SIBYL SeIsmic monitoring and vulneraBilitY framework for civiL protection

Task D
Real-time monitoring during a seismic sequence

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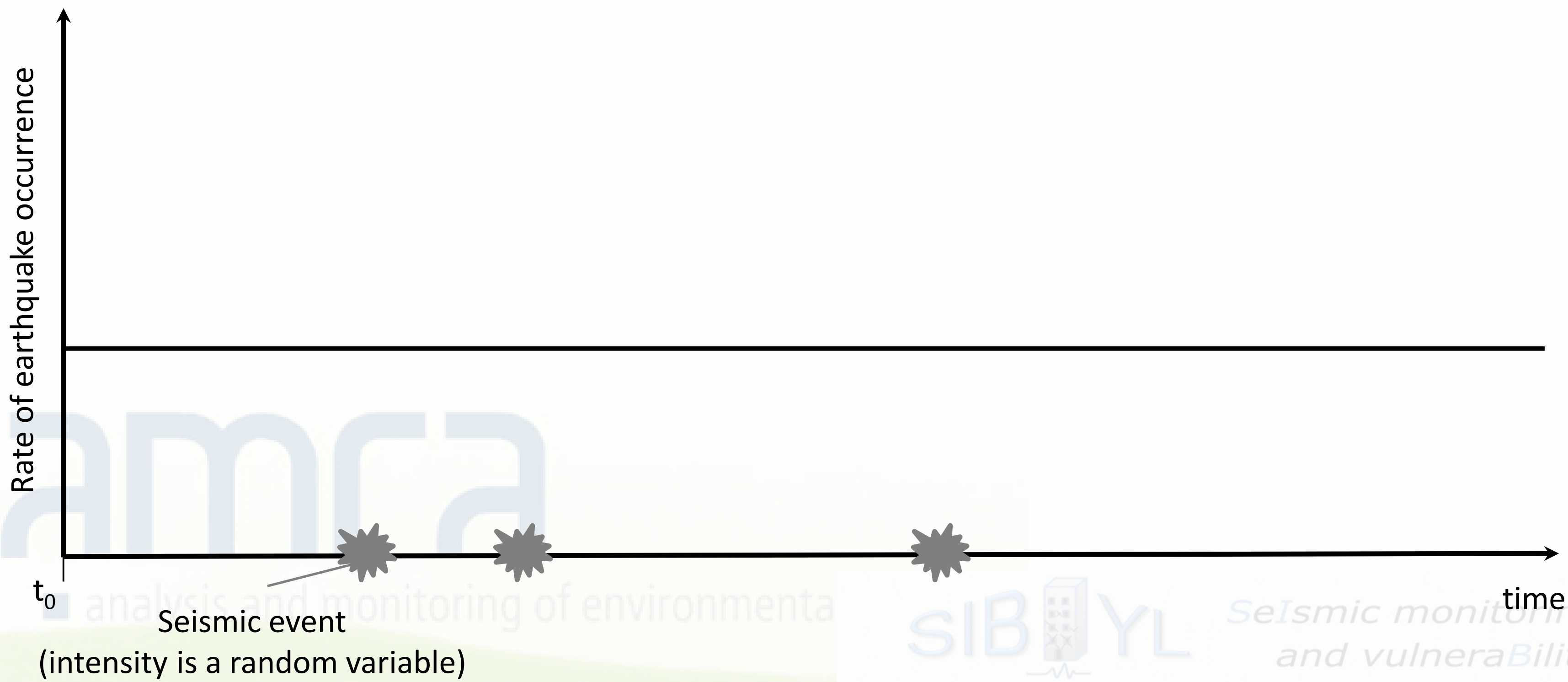
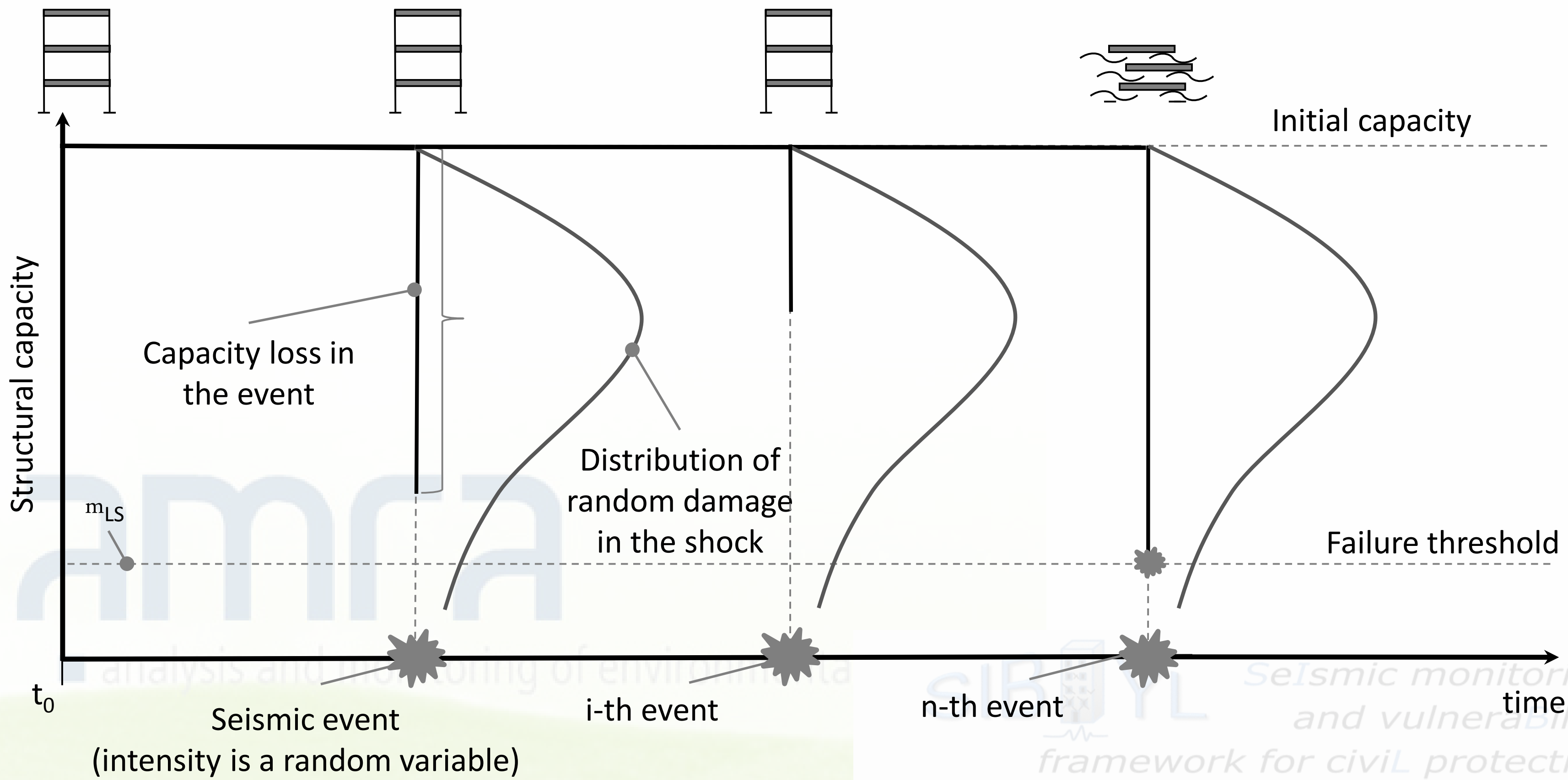
Traditional approach to seismic risk

