Valutazione delle prestazioni sismiche di un edificio e criteri per il consolidamento

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IUSS Pavia

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MITIGAZIONE DEL RISCHIO SISMICO

Uso ottimale delle risorse
Terremoti di progetto e livelli prestazionali
Parametri di valutazione
Stime delle perdite

Uso ottimale delle risorse

Il problema impossibile: necessità e risorse.

Schemi di priorità: adeguare le prestazioni alle risorse disponibili nei in tempi ragionevoli.

Il costo per raggiungere una prestazione differisce da caso a caso, anche in presenza dello stesso livello di rischio, in funzione delle possibili scelte per il rinforzo.

La relazione tra costo di intervento e livelli di prestazione è rappresentabile con funzioni a gradini, può quindi risultare irrazionale, in termini di rapporto costi-benefici, perseguire un livello di prestazione determinato a priori.

Scelte di priorità:

a) Pericolosità
b) Rischio
c) Riduzione del rischio
d) Rapporto tra costo e riduzione del rischio

Terremoti di progetto e livelli prestazionali

Vision-2000 (SEAOC (1995)

Performance Level	Performance Description	Storey Drift (%)
Fully Operational	Continuous service, negligible damage	**0.2 %**
Operational	Safe for occupancy, light damage, repairs for non-essential operations	**0.5 %**
Life Safety	Moderate damage, life safety protected, repair possible but may be impractical	**1.5 %**
Near Collapse	Severe damage, collapse prevented, falling of non-structural elements	**2.5 %**

Parametri di valutazione

(Mitrani-Reiser (2007))

Danno strutturale	**deformation damage index (i.e. inter-storey drift)**
Danno non strutturale	**peak transient drift (partitions, glazing)** **peak floor diaphragm acceleration (acoustical ceilings, sprinklers),** **peak ground acceleration (elevators)** **ratio of damaged area (paint)**

Spostamenti e deformazioni rivestono un ruolo fondamentale

EAL - Expected annual loss

Il costo medio annuo da sostenere per riparare i danni e coprire le perdite indotte da eventi sismici

Per edifici in CA, progettati secondo norme mederne:

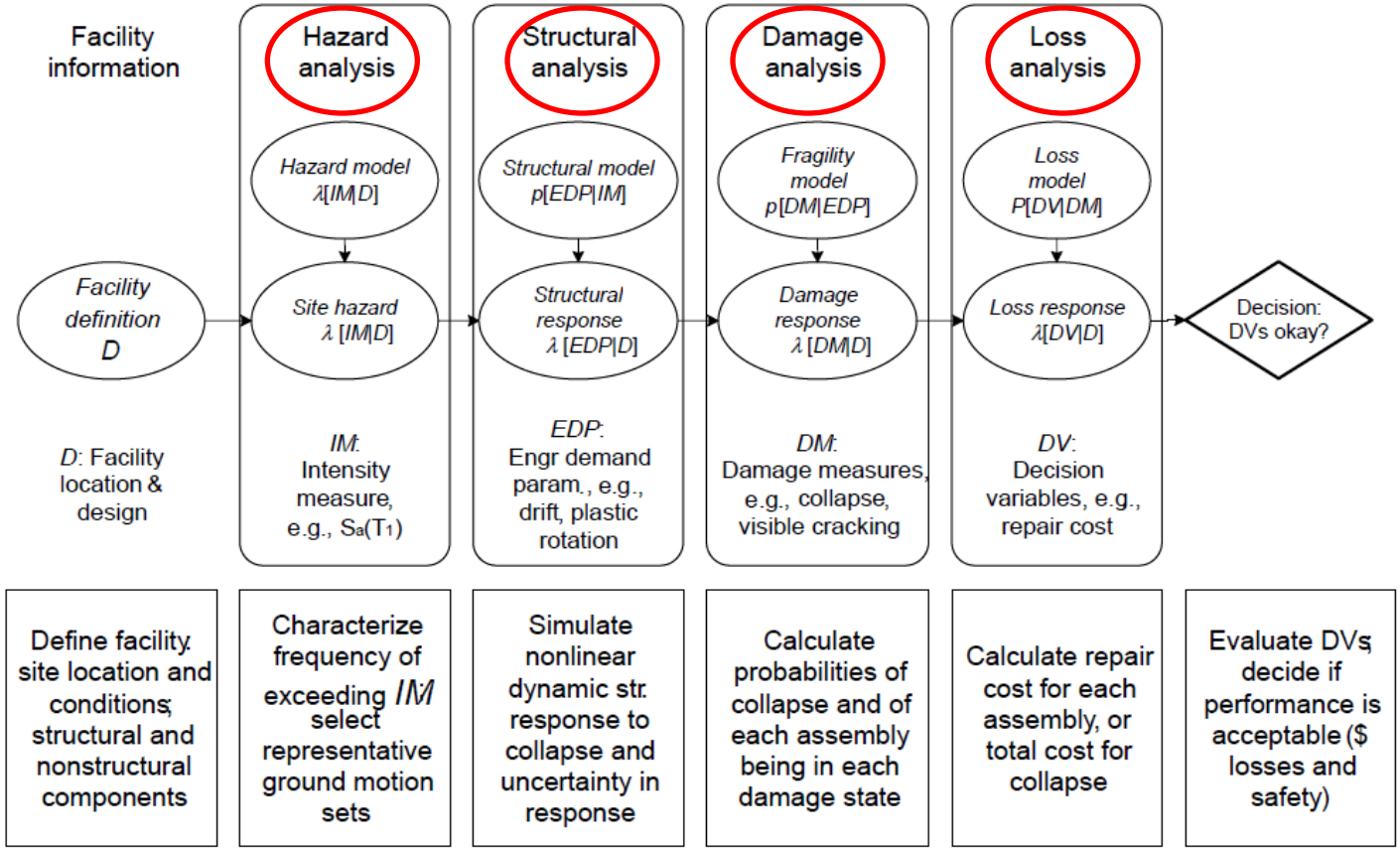
EAL tra 0.5 e 1 % del costo di ricostruzione

Per edifici costruiti in assenza di norme simsiche:

EAL > 2.5 % del costo di ricostruzione

"Performance-based assessment"

$$\lambda[DV \mid D] = \iiint p[DV \mid DM, D]\, p[DM \mid EDP, D]\, p[EDP \mid IM, D]\, \lambda[IM \mid D]\, dIM\, dEDP\, dDM$$

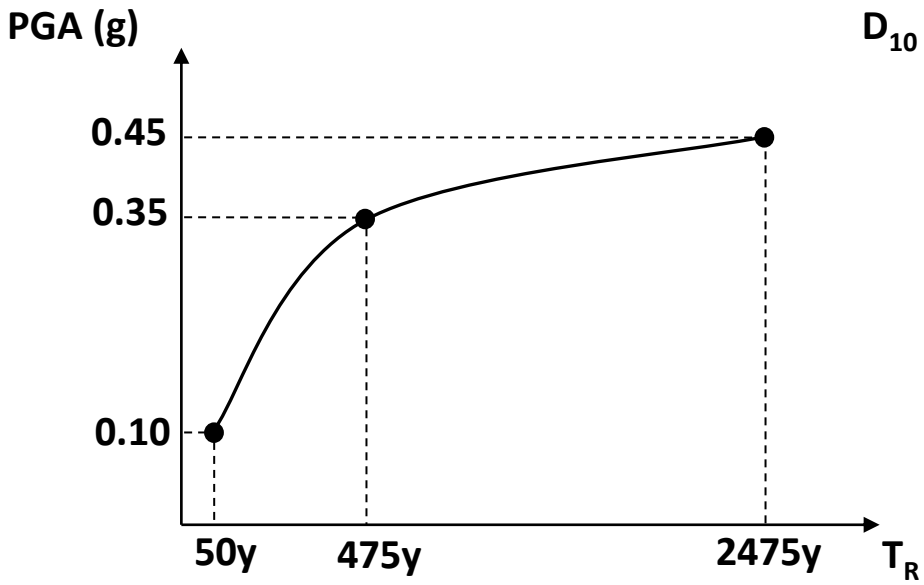


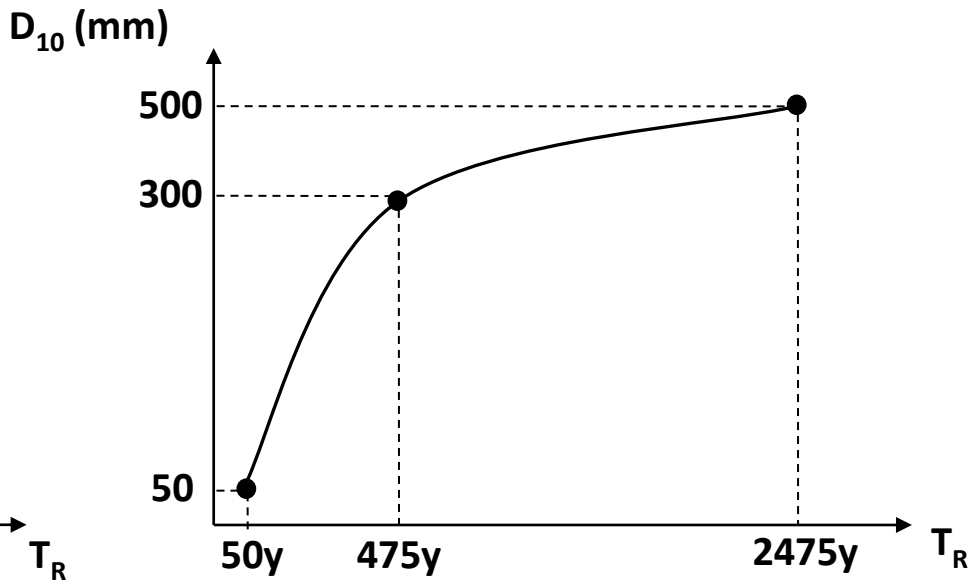
PEER methodology

Dal sito alla pericolosità:
Qual'è la probabilità che Sa(T) sia uguale ad 1.0g ?

