SIBYL Seismic monitoring and vulnerability framework for civil protection

Task D
Real-time monitoring during a seismic sequence

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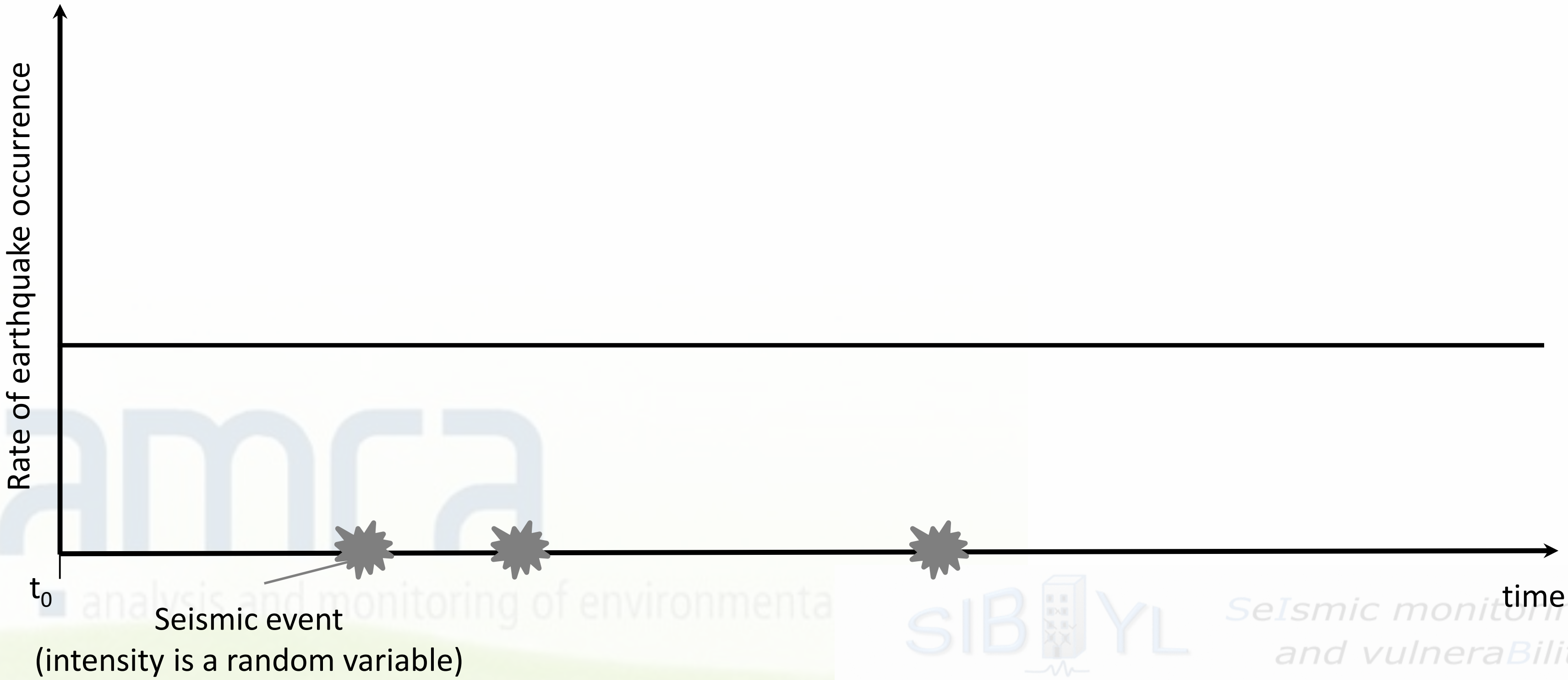
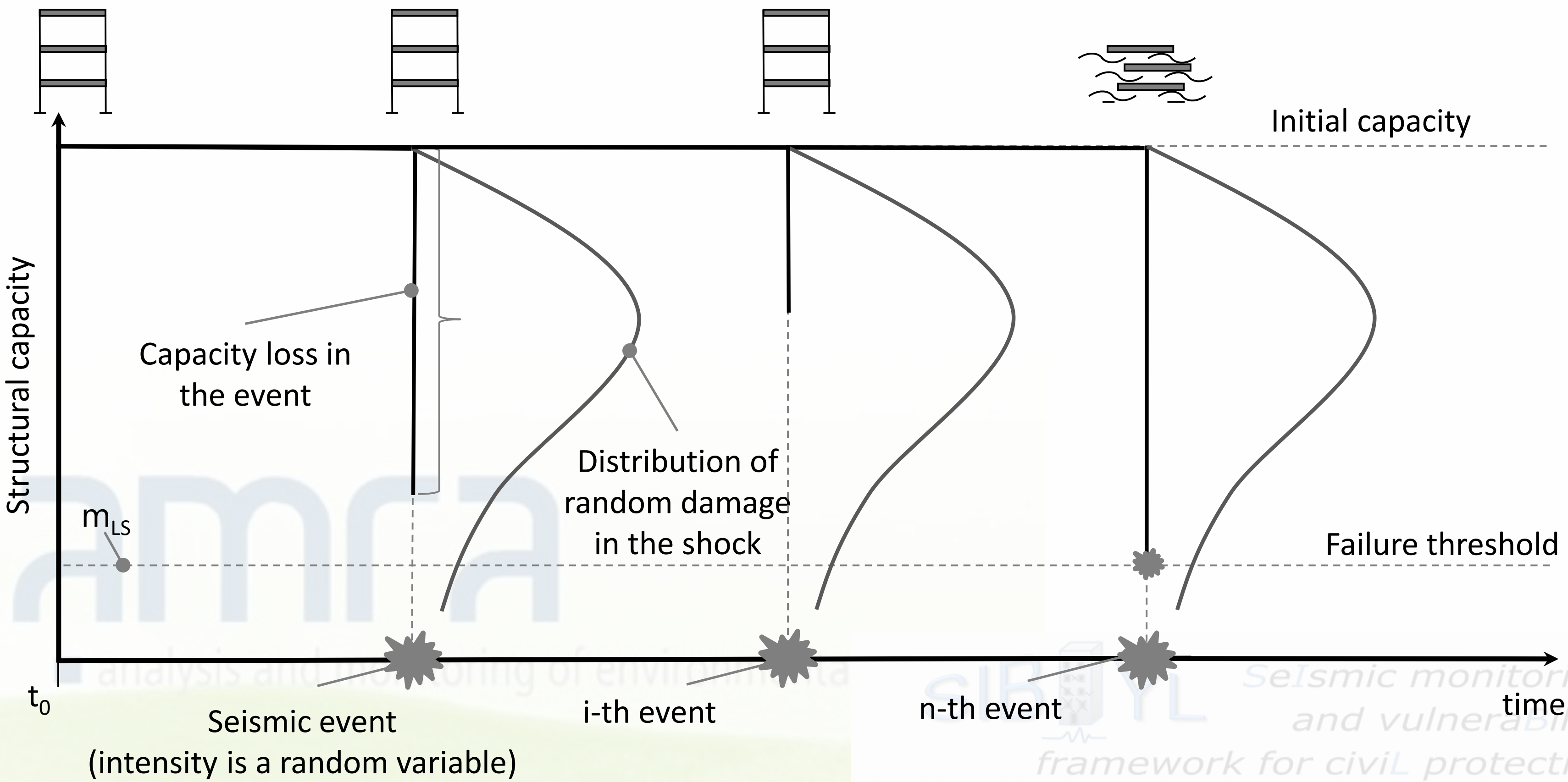
Traditional approach to seismic risk