- Constant rate of earthquake occurrence in the unit time interval



Traditional approach to seismic risk

- Constant rate of earthquake occurrence in the unit time interval
- Non evolutionary vulnerability: the structure is not damaged by non-collapsing earthquakes



Time-dependency in seismic risk

Daily rate of aftershocks' occurrence for non-homogenous Poisson process:

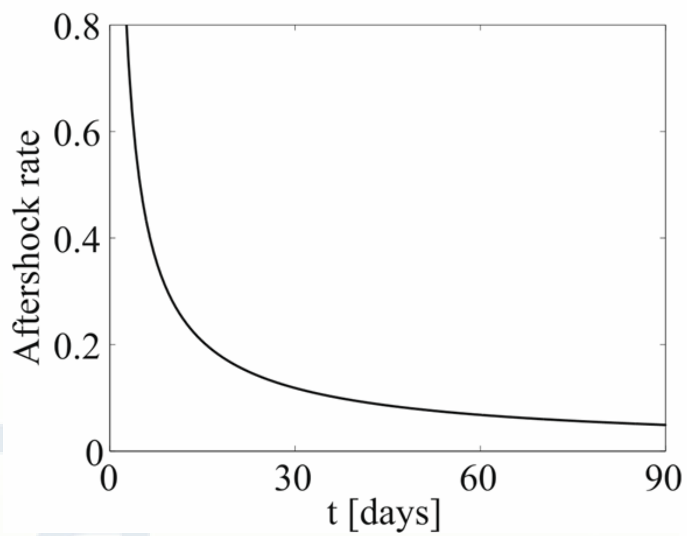
$$\lambda(t) = \left(10^{a+b\cdot(m_m - m_l)} - 10^{a}\right) \Big/ (t+c)^{p}$$

