

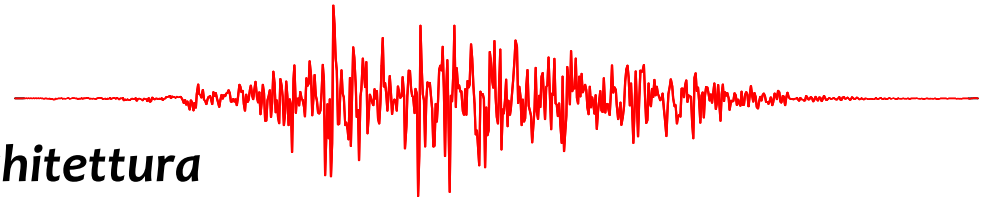
RISCHIO SISMICO

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Dipartimento di Ingegneria e Architettura

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Rischio Sismico?

pericolosità



***fenomeno
sismico***

vulnerabilità



***relazione fra
intensità del
sisma ed effetti
sui «beni»
esposti***

esposizione



***ciò che può
essere affetto
da un sisma***

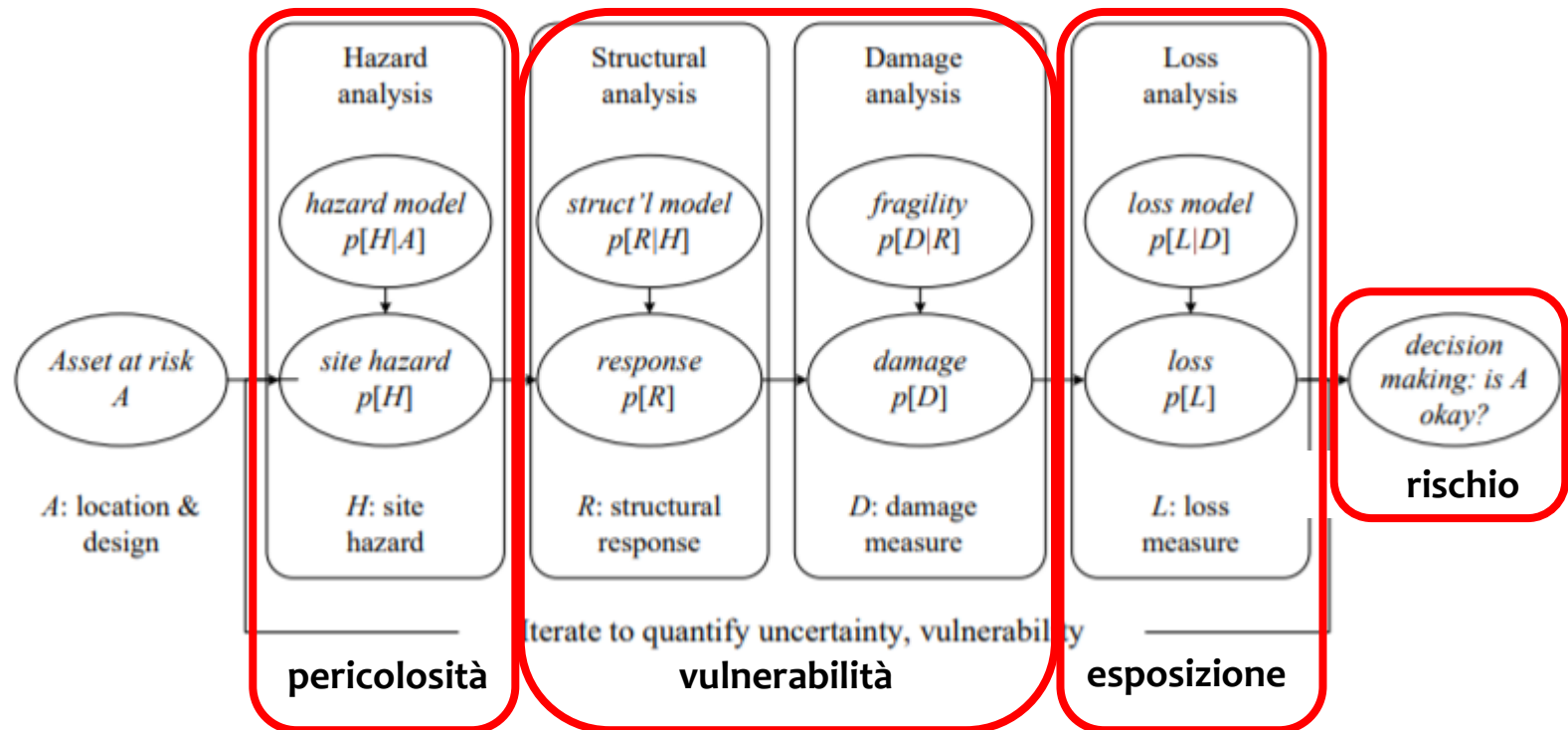
PEER approach

$$\lambda(dv) = \int \int \int G(dv|dm) f(dm|edp) ddm f(edp|im) dedp |d\lambda(im)|$$

DM EDP IM

«Standard» approach

$$P(D > d) = \int P(D > d|IM) \times d\lambda(IM > im)$$

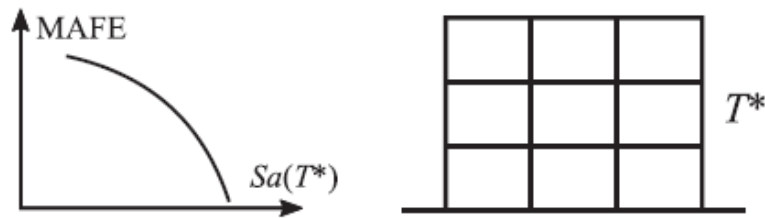


PEER approach

$$\lambda(dv) = \int \int \int_{DMEDP IM} G(dv|dm)f(dm|edp)ddmf(edp|im)dedp|d\lambda(im)|$$

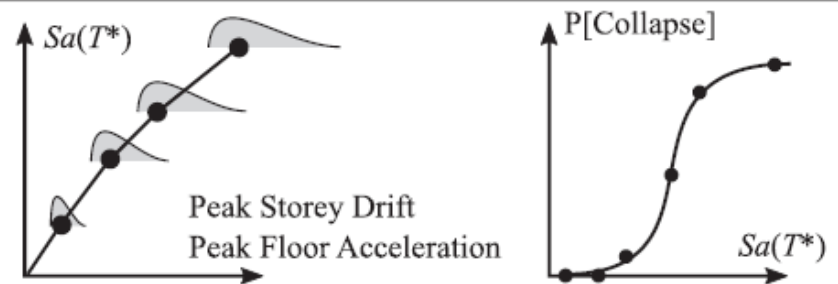
Step 1: Hazard Characterisation and Numerical Modelling

Modal Properties
Site Hazard Curve



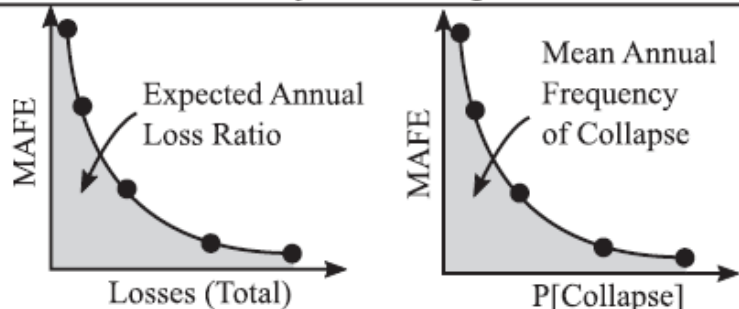
Step 2: Characterising Structural Response

Peak Storey Drift and Floor Accelerations
Collapse Fragility Function



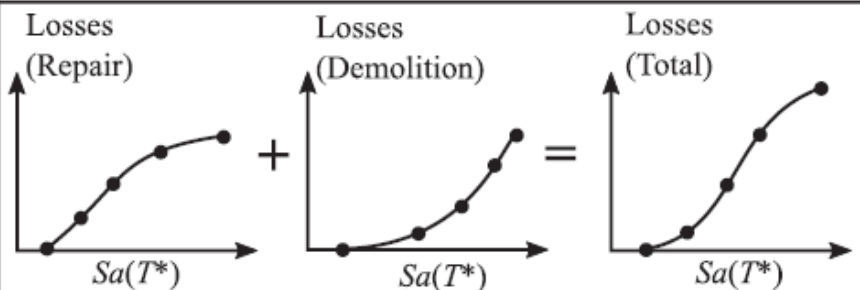
Step 4: Decision Making

Expected Annual Loss Ratio
Annual Probability of Collapse



Step 3: Loss Estimation

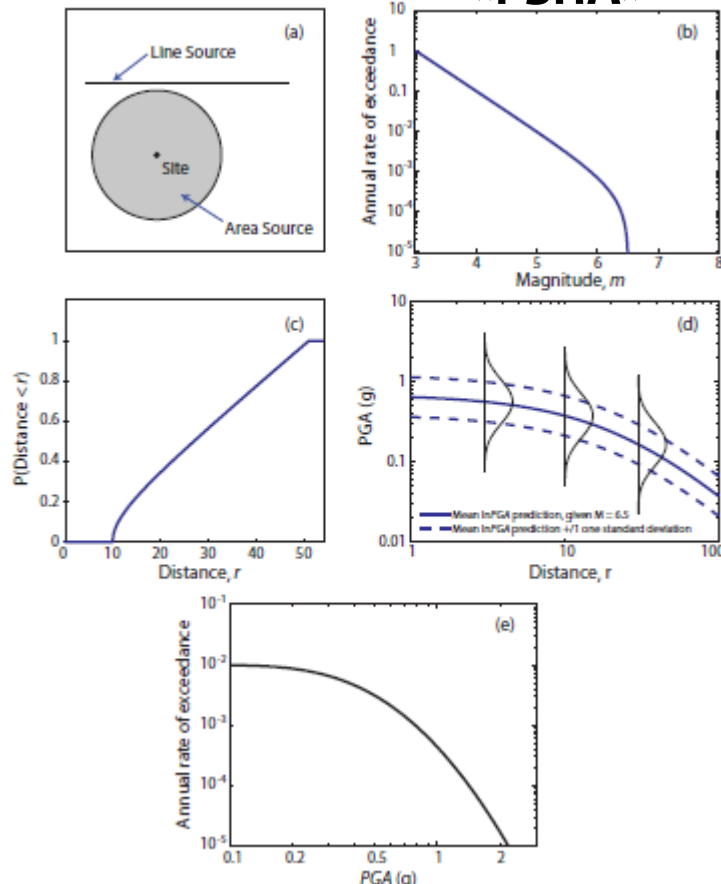
Expected Losses versus Intensity
Loss Disaggregation (Structural & Non-Structural)



Pericolosità Multiscenario

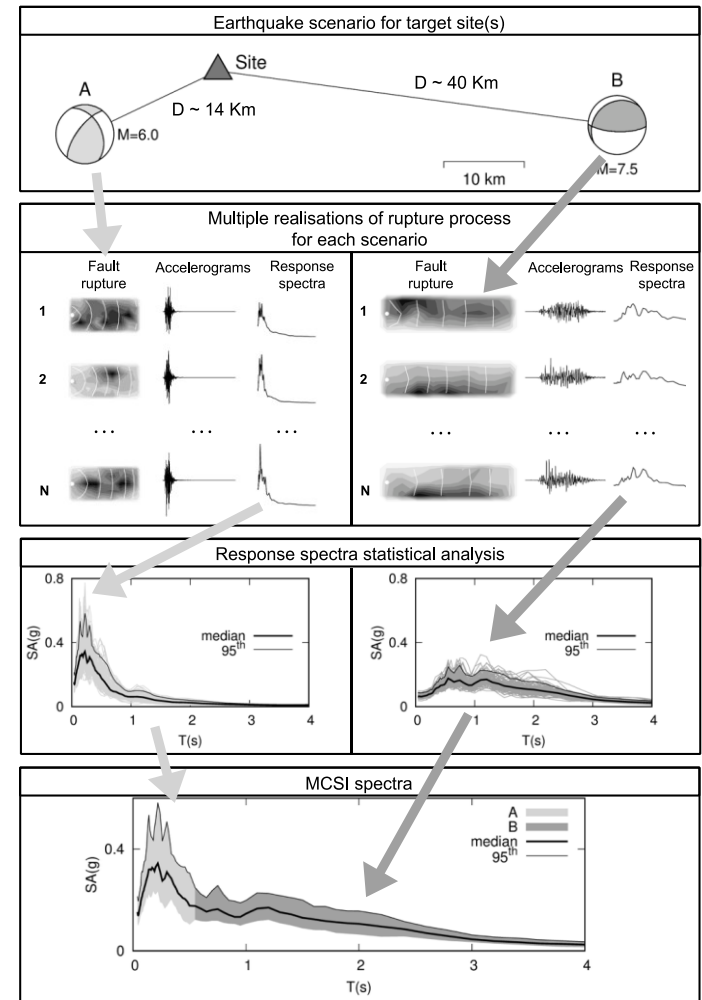
Con modello di occorrenza

«PSHA»



Senza modello di occorrenza

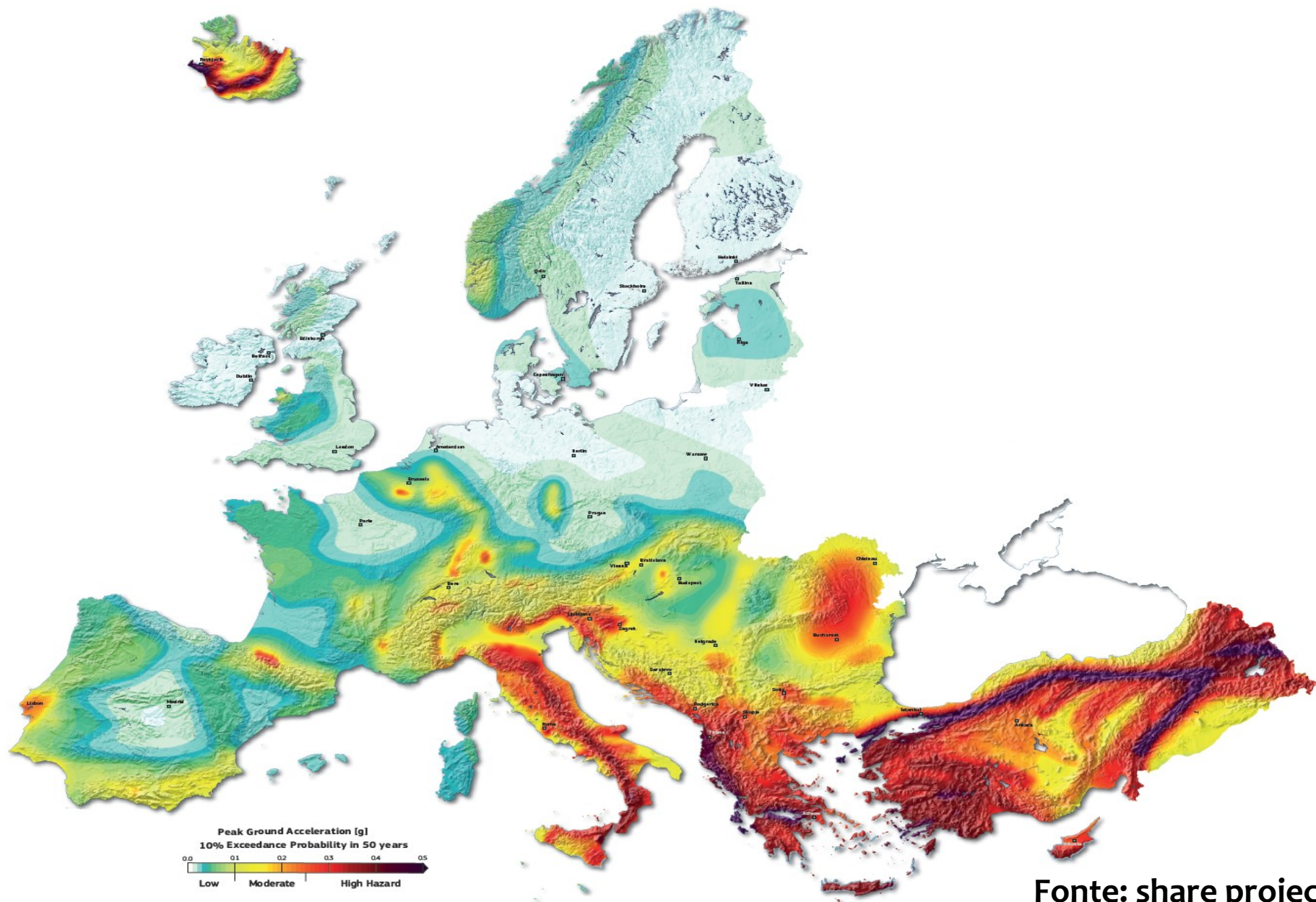
«determinitica»



$$\lambda(IM > x) = \sum_{i=1}^{n_{sources}} \lambda(M_i > m_{min}) \int_{m_{min}}^{m_{max}} \int_{r_{min}}^{r_{max}} P(IM > x | m, r) f_{M_i}(m) f_{R_i}(r) dr dm$$