Parametri e analisi di pericolosità

to estimate an intensity measure of an earthquake expected with a given occurrence, (i.e. with a given yearly probability of exceedence or average return period).

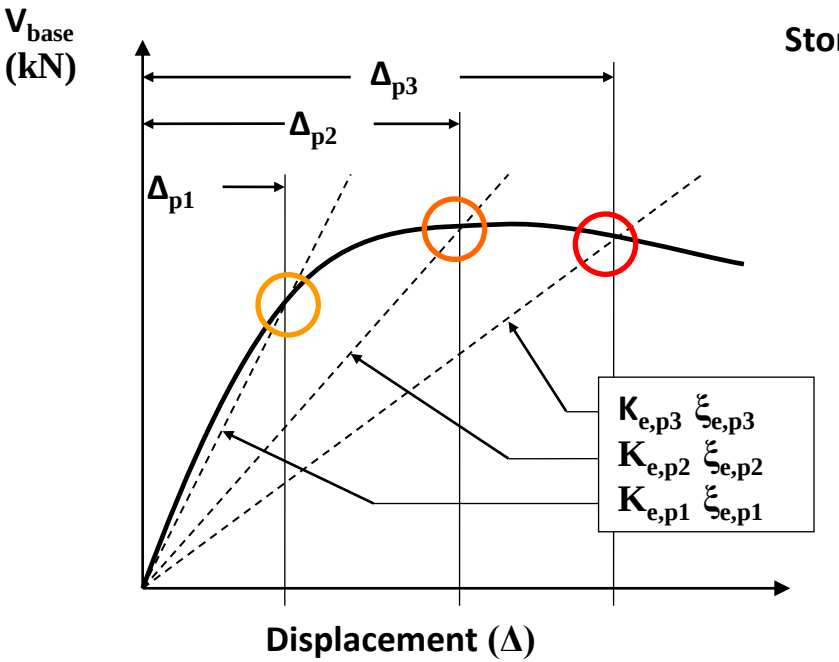


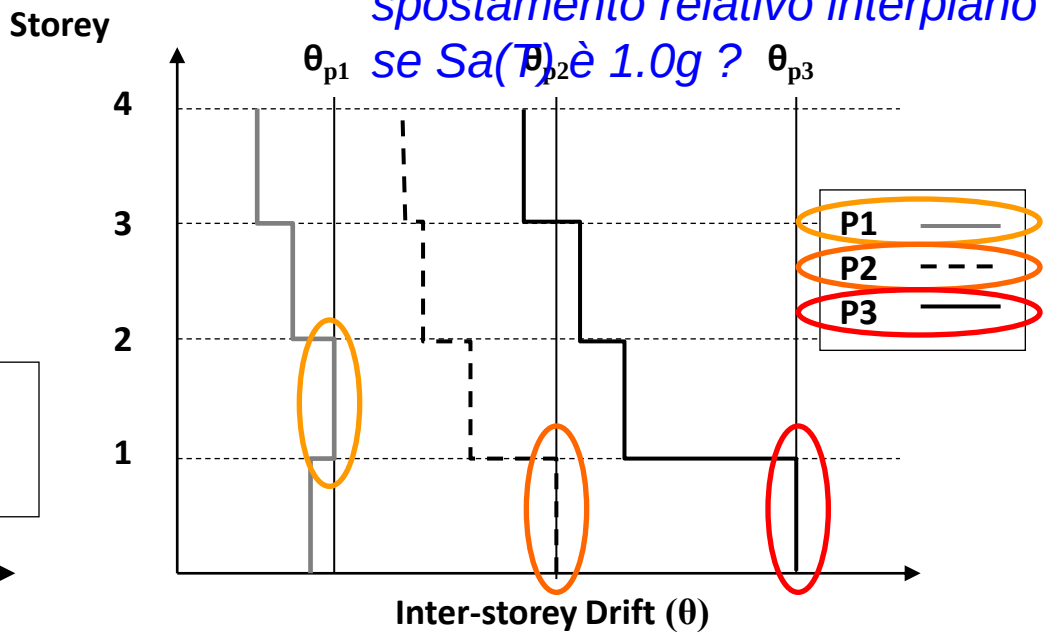


PGA or D_{10} + spectral shape

Analisi strutturale

Dalla pericolosità a parametri di risposta:
Qual'è il più probabile spostamento relativo interpiano se Sa(T) è 1.0g ?



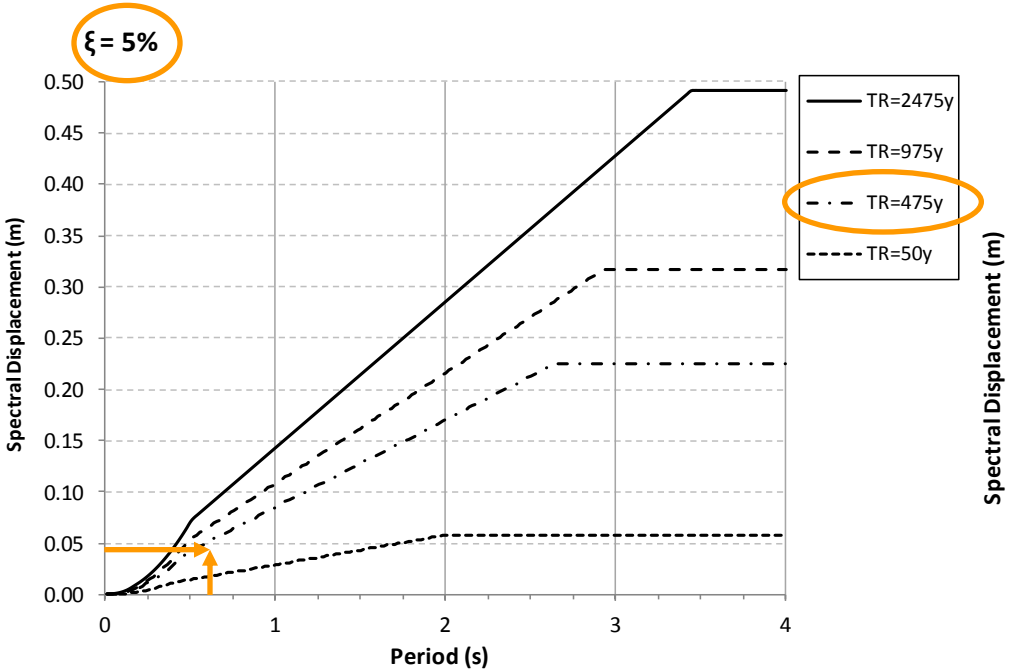


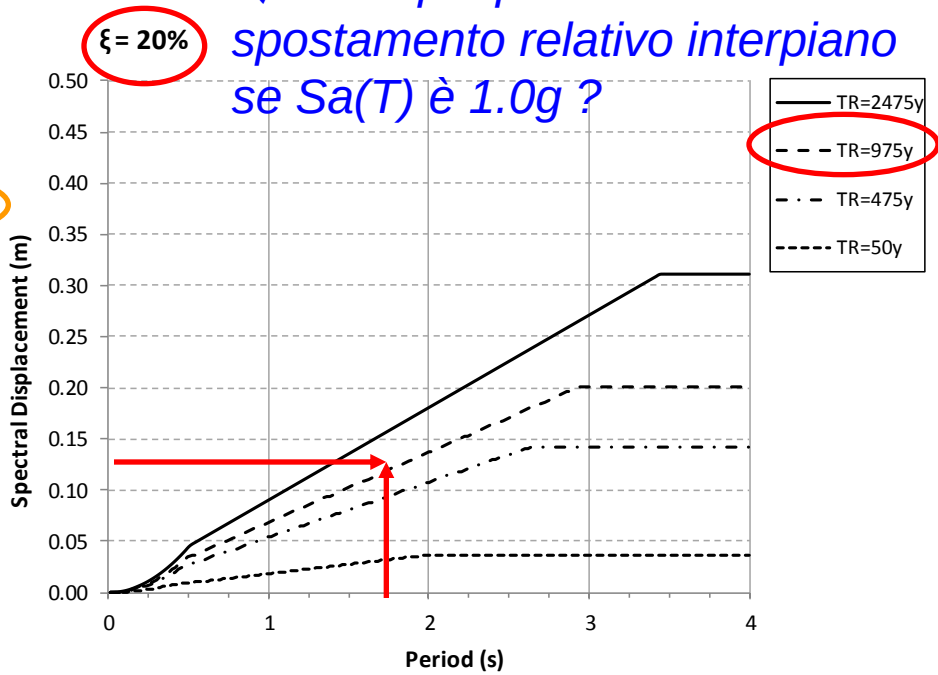
Domanda tradizionale:
"Qual'è la risposta attesa per un certo livello di moto alla base"

Domanda razionale:
"Qual'è il livello di moto alla base che induce una determinata prestazione"

Analisi strutturale

Dalla pericolosità a parametri di risposta:
Qual'è il più probabile spostamento relativo interpiano se Sa(T) è 1.0g ?