Modified Omori law

Gutenberg-Richter coefficients

Magnitude range

Time since the mainshock



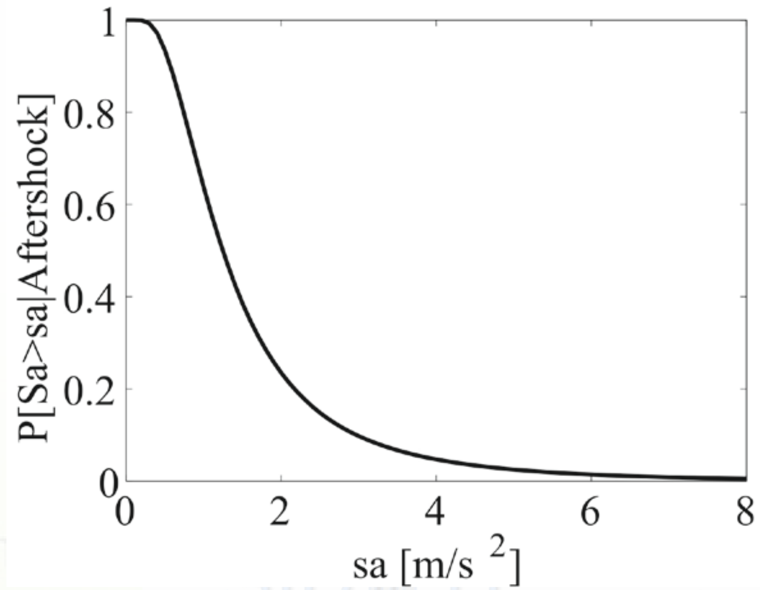
Yeo G.L., Cornell C.A. (2009). A probabilistic framework for quantification of aftershock ground-motion hazard in California, Earthquake Engng. Struct. Dyn. 38(1): 45-60

Time-dependency in seismic risk

APSHA *filters* the rate by the (time-invariant) probability that the ground motion intensity measure, *IM*, at the site of interest exceeds a threshold:

$$\lambda_D(t) = \lambda(t) \cdot P\left[IM > im^*\right] = \lambda(t) \cdot \iint_{m,r_s} P\left[IM > im^* \mid m, r_s\right] \cdot f_{M,R_s}(m, r_s) \cdot dm \cdot dr_s$$

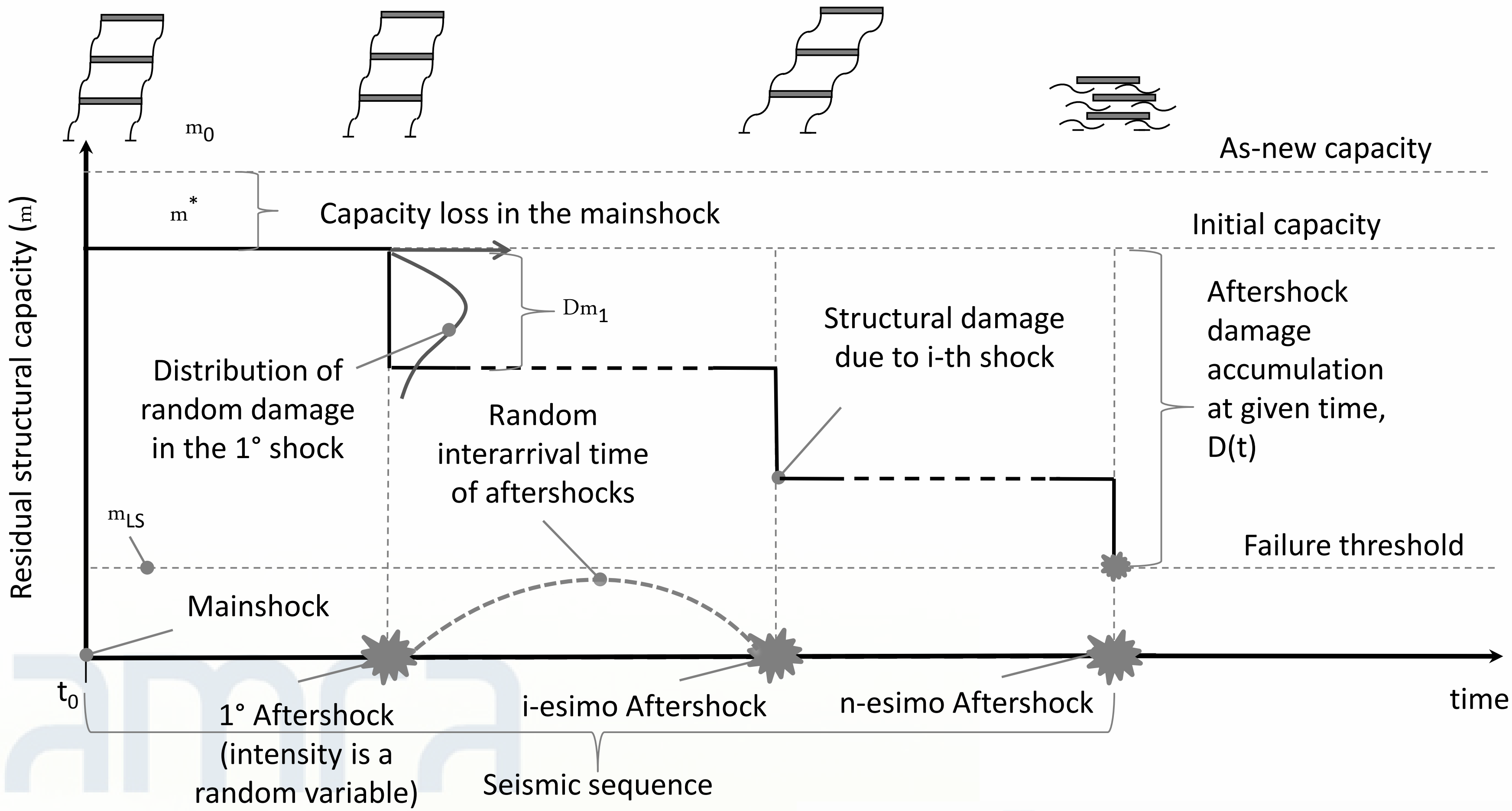
Joint pdf of magnitude and source-to-site distance