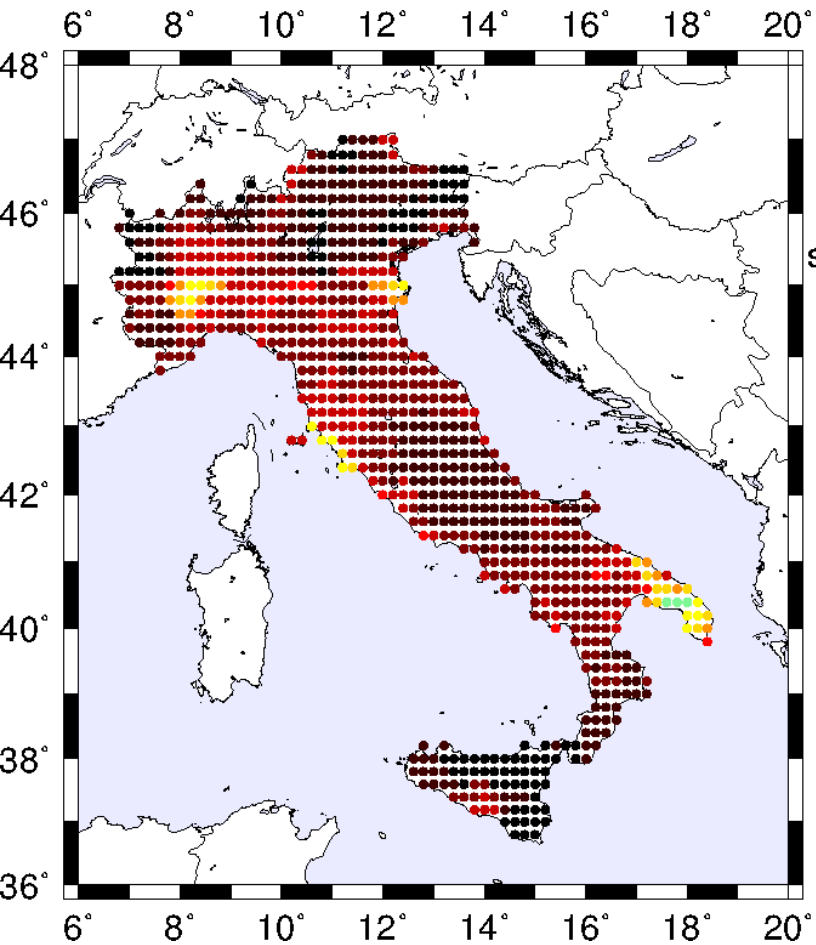
$$\lambda(IM > x) = \sum_{i=1}^{n_{sources}} \lambda(M_i > m_{min}) \sum_{j=1}^{n_M} \sum_{k=1}^{n_R} P(IM > x | m_j, r_k) P(M_i = m_j) P(R_i = r_k)$$

Pericolosità >> rappresentazione

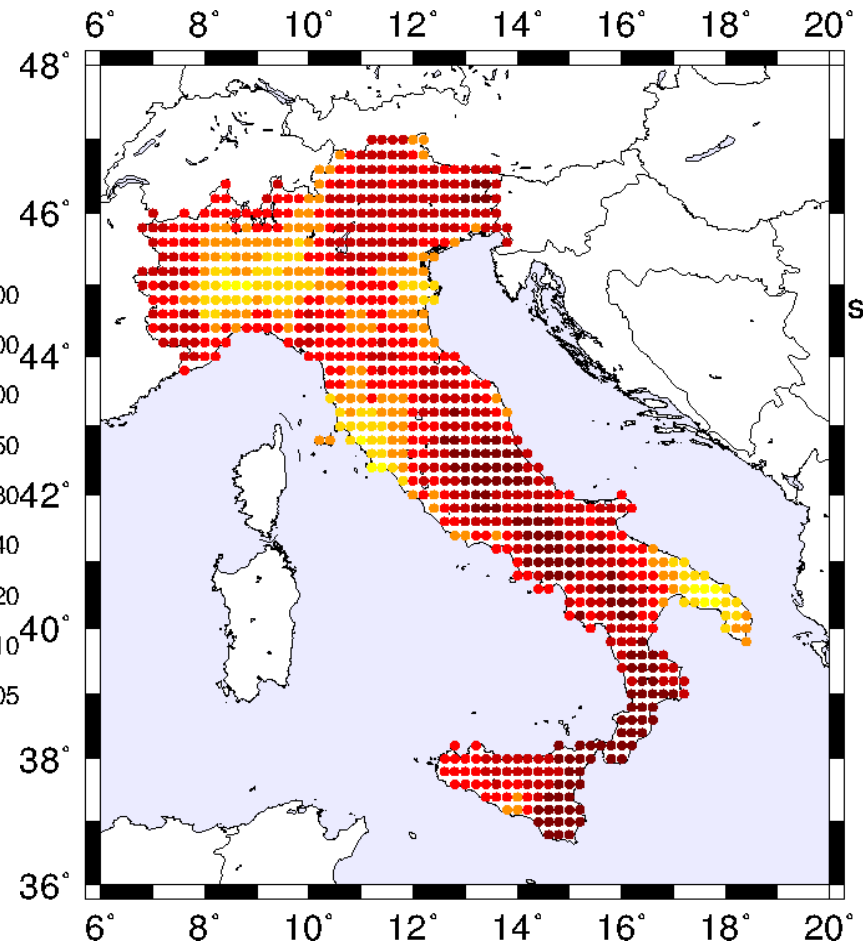
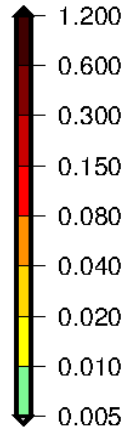


Fonte: share project

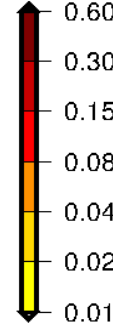
Pericolosità >> rappresentazione – 2



SA_{50-0.2s}(g)



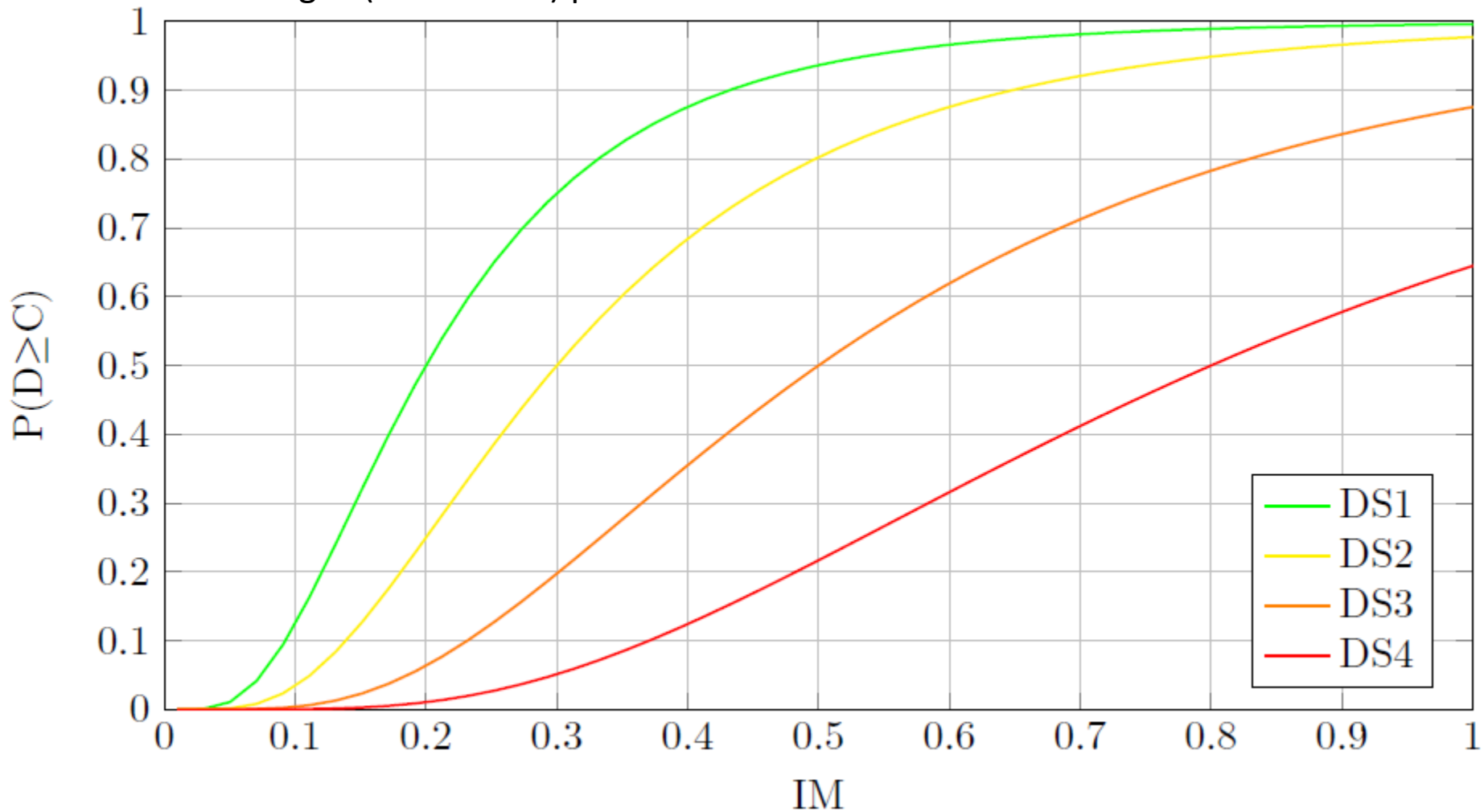
SA_{50-1s}(g)



Fragilità

Le curve di fragilità sono uno degli strumenti più efficaci e utilizzati per valutare la vulnerabilità sismica delle strutture.

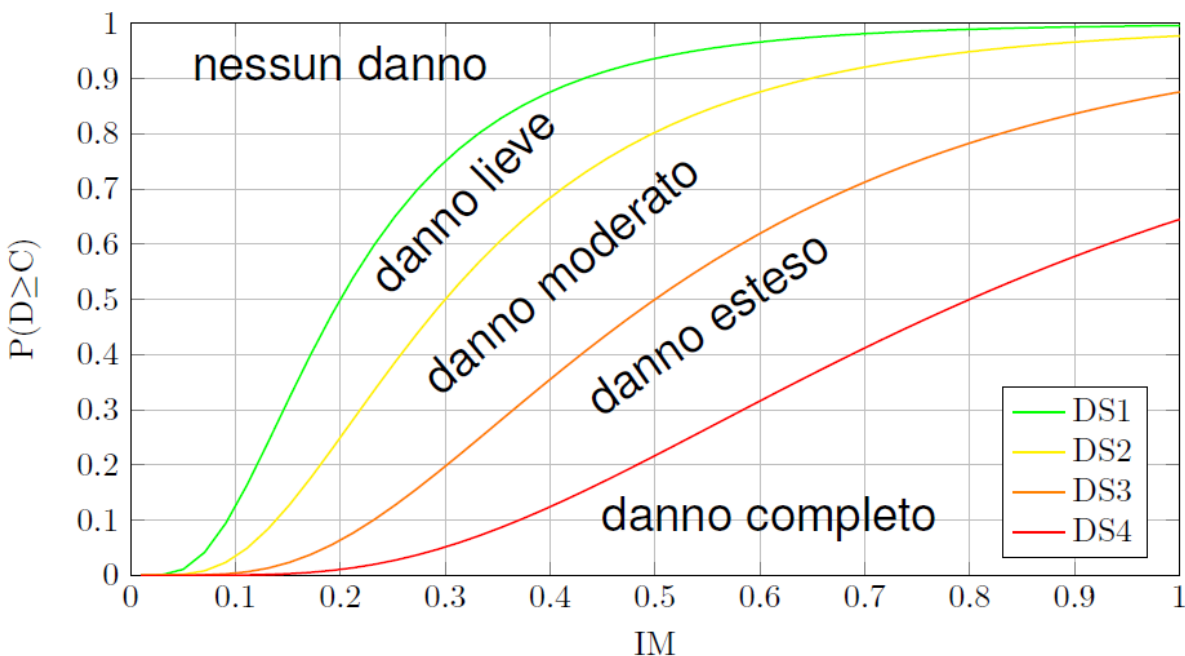
Sono funzioni che esprimono la probabilità di superare determinate soglie (Stati Limite) per una data intensità dell'azione considerata



Fragilità

Le curve di fragilità sono uno degli strumenti più efficaci e utilizzati per valutare la vulnerabilità sismica delle strutture.

Sono funzioni che esprimono la probabilità di superare determinate soglie (Stati Limite) per una data intensità dell'azione considerata



Si differenziano per:

- metodo utilizzato per definirle;
- misura dell'intensità sismica;
- livelli di danno/soglie scelte.

Fragilità

- Empiriche
- **Numeriche**
- Giudizio esperto



• IDA

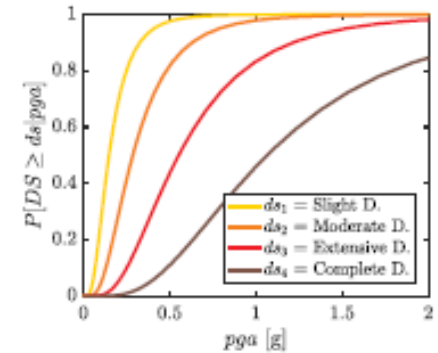
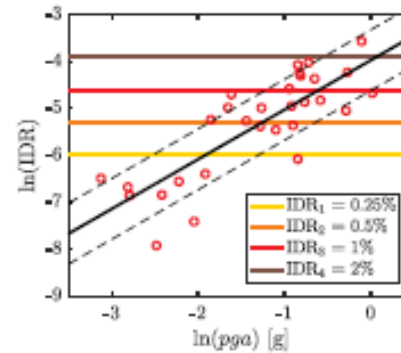
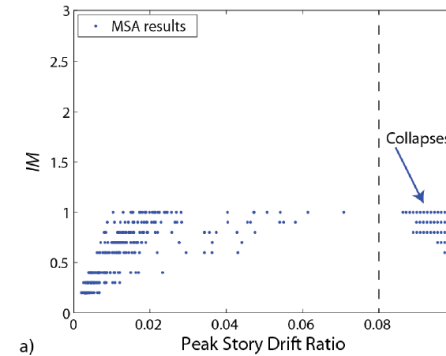
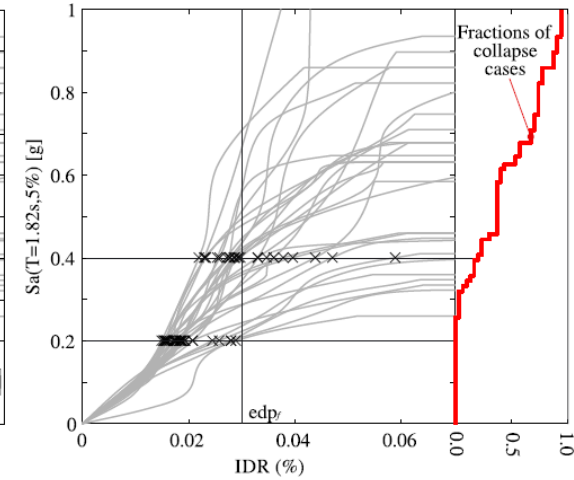
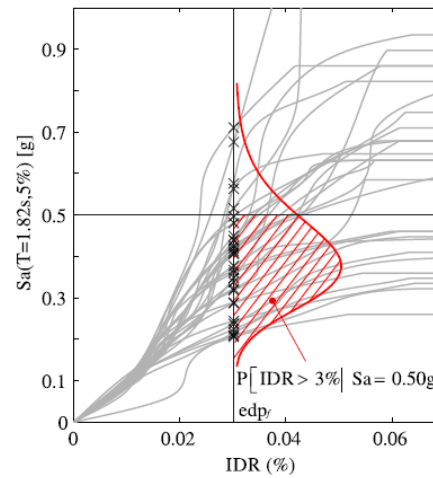
- Numeriche