- Constant rate of earthquake occurrence



Traditional approach to seismic risk

- Constant rate of earthquake occurrence
- Non evolutionary vulnerability: the structure is considered in the as-new condition right after each seismic event.



Time-dependency in seismic risk

Daily rate of aftershocks' occurrence for non-homogenous Poisson process give the magnitude of the mainshock, m_E:

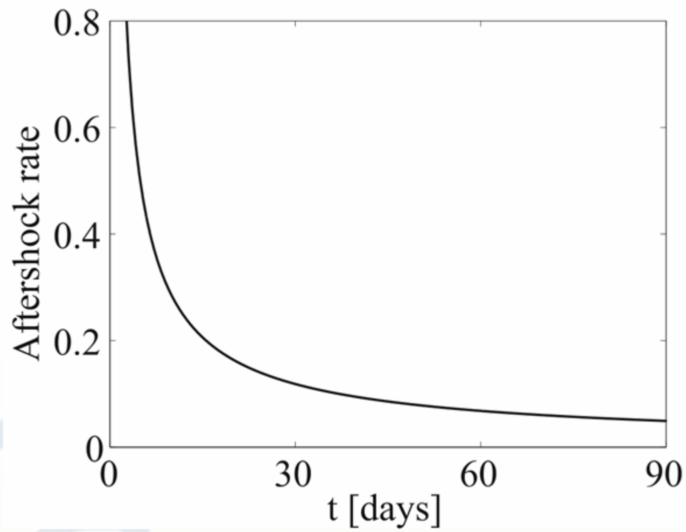
$$\lambda_{A|m_E}(t) = \left(10^{a+b\cdot(m_E - m_l)} - 10^{a}\right) / (t+c)^{p}$$

