Seismic risk analysis: state-of-the-art research and technology transfer

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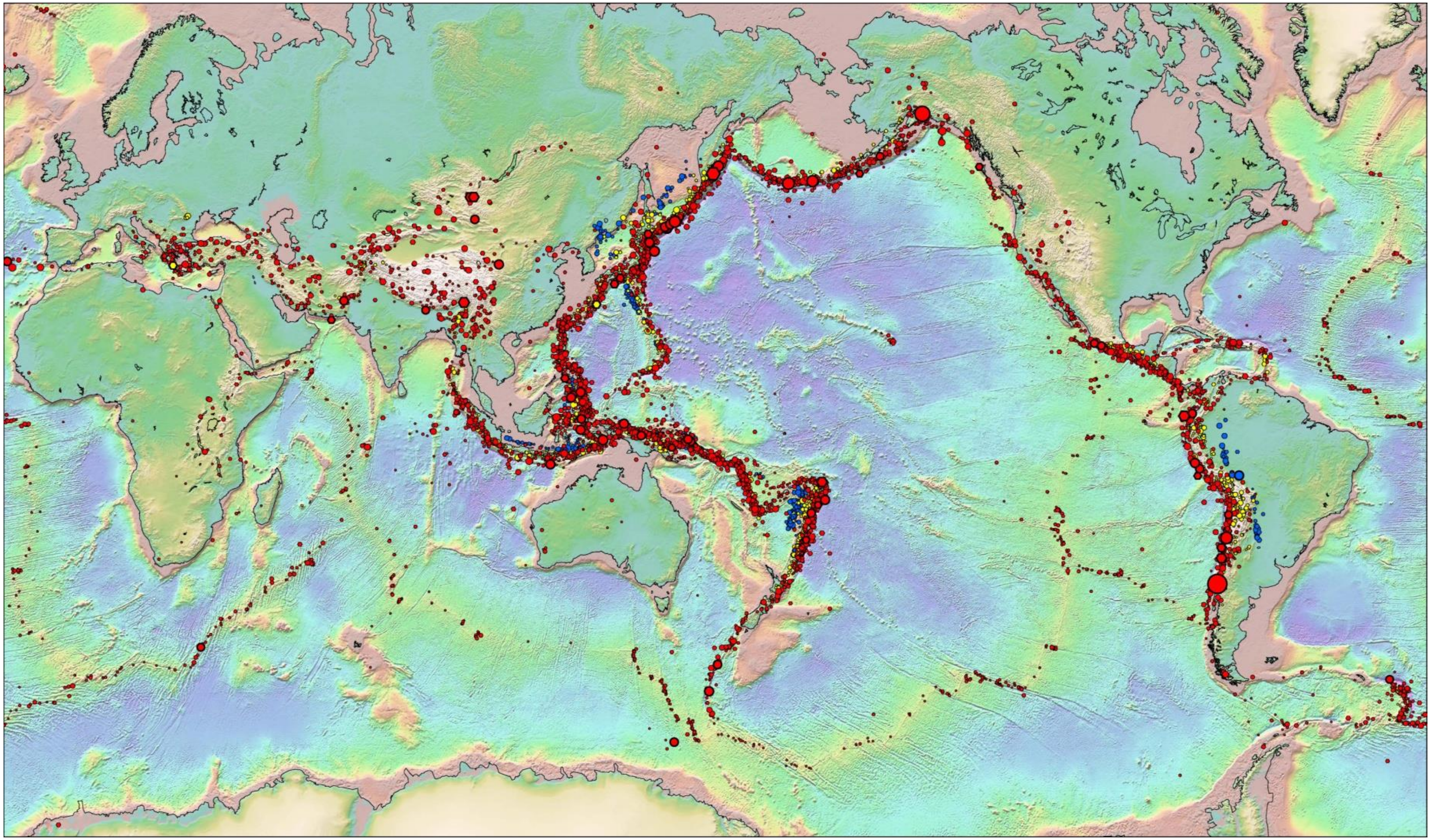
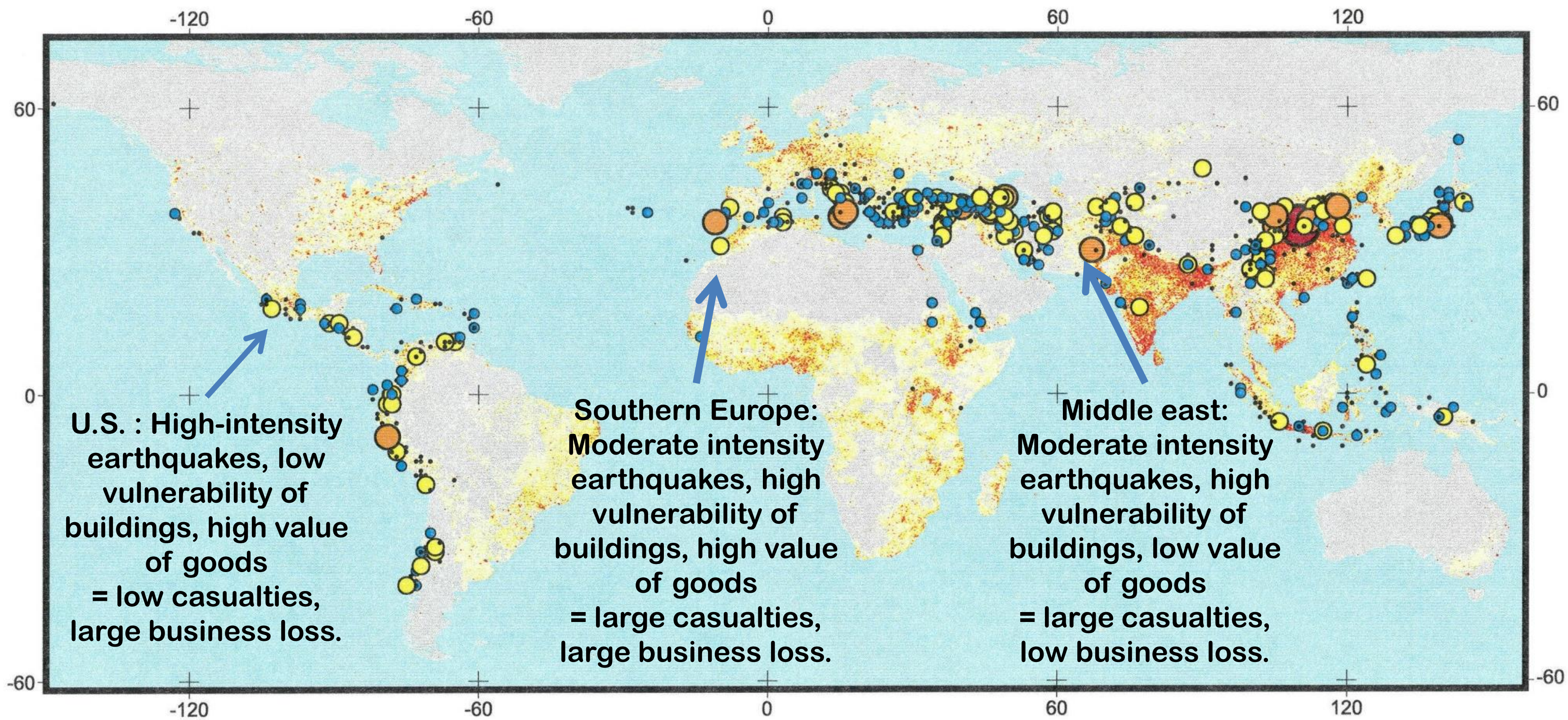
Earthquakes are uncertain in size and time of occurrence, but not randomly located.



In the picture the size of circles is proportional earthquake energy (i.e., magnitude).

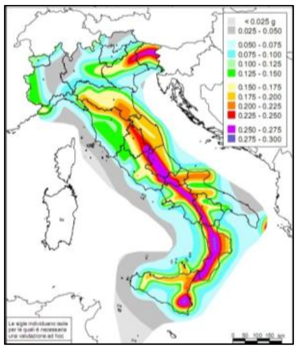
Losses are not following the same distribution of earthquakes



In the picture the size of circles is proportional to loss amount. Loss depends on earhtuquake intensity, damage susceptibility of built enviroment in the region affected, and value of goods and activities hosted by the damaged built enviroment.

Risk = function of: H, V, E.

Hazard (H)



Frequency and intensity of the ground shaking
Seismology

Vulnerability (V)

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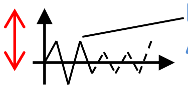
Structural fragility
Structural Engineering

Exposure (E)

Value of the consequences of damaging earthquakes
Risk Management

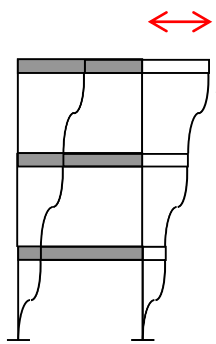
CAUSE → EFFECT → CONSEQUENCES

Performance-based earthquake engineering framework (PBEE)

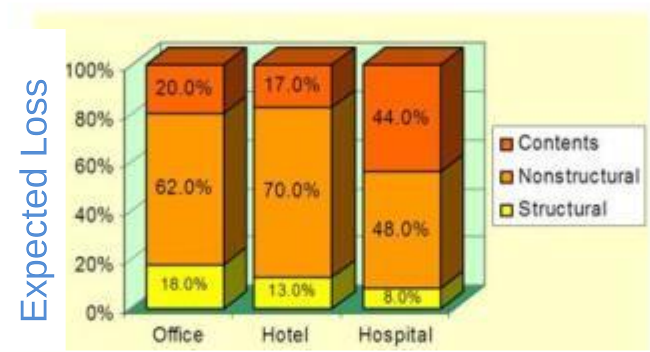


IM (e.g., Peak Ground Acceleration or PGA)

Ground motion intensity (IM)



EDP (e.g., Maximum Interstory Drift Ratio)



Expected annual seismic loss

$$E[L]=E[L|Failure]\cdot P_f = E[L|Failure]\cdot \int_{im} P[Failure|IM]\cdot|d\lambda_{IM}|$$

