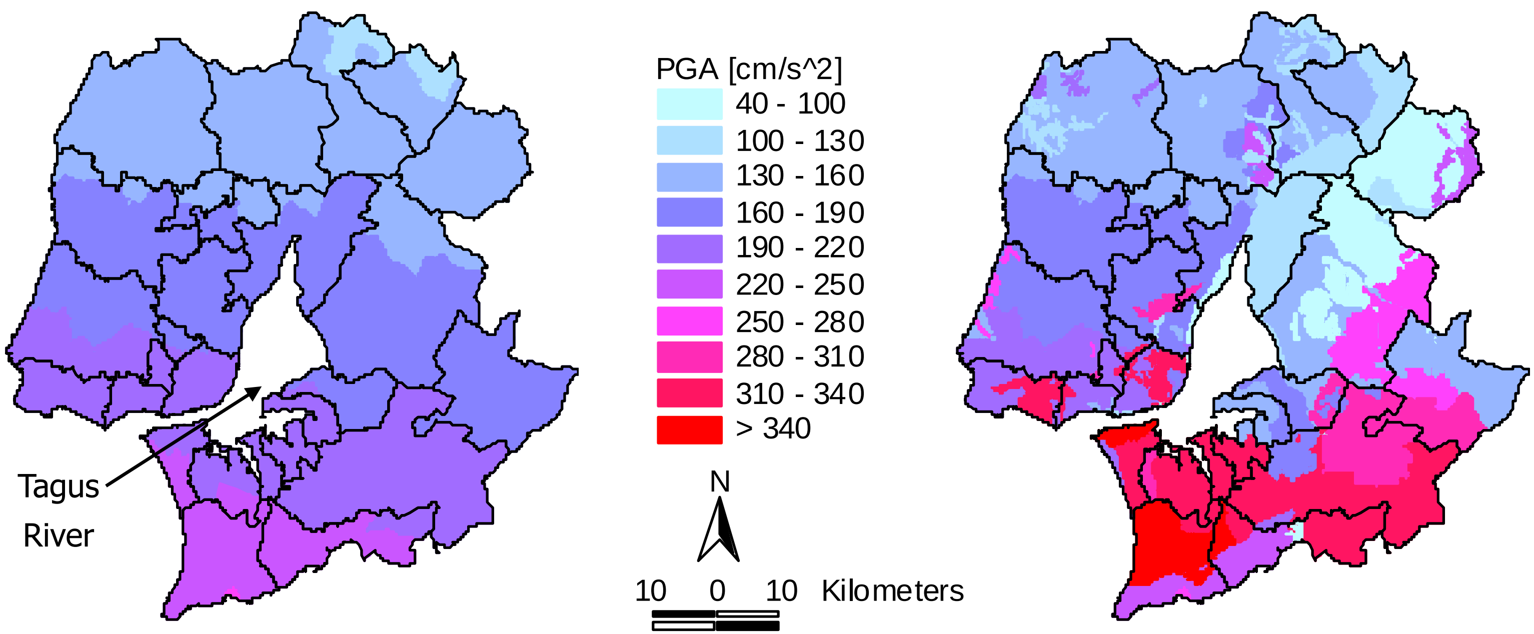
Return Period	Location		Magnitude
	X [Km]	*Y [Km]*	*M*
95	**67.3**	**-4.4**	**7.2**
200	**67.3**	**-4.4**	**7.6**
475	**67.3**	**-4.4**	**7.9**
700	**67.3**	**-4.4**	**8.1**
975	**67.3**	**-4.4**	**8.2**
2000	**67.3**	**-4.4**	**8.4**
5000	**67.3**	**-4.4**	**8.5**