Modified Omori law

Gutenberg-Richter coefficients

Magnitude range

Time since the mainshock



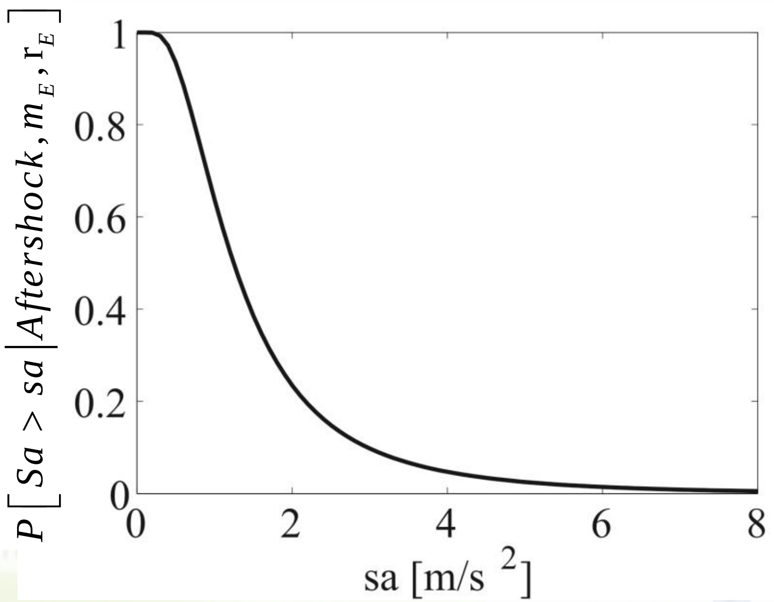
Yeo G.L., Cornell C.A. (2009). A probabilistic framework for quantification of aftershock ground-motion hazard in California, Earthquake Engng. Struct. Dyn. 38(1): 45-60

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:

$$\lambda_D(t) = \lambda_{A|m_E}(t) \cdot P\left[IM > im^* \middle| m_E, \mathrm{r}_E\right] = \lambda_{A|m_E}(t) \cdot \iint_{m,r} P\left[IM > im^* \mid m, r\right] \cdot f_{M,R_s|m_E,\mathrm{r}_E}(m,r) \cdot dm \cdot dr$$

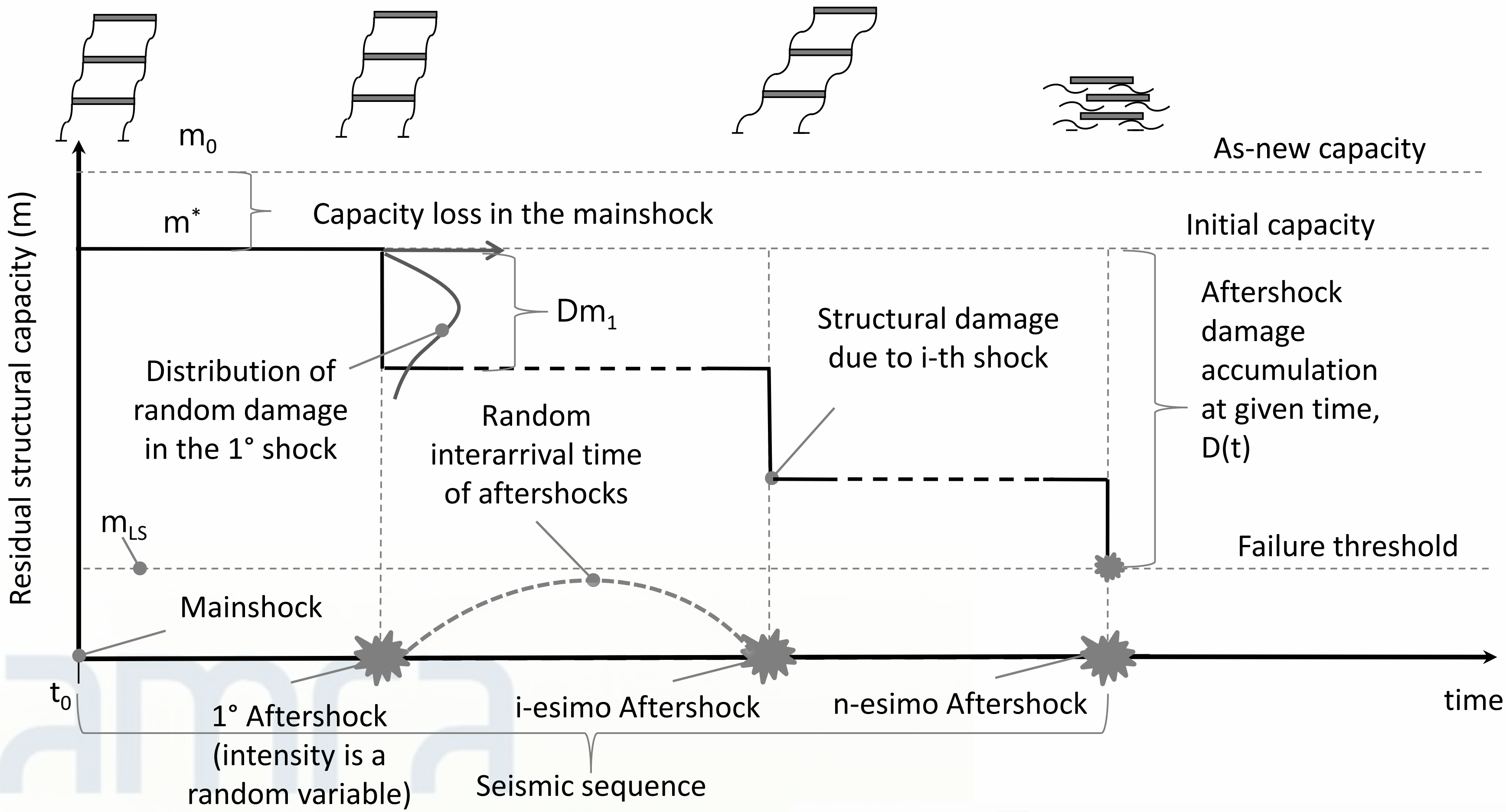
Joint pdf of magnitude and source-to-site distance