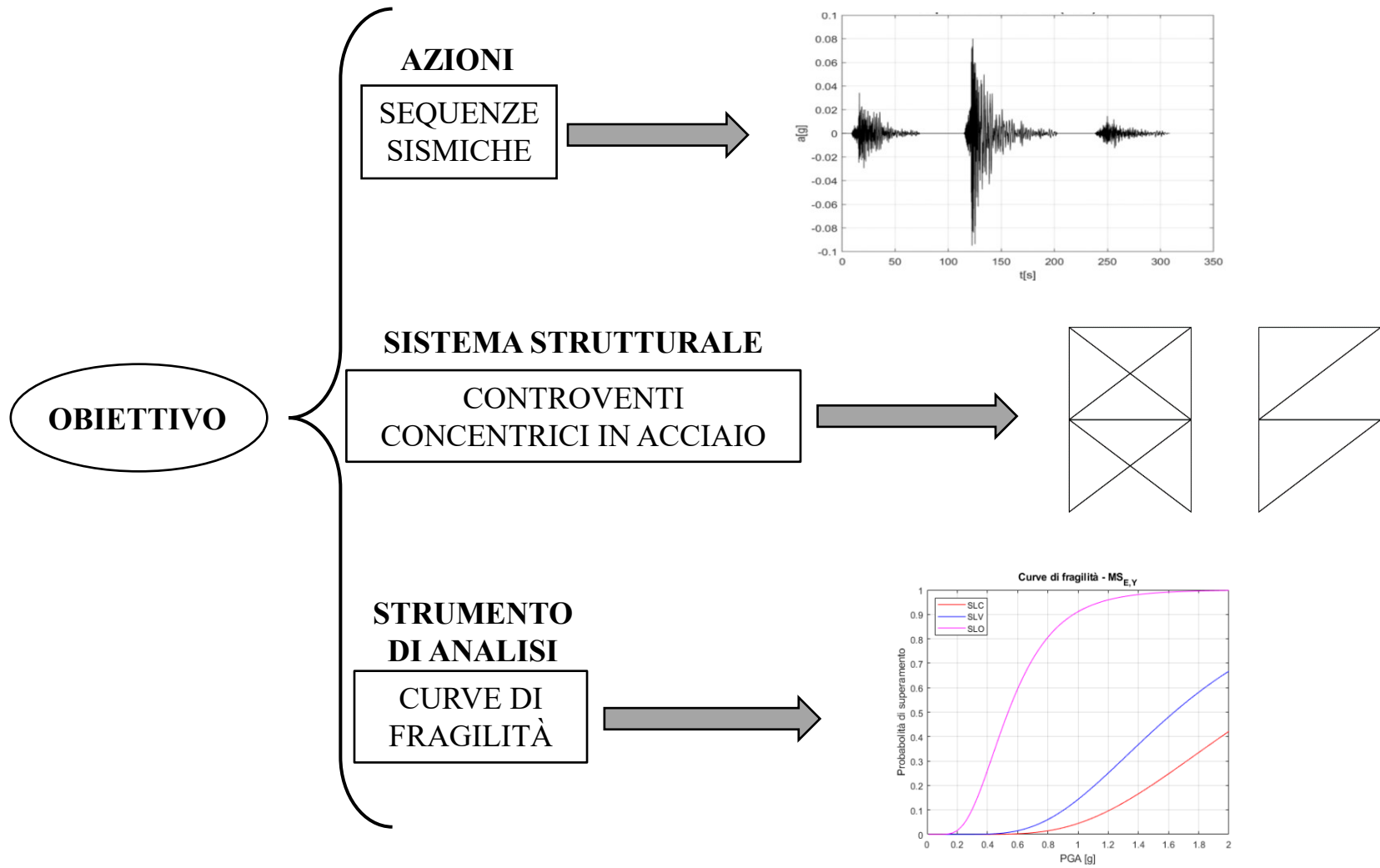
• MSA



• Cloud

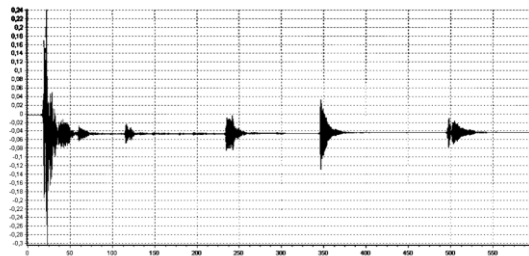
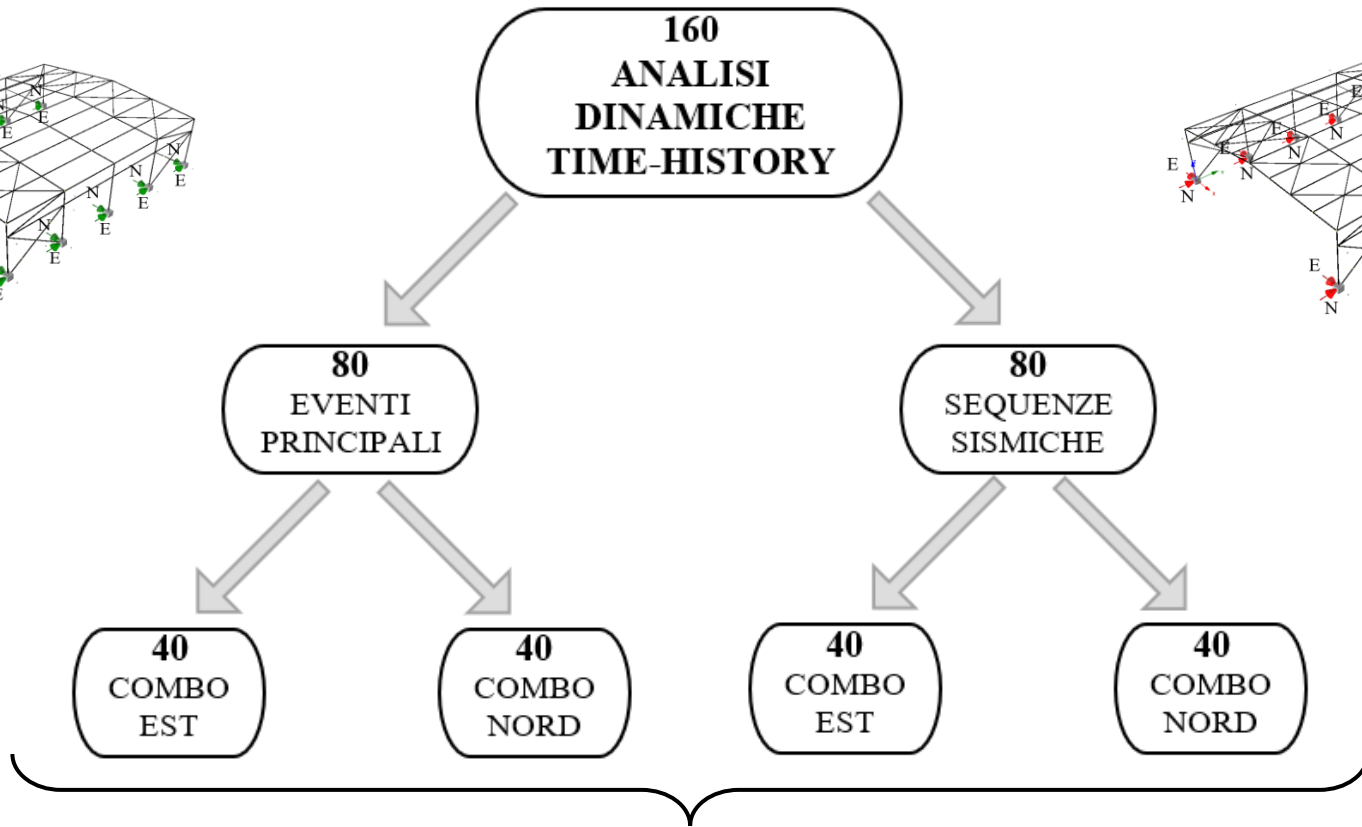
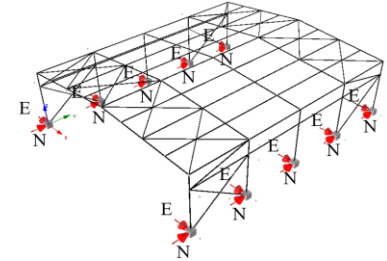
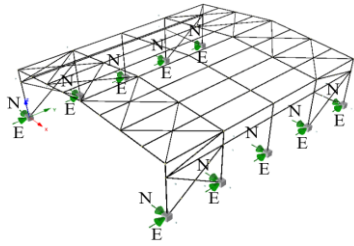


Fragilità



Fragilità

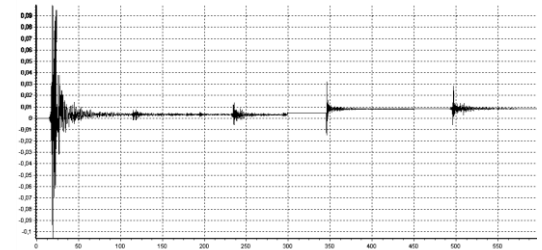
Sistema Strutturale



SPOSTAMENTI MASSIMI
DI PIANO

d_x

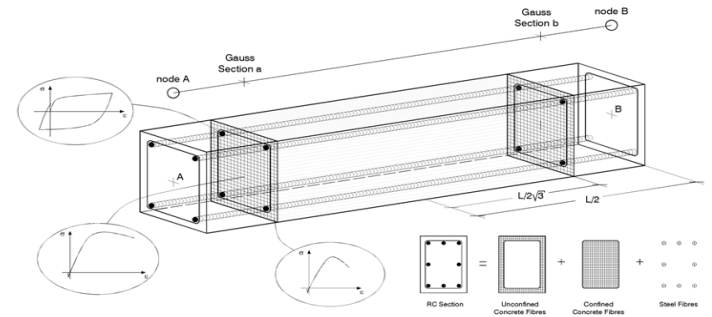
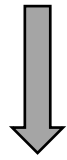
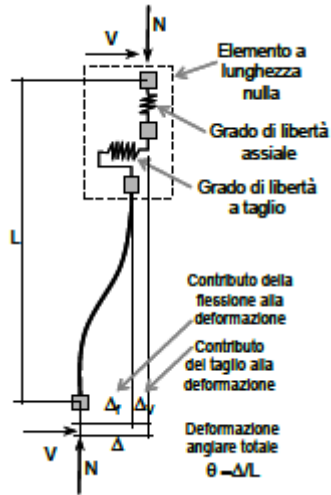
d_y



Fragilità

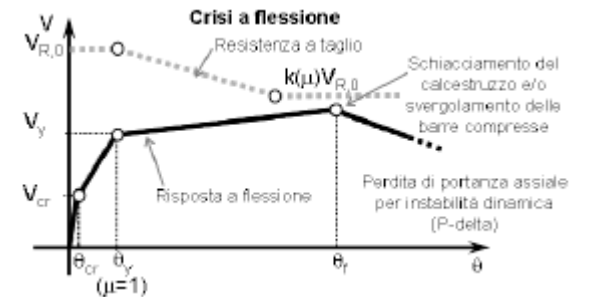
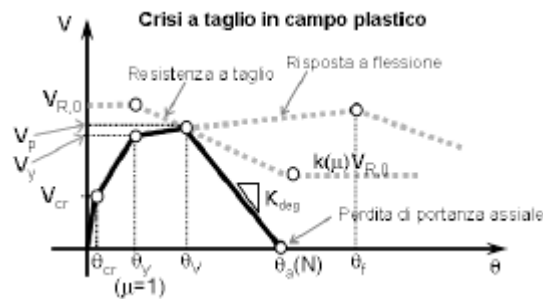
Sistema Strutturale

MODELLAZIONE
ELEMENTI FINITI



ELEMENTI FINITI

A FIBRE
APPROCCIO DELLE FORZE



Fragilità

CONTROVENTI CONCENTRICI

CARATTERISTICHE

- SISTEMA SISMORESISTENTE ECONOMICO
- ASTE DIAGONALI PASSANTI PER L'INTERSEZIONE DEGLI ASSI TRAVE-COLONNA
- ASTE SOGGETTE PREVALENTEMENTE A SFORZI NORMALI

FUNZIONI

- RIPRENDERE FORZE ORIZZONTALI E TRASFERIRLE IN FONDAZIONE
- DISSIPARE ENERGIA IN CAMPO PLASTICO

GERARCHIA DELLE RESISTENZE

DIAGONALI



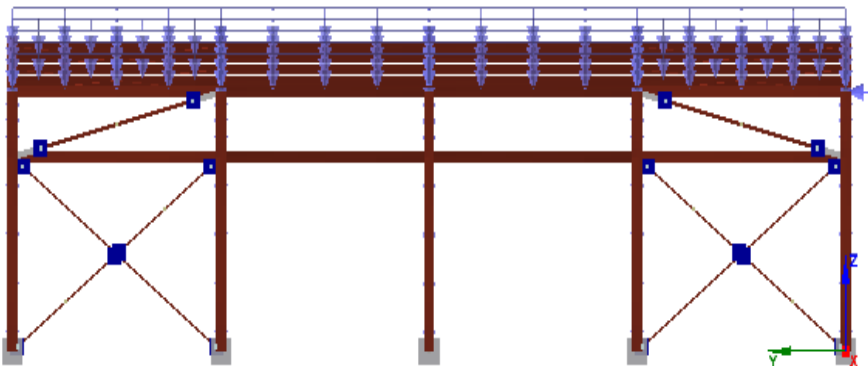
UNICO ELEMENTO CHE DISSIPA



TRAVI & COLONNE



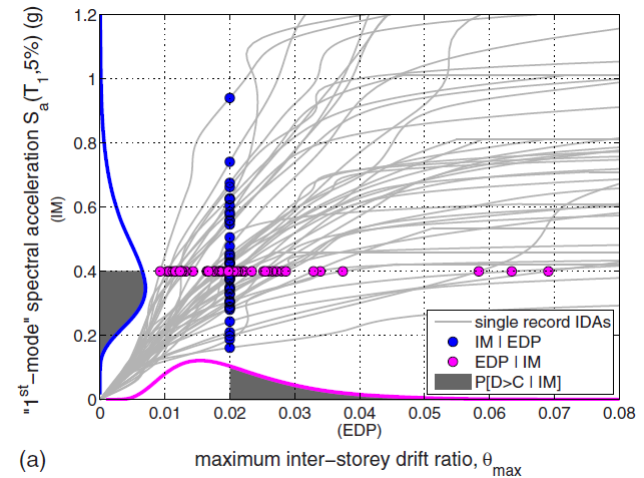
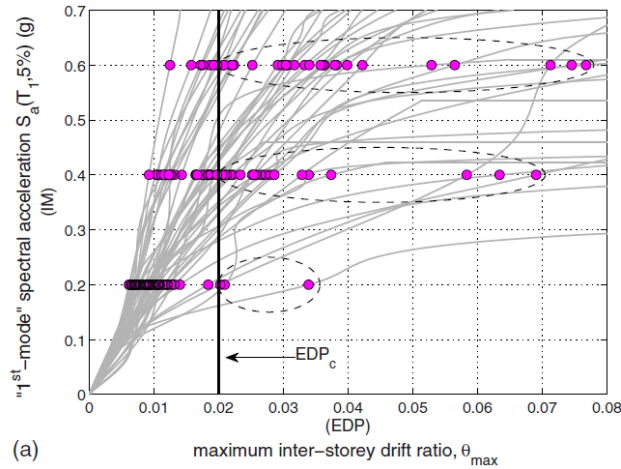
SOVRARESISTENTI/ELASTICHE



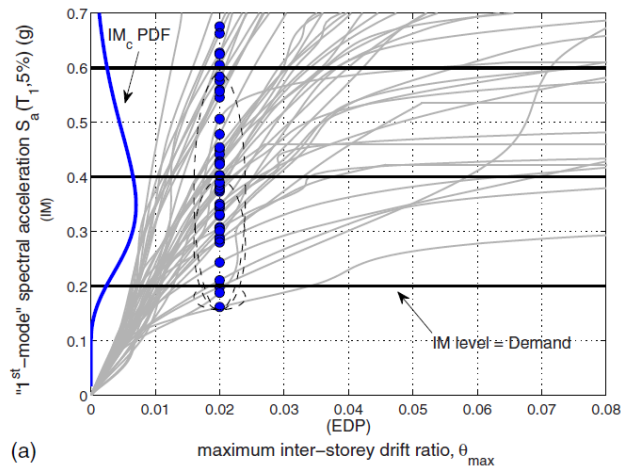
Fragilità - IDA

EDP-based

$$F_{LS}(IM) = P[EDP > EDP_C | IM] = \frac{\sum_{j=1}^{N_{rec}} I[EDP^j > EDP_C | IM]}{N_{rec}}$$



IM-based



$$F_{LS}(IM) = P[IM > IM_C] = \frac{\sum_{j=1}^{N_{rec}} I[IM > IM_C^j]}{N_{rec}}$$

$$\begin{cases} \hat{\eta} = \frac{1}{n} \sum_{i=1}^n \log(im_i) \\ \hat{\beta}^2 = \frac{1}{n-1} \sum_{i=1}^n [\log(im_i) - \hat{\eta}]^2 \end{cases}$$

Fragilità - Cloud



- PROBABILITÀ DI SUPERAMENTO DI UN DETERMINATO LIVELLO DI DANNEGGIAMENTO DEL SISTEMA IN FUNZIONE DI IM

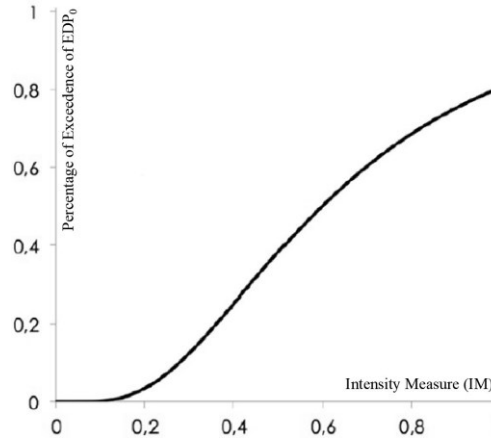
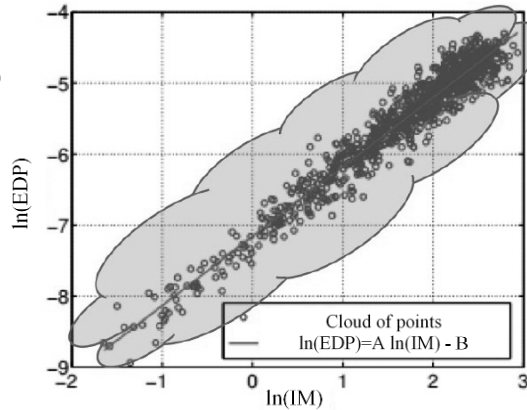
• CORRELAZIONE
IM-EDP