Case Study of Probabilistic Risk Analysis

Shake Maps Scenarios

- Modelling earthquake scenario

475 years RP scenario



PGA for bedrock

PGA considering soil amplification

Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Loss estimation

- Loss estimates for actual region

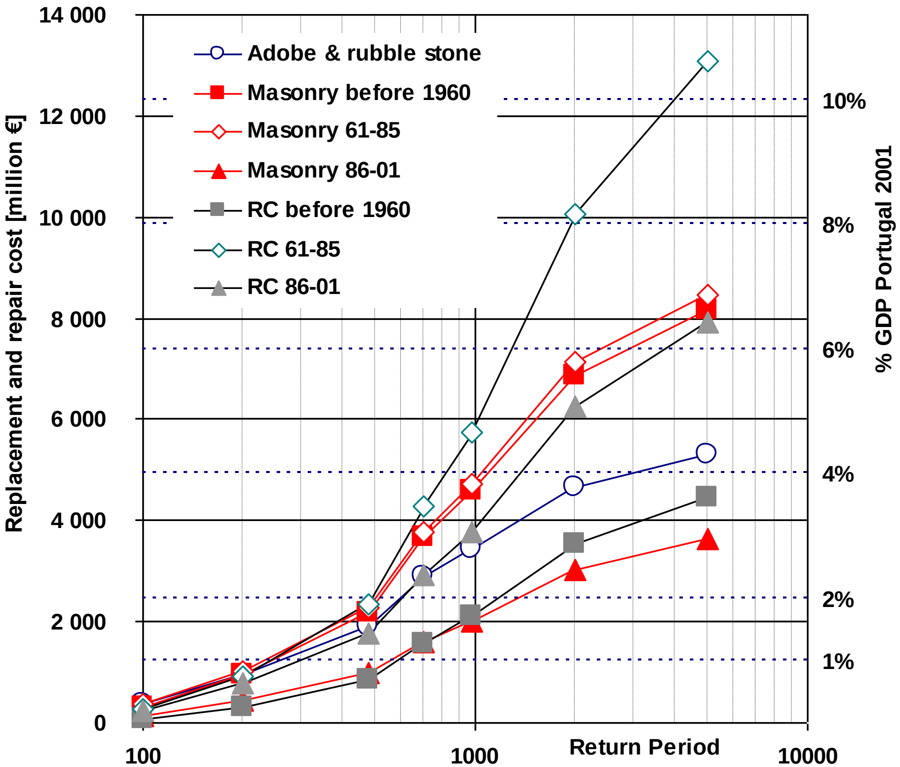
$$E(L \mid u) = Ne_T \cdot \sum_d \sum_v A_v \cdot DR_d \cdot P_D(D = d \mid u) \cdot P_V(V = v)$$

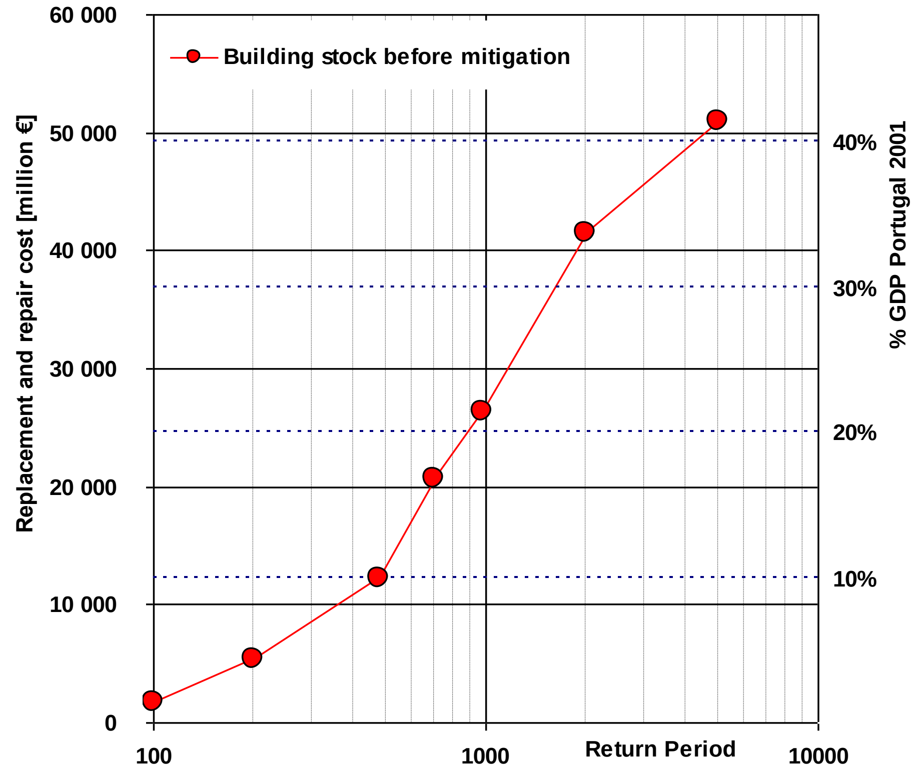
Ne_T - total number of buildings in the studied region
A_v - is the average floor area of with vulnerability v
$P_D(D = d \mid u)$ - is the damage probability matrix
$P_V(V = v)$ – existing relative frequency of v typological class in the studied region
DR_d – Damage ratio which defines the % of loss of a building that are in damage state d
$E(L|u)$ x replacement cost/m^2 = Loss in terms of replacement cost