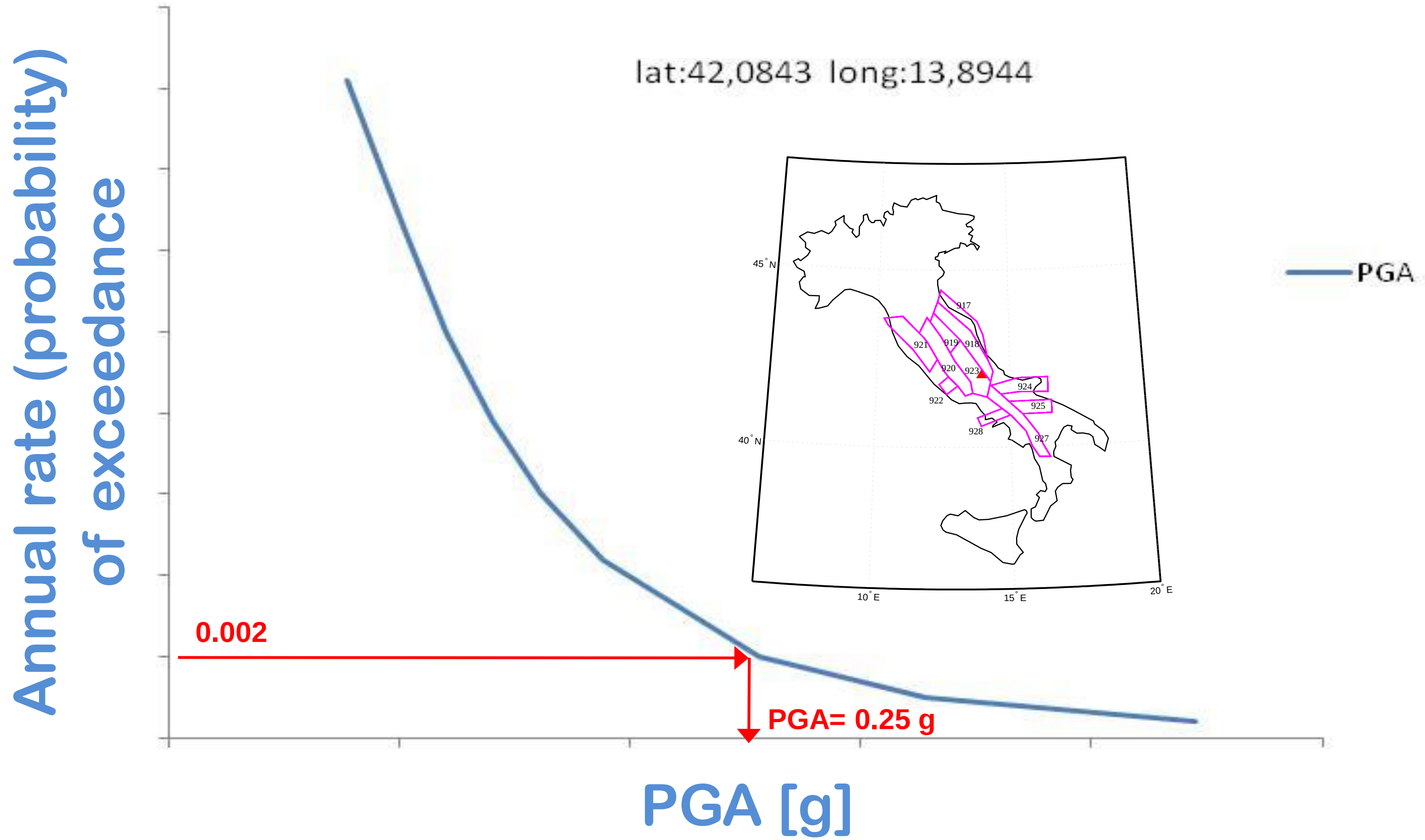
Loss given failure (or damage) that is exposure

Annual failure probability

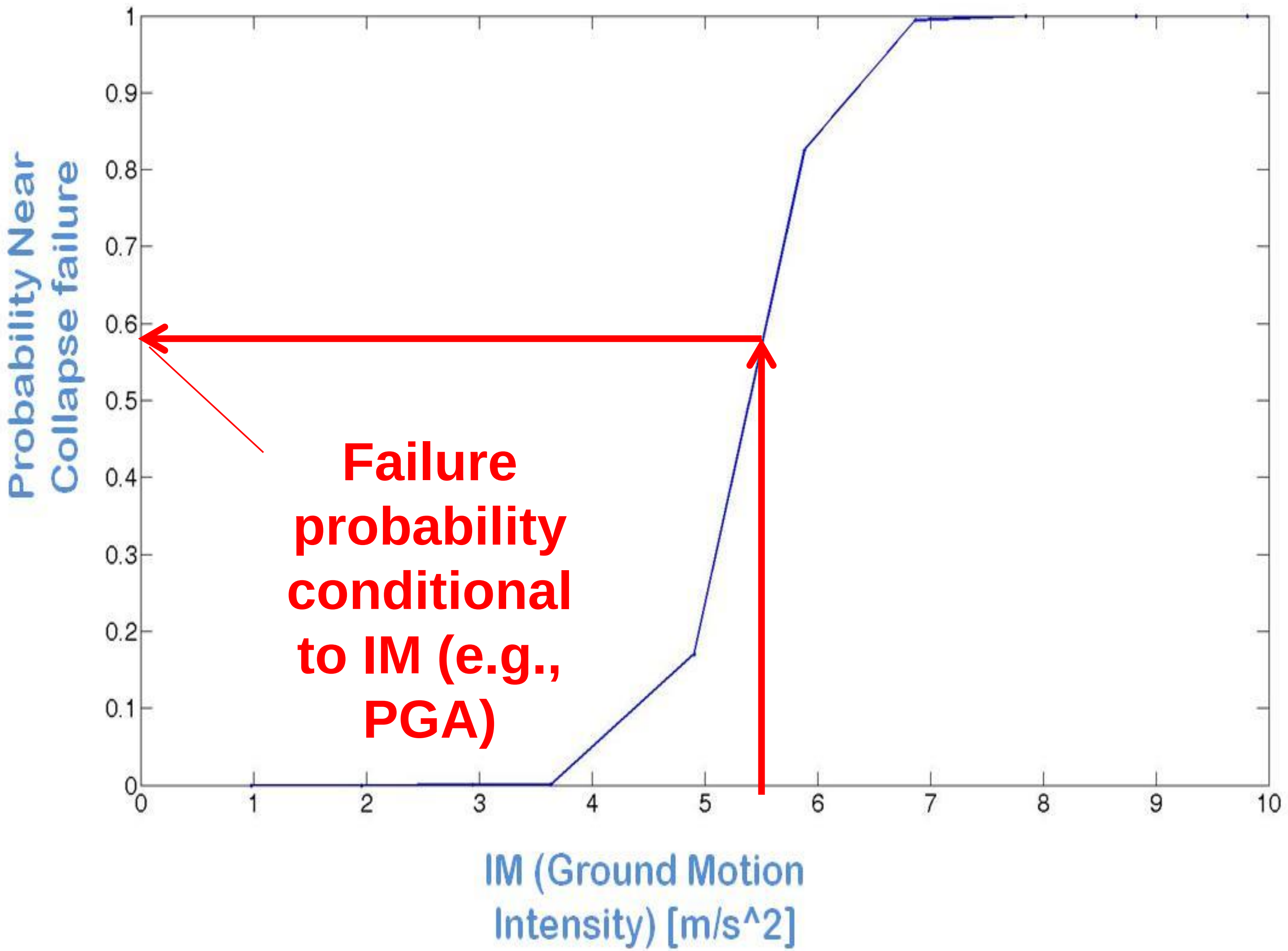
Fragility curve (Vulnerability)

Hazard curve

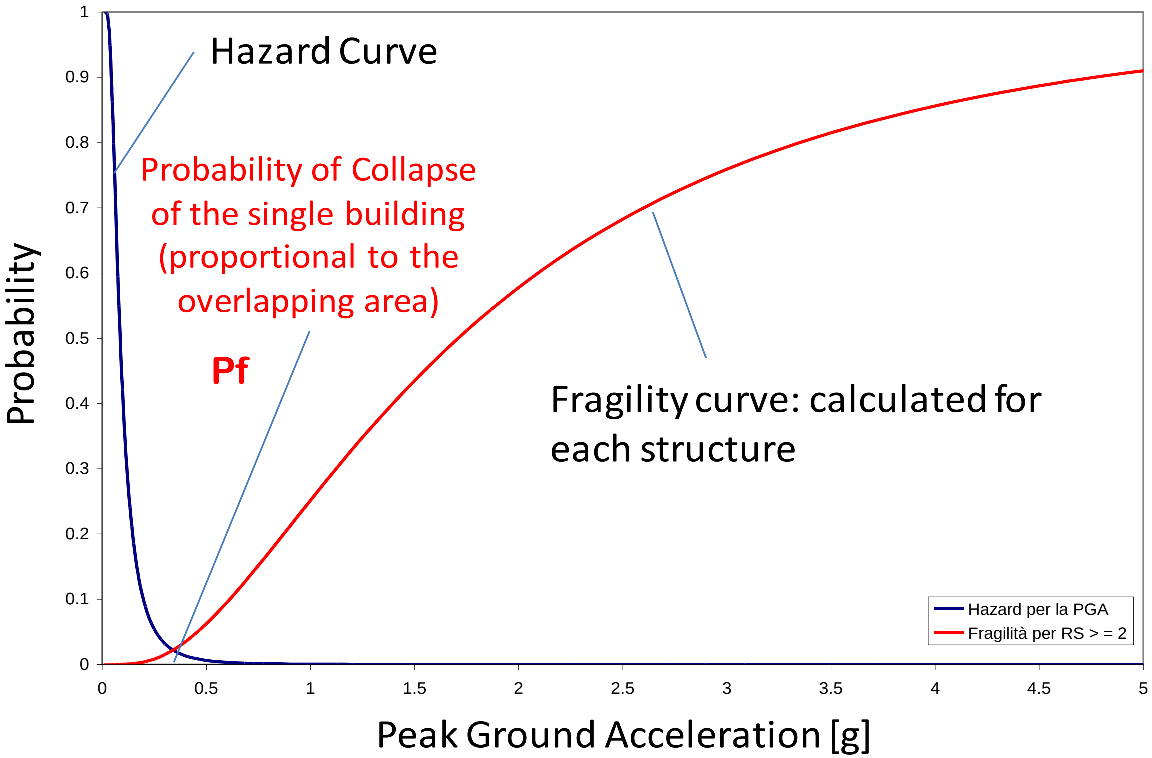
Result of probabilistic seismic hazard analysis: hazard curves