INTENSITY MEASURE

ENGINEERING DEMAND PARAMETER

- PGA
- Sa(T)

- SPOSTAMENTO MASSIMO GLOBALE
- SPOSTAMENTO MASSIMO D'INTERPIANO



- Selezione di 25-30 accelerogrammi naturali.
- Esecuzione di 25-30 analisi dinamiche non lineari.
- Registrazione di EDP e del corrispondente IM;
- Assunzione di una distribuzione log-normale dell'EDP.
- Regressione lineare dei dati nel piano bi-logaritmico.
- Determinazione degli stati di danneggiamento limite (EDP₀).
- Costruzione delle curve di fragilità per mezzo della CDF (Cumulative Distribution Function).

$$\ln(\widehat{EDP}) = A \ln(IM) + B$$

$$ei = \ln(EDP_i) - [A \ln(IM_i) + B]$$

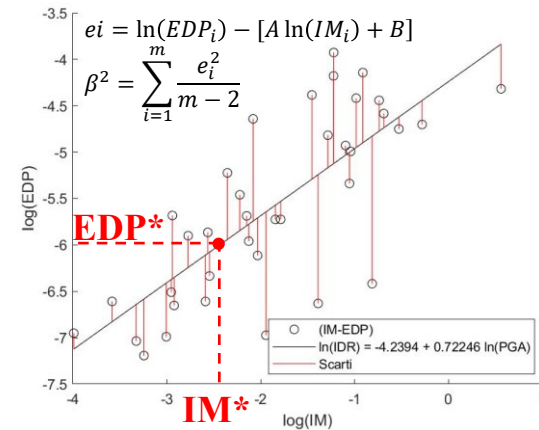
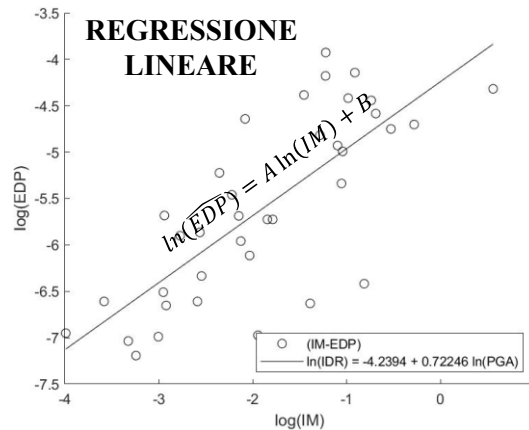
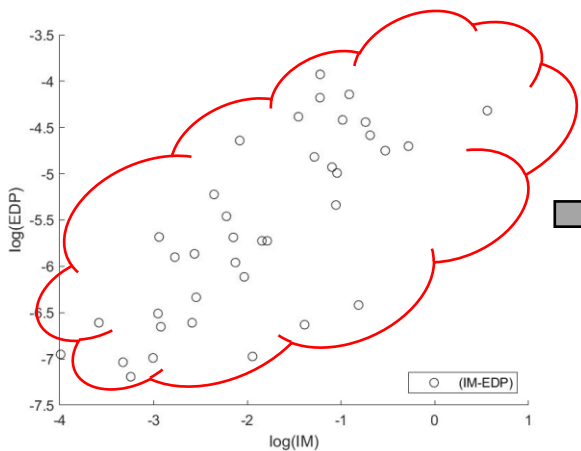
$$\beta^2 = \sum_{i=1}^m \frac{e_i^2}{m-2}$$

$$FC(IM) = 1 - \phi\left(\frac{\ln(EDP_0) - \ln(\widehat{EDP})}{\beta}\right)$$

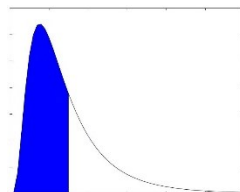
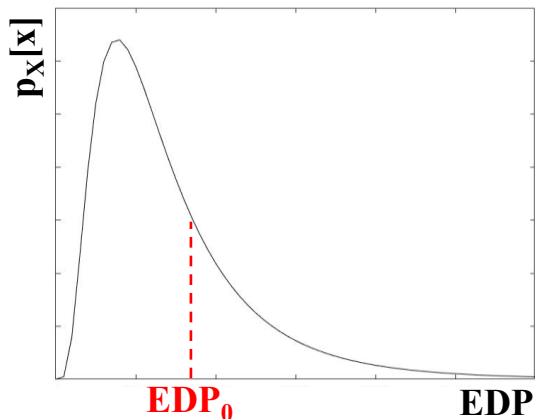
$$\phi\left(\frac{\ln(EDP_0) - \ln(\widehat{EDP})}{\beta}\right) = \int_{-\infty}^{EDP_0} \frac{1}{x \beta \sqrt{2\pi}} e^{-\frac{[\ln(dx) - \ln(\widehat{EDP})]^2}{2\beta^2}} dx$$

Fragilità

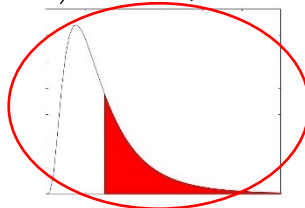
COSTRUZIONE CURVE DI FRAGILITÀ



DISTRUBUZIONE LOG-NORMALE

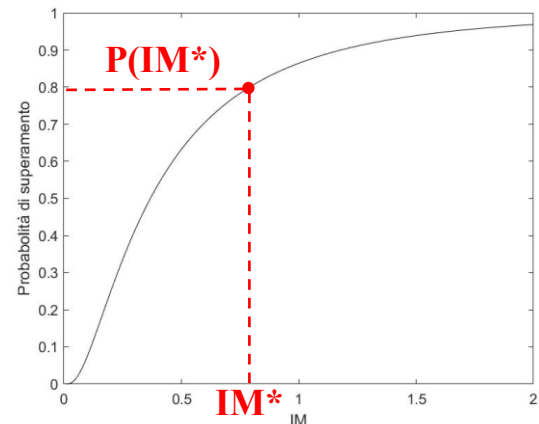


$$\phi\left(\frac{\ln(\text{EDP}_0) - \ln(\widehat{\text{EDP}})}{\beta}\right) = \int_{-\infty}^{\text{EDP}_0} \frac{1}{x \beta \sqrt{2\pi}} e^{-\frac{[\ln(dx) - \ln(\widehat{\text{EDP}})]^2}{2\beta^2}} dx$$

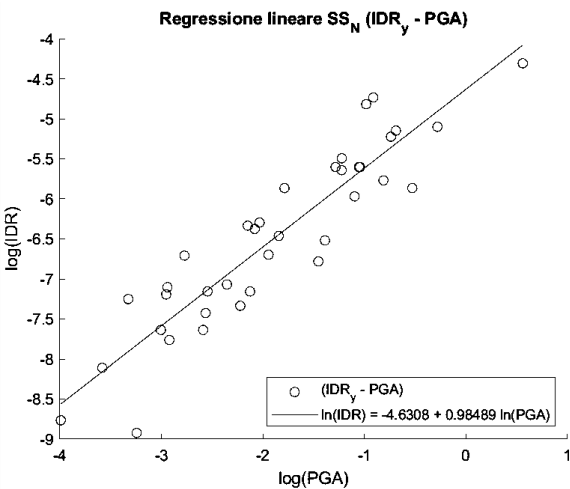
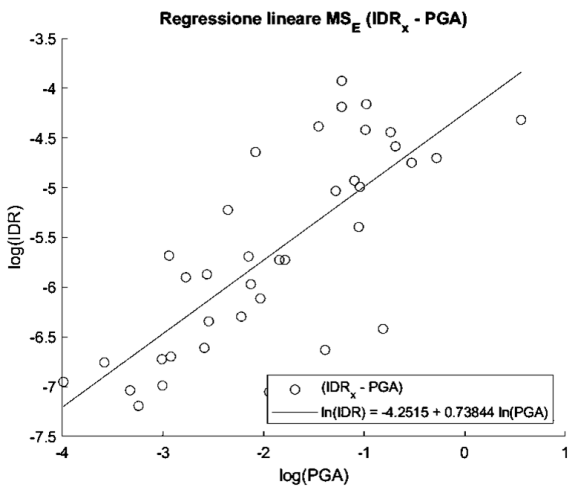


$$\text{FC}(\text{IM}) = 1 - \phi\left(\frac{\ln(\text{EDP}_0) - \ln(\widehat{\text{EDP}})}{\beta}\right)$$

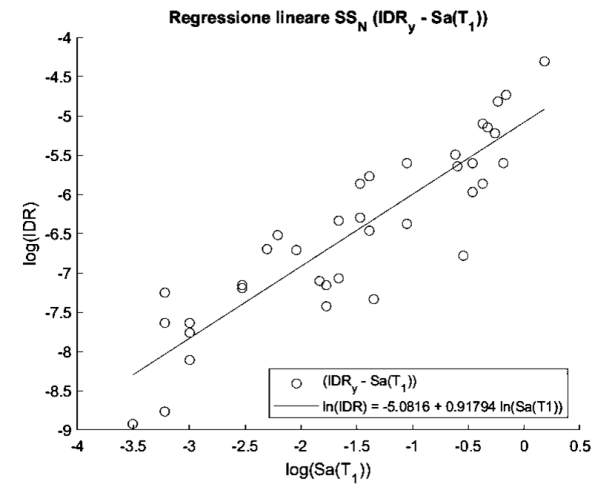
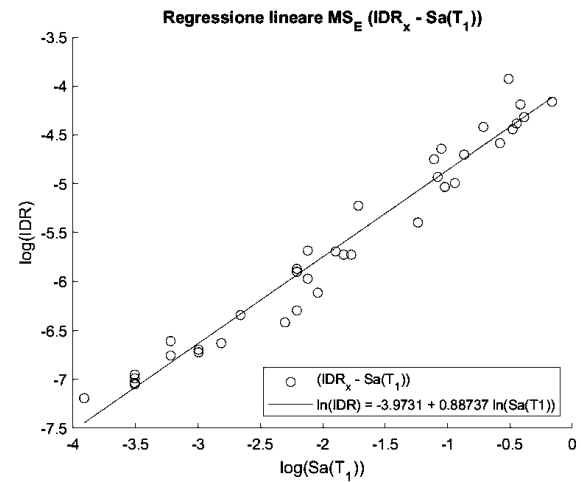
CURVA DI FRAGILITÀ



Fragilità



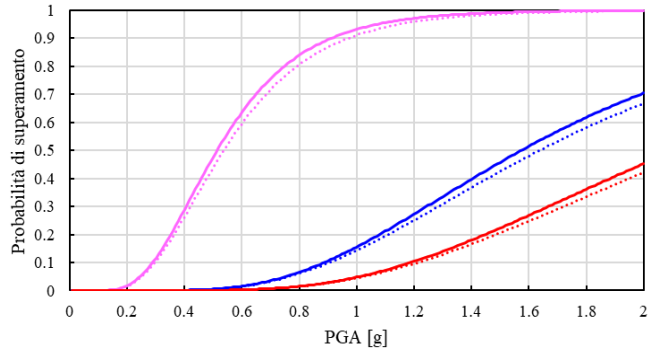
DEVIAZIONI STANDARD	COMBINAZIONE	EST		NORD	
		X	Y	X	Y
MS	PGA	0,66	0,46	0,69	0,49
	Sa	0,20	0,48	0,49	0,53
SS	PGA	0,66	0,44	0,70	0,45
	Sa	0,17	0,50	0,49	0,50