Damage state	Damage Ratio, DR_d [%]
Slight	2
Moderate	10
Severe	50
Complete	100

Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

- Loss estimates for region without mitigation





Most of the loss comes from:

1. Non ductile RC buildings constructed between 1961-1985
2. Masonry buildings constructed between 1961-1985 and before 1960

60%

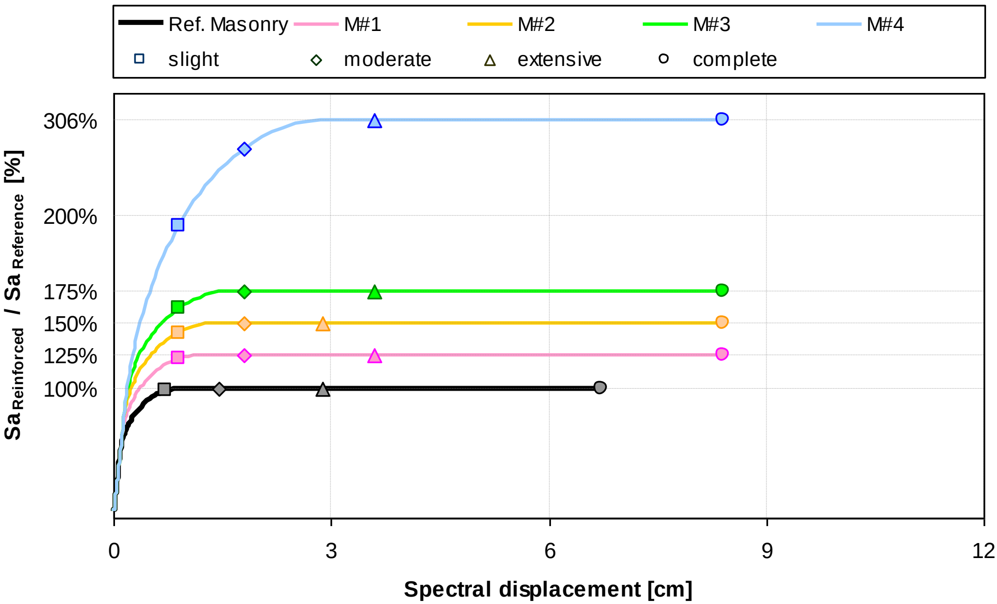
Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

- Loss estimates for modified city

Modeling strengthening interventions – Selective interventions

(*R. Pinho, 1998*)