Yeo G.L., Cornell C.A. (2009). A probabilistic framework for quantification of aftershock ground-motion hazard in California, Earthquake Engng. Struct. Dyn. 38(1): 45-60

Time-dependency in seismic risk

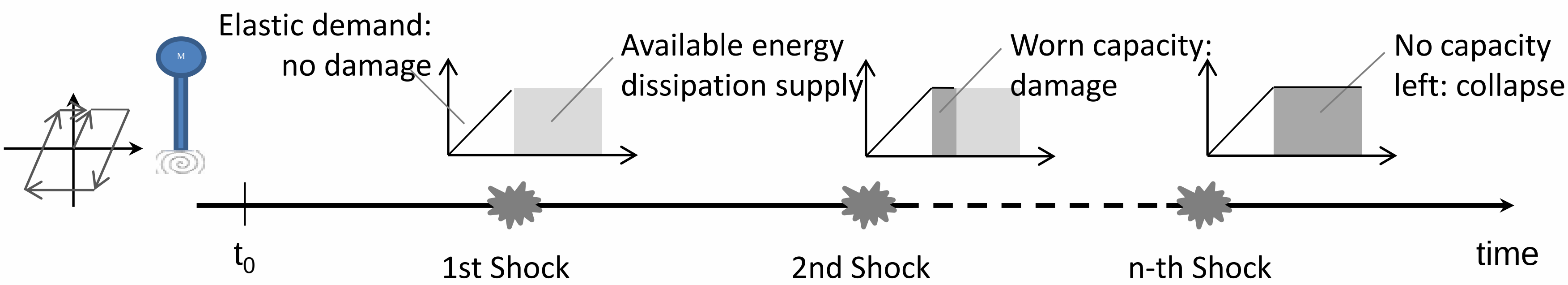
Damage accumulation for a mainshock-damaged structure in an aftershock sequence.



$$\mu(t)=\mu^*-D(t)=\mu^*-\sum_{i=1}^{N(t)}\Delta\mu_i$$

$$P_f(t)=1-R(t)=P\left[\mu(t)\le\mu_{LS}\right]=P\left[D(t)\ge\mu^*-\mu_{LS}\right]=P\left[D(t)\ge\bar{\mu}\right]$$

Non-evolutionary SDoF: Illustrative application



Non-evolutionary SDoF: Illustrative application

$$P_f(t) = \sum_{k=1}^{+\infty} P\left[D(t) \geq \bar{\mu} \middle| N(t) = k\right] \cdot P\left[N(t) = k\right]$$

Non-homogenous Possoin

$$P\left[N(t) = k\right] = \frac{\left(E\left[N(t)\right]\right)^k}{k!} \cdot e^{-E[N(t)]}$$

It can be easy addressed if three conditions are met:

✓Damages in different earthquakes are independent RVs

✓Damage in the generic earthquake has always the same distribution marginal with respect to IM, $f_{\Delta\mu_i}(\cdot) = f_{\Delta\mu}(\cdot) \quad \forall i$

✓The distribution of sum of damage can be expressed in a simple form

Structure and damage index

Stochastic distribution (reproductive property)

Gamma distribution

$$f_{\Delta\mu}(\delta\mu) = \int_{im} f_{\Delta\mu|IM}(\delta\mu|x) \cdot f_{IM}(x) \cdot dx \cong \frac{\gamma_D \cdot (\gamma_D \cdot \delta\mu)^{\alpha_D - 1}}{\Gamma(\alpha_D)} \cdot e^{-\gamma_D \cdot \delta\mu}$$

- Non-negative increments;
- Reproductive in addition sense;
- Defined by scale and shape parameter: g_D; a_D