Measure of vulnerability: fragility curve



Quantitative definition of seismic risk and quantitative loss measures

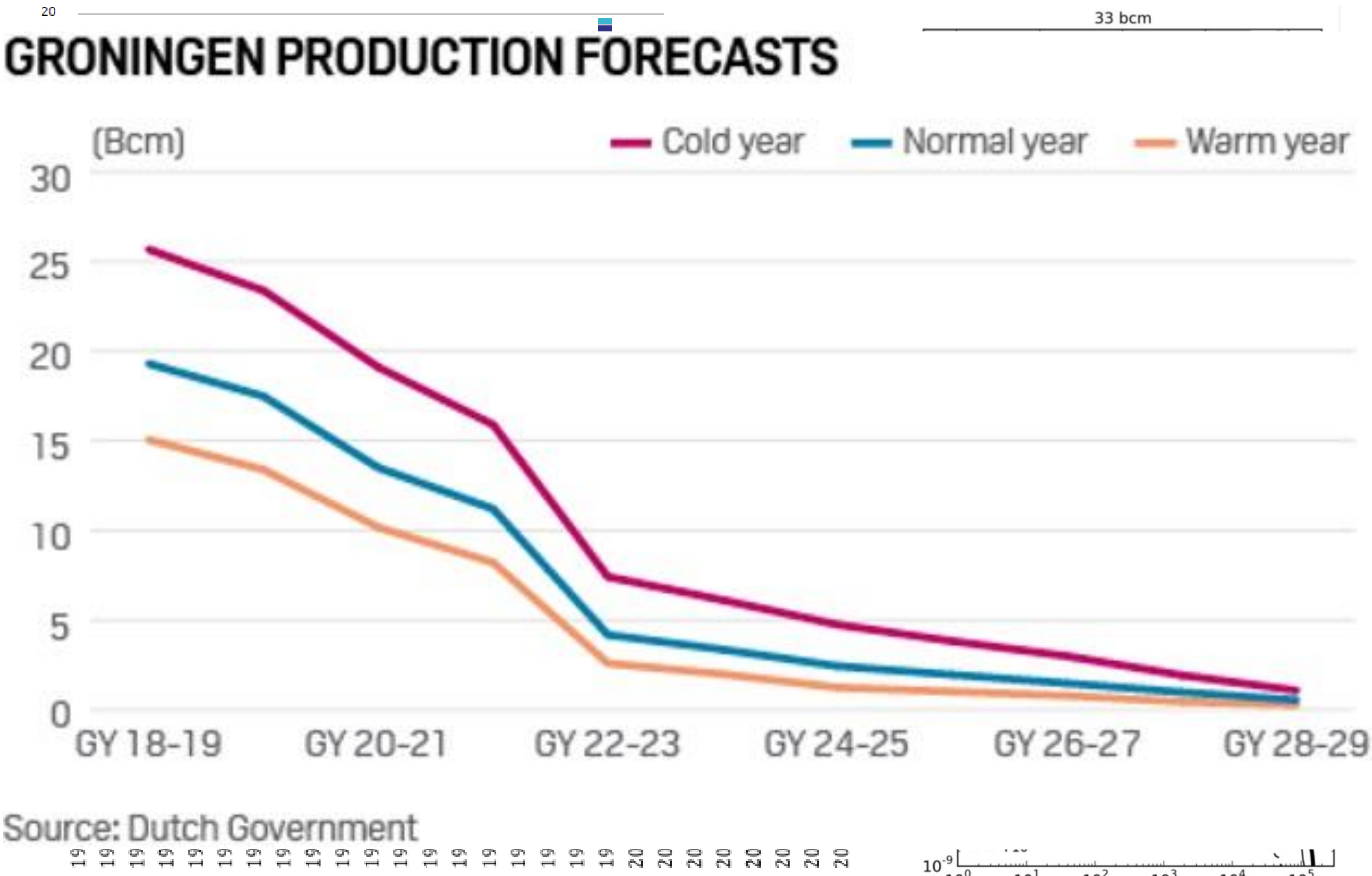


Expected loss: from stakeholdes

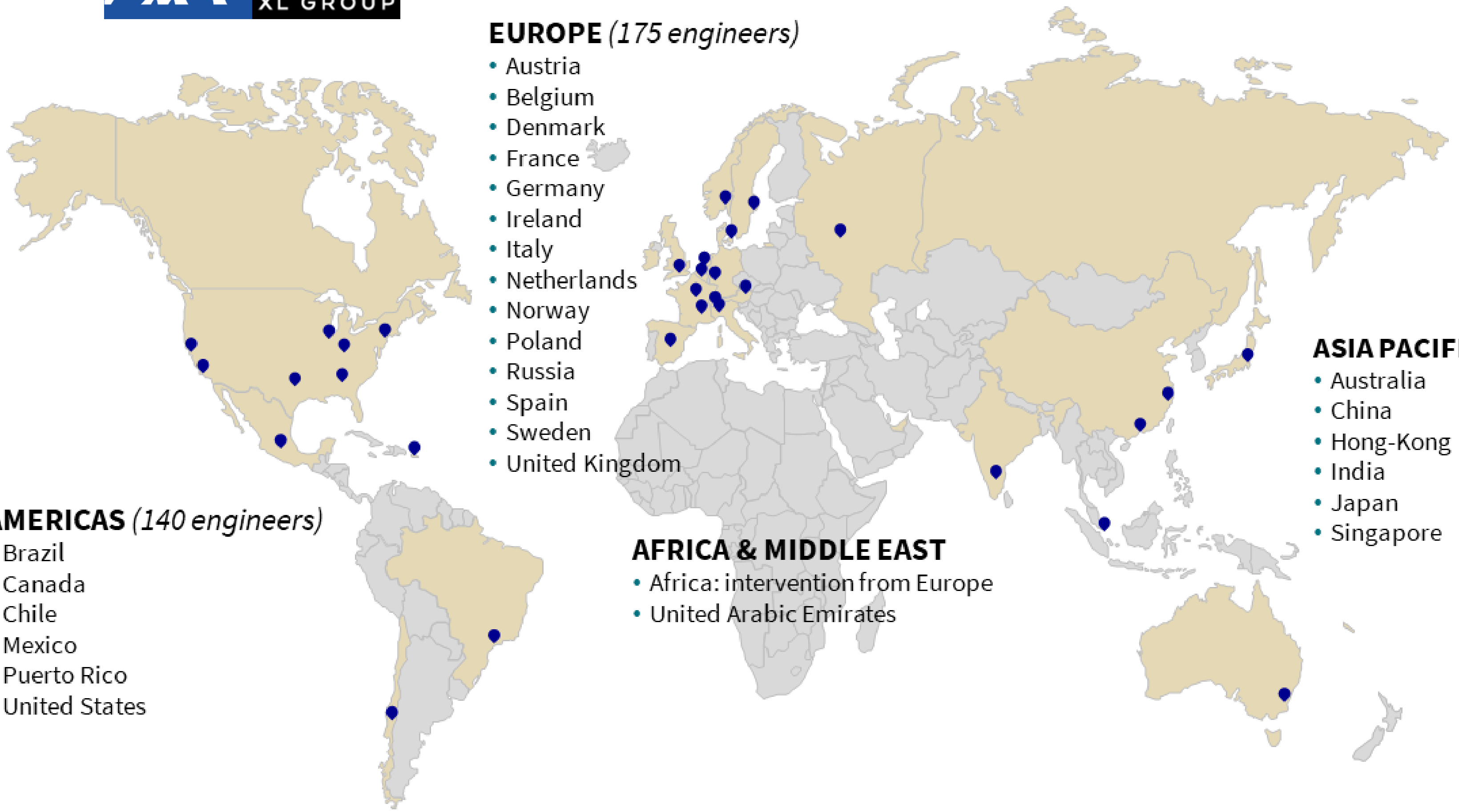
Expected loss given collapse E[L|f]

E[L]=E[L|f]*Pf

The Groningen (NL) case



AXA XL Risk Consulting



EUROPE *(175 engineers)*
- Austria
- Belgium
- Denmark
- France
- Germany
- Ireland
- Italy
- Netherlands
- Norway
- Poland
- Russia
- Spain
- Sweden
- United Kingdom

AMERICAS *(140 engineers)*
- Brazil
- Canada
- Chile
- Mexico
- Puerto Rico
- United States

AFRICA & MIDDLE EAST
- Africa: intervention from Europe
- United Arabic Emirates

ASIA PACIFIC *(35 engineers)*
- Australia
- China
- Hong-Kong
- India
- Japan
- Singapore

2 300	7 800	350	24
Clients	*Loss Prevention Visits/ Year*	*Engineers*	*Countries/ Languages*

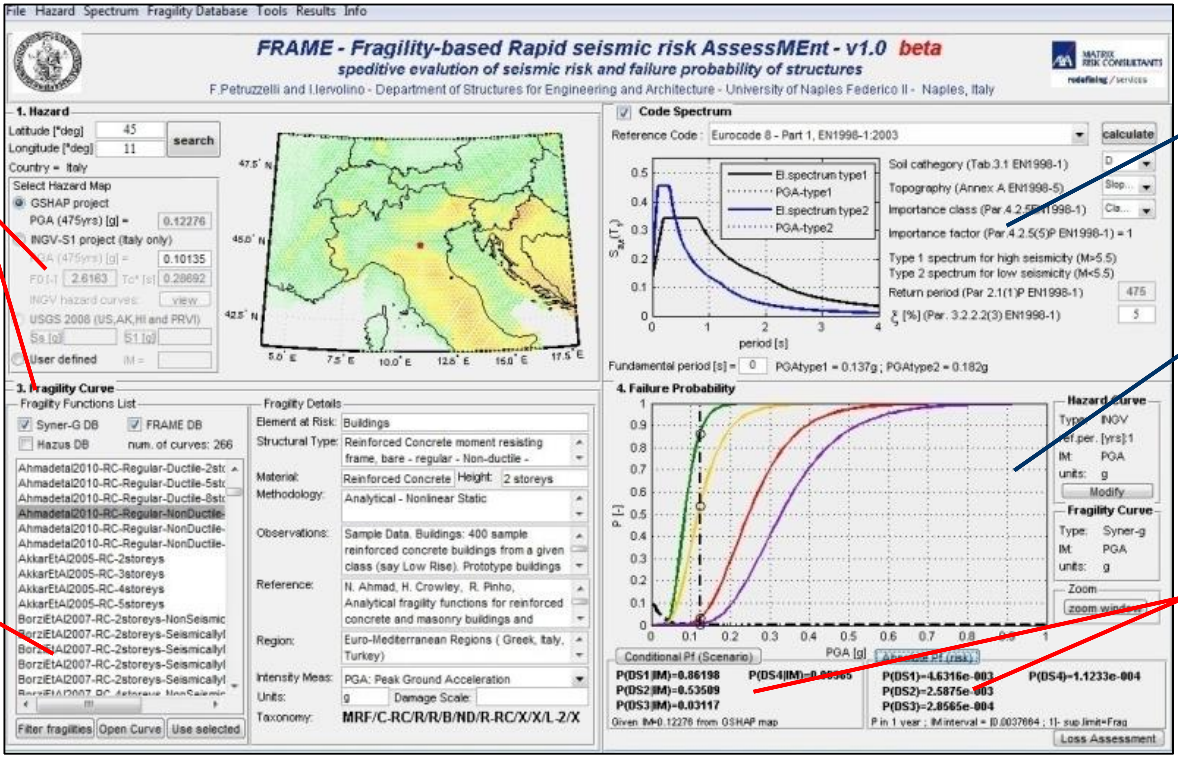
AXA XL GROUP

PBEE tools for insurance industry (2010-present)

1. HAZARD definition
Required Input:
Location of the structure (geographical coordinates)

Output:
- GSHAP PGA_{475yrs} *(worldwide)*
- INGV PGA_{Tr} *(Italy)*
- INGV Hazard Maps *(Italy)*
- USGS $S_a(T_s)$ $S_a(T_1)$ *(US, Puertorico, Virgin Islands, Alaska)*
- User-defined IM

2. FRAGILITY definition
Required Input:
Choose of the Fragility Curve from the Inventory



Optional: Elastic Spectra
According to: *International Building Code* (IBC, 2012); *Eurocode* 8 (EC8); *Italian Building Code* (NTC2008).

Plot of fragility and Hazard

3. FAILURE PROBABILITIES
Computed for the Damage States provided by the fragility curves

- ***475 yr. scenario loss analysis***
- ***Unconditional loss analysis***

Datasets included in FRAME

Hazard databases:

- Gshap map (Giardini et al., 2009) – *worldwide.*
- INGV S1 project (including Hazard curves) – *Italy.*
- USGS 2008 hazard maps (Pedersen et al., 2008)
  US, Haiti, Alaska, Puerto Rico, Virgin Islands.

Fragility databases:

- **Syner-g. (2009).** Deliverable D 3.1. Fragility functions for common RC building types in Europe .
- **LESSLOSS (2005).** Deliverable 84
- **RISK-UE (2001-2004).**
- Jaiswal, K. S., and Wald, D. J. (2010). **(PAGER) System**.