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.



$$\mu(t) = \mu^* - D(t) = \mu^* - \sum_{i=1}^{N(t)} \Delta\mu_i \qquad P_f(t) = 1 - R(t) = P\left[\mu(t) \leq \mu_{LS}\right] = P\left[D(t) \geq \mu^* - \mu_{LS}\right] = P\left[D(t) \geq \bar{\mu}\right]$$

Iervolino, I., Giorgio, M., Chioccarelli, E. (2015). Markovian modelling of seismic damage accumulation, EESD, 2015, doi: 10.1002/eqe.2668.

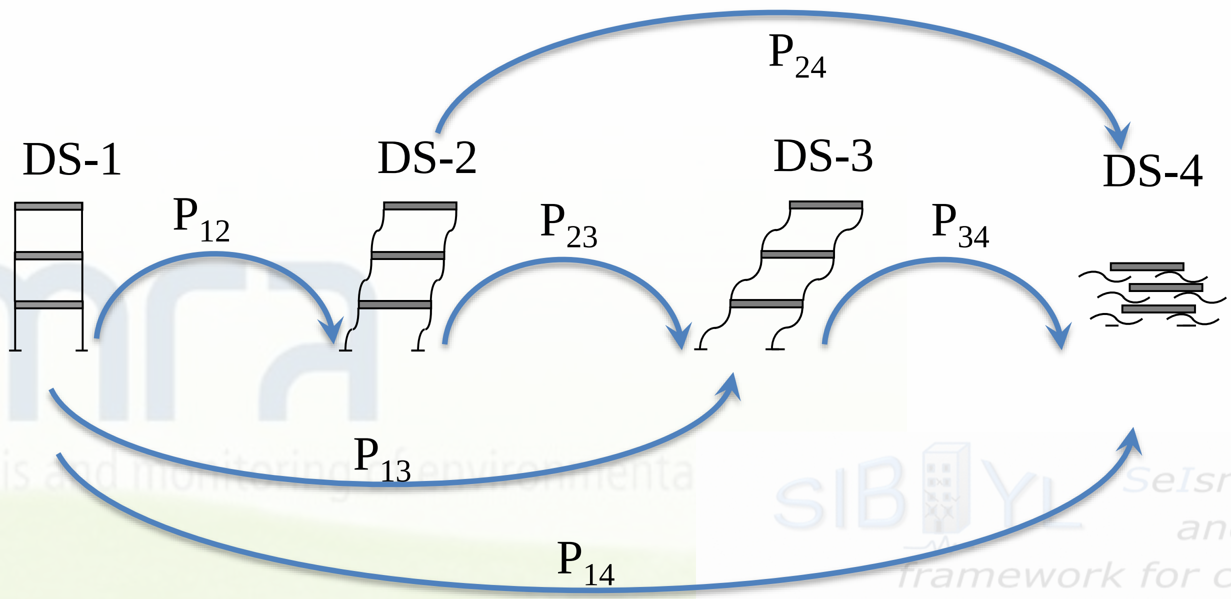
Evolutionary SDoF and history-dependent damage measures