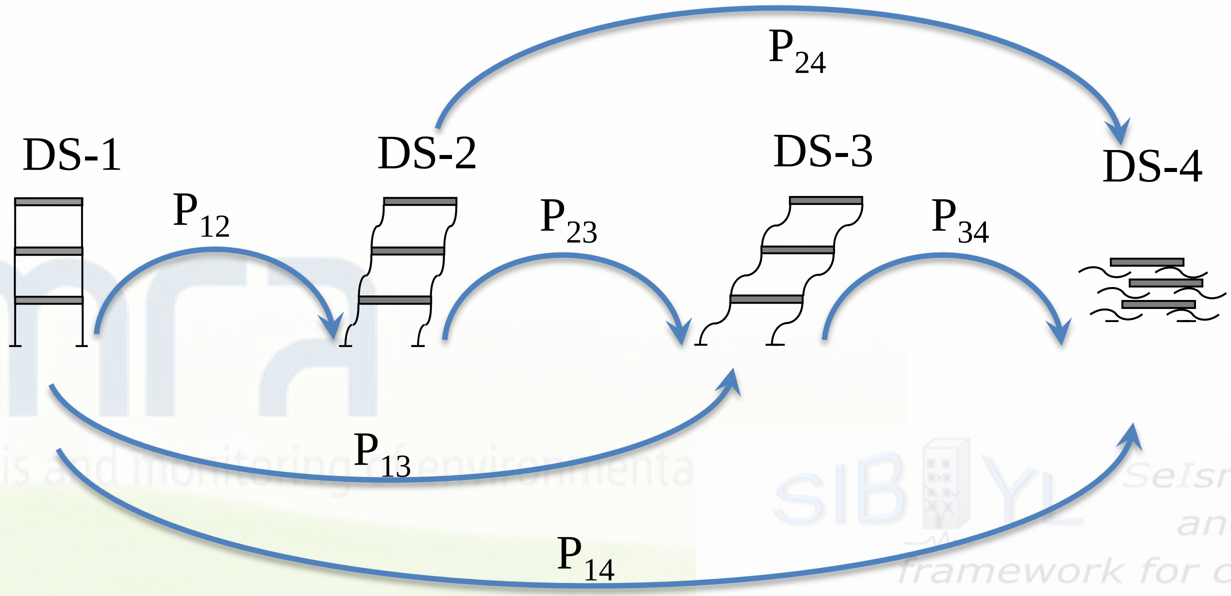
Evolutionary SDoF and history-dependent damage measures

Earthquake damage is instantaneous with respect to the lifespan of the structure

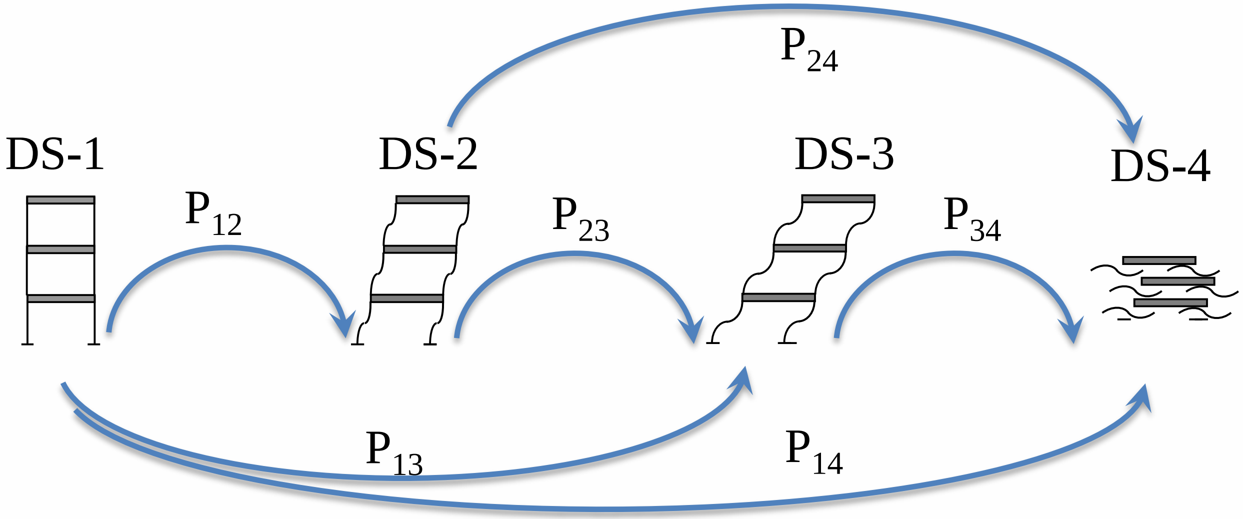
Damage distribution is dependent on the state of the structure at the time of each seismic shock

Structural conditions can be discretized in a finite number of damage states

Earthquake damage accumulation can be modelled via a Markov chain



Seismic Damage



$$P_{ij|E} = \int_{im} P\left[j-th\ state \,\middle|\, i-th\ state \cap IM = z \right] \cdot f_{IM|E}(z) \cdot dz$$