} 415 sets of fragility curves
284 Reinforced Concrete
125 Masonry
6 Mixed (RC-Masonry)

- **HAZUS MR4** vulnerability functions (FEMA, 2003)

} 124 sets of fragility curves
36 Reinforced Concrete
16 Precast Concrete
28 Masonry
52 Steel
8 wood

- Fragility Curves computed for the **steel structures of the Sulmona Facility** (Iervolino et al., 2012)

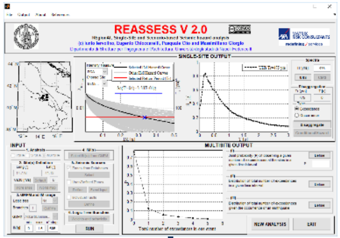
} 6 sets of fragility curves (steel)

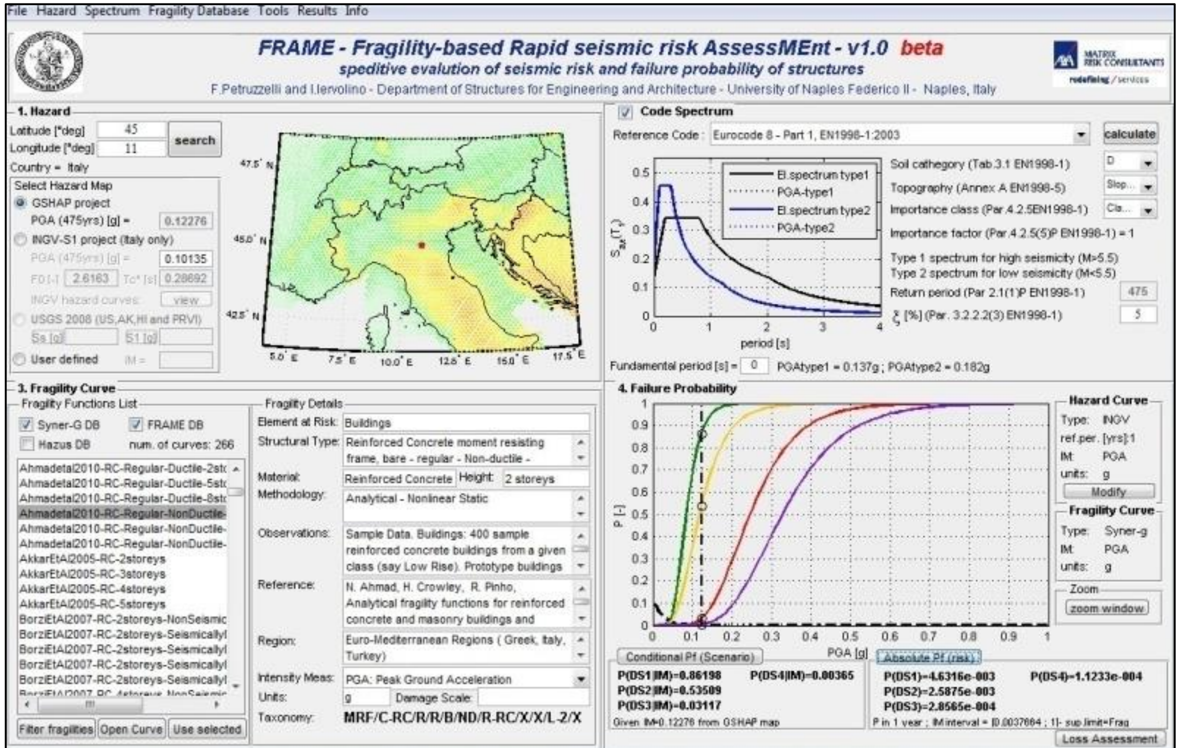
Loss functions (ki):

- Provided by AXA Matrix for *building, stock* and *machineries & equipment*
- 6 main activity occupancies
- 18 sub-categories of occupancy

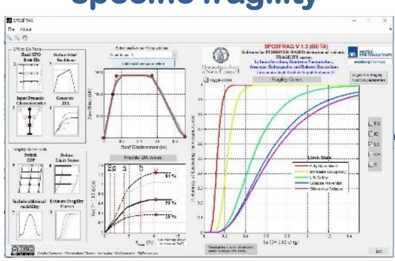
FRAME-feeding software

Probabilistic seismic hazard

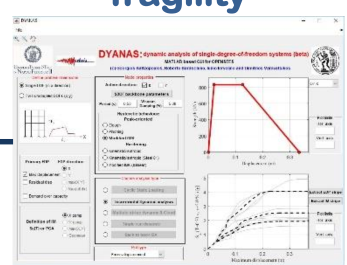




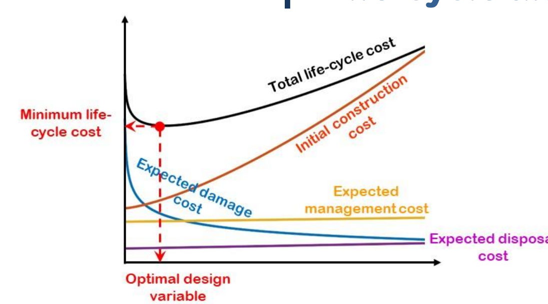
Structure-specific fragility



Class-scale fragility



Life-cycle analysis



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Petruzzelli, F., Della Corte, G., Iervolino, I.Rischio sismico di edifici industriali esistenti in acciaio: un caso studio, atti di XIV Convegno Nazionale "L'Ingegneria Sismica in Italia", Bari, settembre 2011, paper no 1048.

Petruzzelli, F., Della Corte, G., Iervolino, I. Modeling and preliminary analysis of existing industrial steel buildings for seismic risk assessment, atti di XXIII Congresso C.T.A. Le Giornate Italiane della Costruzione in Acciaio, Ischia, ottobre 2011.

Petruzzelli F., Della Corte G., Iervolino I. (2012) Seismic Risk Assessment of an Industrial Steel Building Part 1: Modelling and Analysis. Proc. of 15WCEE, Lisboa, PT. Paper No. 3086.

Petruzzelli F., Della Corte G., Iervolino I. (2012) Seismic Risk Assessment of an Industrial Steel Building Part 2: Fragility and Failure Probabilities. Proc. of 15WCEE, Lisboa, PT. Paper No. 3088.

Petruzzelli F., Iervolino I., (2014) FRAME V.1.0: A rapid fragility-based seismic risk assessment tool. Proc. of Second European Conference on Eartquake Engineering and Seismology, 2ECEES, – Istanbul, Turkey, August 24-29.

Iervolino I., Chioccarelli E., Cito P. (2016). REASSESS V1.0: a computationally-efficient software for probabilistic seismic hazard analysis. Proc. of VII European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS, Crete Island, Greece, 5–10 June.

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.

Baltzopoulos G, Baraschino R, Iervolino I, Vamvatsikos D (2017) SPO2FRAG: Software for seismic fragility assessment based on static pushover. Bulletin of Earthquake Engineering, 15:4399-4425. DOI: 10.1007/s10518-017-0145-3

Baltzopoulos G., Baraschino R., Iervolino I., Vamvatsikos D. (2018) Dynamic analysis of single-degree-of-freedom systems (DYANAS): A graphical user interface for OpenSees. Engineering Structures, 177: 395-408.

Chioccarelli E., Cito I., Iervolino I., Giorgio M. (2018) REASSESS V2.0: Software for single- and multi-site probabilistic seismic hazard analysis, Bulletin of Earthquake Engineering, in review.

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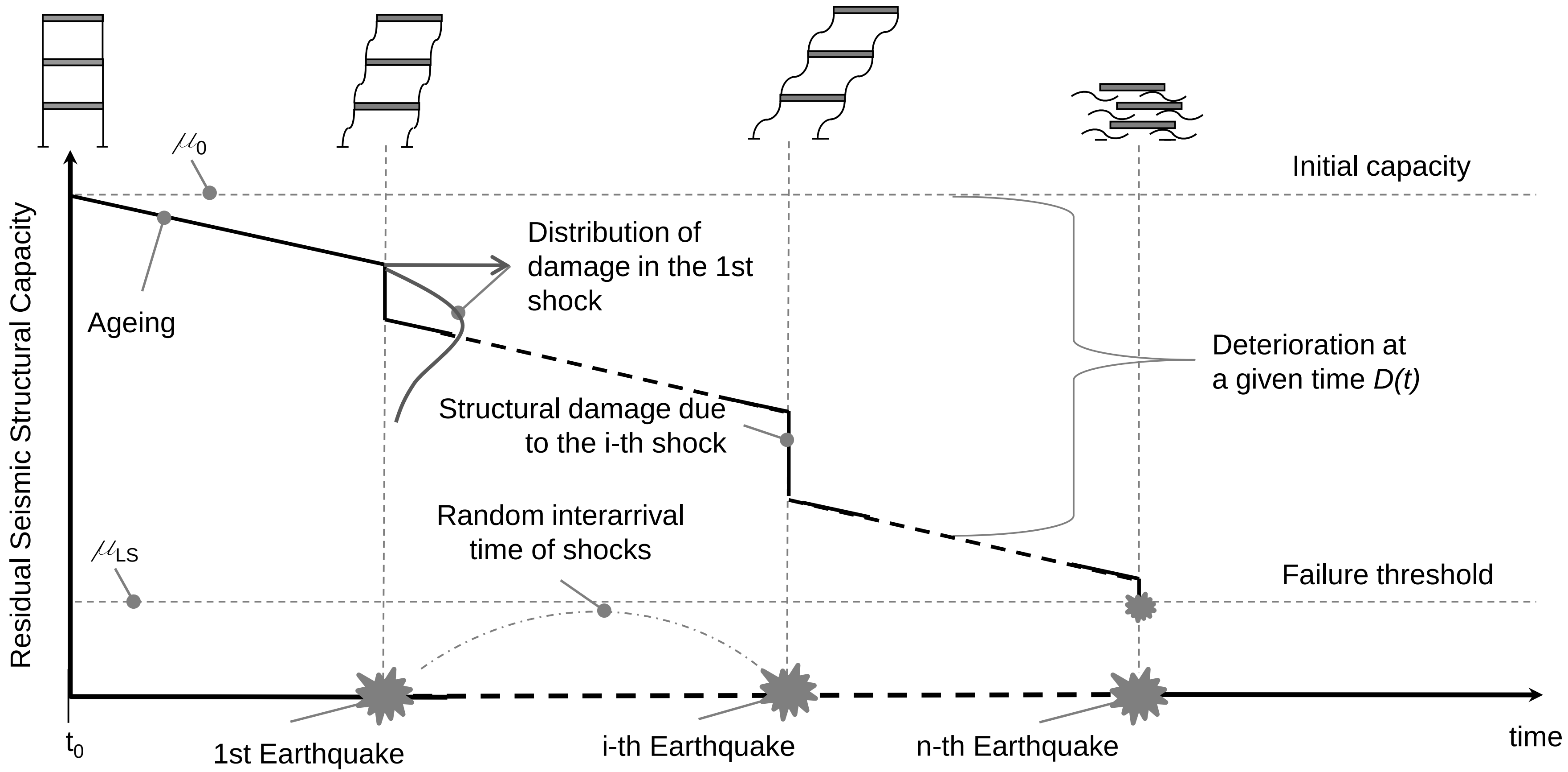
Chioccarelli E., Suzuki A., Iervolino I. (2019) Markov-based seismic reliability of structures considering mainshock and aftershock damage, Proceeding of 7th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN2019), 24-26 June, Crete, Greece.