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Analisi strutturale

Dalla pericolosità a parametri di risposta:
Qual'è il più probabile spostamento relativo interpiano se Sa(T) è 1.0g ?

Step changes ⇒

hazard — **smooth functions**
performance — **abrupt changes: stiffness or local/global failure**

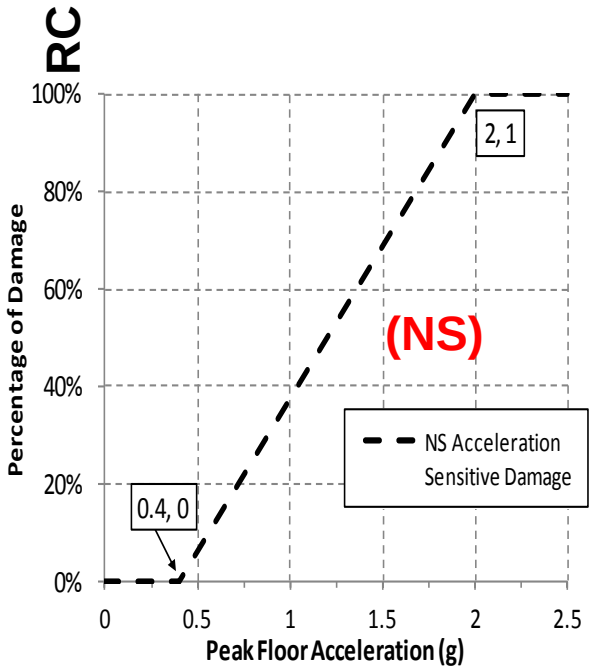
- the definition of a given yearly probability of exceedence is conventional
- the association of a performance to physical events is possible and desirable
- the economical resources required to reach a given performance are normally changing with finite steps inducing discontinuities in any cost – benefit function.

Domanda tradizionale:
"Qual'è la risposta attesa per un certo livello di moto alla base"

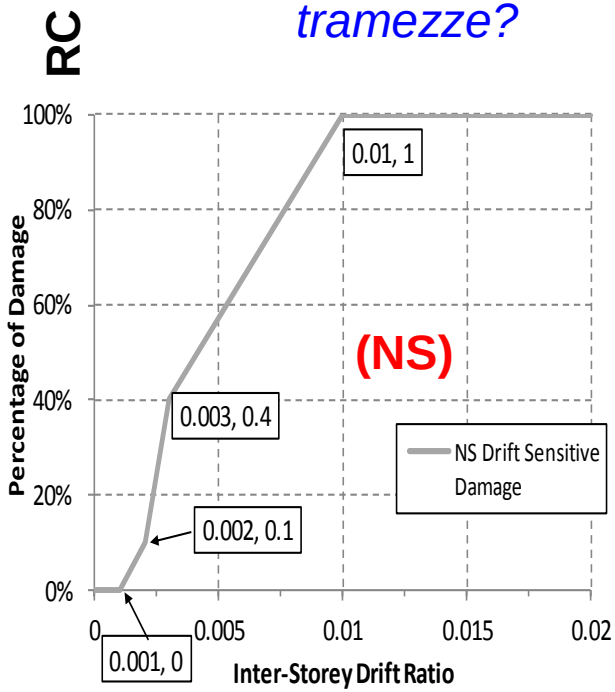
Domanda razionale:
"Qual'è il livello di moto alla base che induce una determinata prestazione"

Analisi del danno atteso

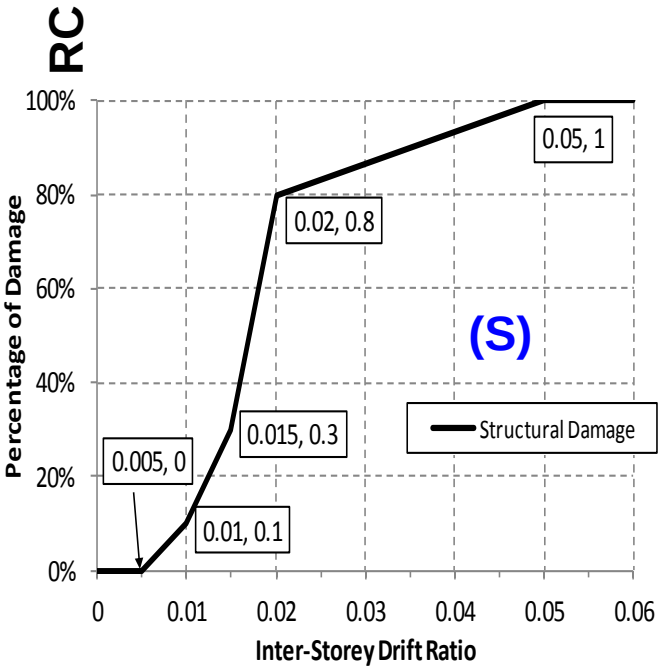
Dalla risposta al danno:
Se lo spostamento è 1% qual'è il danno alle tramezze?



PFA



Δ_i



Δ_i

Inter-storey drift (Δ_i)
Peak floor acceleration (PFA)

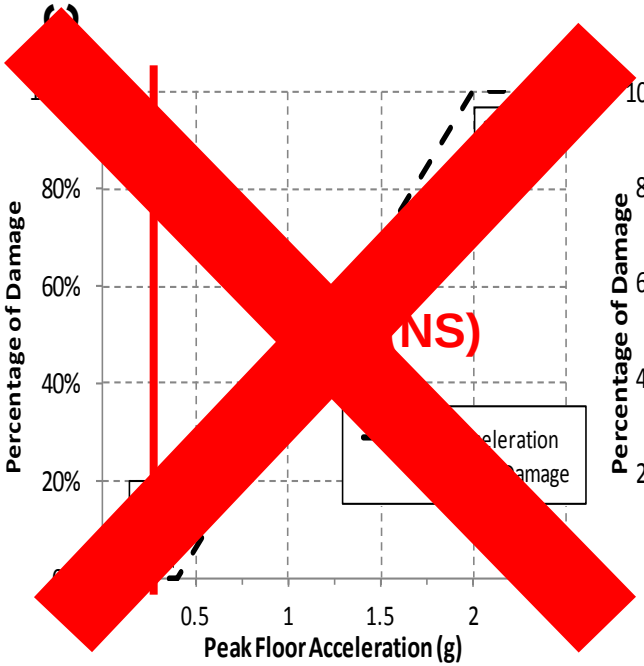
Structural damage (S)
Non structural damage (NS)

As a percentage of cost of reconstruction (%RC)

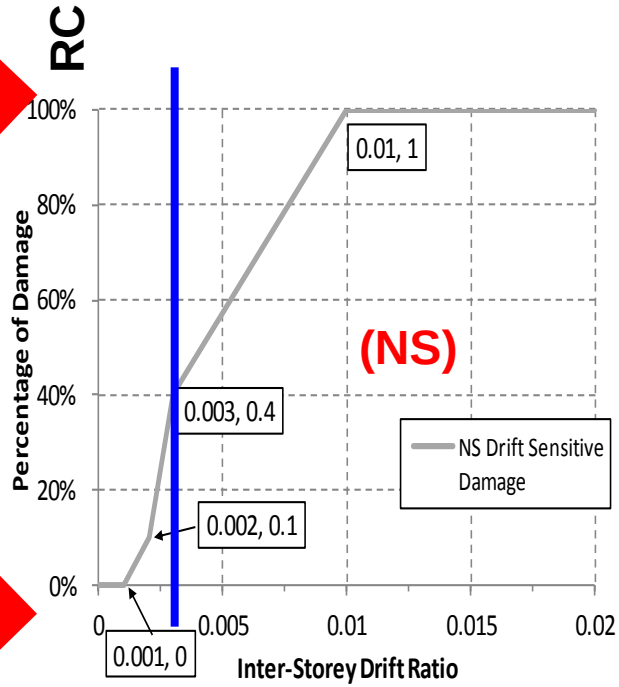
L'isolamento alla base elimina il danno?

Assume a base shear cut at 10% of g ⇨ Peak floor acc. 25% of g?