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

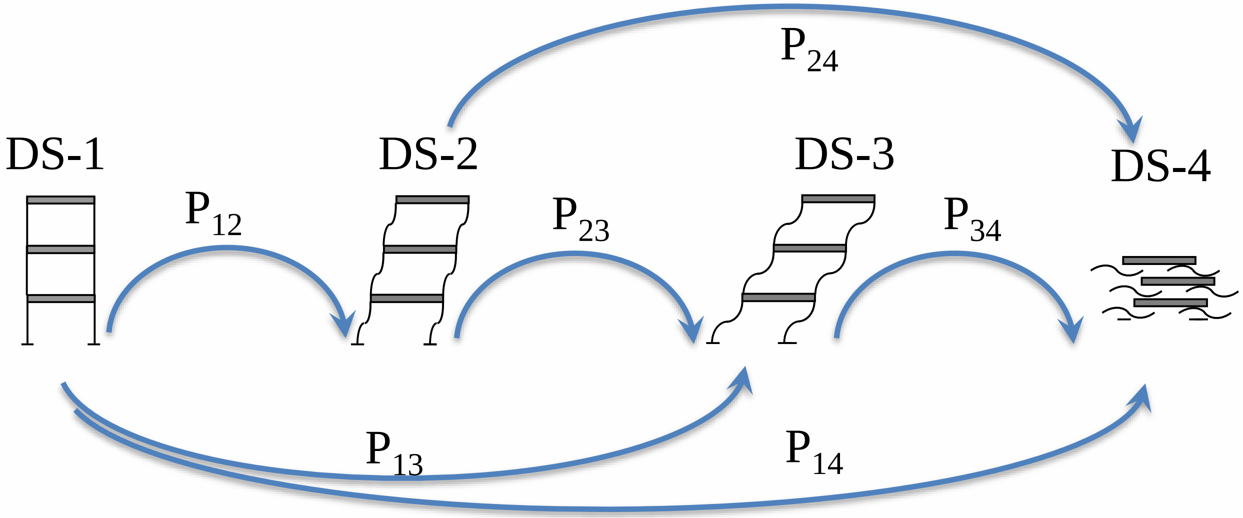
Damage distribution is dependent on the state of the structure at the time of each seismic shock

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

→ Earthquake damage accumulation can be modelled via a Markov chain



Seismic Damage



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

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:

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

Rate of aftershock occurrence

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

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

Earthquake occurrence in the unitary time interval

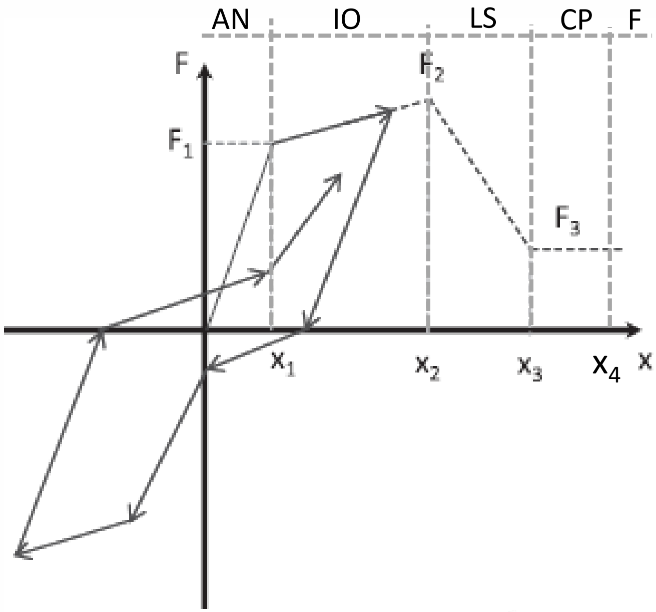
No Earthquake in the unitary time interval

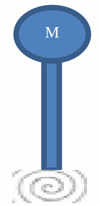
Certitude that the structure remains in the same state if no earthquakes occur.