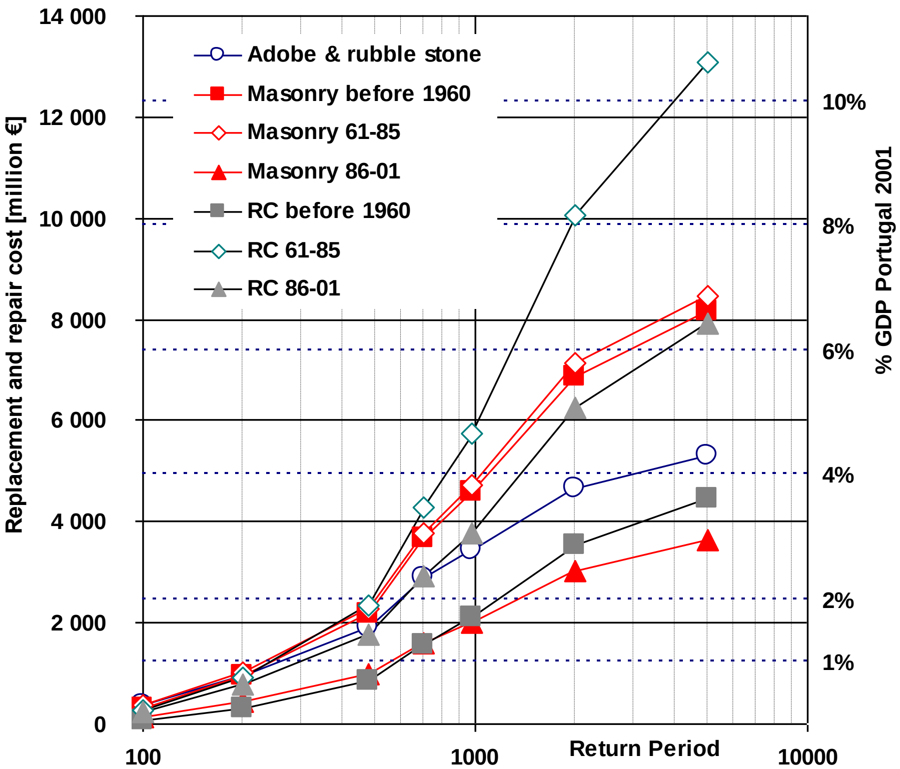
# Streng	Masonry	RC	Improvement of force capacity λ	Improvement of force capacity γ	Improvement of ductile capacity. δ_d
1	✓	✓	-	25%	25%
2	✓	✓	-	50%	25%
3	✓	✓	-	75%	25%
4	✓	✓	75%	75%	25%
5	✓	✓	-	25%	50%
6	✓	✓	-	50%	50%
7	✓	✓	-	75%	50%
8	✓	✓	75%	75%	50%
9		✓	-	25%	75%
10		✓	-	50%	75%
11		✓	-	75%	75%
12		✓	75%	75%	75%



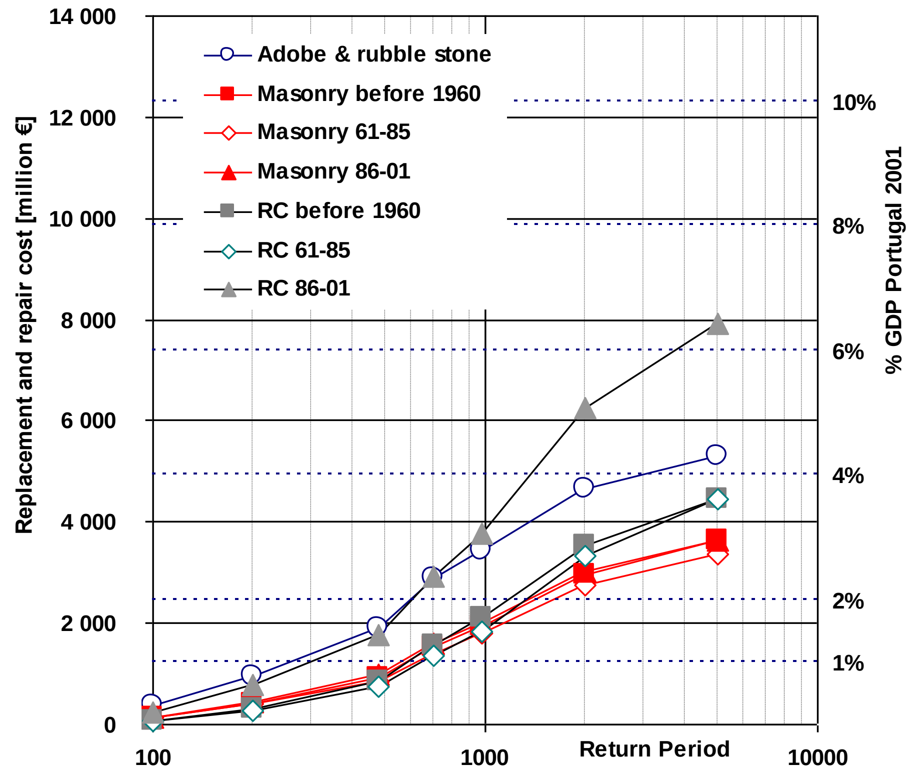
Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