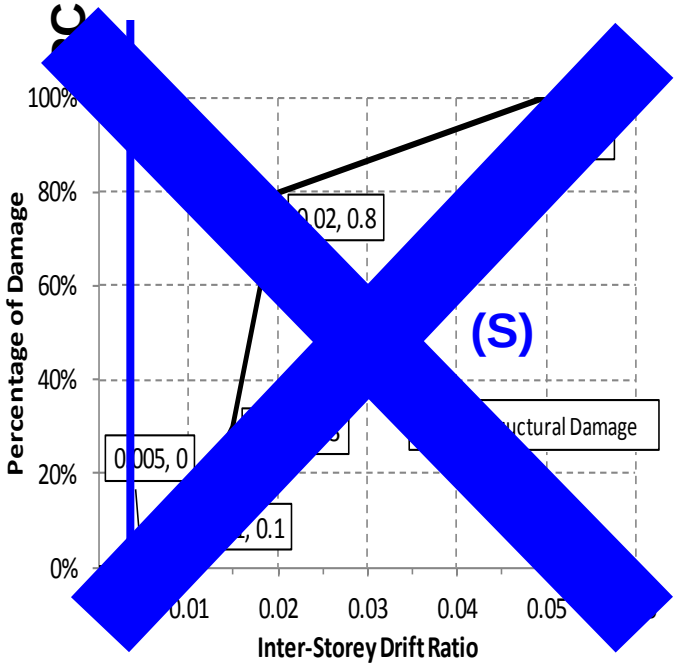
Assume consequently a maximum interstorey drift of 0.3 %



PFA

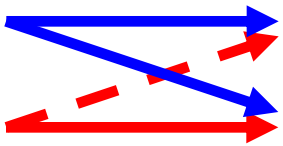


Δ_i



Δ_i

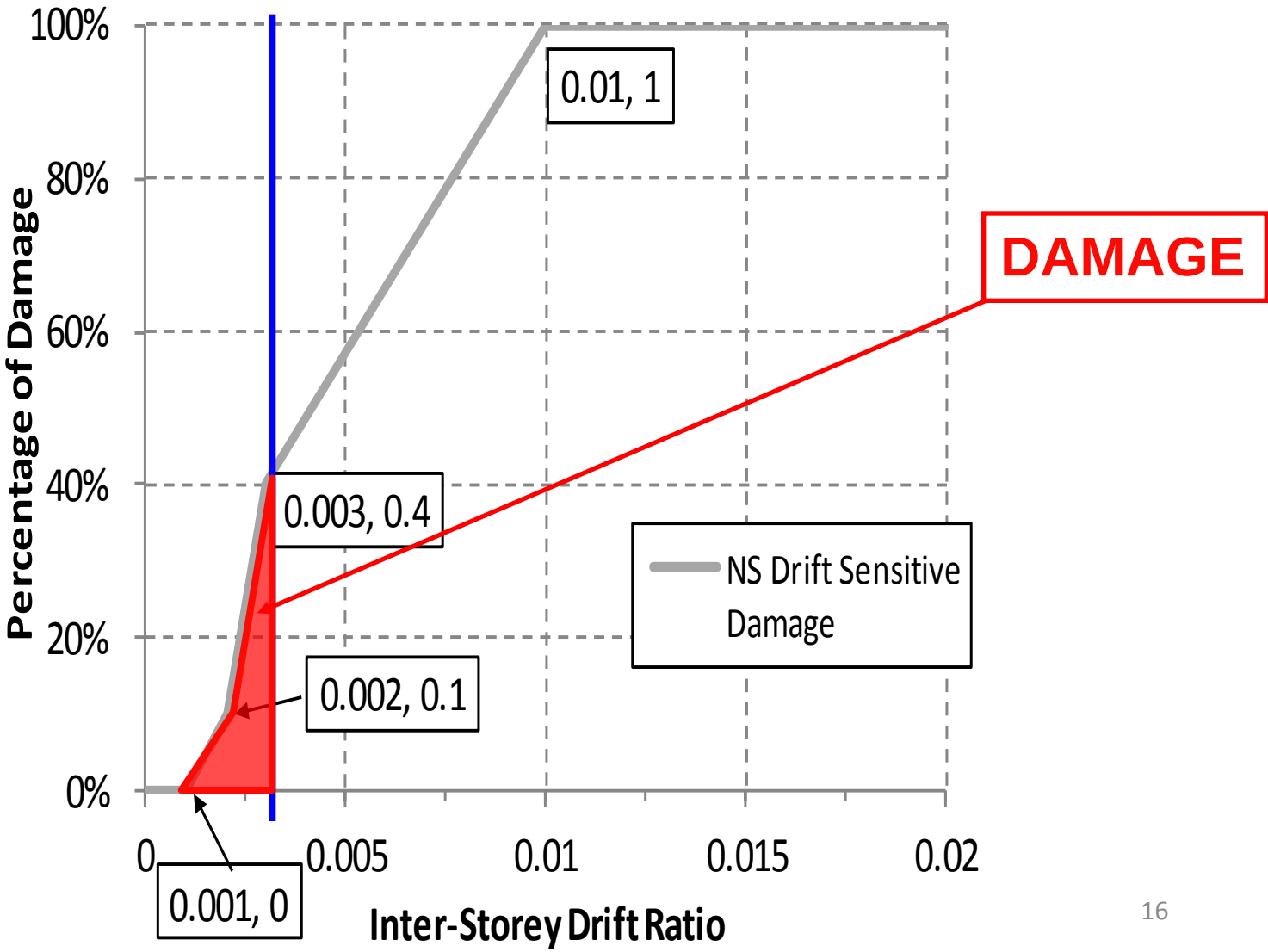
Inter-storey drift (Δ_i)
Peak floor acceleration (PFA)



Structural damage (S)
Non structural damage (NS)

As a percentage of cost of reconstruction (%RC)

L'isolamento alla base limita e controlla il danno



Dal danno alle perdite: Qual'è il costo di riparazione associato ad un certo livello di danno?

Analisi delle perdite

E.G.:

Assume that cost of repair is proportional to damage, associating 75% of the value of the building to non structural content and 25 % to structures

Yes, but:

Decision imply to evaluate alternative strengthening measures, associating to each one of them an evaluation of present cost and future benefit

SCELTE ALTERNATIVE PER IL RINFORZO E L'ADEGUAMENTO

Modification of damage and collapse modes
- ***Strengthening elements***
- ***Locally increasing the deformation capacity***
- ***Inserting additional elements***

Introduction of isolation systems
- ***Capacity protecting the existing structures***
- ***Procedures for devices introduction***

Reduction of displacement demand
- ***Adding damping***
- ***Introducing tuned masses***

Local problems in force transfer

Combination of different strengthening approaches

G. M. CALVI, Choices and Criteria for Seismic Strengthening. *Journal of Earthquake Engineering*, 2013

Modification of damage and collapse modes

Strengthening elements/ Locally increasing the deformation capacity

carbon fibres wrapping to increase the shear strength in a column
cost about 810 €/el

concrete casting to increase shear and flexural strength
cost about 400 €/el

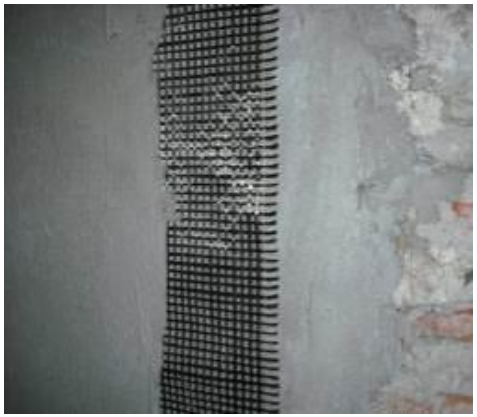
steel encasing for the same purpose

cost about 650 €/el

Rough average cost, to be used for a first estimate about 200 € per meter of beam or column

Modification of damage and collapse modes

Inserting additional elements



- **Steel bracings**
- **Shotcrete**
- **Concrete walls**

Introduction of isolation systems

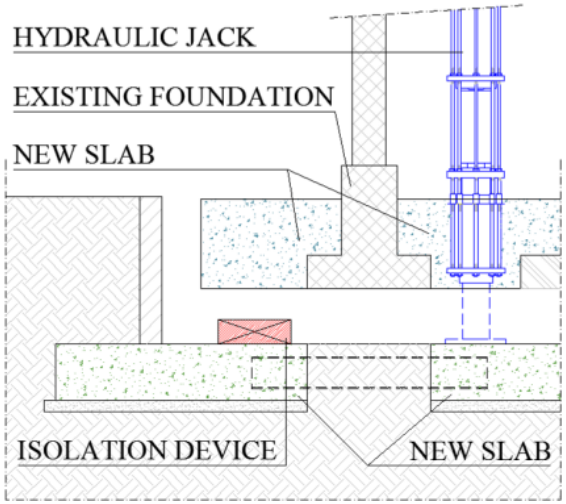
Capacity protecting the existing structures
Procedures for devices introduction

Introduction of an isolator: column cutting, temporary support, fixing

cost around 150 €/m² of building plan
additional measures around 150 €/m²

Introduction of isolation systems

Capacity protecting the existing structures
Procedures for devices introduction

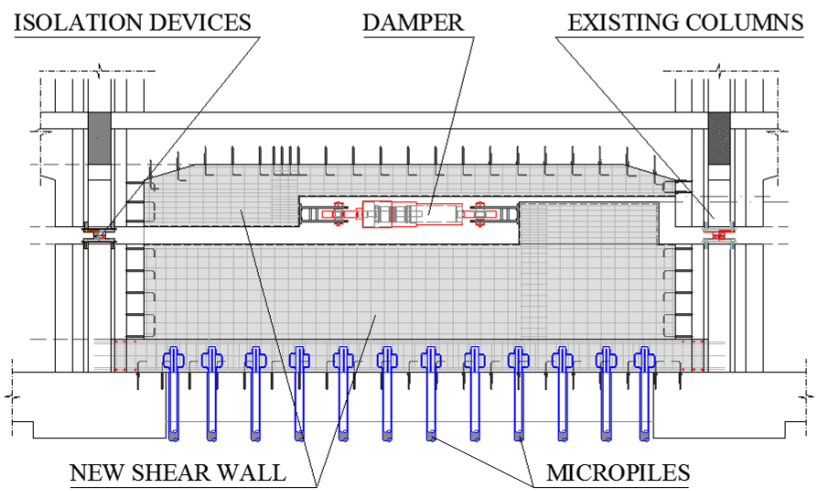


Building uplifting on new foundations and insertion of isolation devices

cost about 1,200 € per square meter of building plan

Reduction of displacement demand

Adding damping



Reduction of displacement demand up to 30 %

cost in the range of 30,000 € per damper

Local problems in force transfer

diaphragm action capacity:

- **application of carbon fibres**
- **insertion of a steel braced truss**
- **concrete casting at the foundation level**

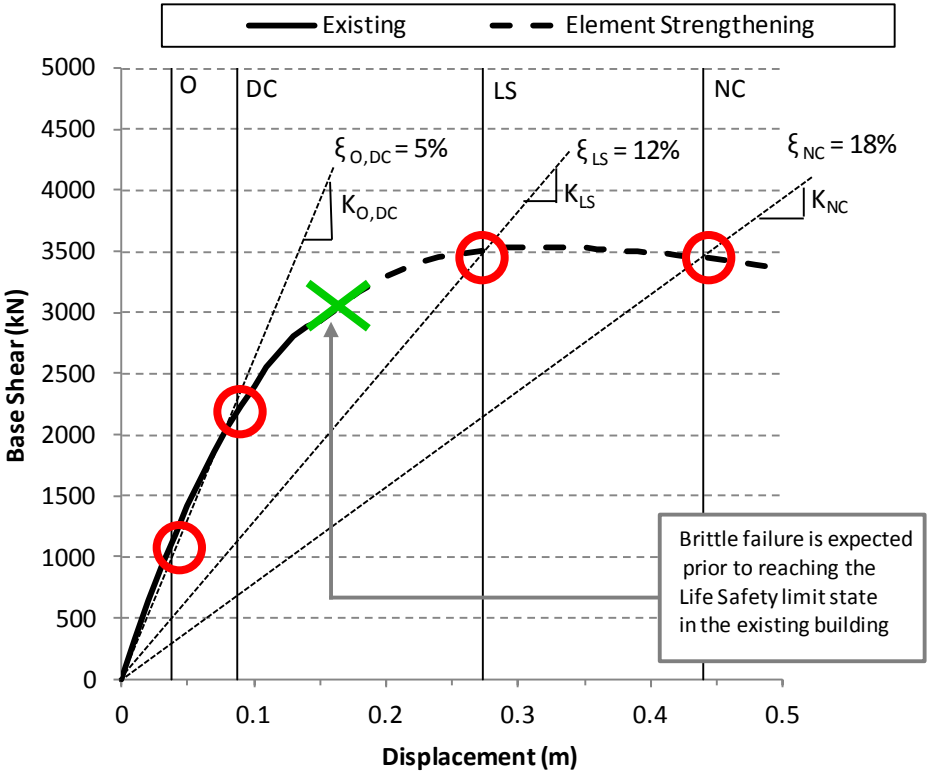
➡ **structural cost around 35€/m^2 or 10 €/m^3**

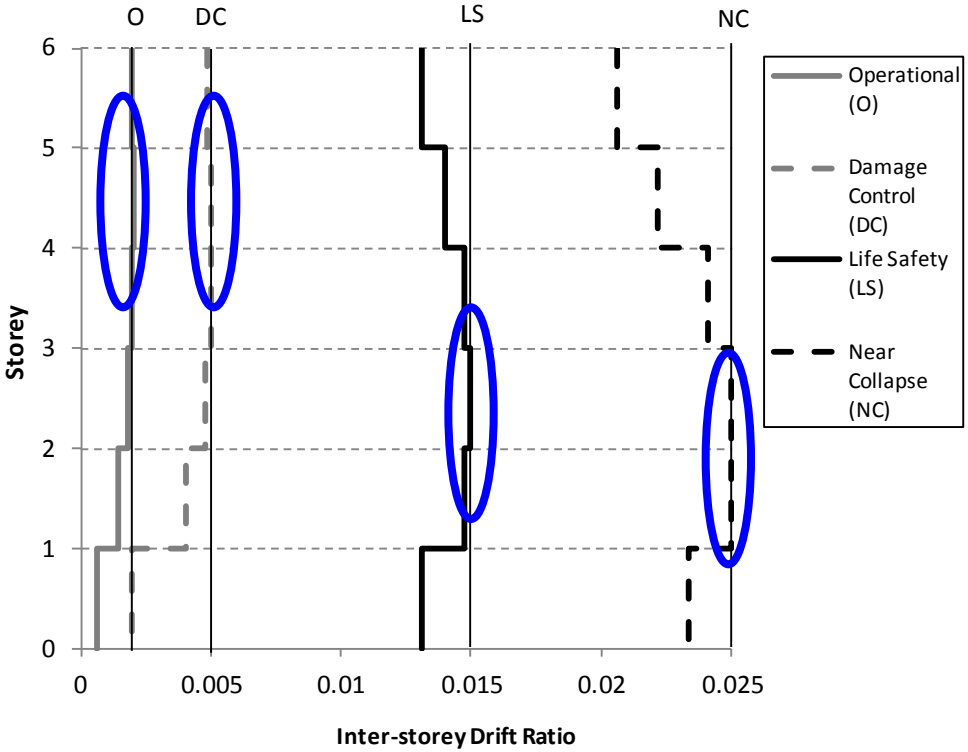
removal and replacement of non structural elements