Fragilità

Curve di fragilità controvento

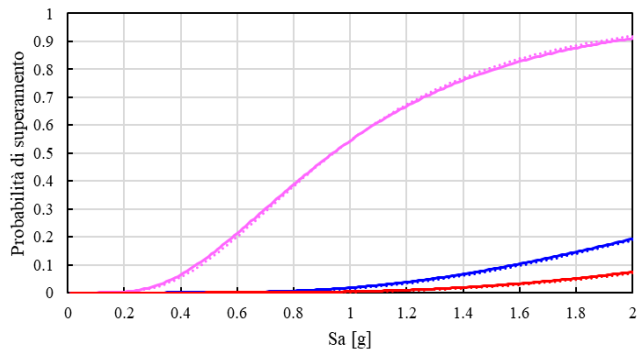
$MS_{E,Y}-SS_{E,Y}$



MS_DL MS_SD MS_NC
SS_DL SS_SD SS_NC

Curve di fragilità controvento

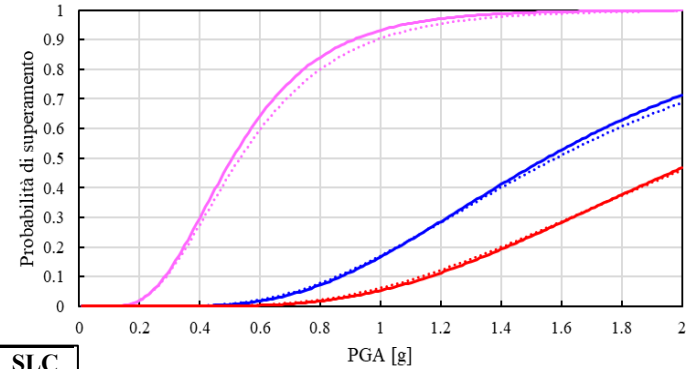
$MS_{E,Y}-SS_{E,Y}$



MS_DL MS_SD MS_NC
SS_DL SS_SD SS_NC

Curve di fragilità controvento

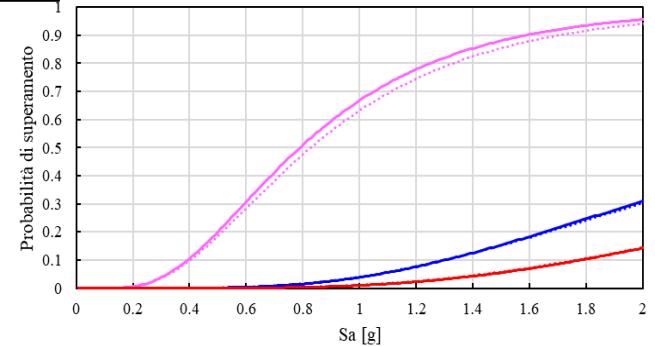
$MS_{N,Y}-SS_{N,Y}$



MS_DL MS_SD MS_NC
SS_DL SS_SD SS_NC

Curve di fragilità controvento

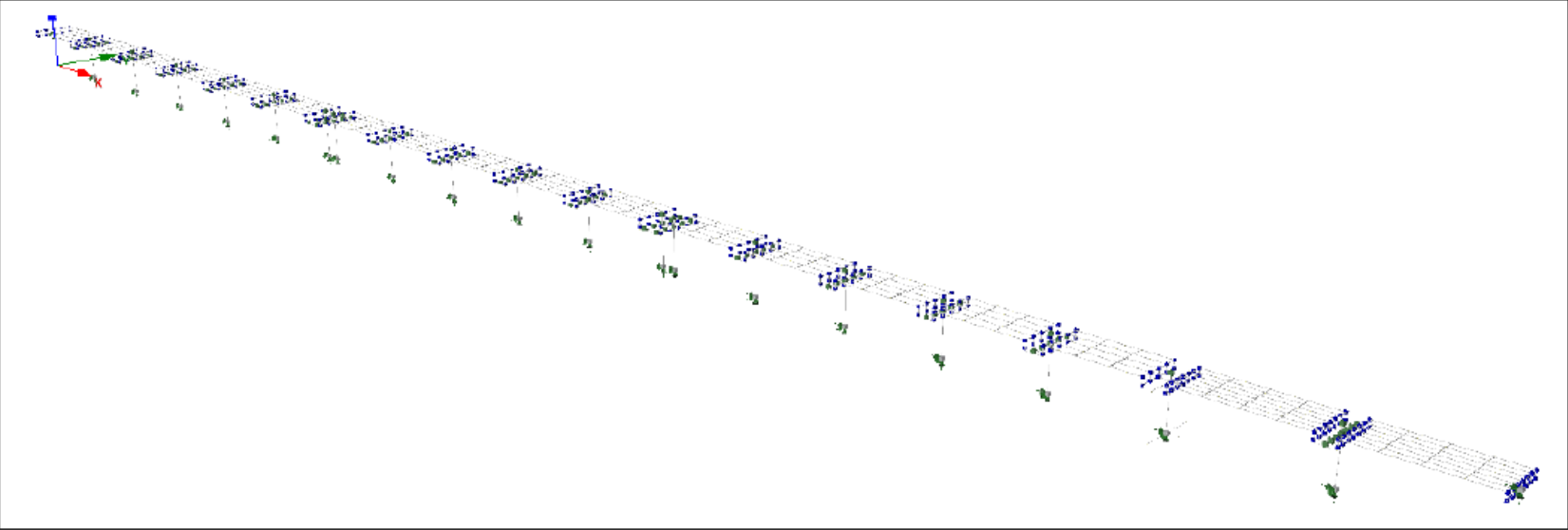
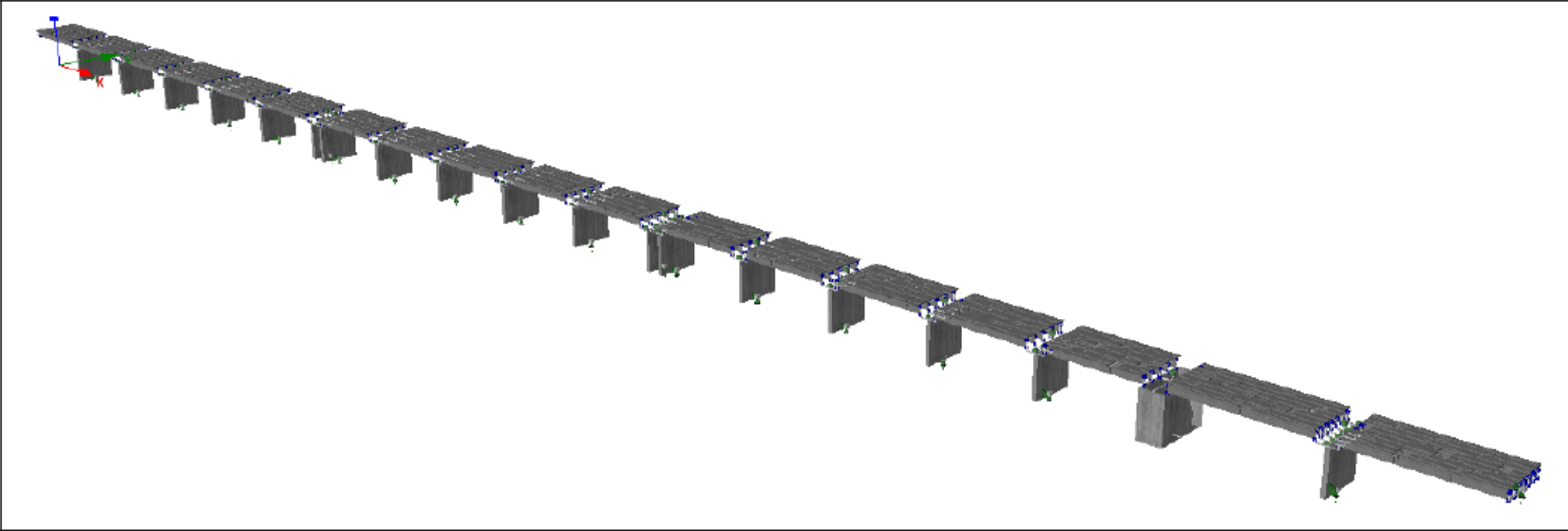
$MS_{N,Y}-SS_{N,Y}$



MS_DL MS_SD MS_NC
SS_DL SS_SD SS_NC

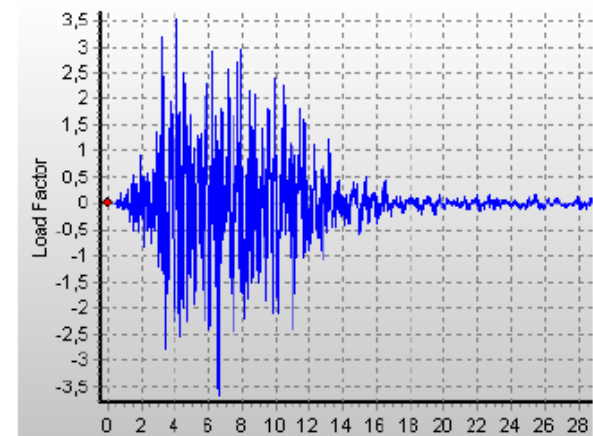
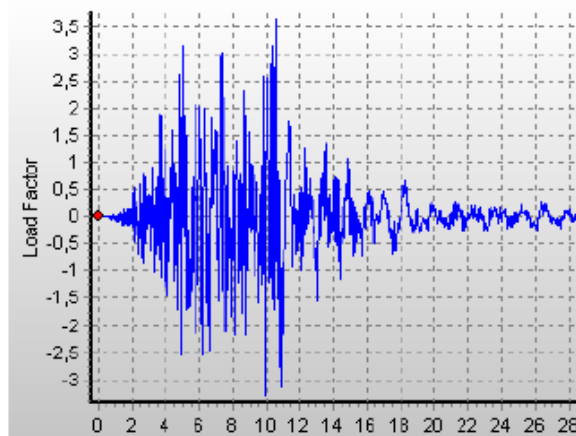
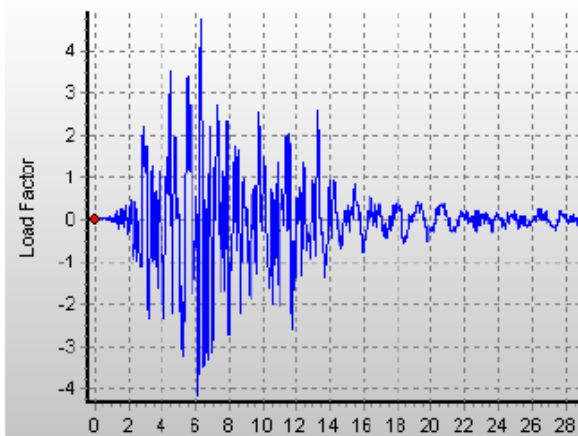
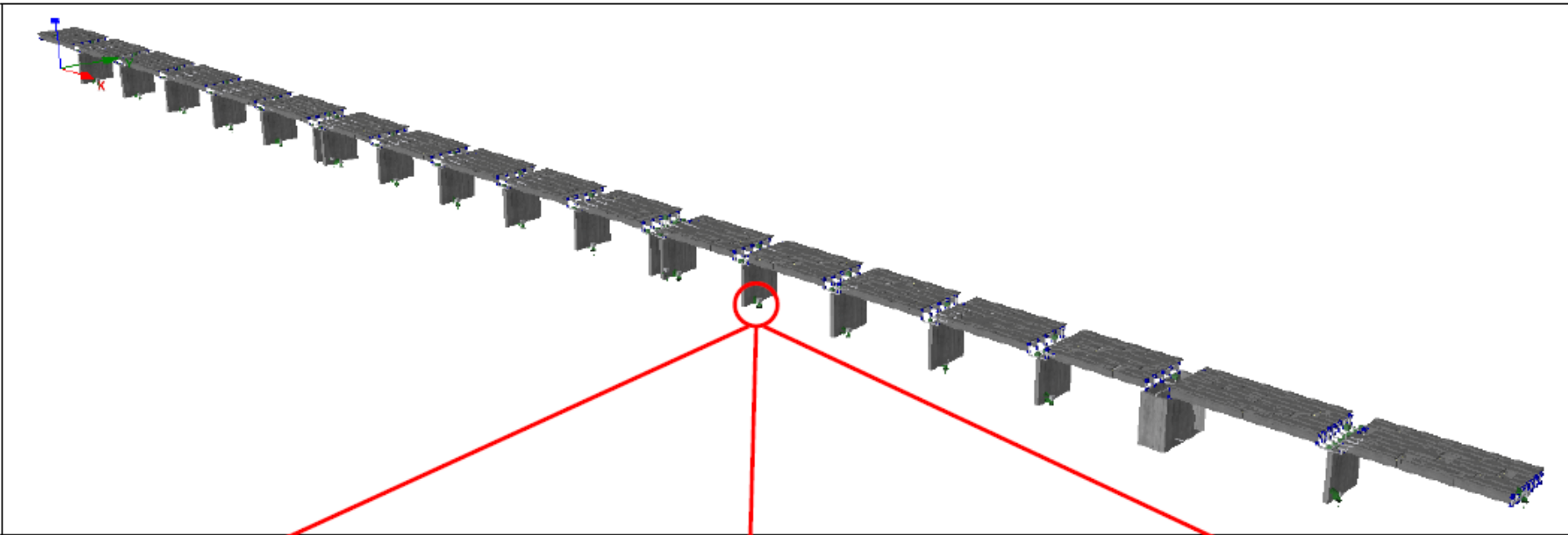
		SLO	SLV	SLC
(SS-MS)_{E,Y}	PGA	4.1%	3.7%	3.1%
	S_a	1.2%	0.6%	0.5%
(SS-MS)_{N,Y}	PGA	4.7%	2.5%	0.8%
	S_a	3.6%	1.8%	0.6%

Fragilità - Modello

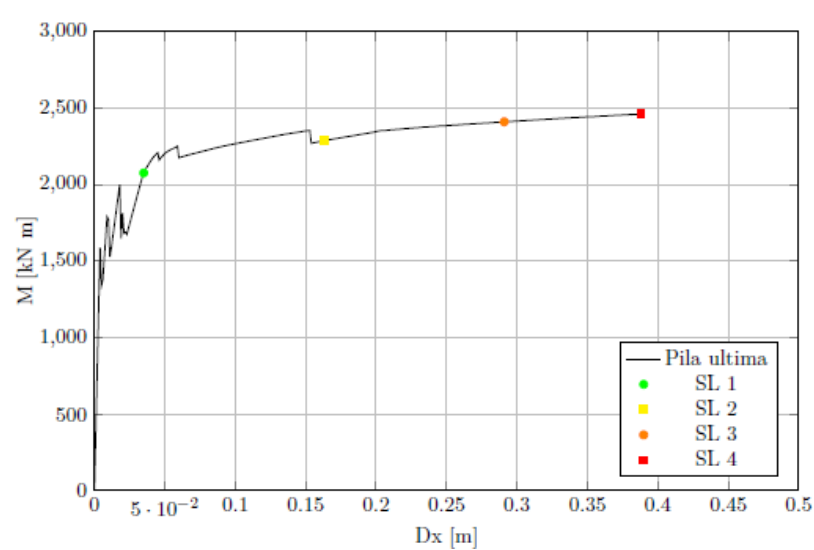
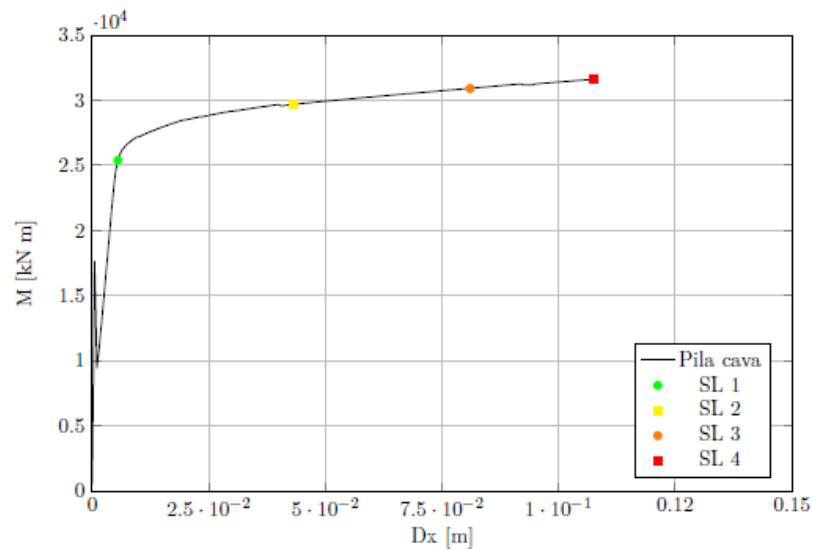
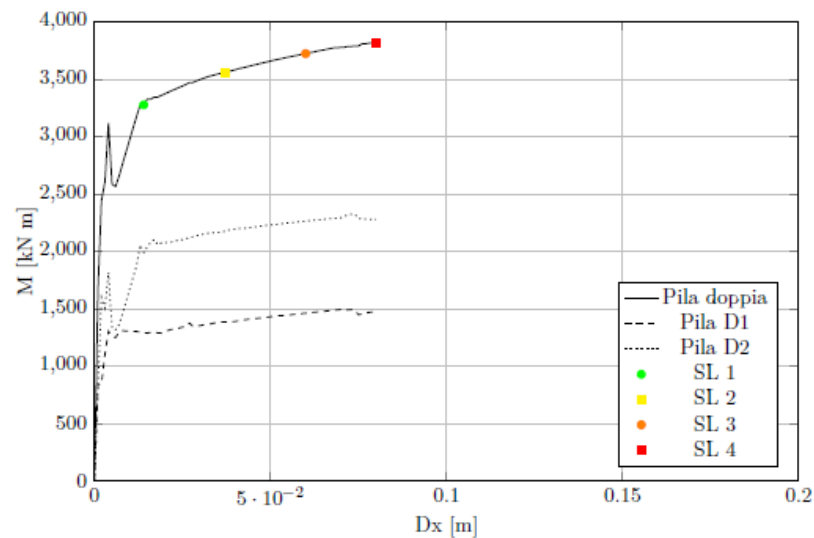
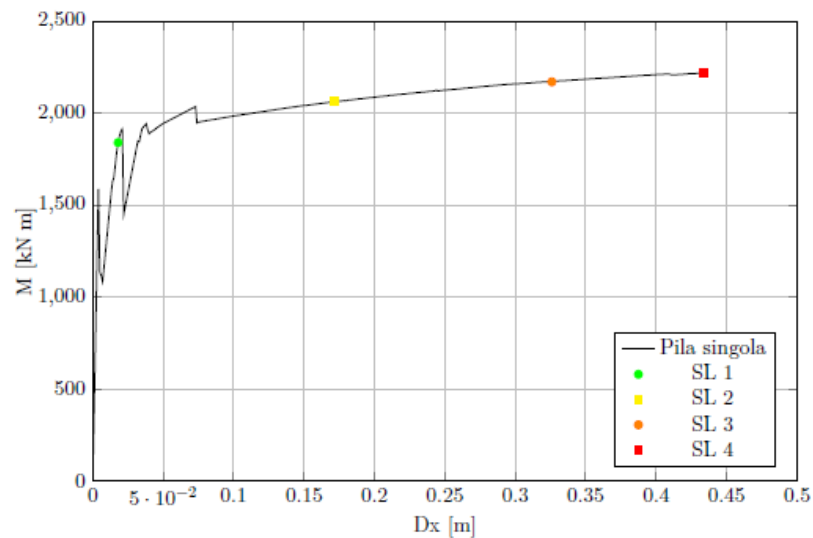


(tesi Ing. Stefano Bozza)

Fragilità - ADNL



Fragilità – Soglie di danno

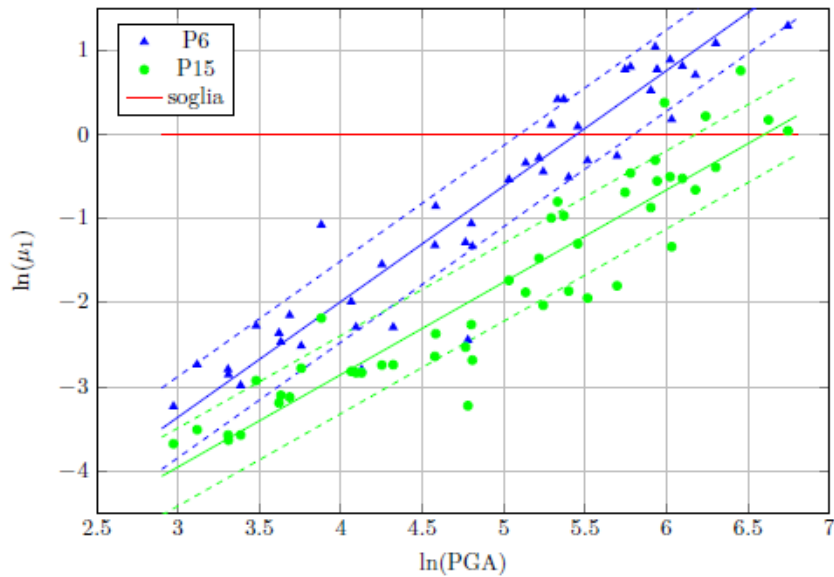


Fragilità – Soglie di danno

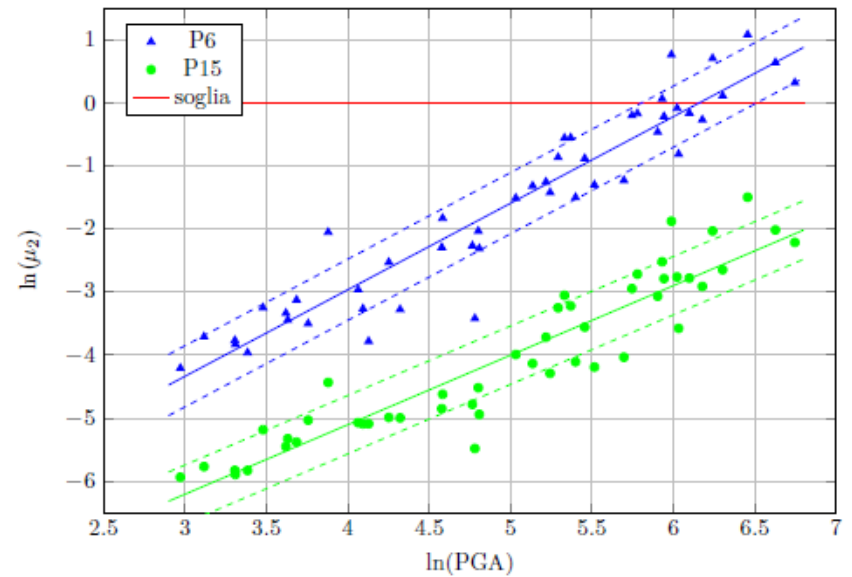
Meccanismo	EDP	Livello di Danno			
		Lieve	Moderato	Esteso	Completo
Appoggi	D_1 app				●
Martellamento	D_1 gap		●		
Rotazione pile	μ_1	●			
	μ_2		●		
	μ_3			●	
	μ_4				●
Resist. a taglio	ρ_{Vx}			●	
	ρ_{Vx}			●	