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

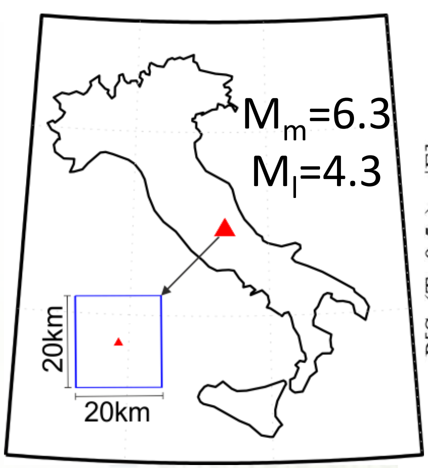




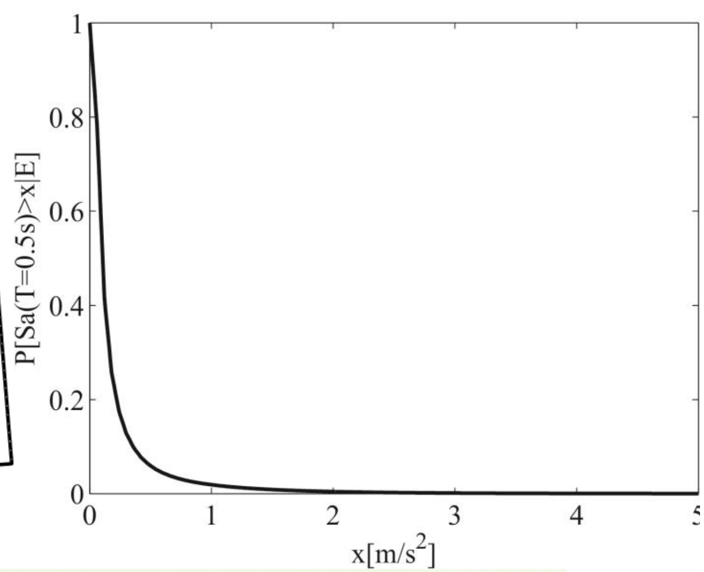
T=0.5s

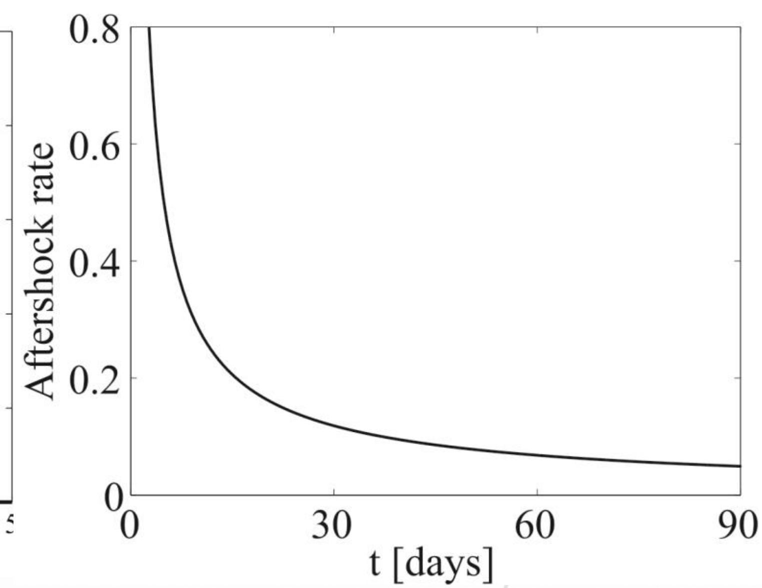
displacement-related damage index: the structure reaches collapse because it exceeds its maximum plastic displacement, that is maximum strain, independently of the amount of dissipated energy;