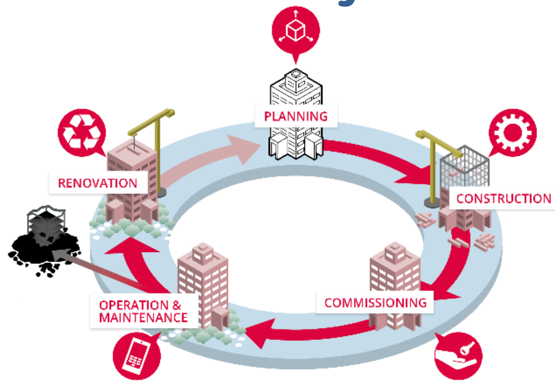
Chioccarelli E., Cito I., Iervolino I. (2019) Optimized geographical locations of structures for minimizing seismic losses, Proceeding of 7th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN2019), Crete, Greece.

Sesimic damage accumulation and ageing (continous deterioration) of structures



Iervolino I., Giorgio M., Chioccarelli E. (2016) Markovian modeling of seismic damage accumulation. *Earthquake Engineering and Structural Dynamics.* 45(3):441–461.

State of the art of life-cycle cost analysis (LCCA)



Expected total cost over a time period ΔT for a design variable X

$$E\left[C(\Delta T, X)\right]$$

=

Expected value of construction cost

$$E\left[C_0(X)\right]$$

+

Expected value of costs due to damages after the occurrence of different hazards

$$E\left[\sum_{i=1}^{N(\Delta T)}\sum_{j=1}^{k} C_j \cdot e^{-\alpha\cdot\Delta T}\cdot P_{ij}\left(X, t_i\right)\right]$$

+

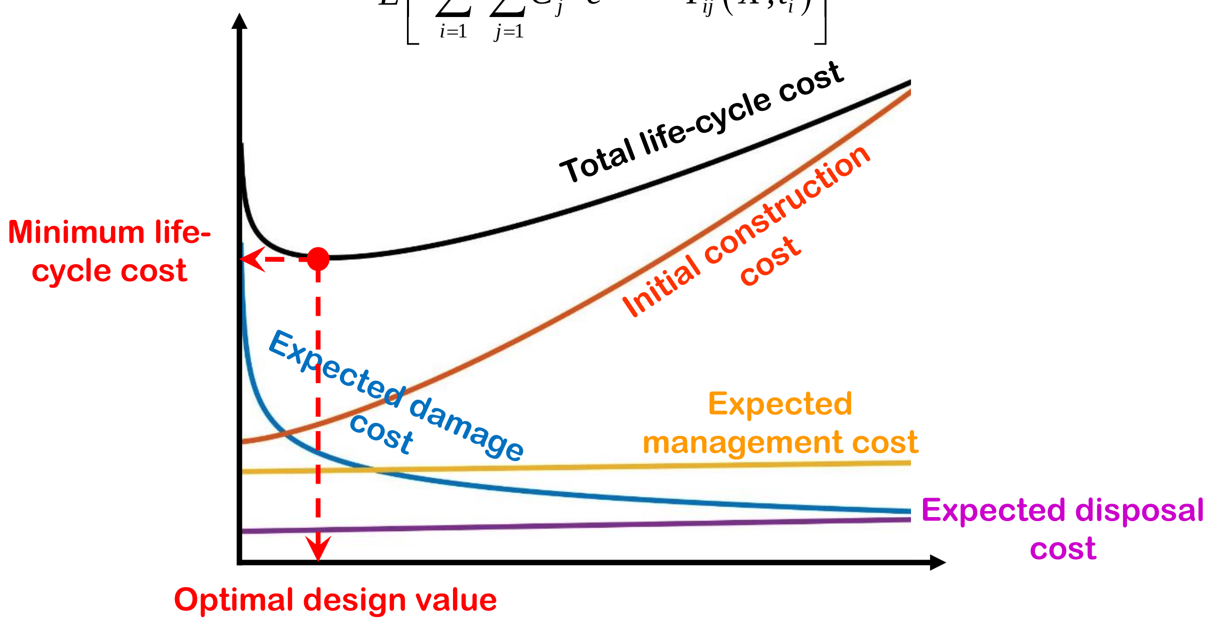
Expected value of operation and maintenance costs

$$\int_0^{\Delta T} C_m(X)\cdot e^{-\alpha\tau}\,d\tau$$

+

Expected value of disposal costs

$$E\left[C_{disp}\right]$$



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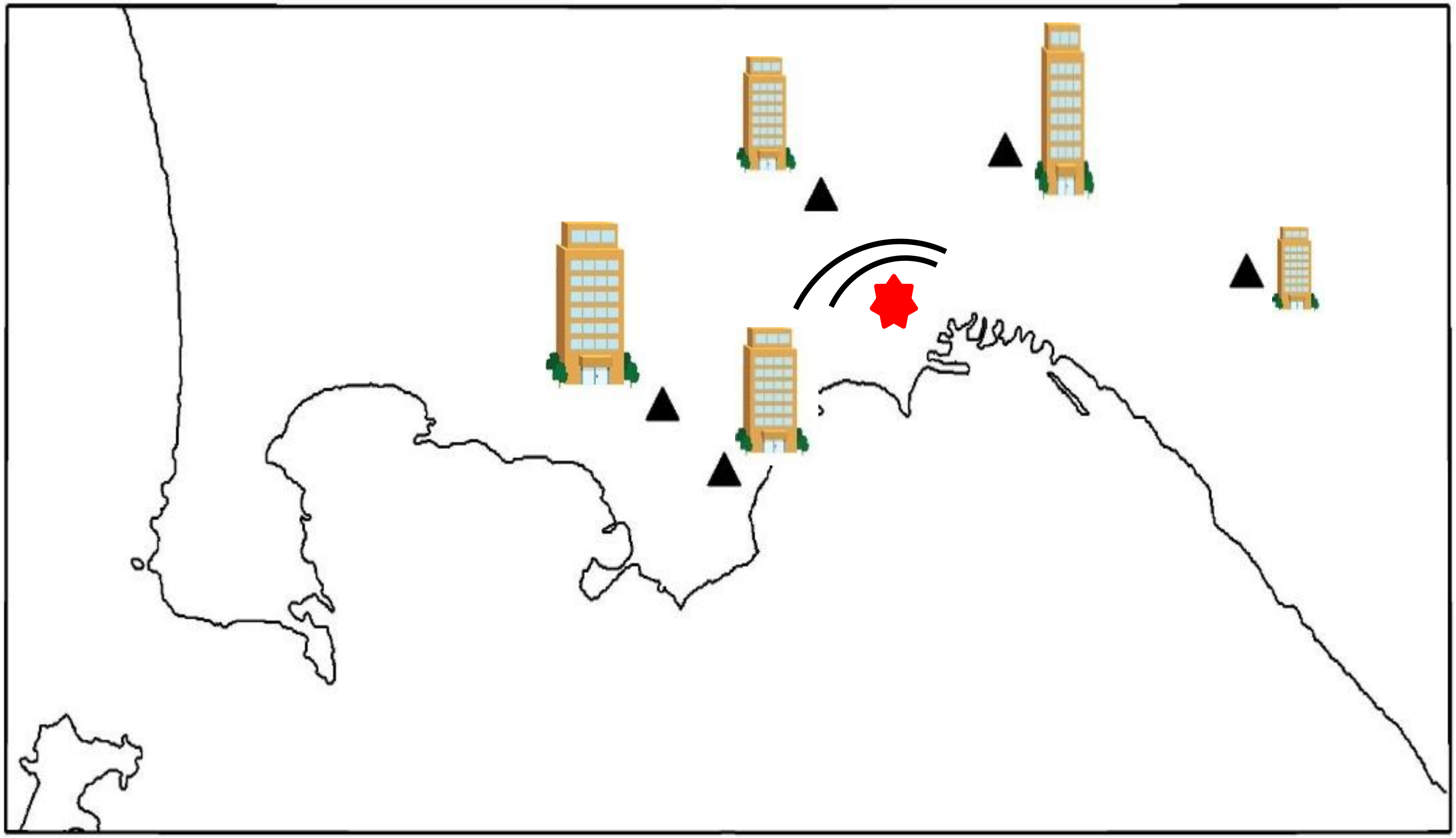
Regional seismic risk analysis (for building portfolios or for infrastructure)



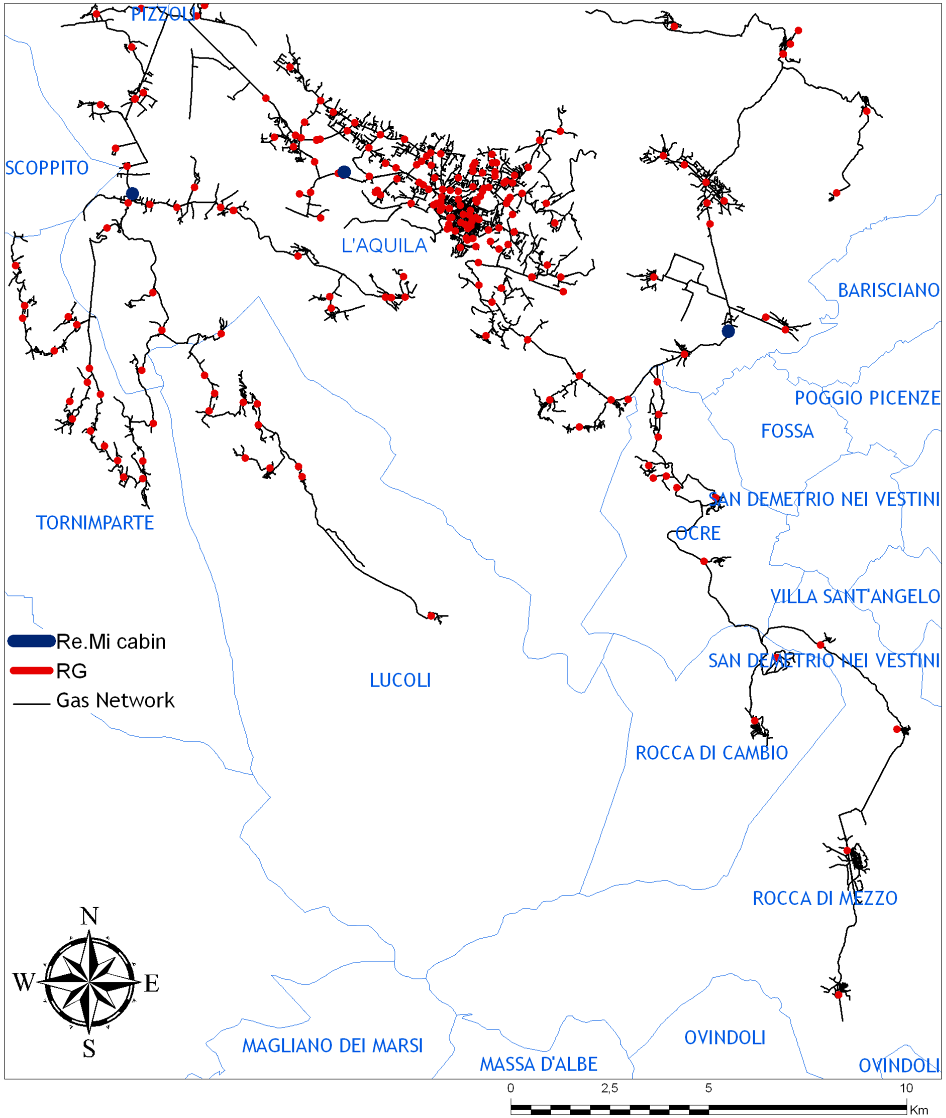
Giorgio M., Iervolino I. (2016) On multi-site probabilistic seismic hazard analysis. *Bulletin of the Seismological Society of America*. 106(3): 1223–1234.