Fragilità – Analisi cloud

Cloud Analysis - rotazione pile SL1

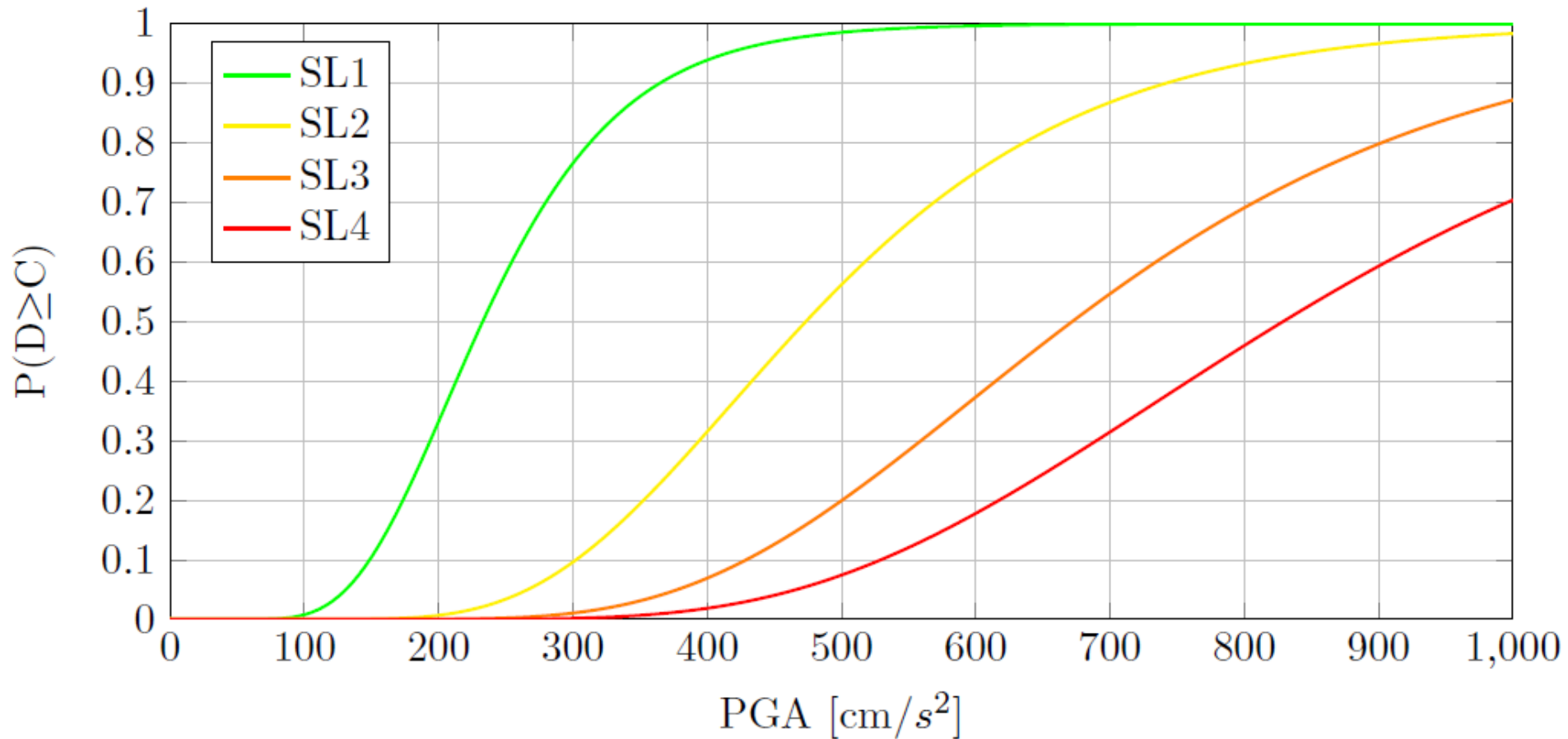


Cloud Analysis - rotazione pile SL2



Fragilità – Curve del Ponte

Curve di fragilità ponte



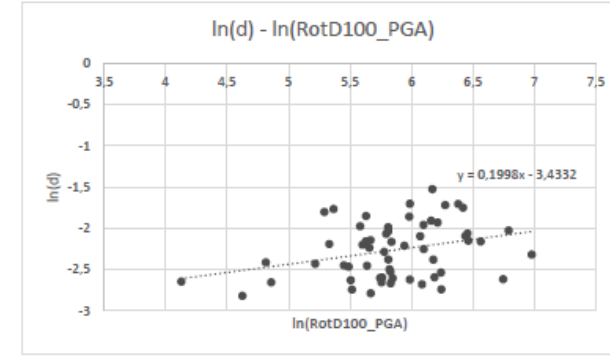
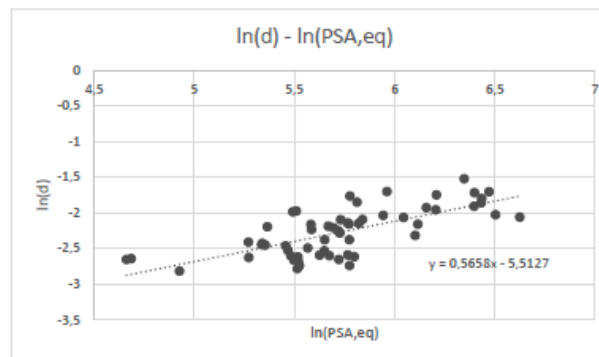
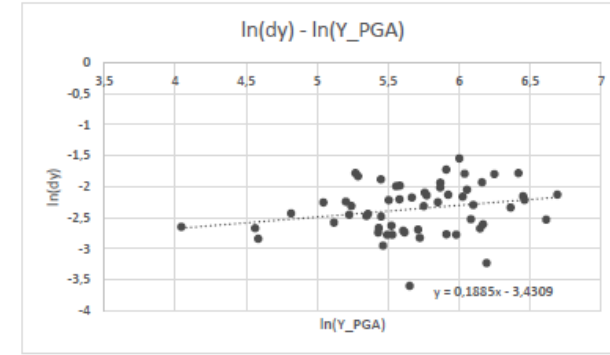
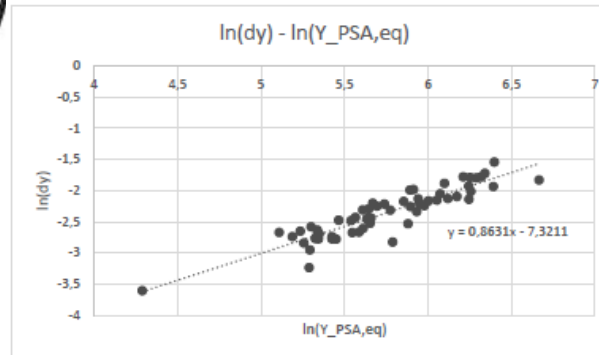
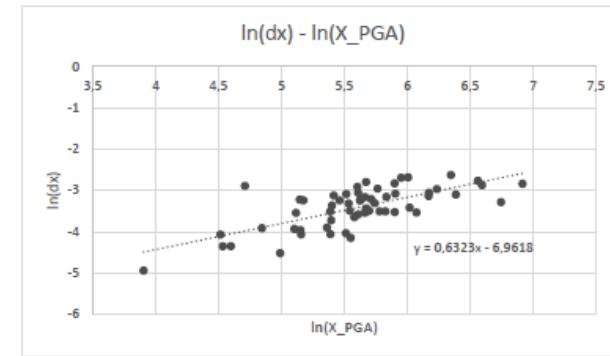
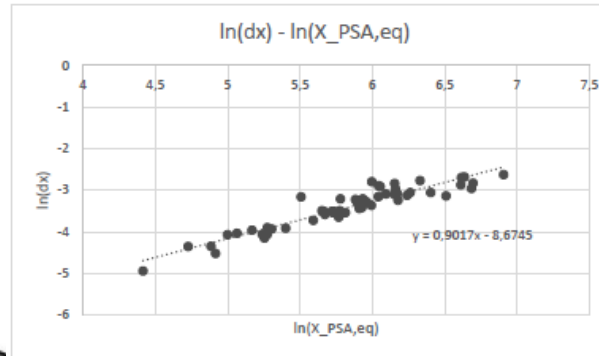
Fragilità – Efficienza IM



$$S_{a,eq,x} = \frac{\sqrt{\sum_{i=1}^N (S_{a,x}(T_i) \cdot m_{i,x})^2}}{\sum_{i=1}^N m_{i,x}}$$

$$S_{a,eq,y} = \frac{\sqrt{\sum_{i=1}^N (S_{a,y}(T_i) \cdot m_{i,y})^2}}{\sum_{i=1}^N m_{i,y}}$$

$$S_{a,eq,res} = \frac{\sqrt{\sum_{i=1}^N (S_a(T_i) \cdot (m_{i,x} + m_{i,y}))^2}}{\sum_{i=1}^N (m_{i,x} + m_{i,y})}$$



Fragilità – Efficienza IM



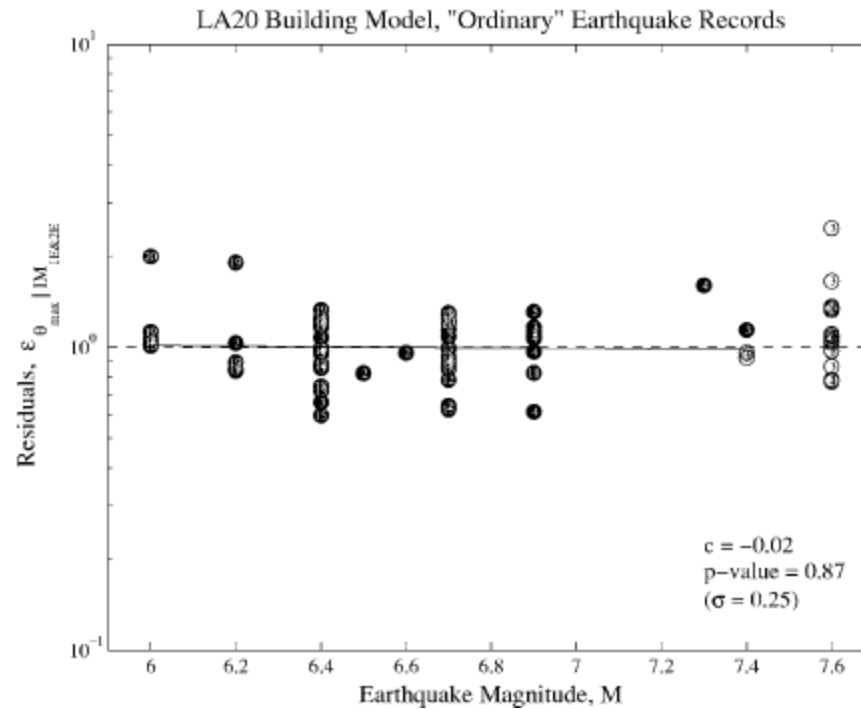
valore minimo,
ottima correlazione

valore massimo,
cattiva correlazione

	regolare		non regolare n.1		non regolare n.2		non regolare n.3	
	con GR	senza GR	con GR	senza GR	con GR	senza GR	con GR	senza GR
$\ln(d) - \ln(Sa,eq,res)$	0,239	0,221	0,241	0,232	0,266	0,313	0,275	0,283
$\ln(d) - \ln(Ei,eq)$	0,249	0,231	0,263	0,257	0,237	0,318	0,246	0,288
$\ln(d) - \ln(PSA,eq)$	0,239	0,220	0,241	0,232	0,266	0,313	0,275	0,283
$\ln(d) - \ln(Ee,mod)$	0,188	0,180	0,211	0,215	0,219	0,275	0,228	0,254
$\ln(d) - \ln(Ee,SRSS)$	0,151	0,162	0,184	0,194	0,214	0,284	0,231	0,263
$\ln(d) - \ln(RotD100_Sa)$	0,299	0,281	0,307	0,286	0,279	0,320	0,283	0,284
$\ln(d) - \ln(Sa,avg(Sa,eq))$	0,202	0,222	0,227	0,214	0,264	0,322	0,265	0,283
$\ln(d) - \ln(Sa,avg(Sa))$	0,222	0,252	0,154	0,180	0,178	0,227	0,167	0,210
$\ln(d) - \ln(PSA)$	0,219	0,251	0,246	0,239	0,220	0,286	0,235	0,249
$\ln(d) - \ln(PSV)$	0,175	0,213	0,226	0,222	0,224	0,288	0,239	0,253
$\ln(d) - \ln(Sd)$	0,153	0,191	0,218	0,215	0,230	0,294	0,245	0,259
$\ln(d) - \ln(RotD100_PGA)$	0,321	0,330	0,348	0,342	0,316	0,368	0,332	0,329
$\ln(d) - \ln(RotD100_PGV)$	0,250	0,248	0,305	0,283	0,269	0,306	0,287	0,287
$\ln(d) - \ln(RotD100_PGD)$	0,292	0,279	0,336	0,314	0,289	0,330	0,311	0,304
$\ln(d) - \ln(RotD100_Housner)$	0,225	0,211	0,297	0,251	0,255	0,287	0,277	0,261
$\ln(d) - \ln(RotD100_IA)$	0,313	0,325	0,341	0,336	0,307	0,364	0,318	0,326

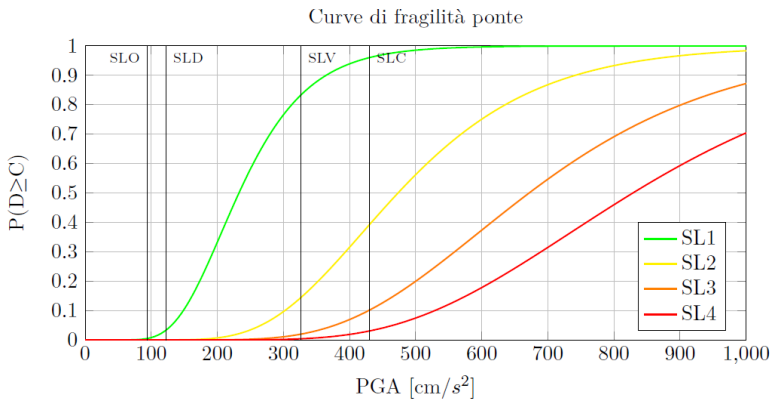
Fragilità – Sufficienza IM

$$\ln(IM|EDP) = a + b M_w$$



Analisi del Danno

Le curve di fragilità possono essere utilizzate per condurre analisi di rischio sul ponte. – ANALISI CONDIZIONALE