➡ **cost around 100 €/m^2 or 30 €/m^3**

ANALISI COSTI - BENEFICI

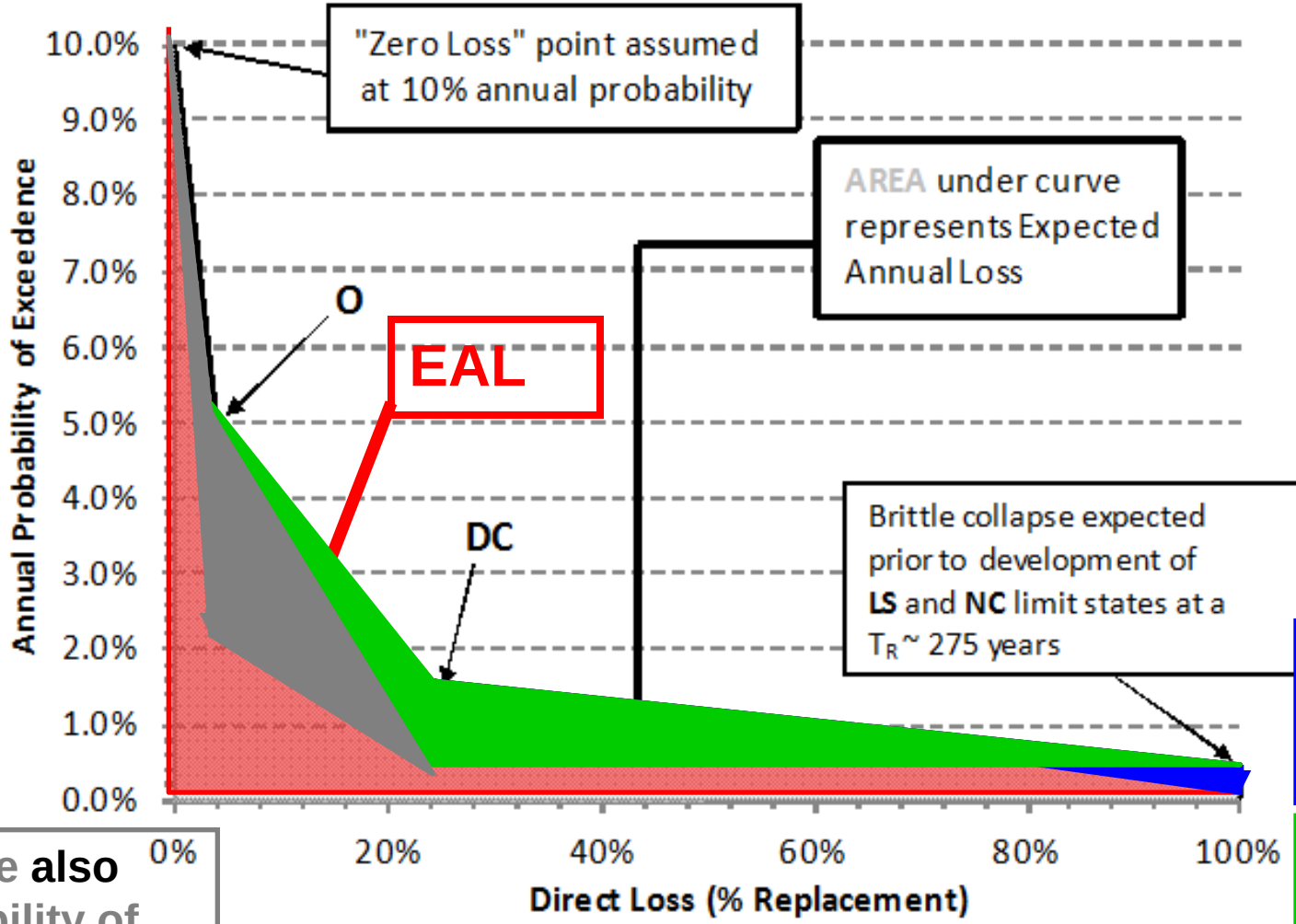
Valutazione della risposta





Stima delle perdite

EAL – Expected Annual Loss

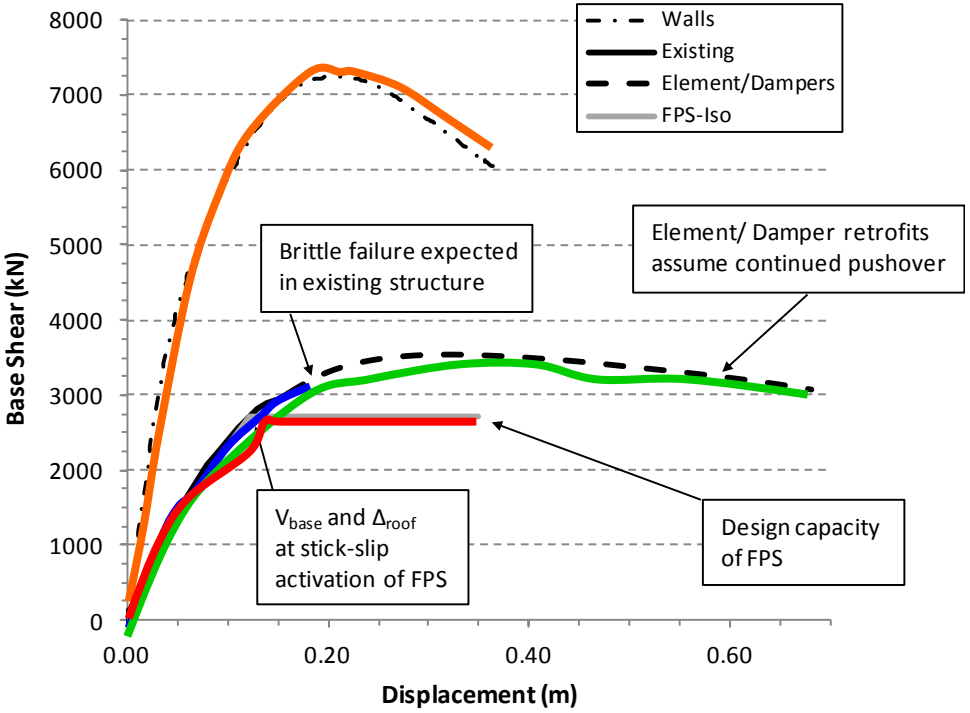


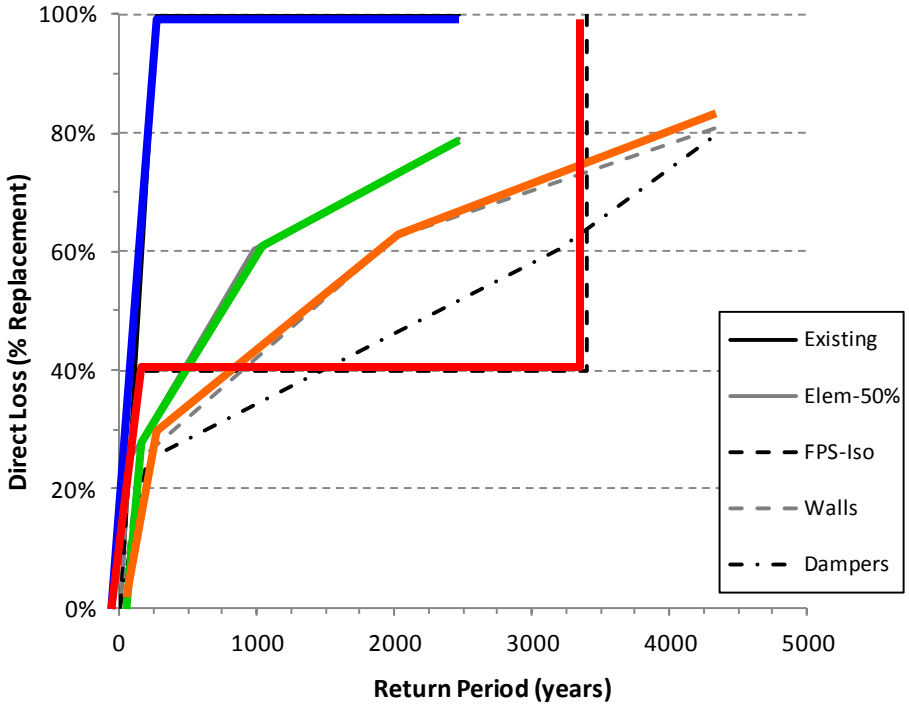
Reduce probability of NC

Reduce probability of DC

Reduce **also** probability of DC

Analisi costi - benefici





Analisi costi - benefici

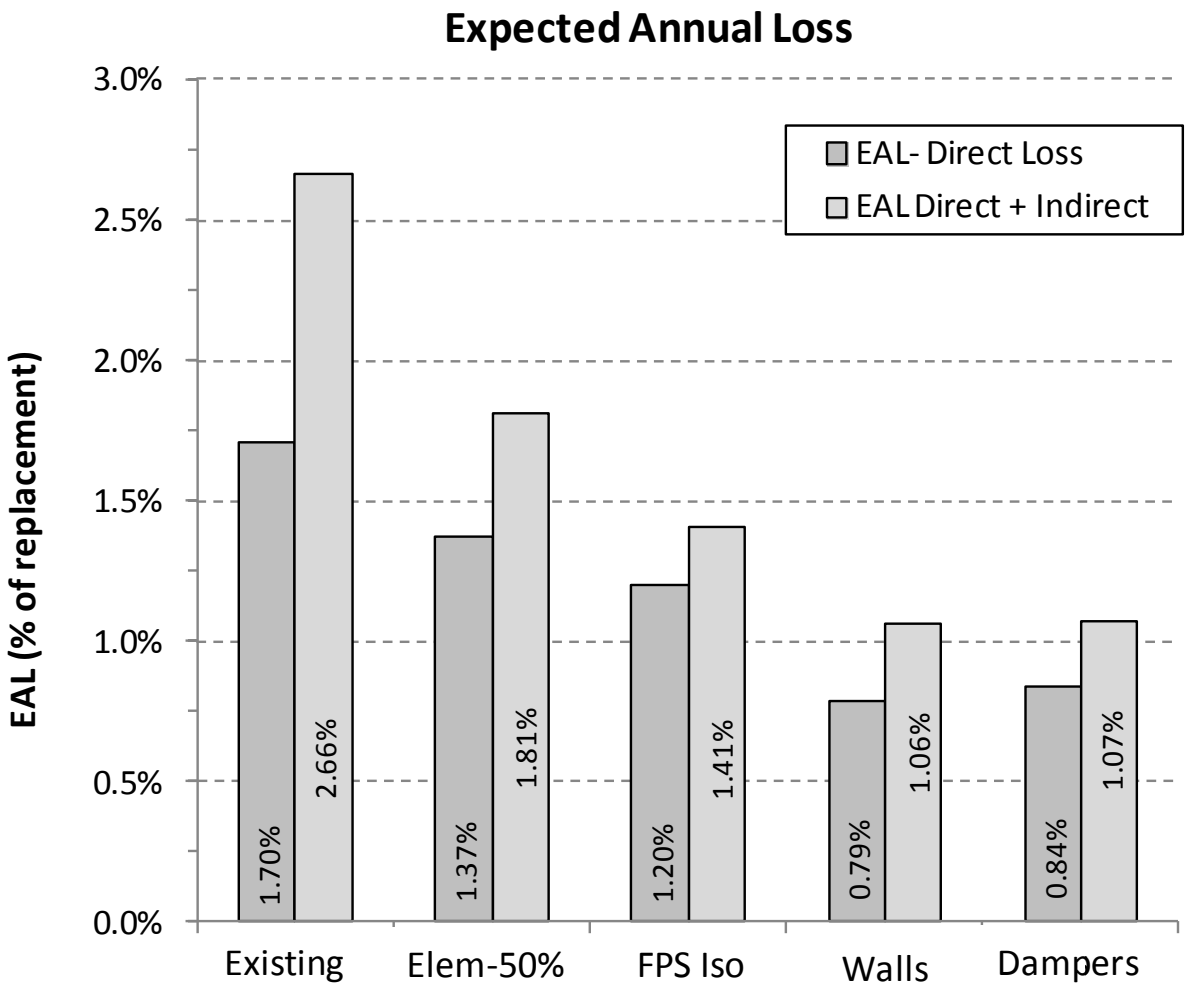
Perdite indirette – esempio nel caso residenziale

Assume that each person occupies a building area of 25 m^2
Assume that cost (to society or to an insurance company) to relocate is 50 €/day
Value of the area occupied by a person: 30,000 € (1,200 [€/m^2] × 25 [m^2])
Indirect loss due to downtime 50 [€/day] / 30,000 [€]
→ 0.17 % of RC per day

Performance	Interruption	Time (days)	$Loss_{indirect}$ (% of RC)
Fully Operational	1 week	7	1.2 %
Damage Control	4 weeks	30	5.0%
Life Safety	6 months	180	30.0%
Near Collapse	1.5 years	540	90.0%

Cost – benefit analysis

Expected annual losses for the strengthened structures



Analisi costi - benefici

Punto di pareggio

benefit–cost ratios calculated by dividing the change in *near present value* (NPV) of *expected annual loss* (EAL) by the total cost of the retrofit