L'Aquila Gas distribution System (1/2)

Gas distribution via a 621 km pipeline (STEEL /HDPE) network:
- **234 Km at Medium Pressure**
- **387 Km at Low Pressure**

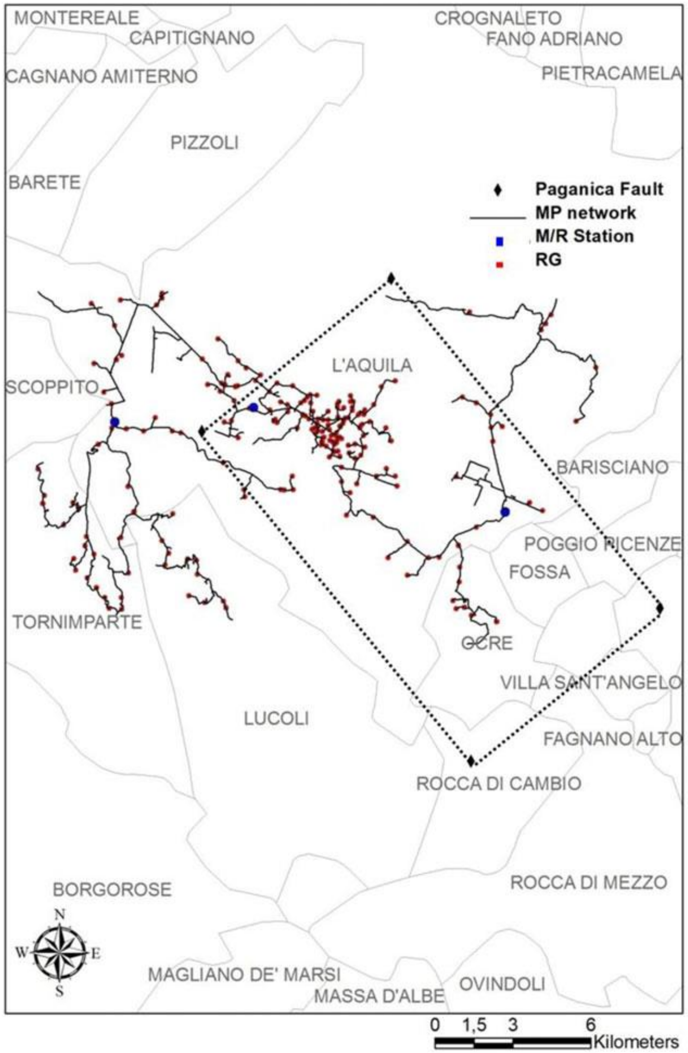
The MP network connection to HP network through 3 Metering / Pressure Reduction M/R Stations

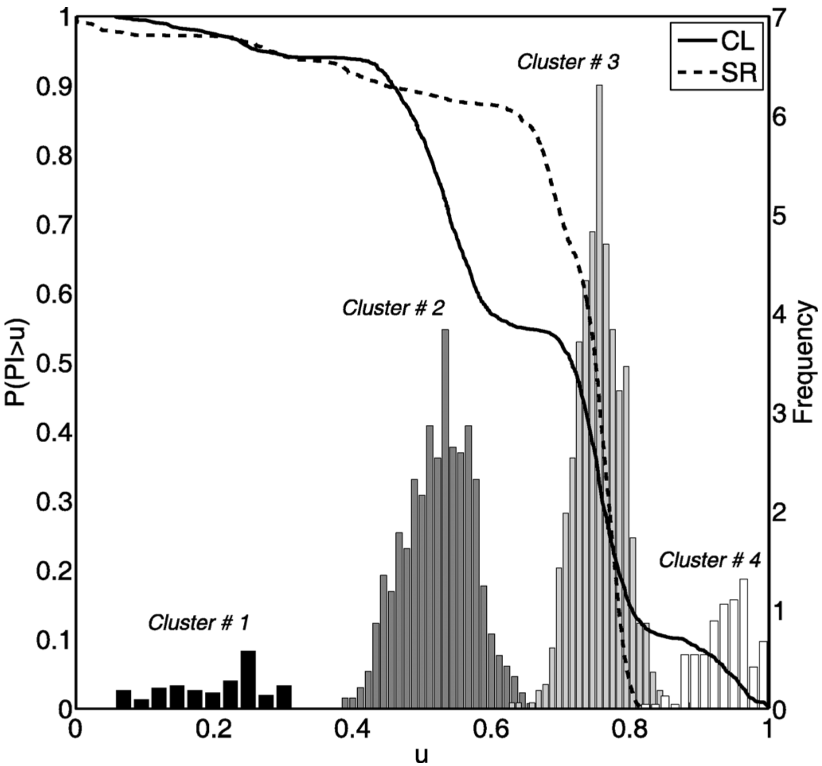
The transformation of the MP into the LP through 300 Final Reduction Groups



Enel Gas
L'energia che ti ascolta.

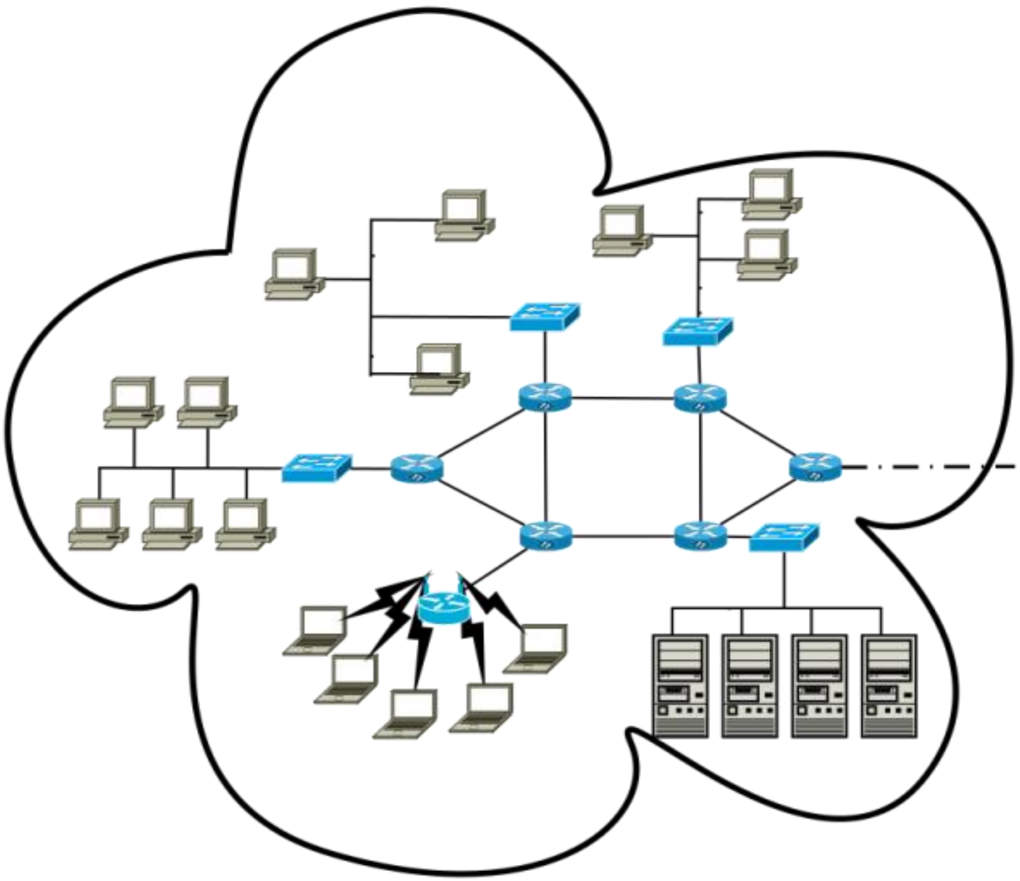
L'Aquila Gas distribution System (2/2)





Esposito S., Iervolino I., d'Onofrio A., Santo A., Franchin P., Cavalieri F. (2015) Simulation-based seismic risk assessment of gas distribution networks. *Computer-Aided Civil and Infrastructure Engineering.* 30(7): 508-523.

Data communication networks



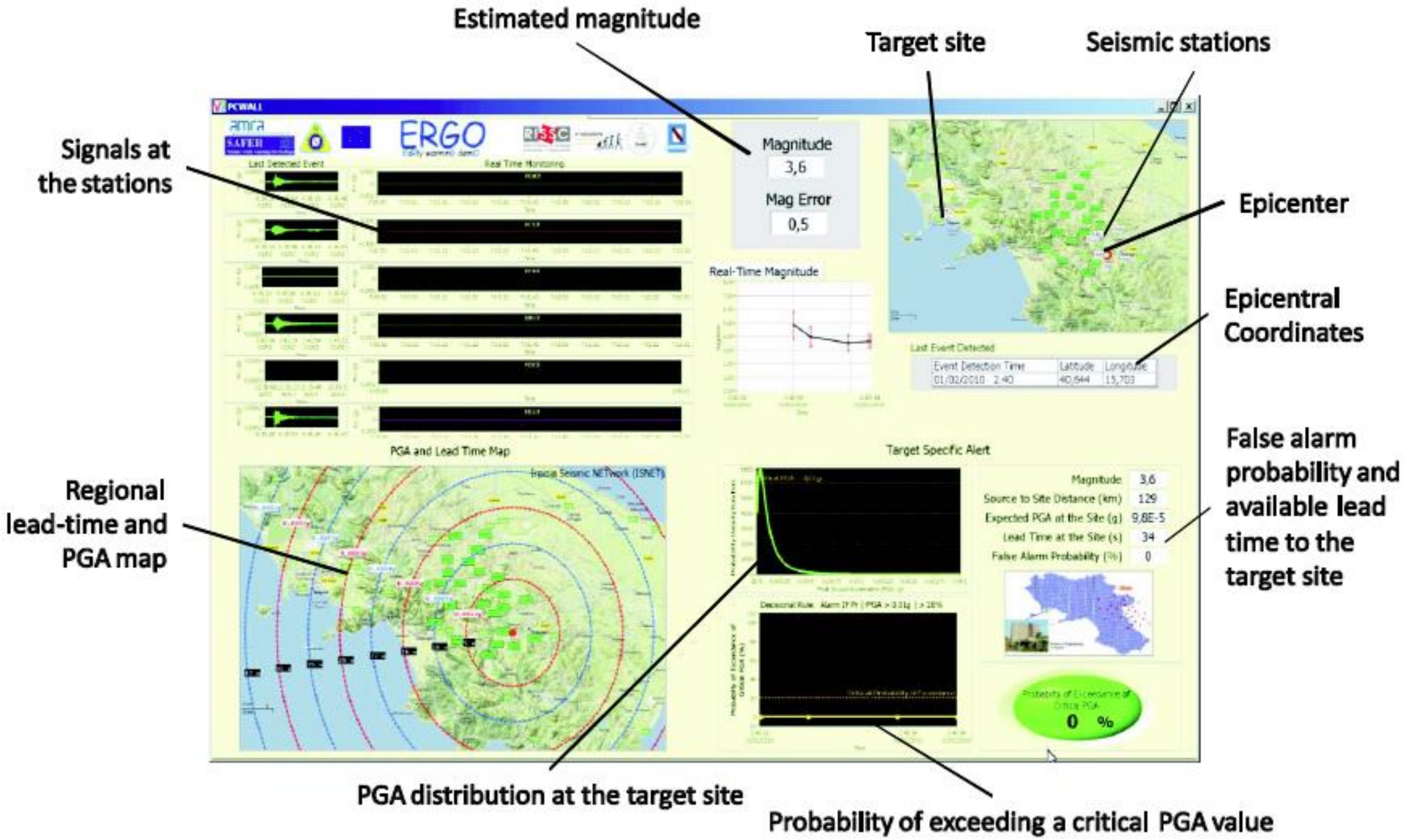
A data communication network provides connectivity between individual networks via a complex and hierarchical interconnection of nodes and links.