State-dependent fragility

Hazard at the site (IM independent and identically distributed random variable in different earthquakes)

$$[P_E] = \begin{bmatrix} 1-\sum_{j=2}^{4} P_{1j} & P_{12} & P_{13} & P_{14} \\ 0 & 1-\sum_{j=3}^{4} P_{2j} & P_{23} & P_{24} \\ 0 & 0 & 1-P_{34} & P_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Seismic Damage due to Aftershock

If the unit-time, rate of occurrence of earthquake shocks is small enough such that the probability of observing more than one seismic event in the unitary time interval is negligible:

$$P\left[j-th\ state \,|\, i-th\ state \right] = P_{ij} = \nu(t)_{E|m_A} \cdot P_{ij|E}$$

Rate of aftershock occurrence

The matrix reporting the probabilities of the structure moving between any two states in a unit-time interval:

$$\left[P(t,t+\Delta t)\right] = \nu(t)_{E|m_A} \cdot [P_E] + \left(1-\nu(t)_{E|m_A}\right) \cdot [I] = [P]$$

Earthquake occurrence in the unitary time interval

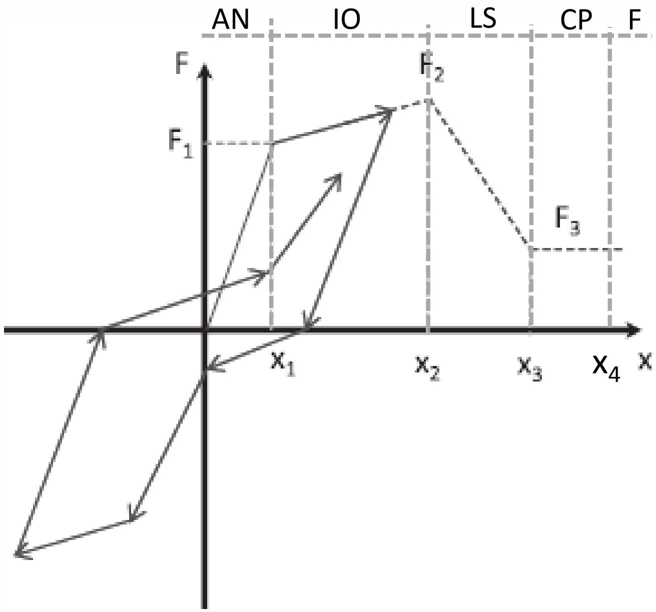
No Earthquake in the unitary time interval

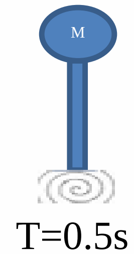
Certitude that the structure remains in the same state if no earthquakes occur.

Because the transition matrix changes with time leading to a non-homogenous Markov chain, the probabilistic prediction of the evolution of damage is:

$$\left[P(t,t+m)\right] = \prod_{i=1}^{m} \left[P(t+i-1, t+i)\right]$$

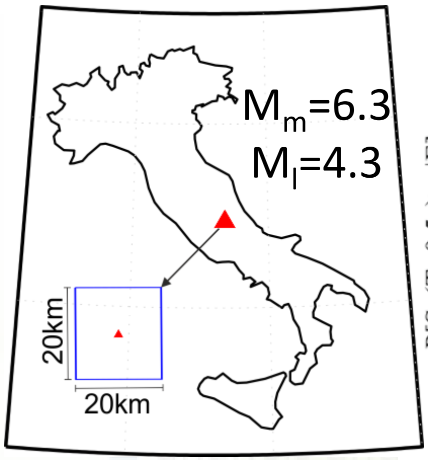
Illustrative Application



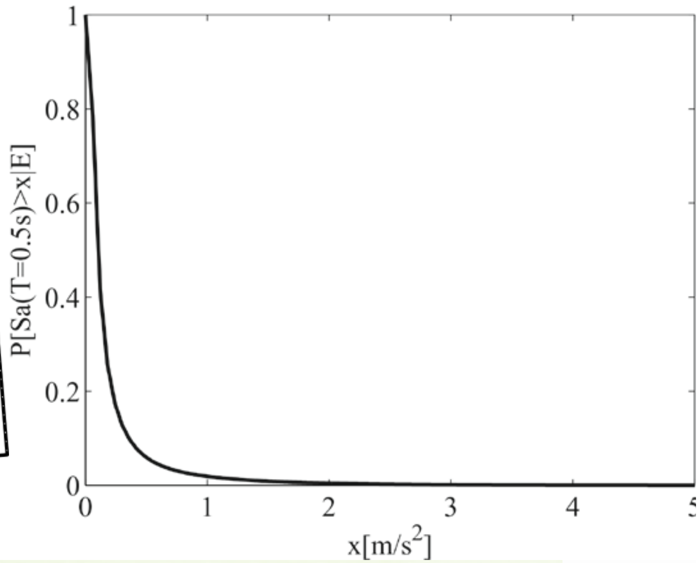


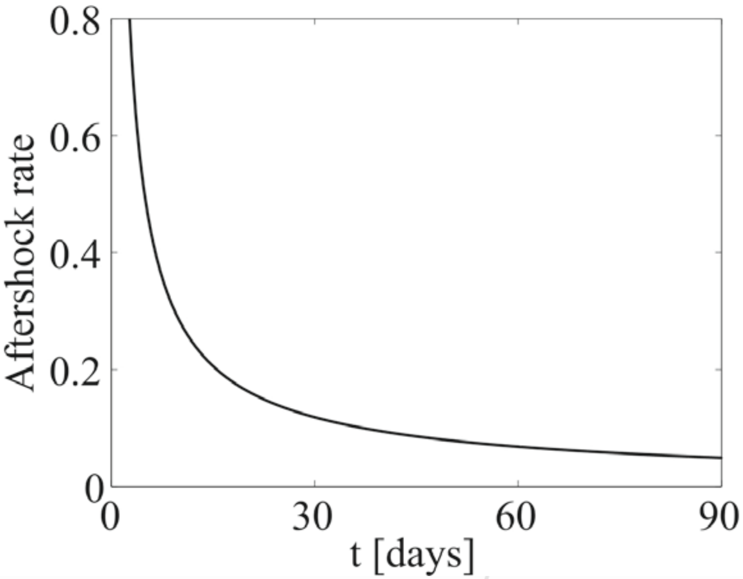
displacement-related damage index: the structure reaches collapse because it exceeds its maximum plastic displacement, that is maximum strain, independently of the amount of dissipated energy;

AN(x_1)	IO(x_2)	LS(x_3)	CP(x_4)	F
0.0076	0.0175	0.0497	0.1	-



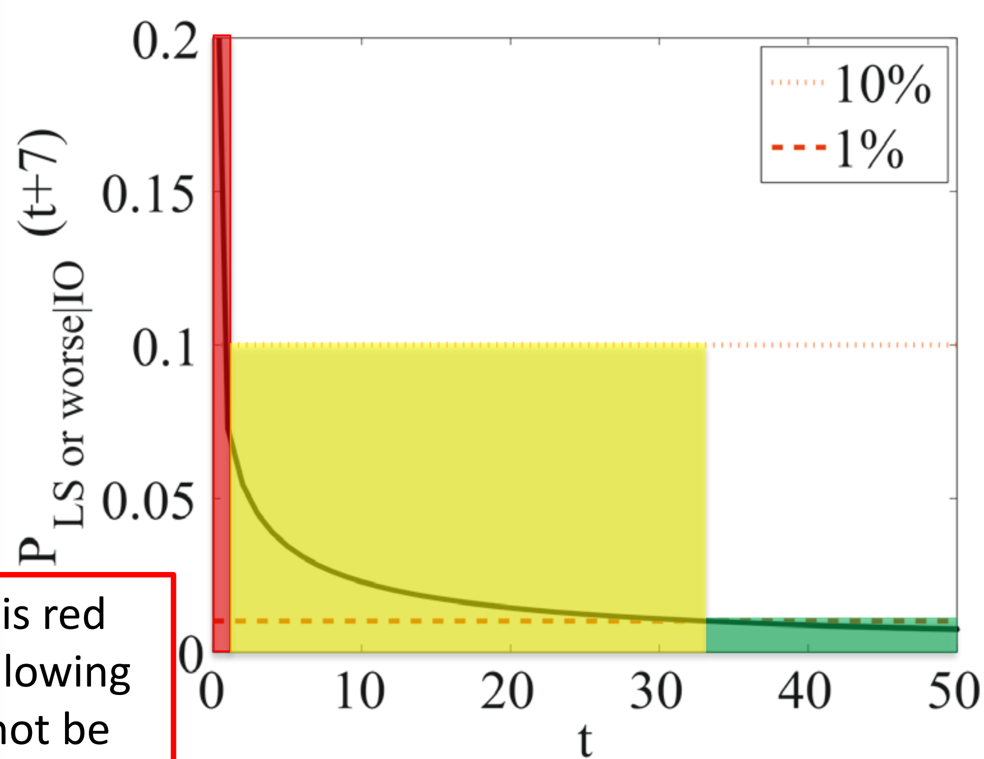
Utsu T., 1970





Iervolino I., Giorgio M., Chioccarelli E. (2013). Markovian modeling of seismic damage accumulation, Earthquake Engineering and Structural Dynamics, 2015, doi: 10.1002/eqe.2668.

Results



The structures is red tagged in the following week: i.e., cannot be accessed.

The structures is yellow tagged in the following week: i.e., can be entered only by trained agents.

The structures is green tagged in the following week: i.e., ordinary week: i.e., ordinary activities can start.