Data la PGA prevista per SLC (Hazard)

$$P[D \geq D_1 | PGA_{SLC}] = 0.96$$

$$P[D \geq D_2 | PGA_{SLC}] = 0.39$$

$$P[D \geq D_3 | PGA_{SLC}] = 0.10$$

$$P[D \geq D_4 | PGA_{SLC}] = 0.03$$

$$P[D = D_0 | PGA_{SLC}] = 1 - P[D \geq D_1 | PGA_{SLC}] = 0.04$$

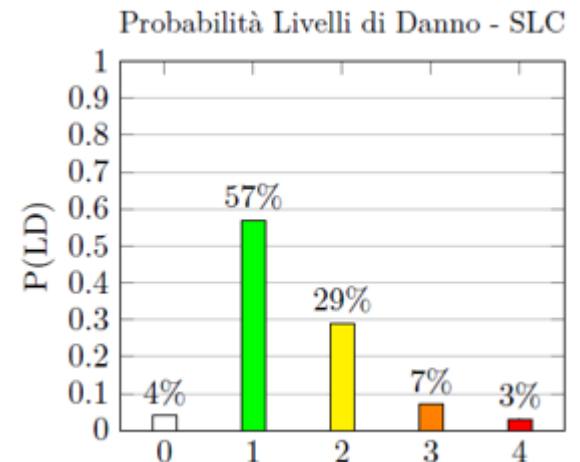
$$P[D = D_1 | PGA_{SLC}] = P[D \geq D_1 | PGA_{SLC}] - P[D \geq D_2 | PGA_{SLC}] = 0.57$$

$$P[D = D_2 | PGA_{SLC}] = P[D \geq D_2 | PGA_{SLC}] - P[D \geq D_3 | PGA_{SLC}] = 0.29$$

$$P[D = D_3 | PGA_{SLC}] = P[D \geq D_3 | PGA_{SLC}] - P[D \geq D_4 | PGA_{SLC}] = 0.07$$

$$P[D = D_4 | PGA_{SLC}] = P[D \geq D_4 | PGA_{SLC}] = 0.03$$

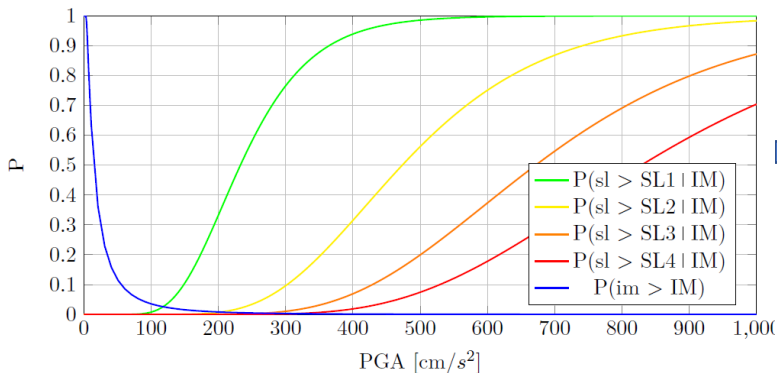
$$P[D = D_i | PGA_n] = \begin{cases} 1 - P[D \geq D_{i+1} | PGA_n] & \text{se } i = 0 \\ P[D \geq D_i | PGA_n] - P[D \geq D_{i+1} | PGA_n] & \text{se } 1 \leq i < n_d \\ P[D \geq D_i | PGA_{SLC}] & \text{se } i = n_d \end{cases}$$



Analisi affidabilistica

Le curve di fragilità possono essere utilizzate per condurre una valutazione affidabilistica del ponte –ANALISI INCONDIZIONALE

Curve di fragilità e curva di pericolosità ponte



$$\lambda_{SL} = \int_0^{\infty} P(sl > SL | IM) \cdot \left| \frac{d\bar{\lambda}(IM)}{dIM} \right| dIM$$

	SL1	SL2	SL3	SL4
λ_{SL}	$2,9 \times 10^{-3}$	$0,55 \times 10^{-3}$	$0,22 \times 10^{-3}$	$0,11 \times 10^{-3}$

$$\lambda_{D \geq D_i} = \int_0^{+\infty} P(D \geq D_i | IM = x) \left| \frac{d\lambda(IM > x)}{dx} \right| dx$$

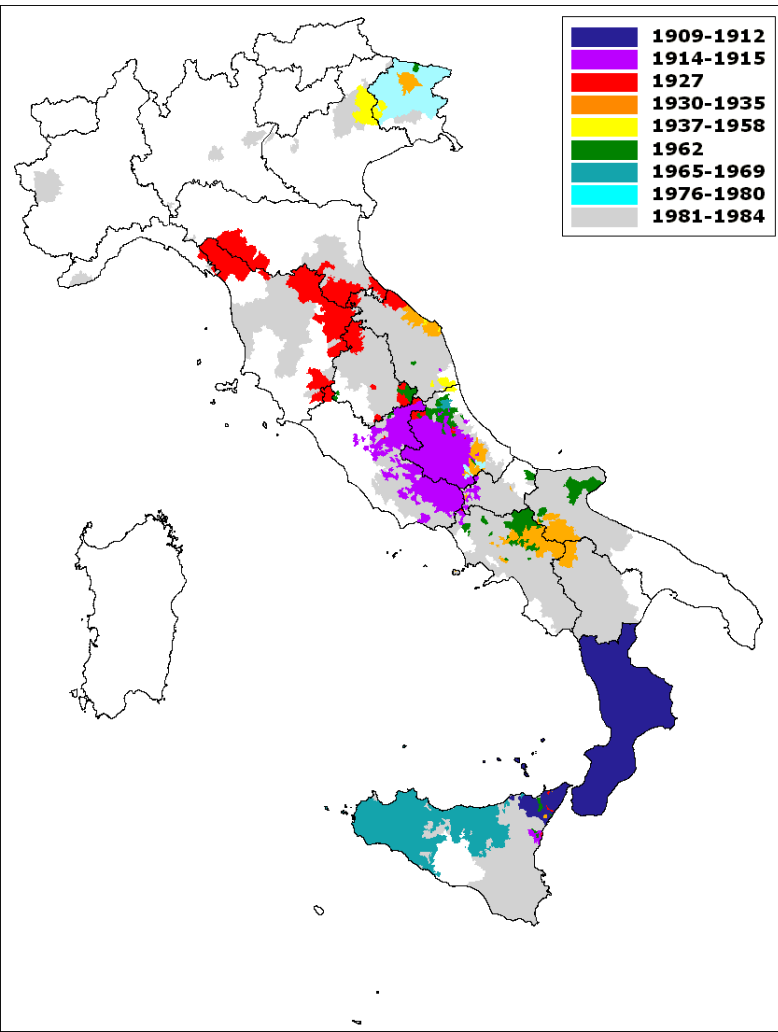
$$\lambda_{D \geq D_i} \approx \sum_{j=0}^n P(D \geq D_i | IM = x_j) |\lambda(IM > x_j) - \lambda(IM > x_{j+1})|$$

Vulnerabilità

Edificio progettati con criteri antisismici >> **BASSA VULNERABILITÀ**

Edificio progettati senza criteri antisismici >> **ALTA VULNERABILITÀ**

Evoluzione della normativa antisismica



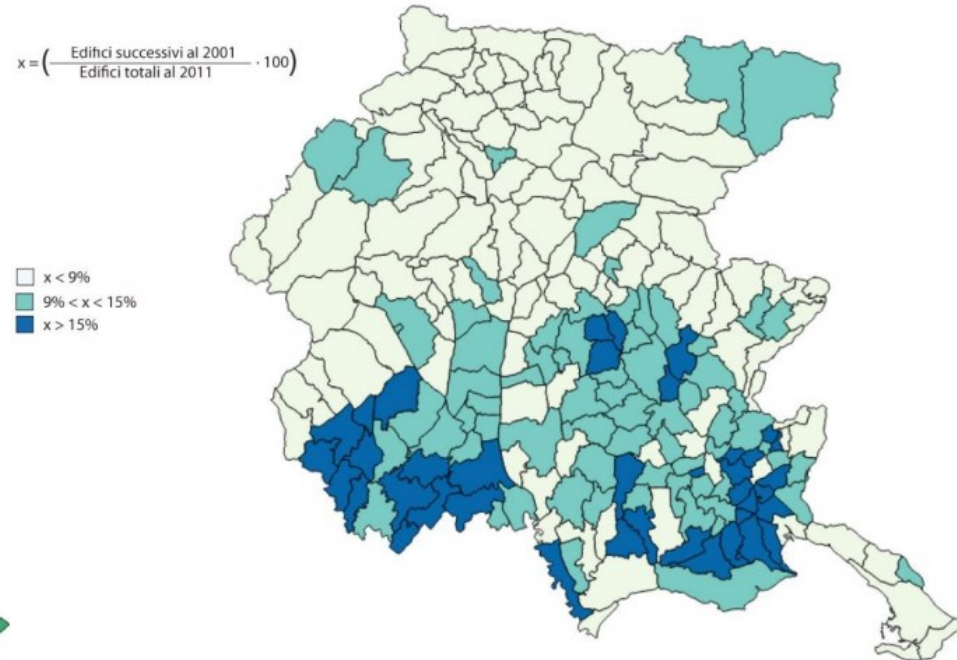
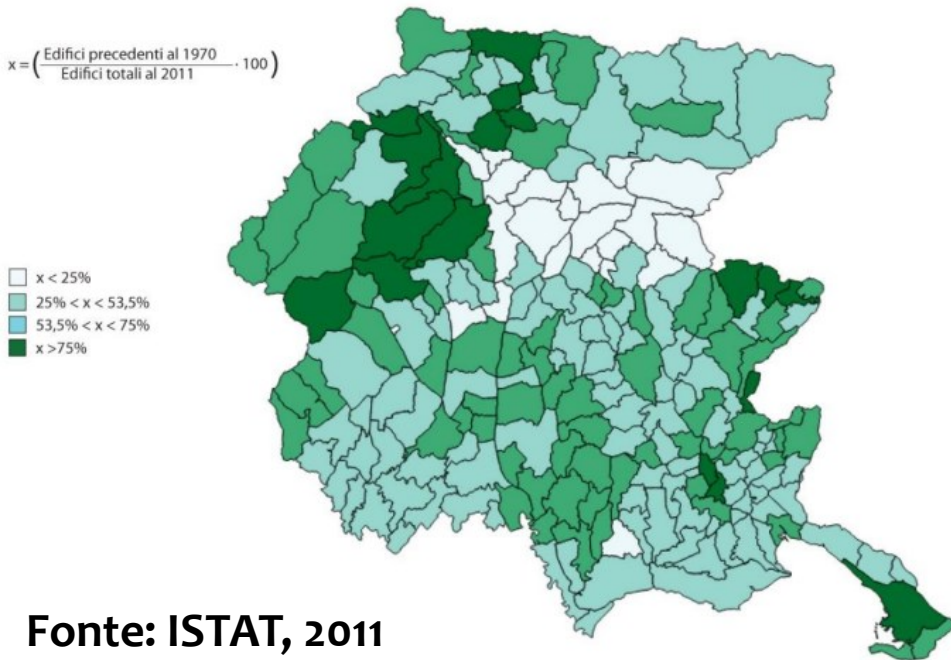
Fino al 2004 un territorio era
classificato sismico solo dopo un
evento