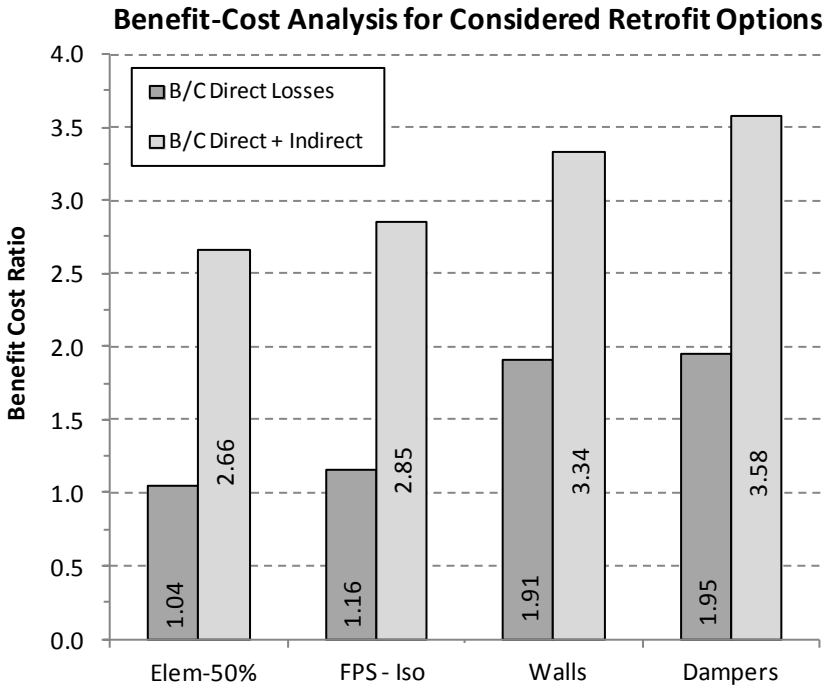
NPV calculated assuming a “design life” of 50 years, an arbitrary and conventional value

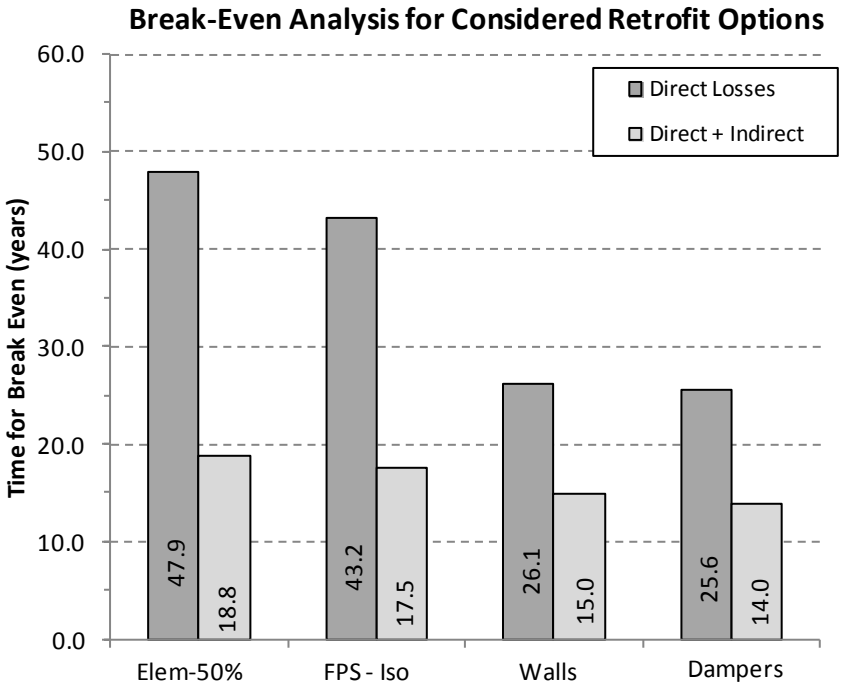
$$\frac{Benefit}{Cost} = \frac{NPV_{Existing} - NPV_{\mathrm{Re}trofit}}{Cost_{\mathrm{Re}trofit}} = \frac{\sum_{t=1}^{50} \frac{EAL_{Existing}}{(1-r)^t} - \sum_{t=1}^{50} \frac{EAL_{\mathrm{Re}trofit}}{(1-r)^t}}{Cost_{\mathrm{Re}trofit}}$$

$$t_{BreakEven} = \frac{Value}{Value / time} = \frac{Cost_{\mathrm{Re}trofit}}{EAL_{Existing} - EAL_{\mathrm{Re}trofit}}$$

Cost – benefit analysis

Breakeven point





Assicurazioni

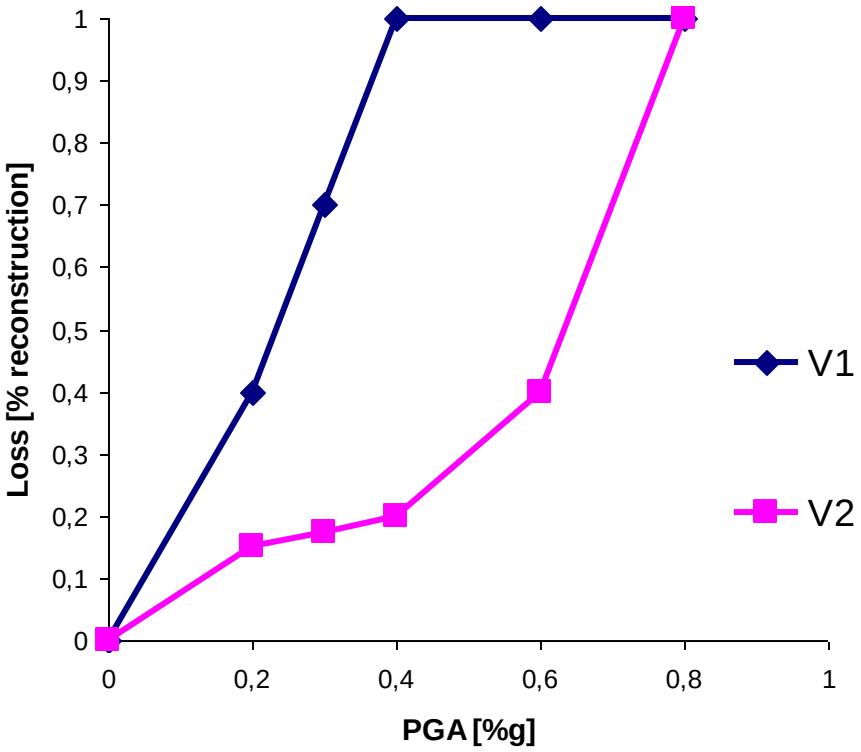
- **Obbligatorie o volontarie?**
- **A prezzo fisso o su specifiche stime di rischio?**
- **Come ridurre il contenzioso in caso di evento?**
- **Pagamento sulla stima del danno effettivo o sulla base di parametri di intensità?**

Filosofia delle norme

- **Azione: definita per diverse probabilità di superamento**
- **Prestazioni: implicitamente definite sulla base delle perdite attese**
- **Prestazione per una azione in funzione dell'importanza dell'edificio (esposizione)**
- **Nessuna distinzione tra il problema delle perdite economiche ed il problema della protezione della vita umana**

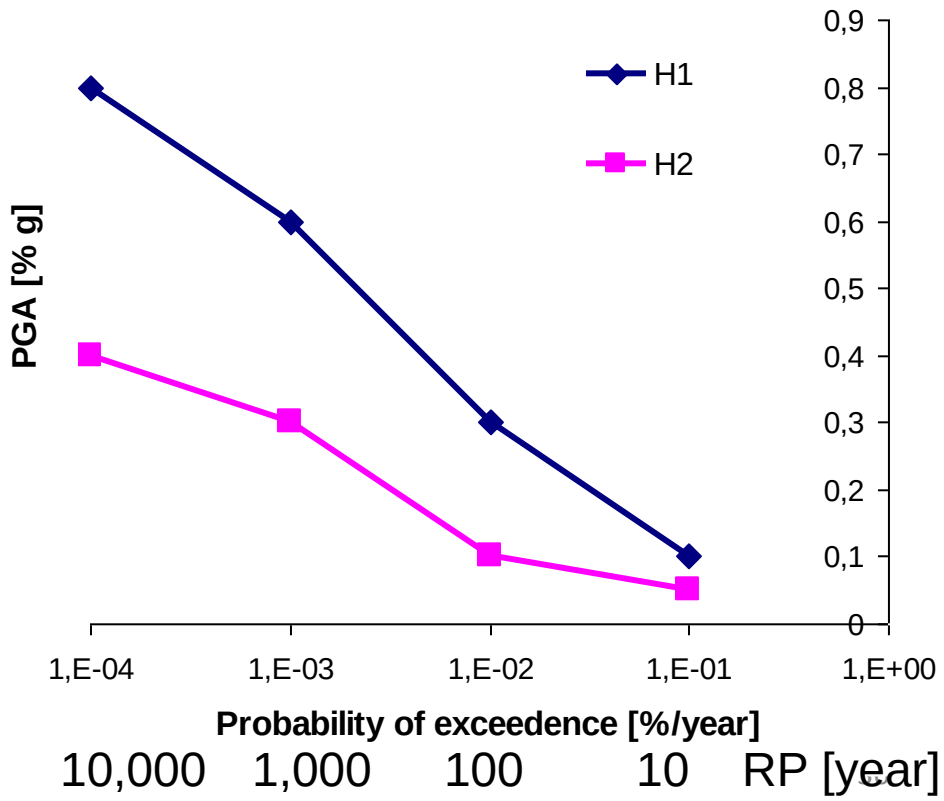
Vulnerabilità di un edificio (Analisi strutturale)