- Loss estimates for modified city

Building Stock Before Str.

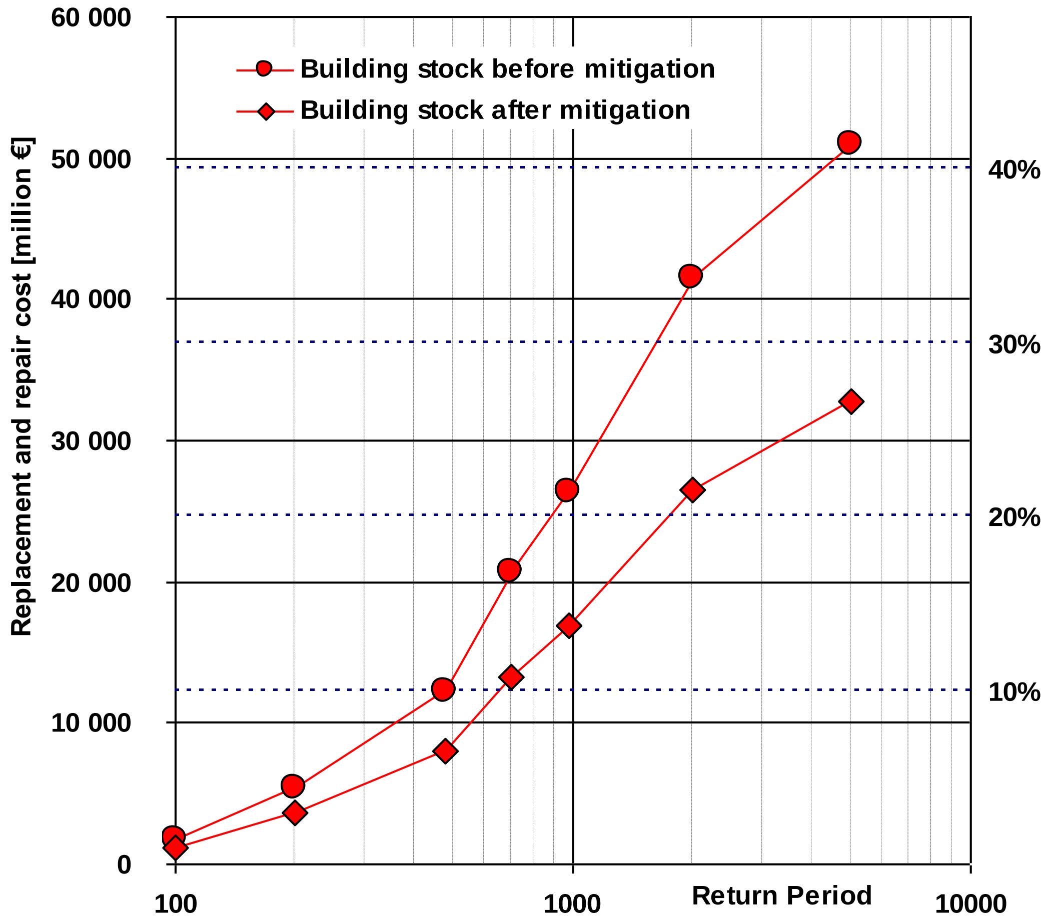


Building Stock After Str.



Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

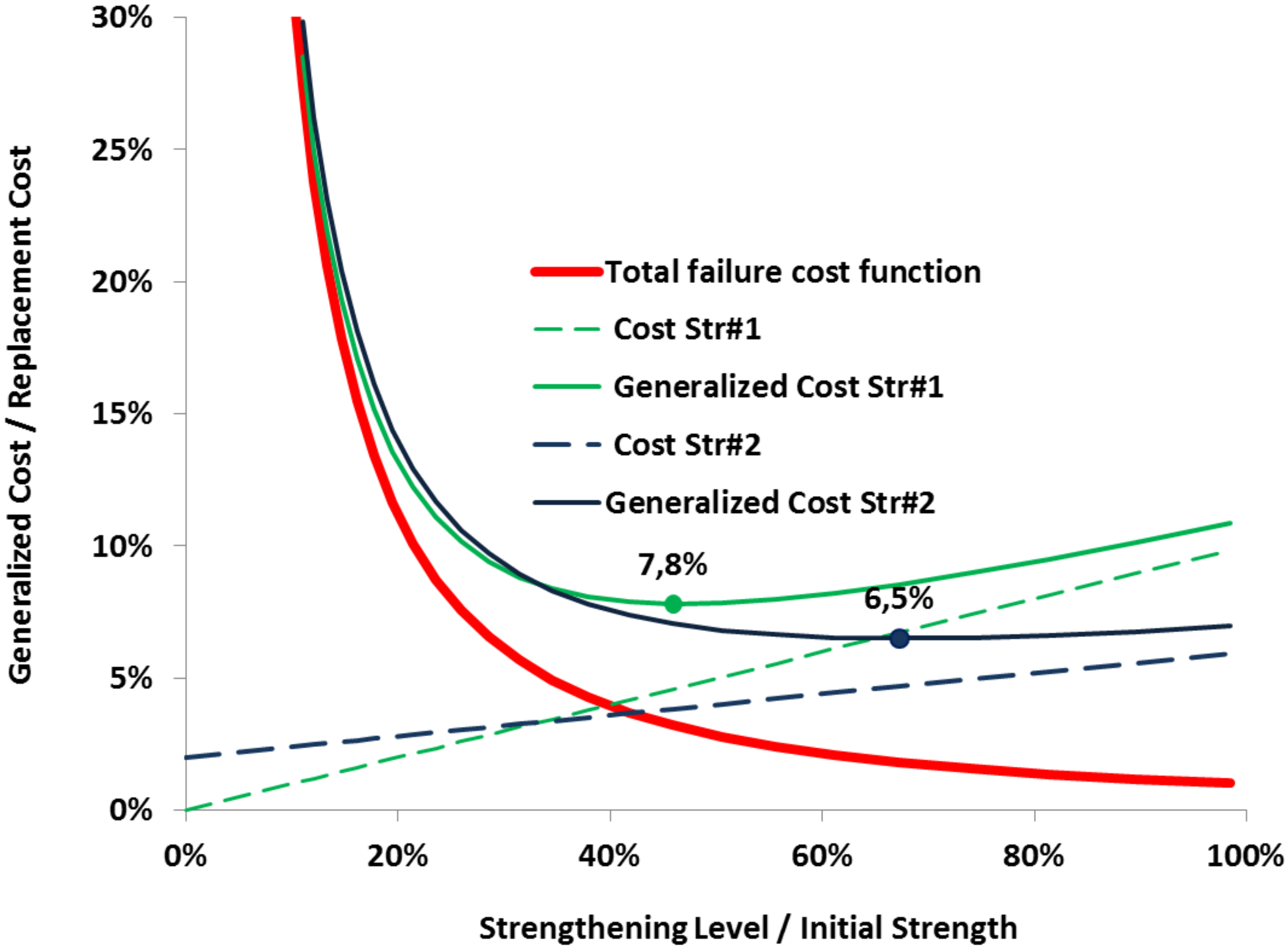
- Loss estimates for modified city



Generalized Cost-Benefit Analysis (*Ferry Borges*)

Generalized Cost – Strengthening Cost + Total failure costs

Benefits – Risk Mitigation + Resilience Increase



Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Conclusions

Economic seismic risk of the Metropolitan Area of Lisbon (MAL), in terms of replacement cost induced to the residential building stock was assessed. It was found that values varying from 1.3%, for 95 years return period, up to 38%, for 5000 years return period, of the total replacement cost of MAL residential stock buildings.

After the implementation of a given strengthening strategy, based on selective retrofitting interventions and applied to typological building classes responsible for the larger amount of the economic seismic risk (60%), it was concluded that economic risk could be mitigated by an amount of 36% for all return periods.

The mitigation of masonry buildings results in higher absolute benefits then mitigation strategies applied to RC structures, mainly when human casualties are considered. When mitigation is analyzed in relative terms, regarding to the reference situation, the selective retrofitting interventions applied to RC structures result in higher benefits.