Conclusions

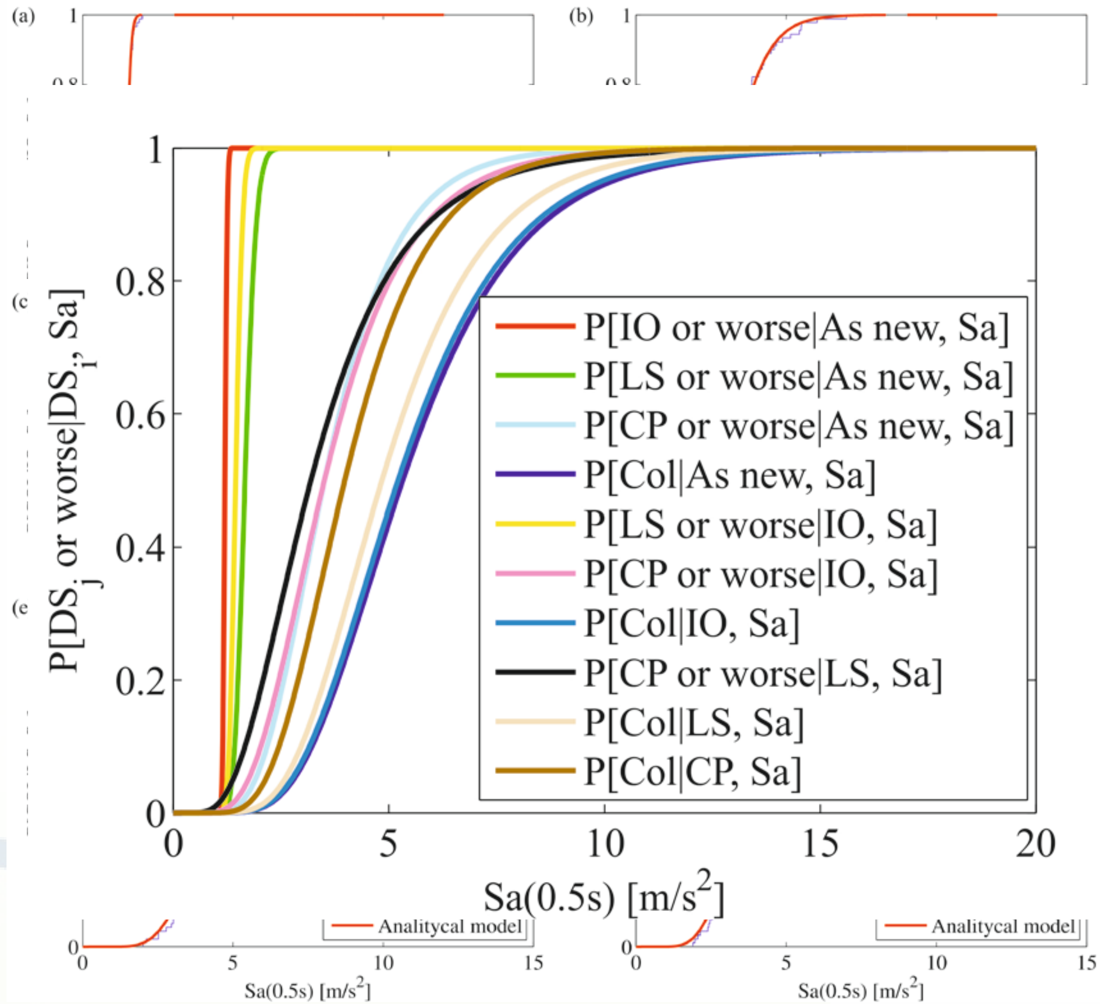
Two alternative models for the assessment of the seismic reliability of single structures during seismic crises have been developed.

Both models require an equivalent SDoF system representative of the protected structure and in both cases, an algorithm for automatic building tagging can be developed and integrated in the monitoring system.

Model 1 – Gamma distribution		**Model 2 – Markovian chain**	
Pros	Cons	Pros	Cons
	Suitable for structures with non-evolutionay behavior	Suitable for any kind of structure for which state-dependent fragility curves can be derived	
It refers to a simple SDoF system easy to be calibrated			Calibration may be time-consuming
	The chosen damage index can not be history-dependent	Any kind of damage index can be used	
Closed-form results	…but results depend only on two parameters	It uses simple matrix computations	The number and the characteristic of each damage states have to be carefully discussed

Thank you for your kind attention

Illustrative Application



Luco, N., Bazzurro, P., and Cornell, C.A. (2004). Dynamic versus static computation of the residual capacity of a mainshock-damaged building to withstand an aftershock, *13 WCEE*, Vancouver, Canada.

Iervolino, I., Giorgio, M., Chioccarelli, E. (2015). Markovian modelling of seismic damage accumulation, Earthquake Engineering and Structural Dynamics, 2015, doi: 10.1002/eqe.2668.