Computers at the border of the network are connected through switches and routers that manage the traffic.

The RIMIC network

Esposito S., Botta A., De Falco M., Iervolino I., Santo A., Pescapé A. (2018) Towards seismic risk analysis of data communication networks. Proc. of 16ECEE – 16th European Conference on Earthquake Enginnering, Thessaloníki, June 2018.

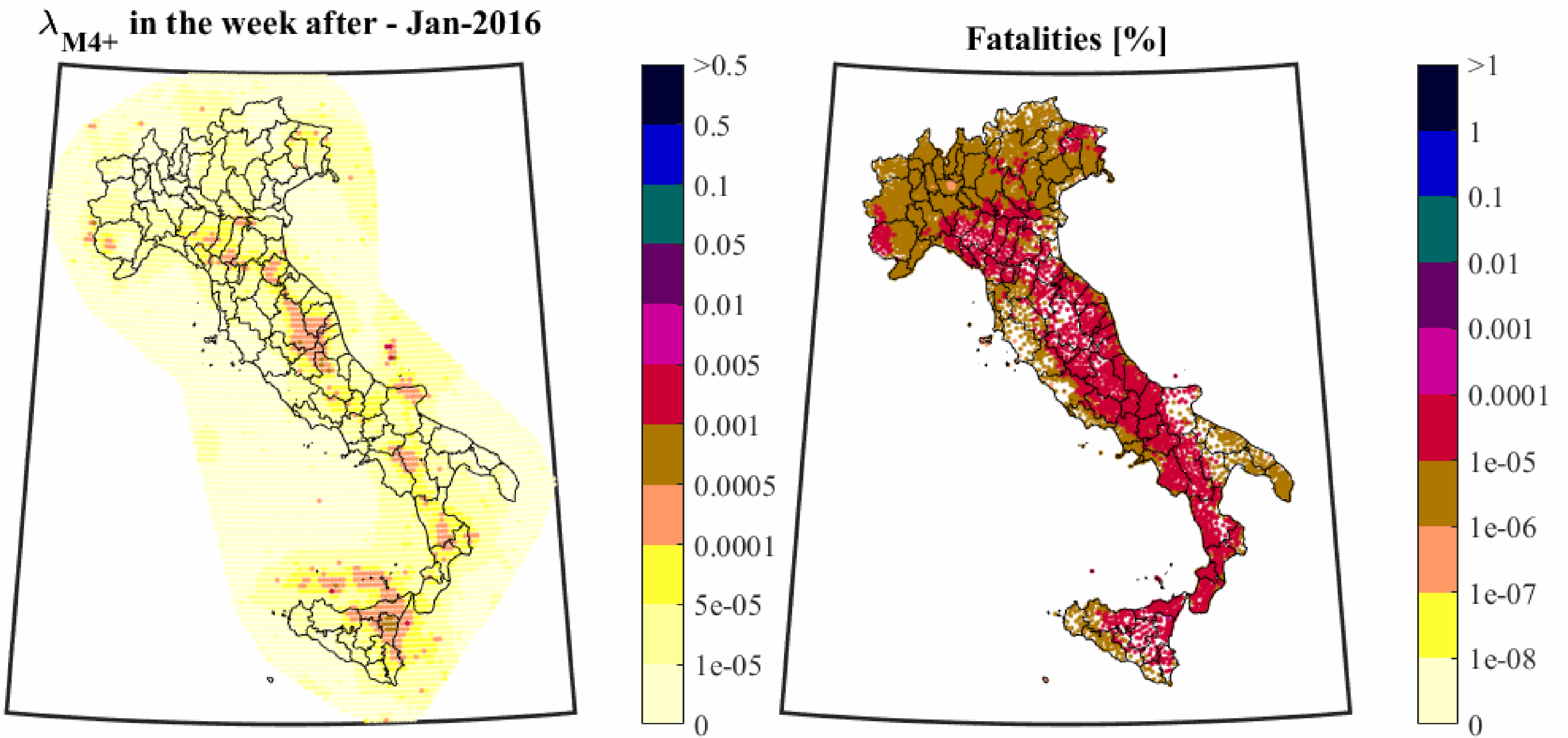
Real-time PBEE for earthquake early warning



$$\lambda_l = \int_{im}\int_{edp}\int_{dm} P\left[L > l \mid DM = dm\right] \cdot f_{DM|EDP}(dm) \cdot f_{EDP|IM}(edp) \cdot d(dm) \cdot d(edp) \cdot \left| d\lambda_{IM} \right|$$

Iervolino I. (2011) Performance-Based Earthquake Early Warning, *Soil Dynamics and Earthquake Engineering.* 31(2): 209-222.

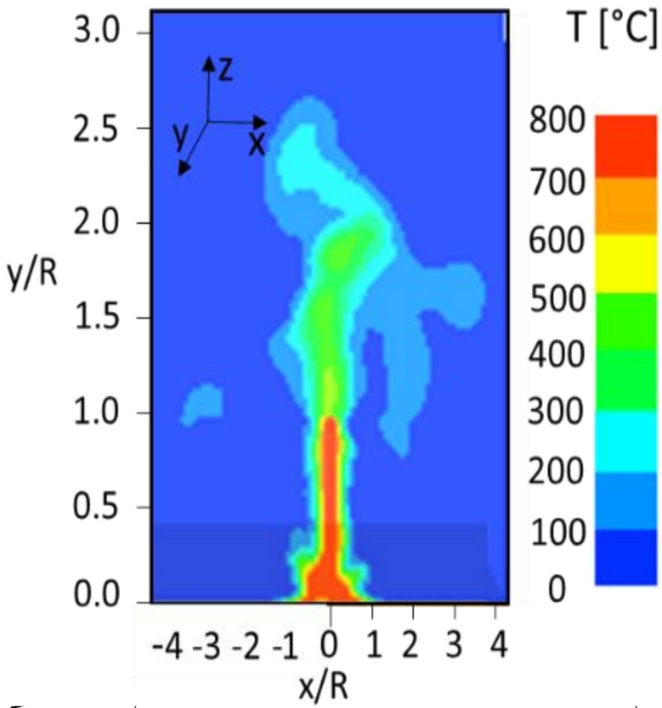
Operational earthquake loss forecasting (quasi-real-time PBEE)

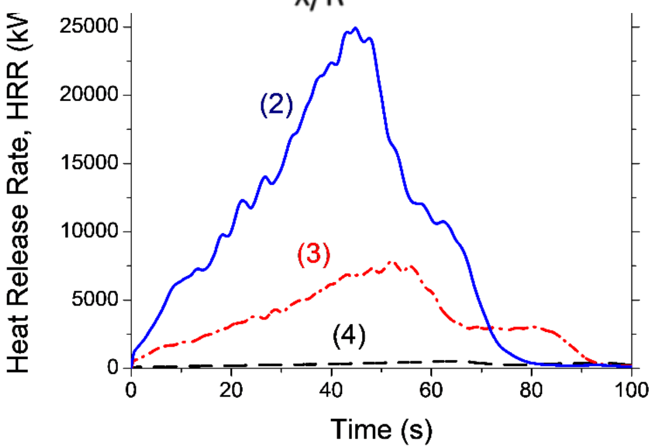


$$\lambda_{Cas^{(k)}}\left(t,w,z\,|\,H(t)\right)=\iint_{x,y}\lambda\left(t,x,y\,|\,H(t)\right)\cdot\sum_{ds}P\left[Cas^{(k)}\,|\,ds\right]\cdot\sum_{ms}P\left[DS^{(k)}=ds\,|\,ms\right]\cdot\int_{m}P\left[MS=ms\,|\,m,R(x,y,w,z)\right]\cdot f_M(m)\cdot dm\cdot dx\cdot dy$$

Iervolino I., Chioccarelli E., Giorgio M., Marzocchi M., Zuccaro G., Dolce M., Manfredi G. (2015) Operational (short-term) earthquake loss forecasting in Italy. *Bulletin of the Seismological Society of America*. 105(4): 2286–2298.

Seismic risk analysis in the process industry (Seveso-type plants)