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



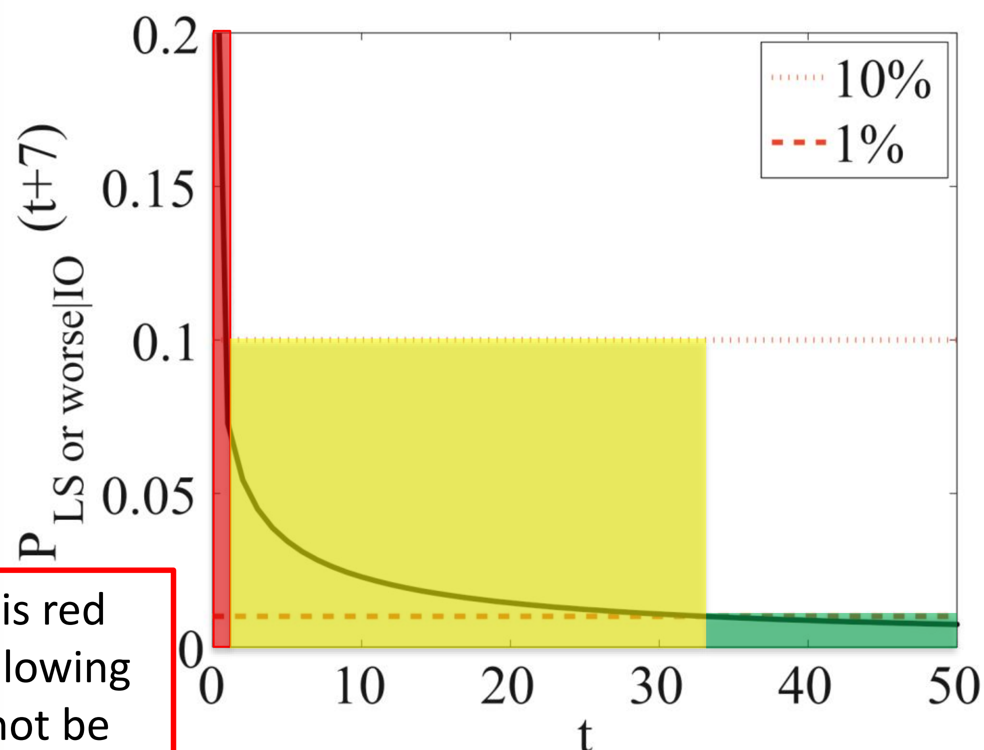
Utsu T., 1970





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

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

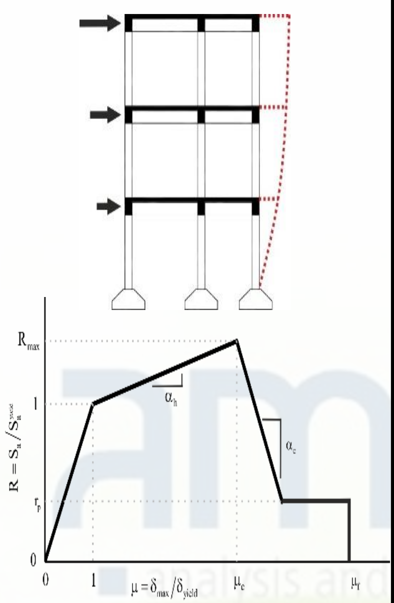
The structures is yellow tagged in the following week: i.e., can be entered only by trained agents.