Seismic Risk Assessment and Mitigation Strategies: the Lisbon case

Conclusions

The maps of loss estimation after the implementation of the purposed mitigation actions show that the chosen mitigation action has predominant effects on the South margin of Tagus River, where intermediate soils prevail.

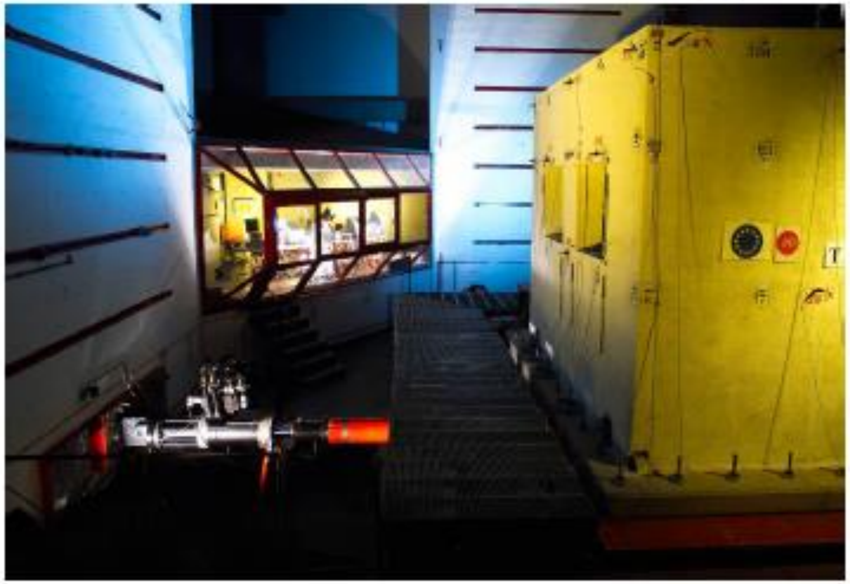
Improvements of ductile capacity play a more important role in mitigation benefits than force capacity improvement does.

Maybe explained by methodology adopted to define damage states which are exclusively based on displacement demands and capacities.

In the absence of a criterion to select the optimal intervention, like a cost-benefit analysis, upper bounds interventions, both in RC as in masonry buildings intervened, correspond to the highest benefits.


Experimental research on seismic strengthening of
buildings in Portugal.

Experimental research in seismic strengthening of buildings in Portugal.



Thanks for your attention

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