Nessuna strategia sistematica di
riduzione del rischio

ALTA VULNERABILITÀ

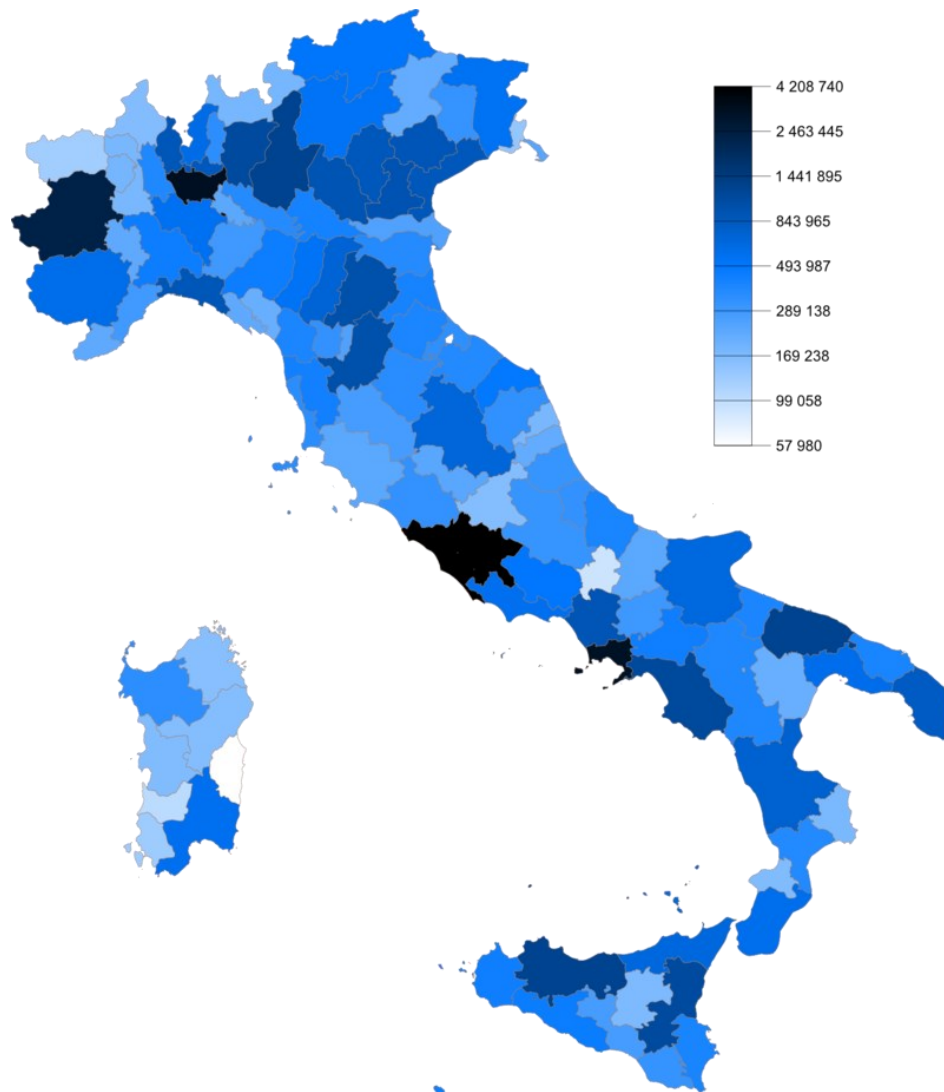
Vulnerabilità - Gorizia

classificata come sismica a partire dal **2004**



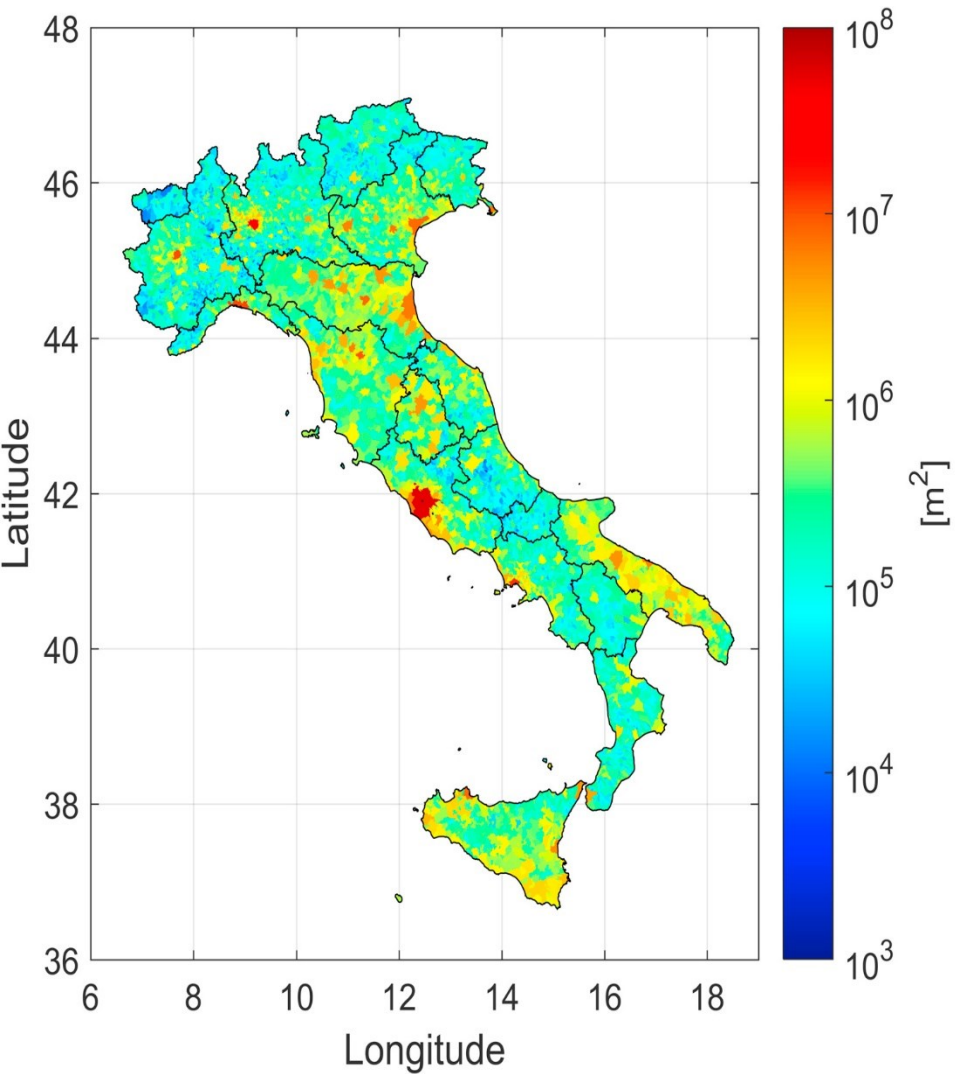
Esposizione - 1

N° di abitanti

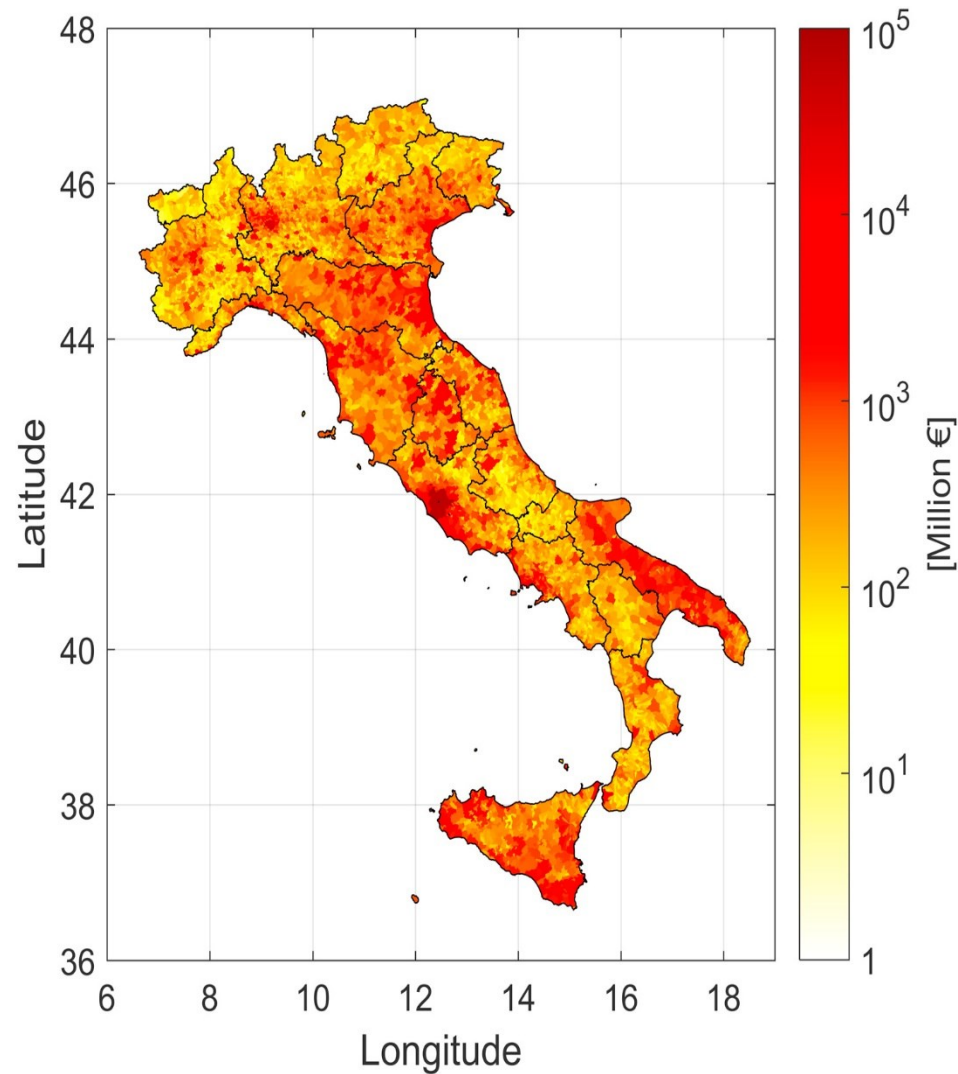


Esposizione - 2

N° di m2 edificati

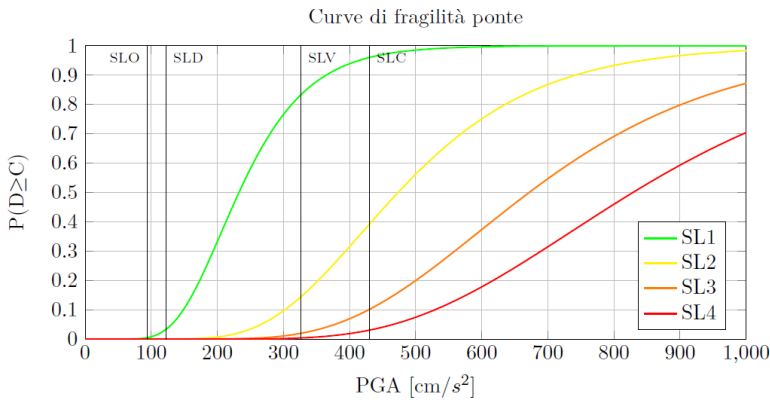


Valore immobiliare



ANALISI DELLE CONSEGUENZE - RISCHIO

- ANALISI DEL DANNO



$$P[D = D_0 | PGA_{SLC}] = 1 - P[D \geq D_1 | PGA_{SLC}] = 0.04$$

$$P[D = D_1 | PGA_{SLC}] = P[D \geq D_1 | PGA_{SLC}] - P[D \geq D_2 | PGA_{SLC}] = 0.57$$

$$P[D = D_2 | PGA_{SLC}] = P[D \geq D_2 | PGA_{SLC}] - P[D \geq D_3 | PGA_{SLC}] = 0.29$$

$$P[D = D_3 | PGA_{SLC}] = P[D \geq D_3 | PGA_{SLC}] - P[D \geq D_4 | PGA_{SLC}] = 0.07$$

$$P[D = D_4 | PGA_{SLC}] = P[D \geq D_4 | PGA_{SLC}] = 0.03$$

- CONSEGUENZE

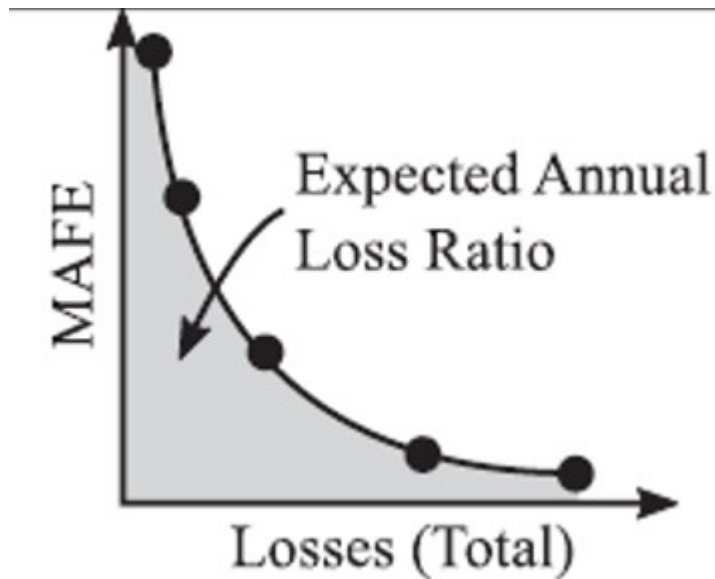
$$E[C | IM = x] = \sum_{i=0}^n E[C | D = D_i] P[D = D_i | IM = x]$$

$$E[C | IM = x] = RC_t \sum_{i=0}^n [RCR_i | D = D_i] P[D = D_i | IM = x]$$

$$E[C | IM = PGA_{SLC}] = RC_t * (0.04 * 0 + 0.57 * 0.07 + 0.29 * 0.15 + 0.07 * 0.5 + 0.03 * 1) = 0.15RC_t$$

ANALISI DELLE CONSEGUENZE - RISCHIO

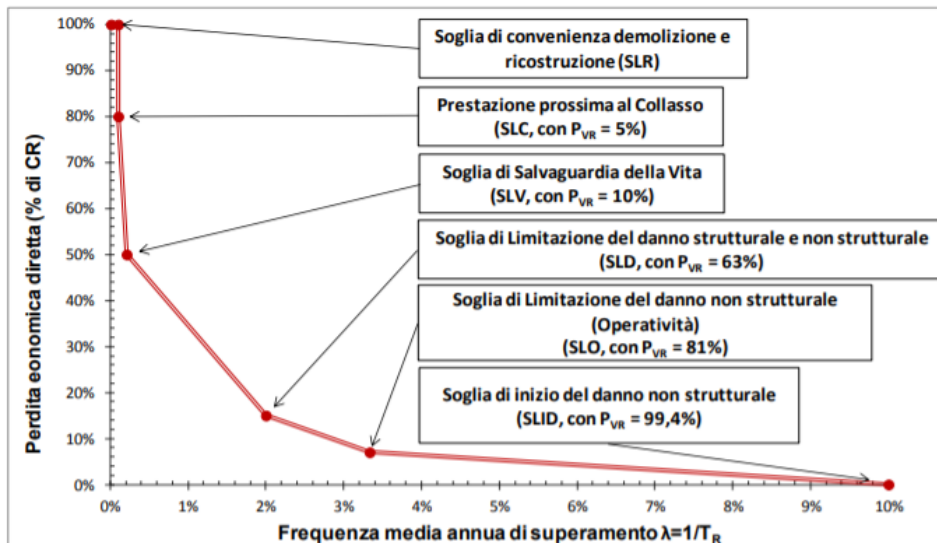
- CONSEGUENZE



Curva di perdita:
 Lego la curva di hazard alla
 curva di perdita condizionata
 alla misura di intensità
 [curva Tasso(IM) – Perdita(IM)]

$$EAL \cong \sum_{i=2}^n \frac{C_i + C_{i-1}}{2} * (\lambda_i - \lambda_{i-1})$$

Sismabonus – D.M. 65/2017



PAM

Perdita Annua Media

classe A+ (meno rischio)

classe A

classe B

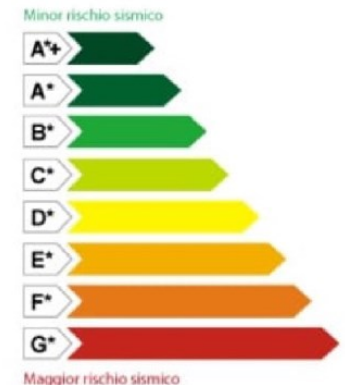
classe C

classe D

classe E

classe F

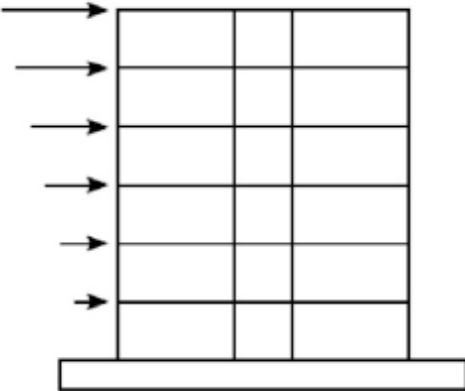
classe G (più rischio)



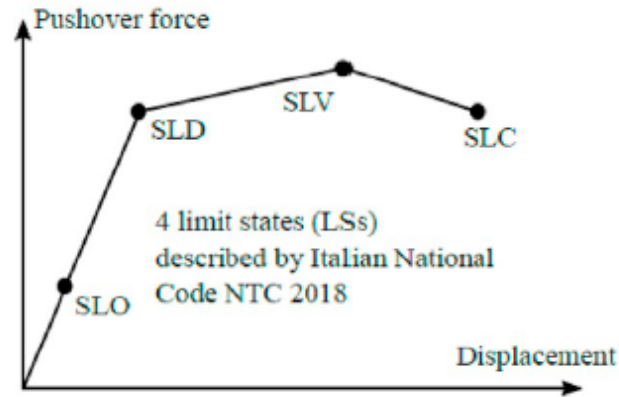
ANALISI DELLE CONSEGUENZE - RISCHIO

- CONSEGUENZE

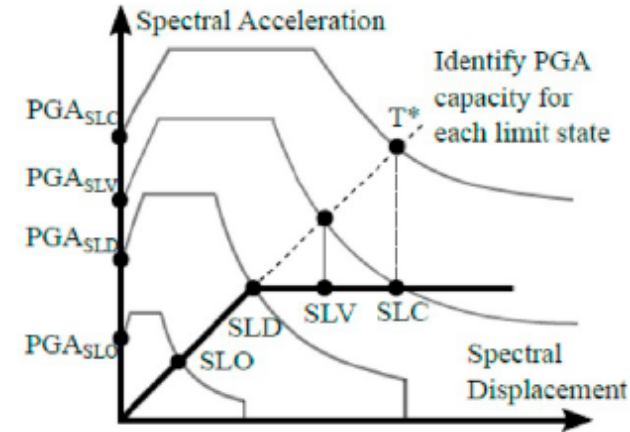
Sismabonus – D.M. 65/2017



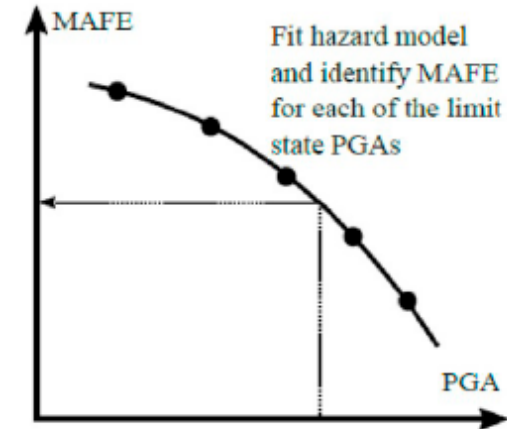
(a) Static Pushover Analysis



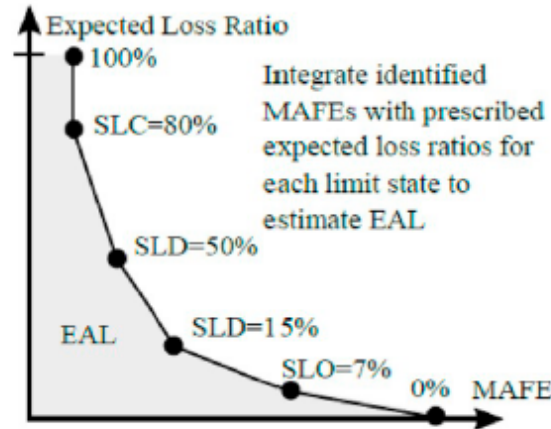
(b) Identification of LSs



(c) Identify PGA of LSs



(d) Identify MAFE of LSs



(e) Compute EAL

Classify the building as the more critical of the EAL and IS-V rankings

EAL Range	IS-V Range	Class
$EAL \leq 0.5\%$	$1.00 < IS-V$	A+
$0.5\% < EAL \leq 1.0\%$	$0.80 \leq IS-V < 1.00$	A
$1.0\% < EAL \leq 1.5\%$	$0.60 \leq IS-V < 0.80$	B
$1.5\% < EAL \leq 2.5\%$	$0.45 \leq IS-V < 0.60$	C
$2.5\% < EAL \leq 3.5\%$	$0.30 \leq IS-V < 0.45$	D
$3.5\% < EAL \leq 4.5\%$	$0.15 \leq IS-V < 0.30$	E
$4.5\% < EAL \leq 7.0\%$	$IS-V < 0.15$	F
$EAL > 7.0\%$		G

(f) Classification Ranking

$$PAM = \sum_{i=2}^5 [\lambda(SL_i) - \lambda(SL_{i-1})] * [CR(SL_i) + CR(SL_{i-1})] / 2 + \lambda(SLC) * CR(SLC)$$

$$T_{rC} = T_{rD} (PGA_C / PGA_D)^\eta \quad \lambda = 1 / T_{rC}$$

Riduzione del rischio sismico *dove agire?*

Prima del terremoto



Dopo del terremoto



riduzione del rischio sismico

pericolosità



Incontrollabile

esposizione



*difficile
diminuirlo*

vulnerabilità



*facile
diminuirlo*

Comunicazione / percezione >> Molti edifici hanno elevata vulnerabilità

DO NOT REMOVE UNDER PENALTY OF LAWF. DO NOT REMOVE UNDER PENALTY OF LAWF. DO NOT REMOVE UNDER PENALTY OF LAWF.



The San Francisco Department of Building Inspection - Tim H.A. S.E., C.S.D., Director
SFBC Section 3408A.1

EARTHQUAKE WARNING!

This Building is in Violation of the Requirements of the San Francisco Building Code Regarding Earthquake Safety.

The owner(s) of this building have not complied with the Mandatory Soft Story Retrofit Program, as required by SFBC Chapter 34B. Please contact the Department of Building Inspection at softstory@sfgov.org or (415) 558-6699 or www.sfdbi.org/softstory.

地震警告! **¡ADVERTENCIA DEL TERREMOTO!**

這棟樓宇違反三藩市建築條例有關地震安全的要求。

Este edificio está en la violación de los requisitos del Código de construcción de San Francisco en cuanto a la seguridad del terremoto.

根據三藩市建築條例第34B章，本棟樓宇尚未遵守軟層建築物的抗震加固計劃強制規定。請立即與樓宇檢查部聯絡。

電話: softstory@sfgov.org 或 (415) 558-6699
或網址: www.sfdbi.org/softstory

El propietario o los propietarios de este edificio no han cumplido con el Programa Obligatorio de Acondicionamiento de Pisos (Mandatory Soft Story Retrofit Program), según lo requiere el Código de Edificios de San Francisco Capítulo 34B (SFBC Chapter 34B). Favor comunicarse con el Departamento de Inspección de Edificios (Department of Building Inspection) a: softstory@sfgov.org o (415) 558-6699 o www.sfdbi.org.

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NOTICE

THIS IS AN UNREINFORCED MASONRY BUILDING. UNREINFORCED MASONRY BUILDINGS MAY BE UNSAFE IN THE EVENT OF A MAJOR EARTHQUAKE.

TSUNAMI HAZARD ZONE



IN CASE OF EARTHQUAKE GO TO HIGH GROUND OR INLAND

Earthquake Warning

This is an unreinforced masonry building.

You may not be safe inside or near unreinforced masonry buildings during an earthquake.