Future developments

SPO2FRAG: BUILDING FRAGILITY ESTIMATION USING STATIC PUSHOVER

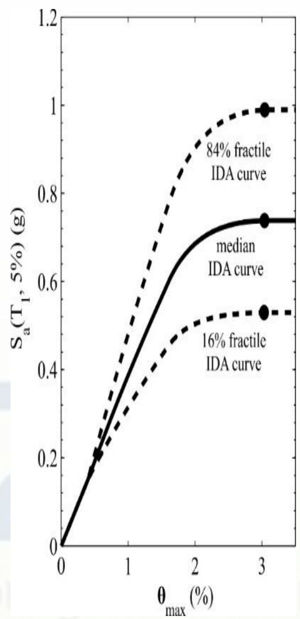
STEP 1

Static Pushover Analysis
Equivalent SDoF formulation



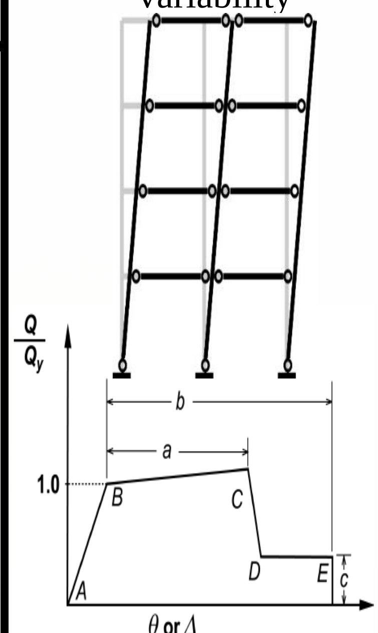
STEP 2

SPO2IDA Implementation to obtain fractile IDA



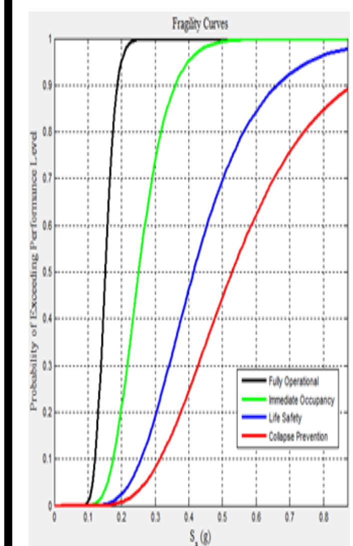
STEP 3

Definition of Limit-State thresholds and variability



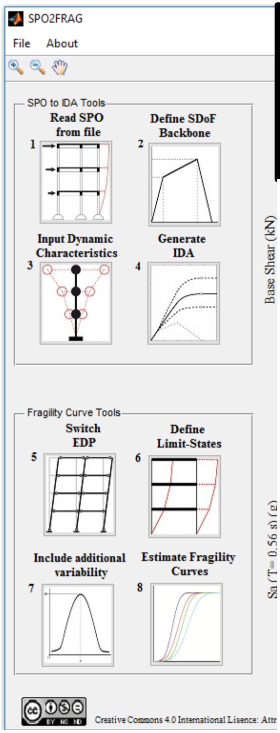
STEP 4

Calculation of Fragility Curves

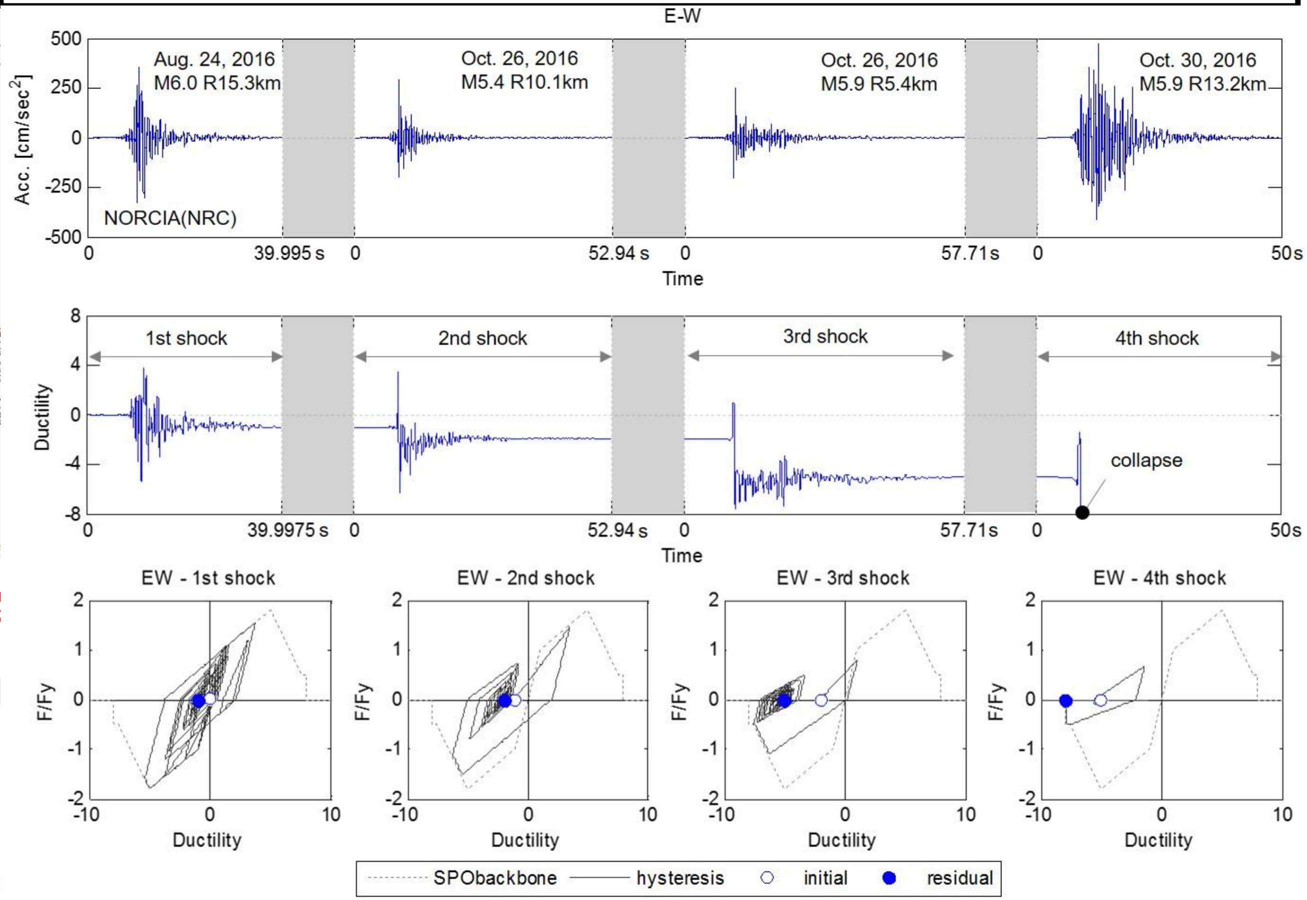


Iervolino I., Baltzopoulos G., Vamvatsikos D., Baraschino R. (2016). SPO2FRAG v1.0: software for PUSHOVER-BASED derivation of seismic fragility curves. Proc. of VII European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS, Crete Island, Greece, 5–10 June.

Future developments



SPO-BASED STATE DEPENDENT FRAGILITY



http://wpage

Damage accumulation example for a SDOF structure, considering a real recorded sequence at NRC station (Norcia) – Central Italy 2016 Sequence

Thank you for your kind attention