- **Defined by owner, based on a certification signed by a registered technician**
- **Expected loss as a function of an intensity parameter, e.g.: PGA**



Pericolosità: intensità dell'evento e probabilità annua di superamento

- **Defined by a public body**
- **Possibly modified by each insurance company, within limits and with a public statement**



Note: this should include local amplification

Combinazione: perdite attese in funzione della probaiblità di superamento

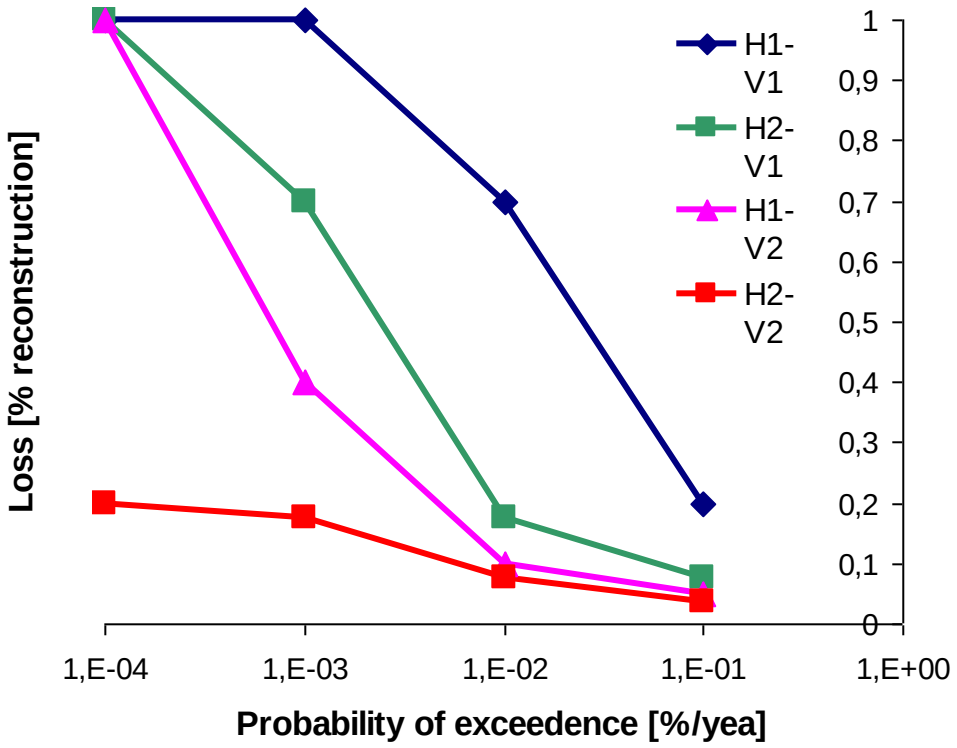
Example:

H1-V1 EAL ≈ 2,81 %

H2-V1 EAL ≈ 1,01 %

H1-V2 EAL ≈ 0,65 %

H2-V2 EAL ≈ 0,47 %



10,000 1,000 100 10 RP [year]

Possibili incentivi:

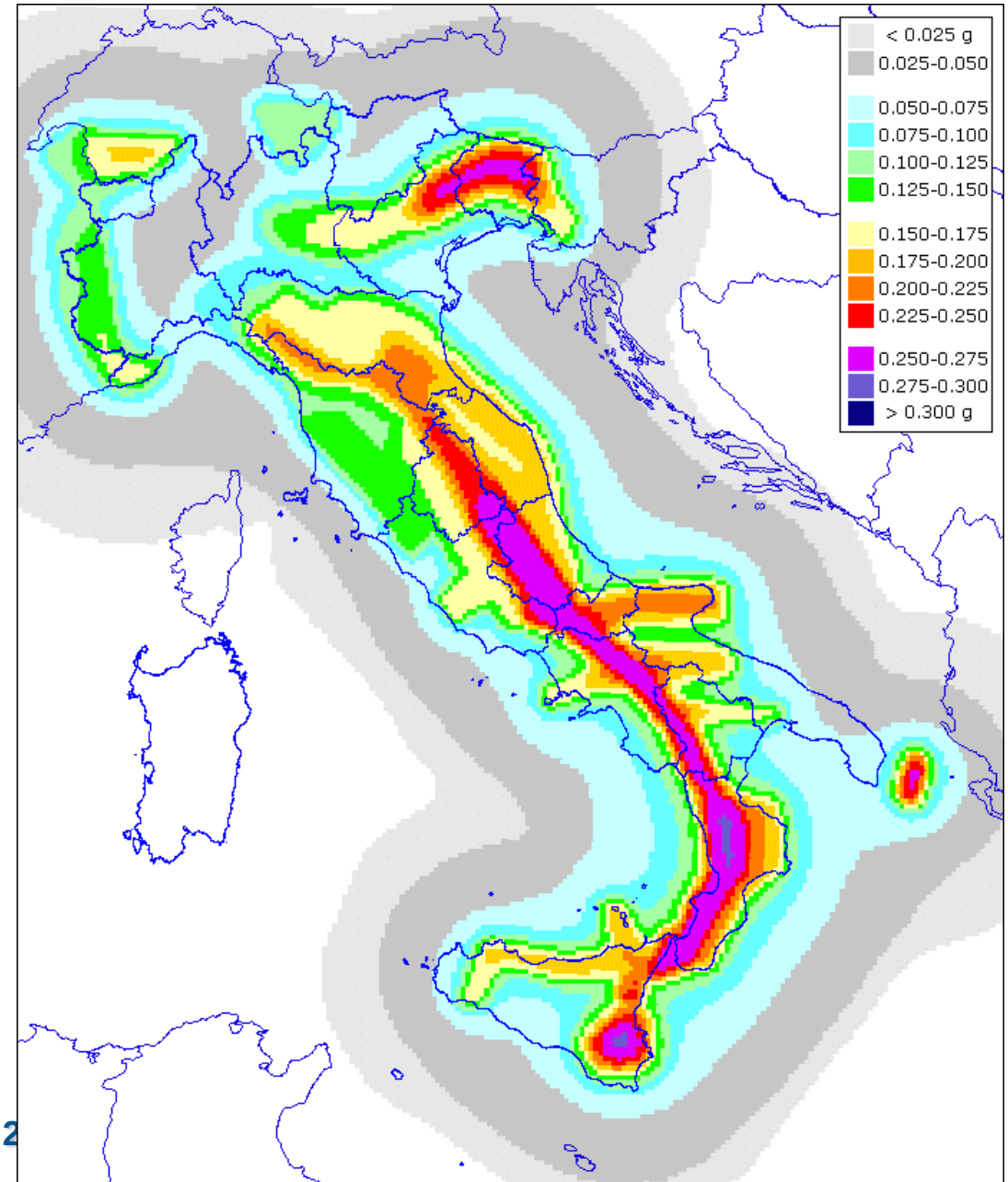
- **Detraibilità di costi in funzione dei benefici attesi**
- **Detraibilità dei costi di assicurazione (considernado EAL+cost+profit)**
- **Prestiti a tasso agevolato in funzione dei benefici attesi**

Norme del futuro:

Distinzione tra vita umana e perdite economiche

In generale:

- **Probabilità di collasso definita dalle norme**
- **Prestazioni delle strutture critche (e.g.: ospedali) definita dalle norme**
- **Prestazioni relative alle perdite economiche: definite e certificate da propietà e progettista**


< 0.025 g
0.025-0.050
0.050-0.075
0.075-0.100
0.100-0.125
0.125-0.150
0.150-0.175
0.175-0.200
0.200-0.225
0.225-0.250
0.250-0.275
0.275-0.300
> 0.300 g

Energy Class	*Residential* - kWh/m^2
A+	$EP_{tot} < 25$
A	$25 < EP_{tot} < 40$
B	$40 < EP_{tot} < 80$
C	$80 < EP_{tot} < 130$
D	$130 < EP_{tot} < 170$
E	$170 < EP_{tot} < 250$
F	$250 < EP_{tot} < 400$
G	$EP_{tot} > 400$

$$EAL_E = \frac{EP_{TOT}[kWh/m^2] \bullet unit\ \ energy\ \ cost\ \ [EUR/kWh]}{construction\ \ cost\ \ [EUR/m^2]}$$

Green Indicator	EAL_E (%)
A+	$EAL < 0.50$
A	$0.50 < EAL < 0.75$
B	$0.75 < EAL < 1.50$
C	$1.50 < EAL < 2.50$
D	$2.50 < EAL < 3.50$
E	$3.50 < EAL < 4.50$
F	$4.50 < EAL < 7.50$
G	$EAL > 7.50$

GRI Classification (*Green* and *Resilient* Indicators)	EAL_E or EAL_S (%)
A+	$EAL < 0.50$
A	$0.50 < EAL < 0.75$
B	$0.75 < EAL < 1.50$
C	$1.50 < EAL < 2.50$
D	$2.50 < EAL < 3.50$
E	$3.50 < EAL < 4.50$
F	$4.50 < EAL < 7.50$
G	$EAL > 7.50$