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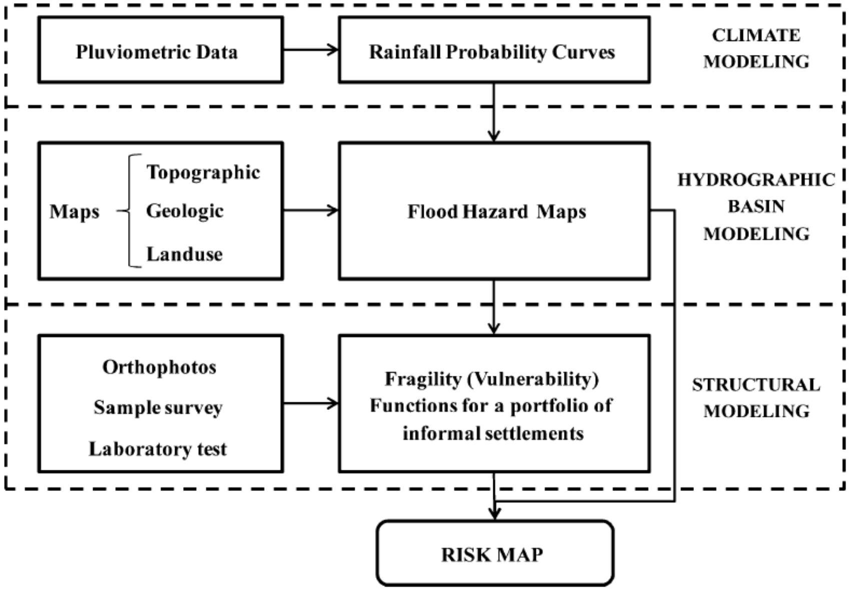
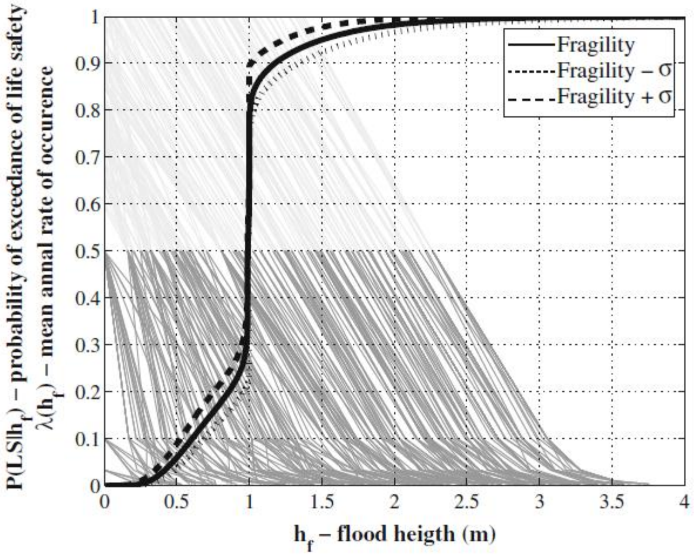
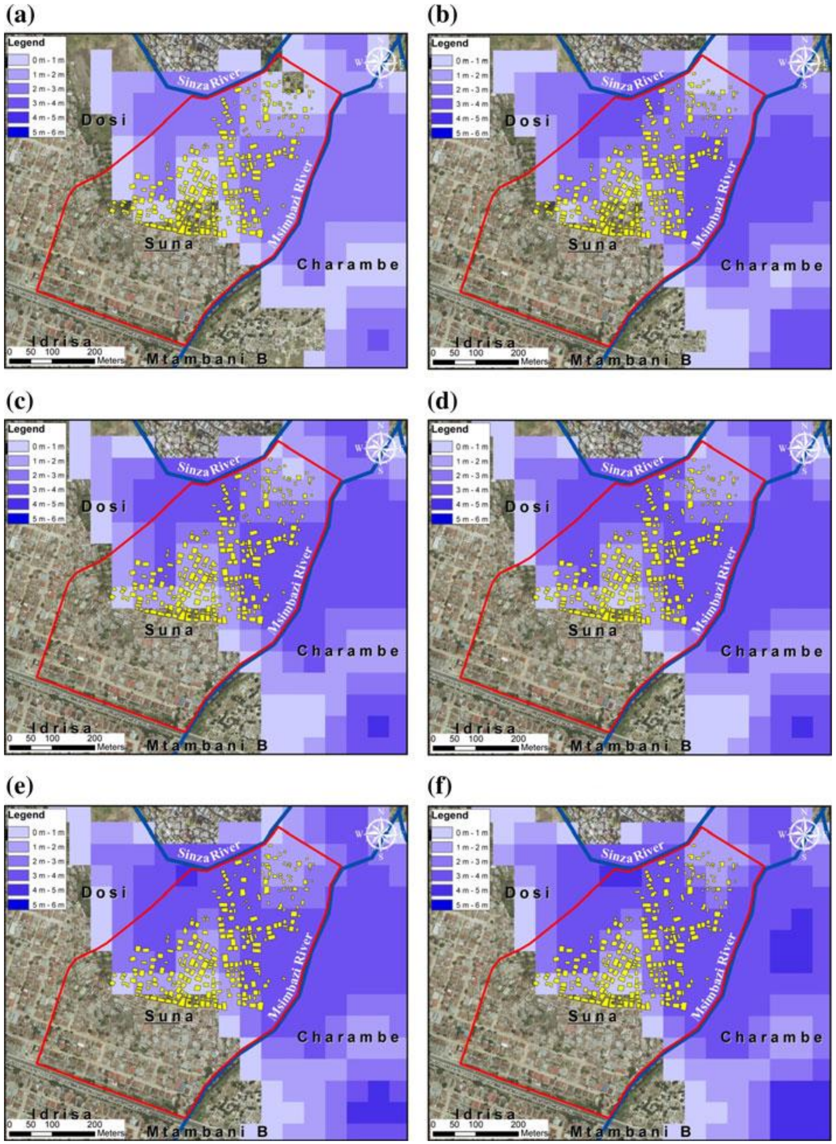
Flood risk assessment of urban dwellings







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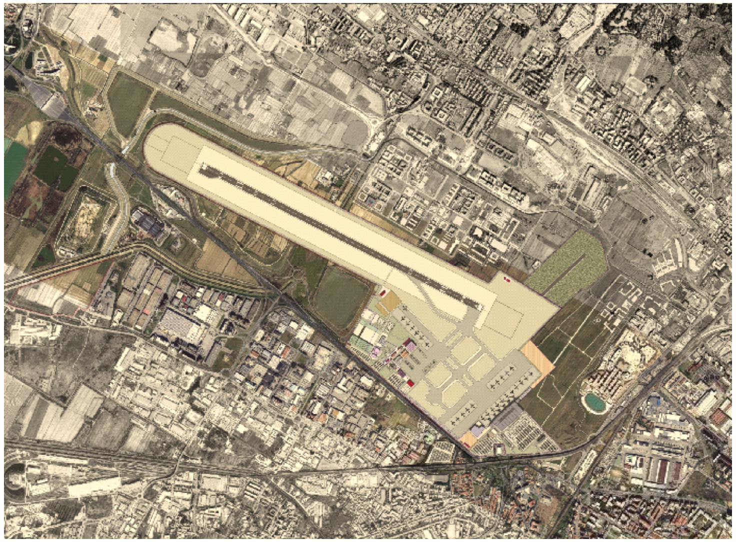
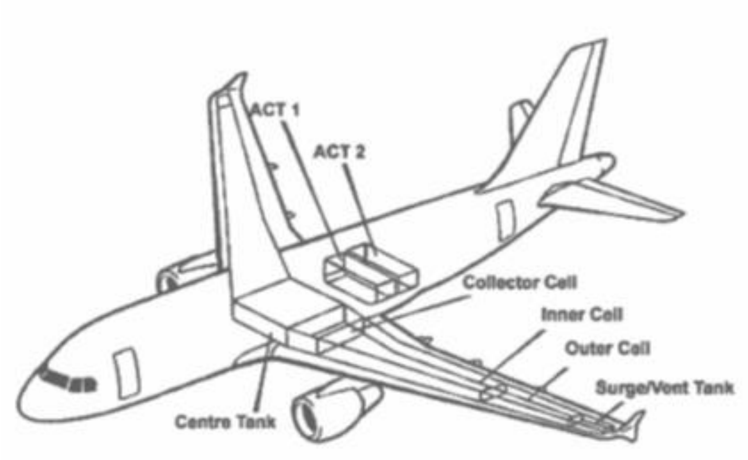
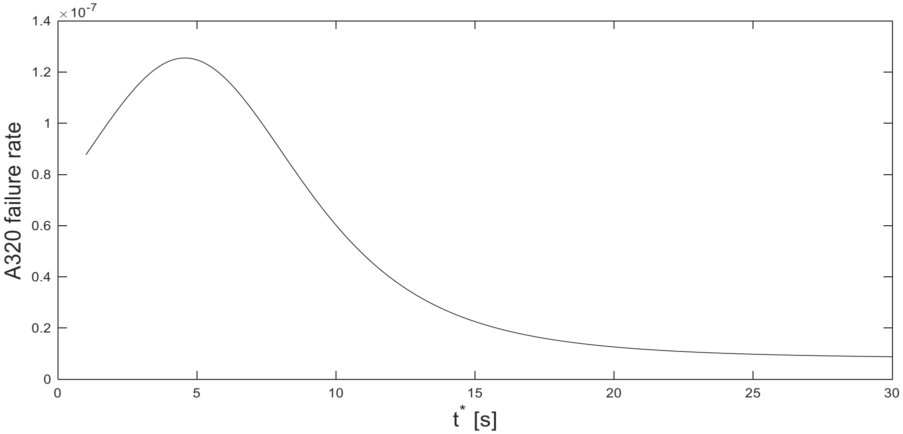
Crash and domino effects' risk analysis for airport facilities (1/2)







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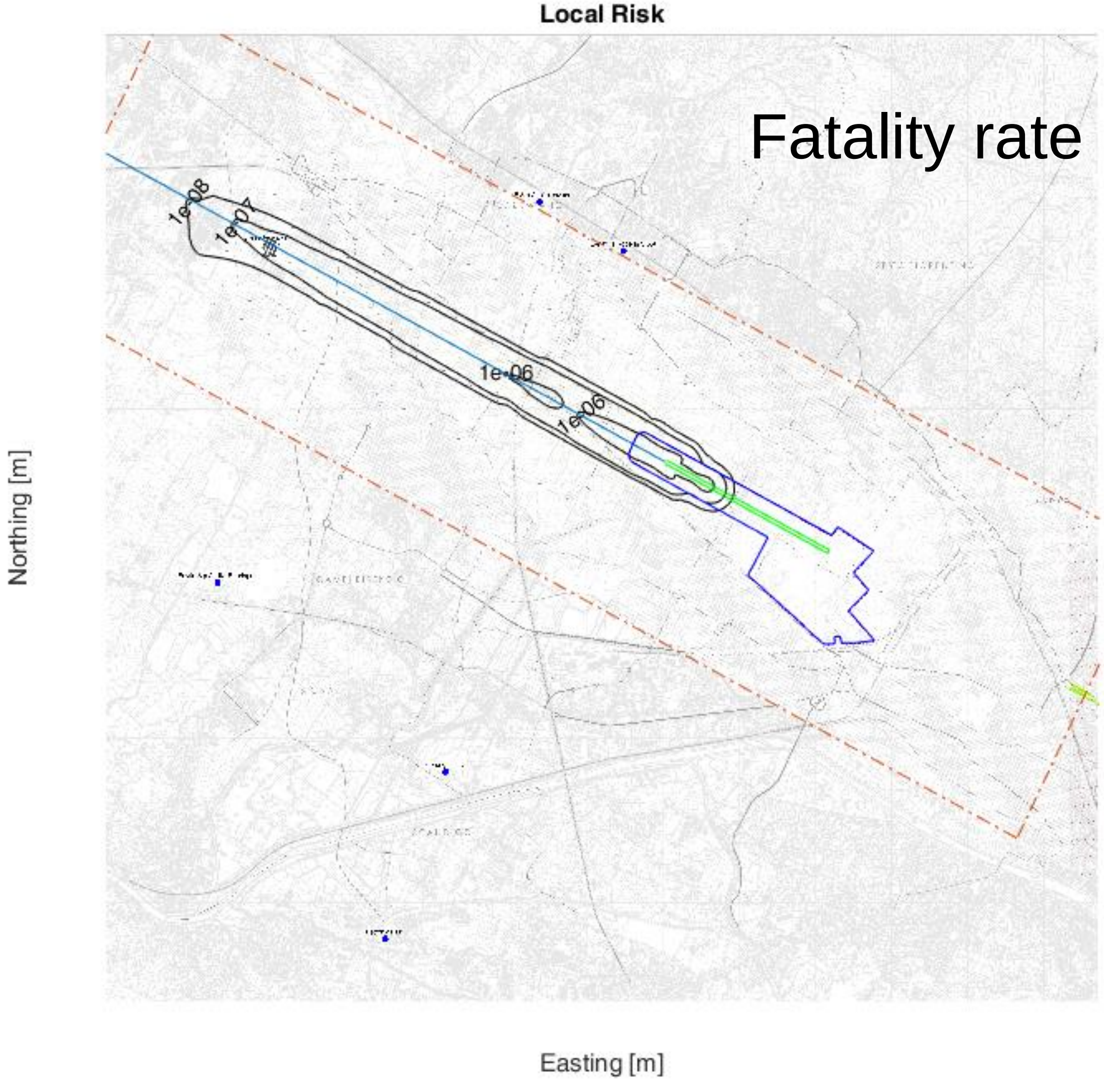
Crash and domino effects' risk analysis for airport facilities (2/2)



Toscana Aeroporti

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