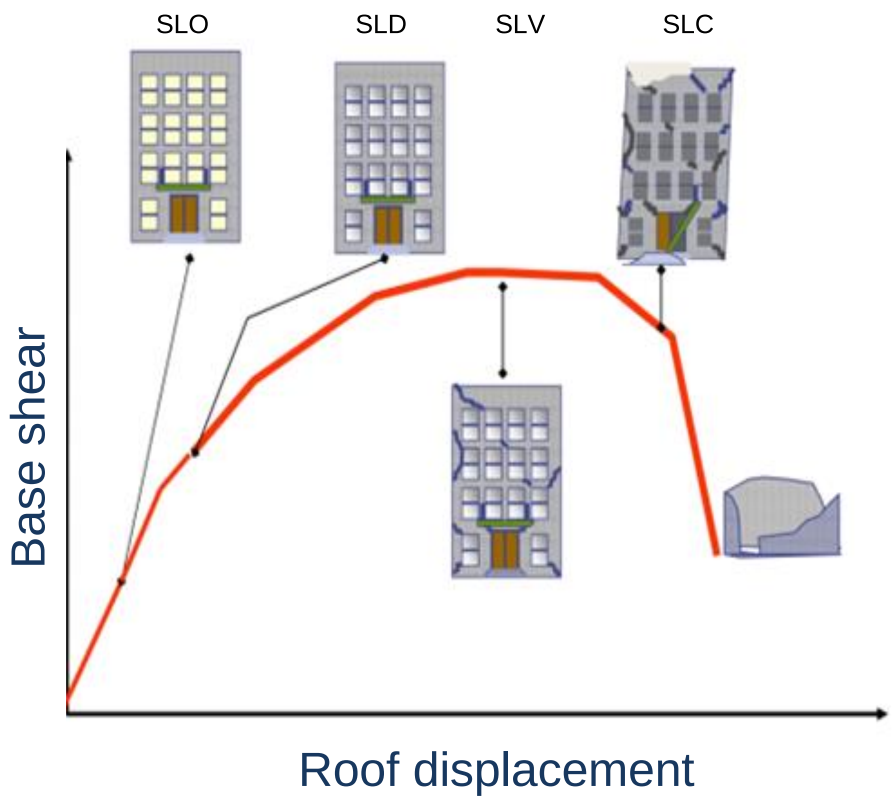
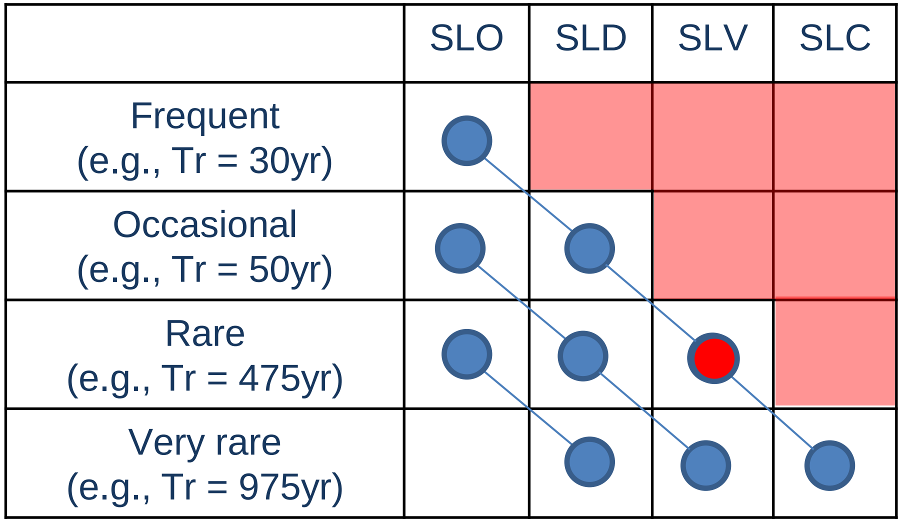
UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

What seismic risk do we design for when we design new buildings?

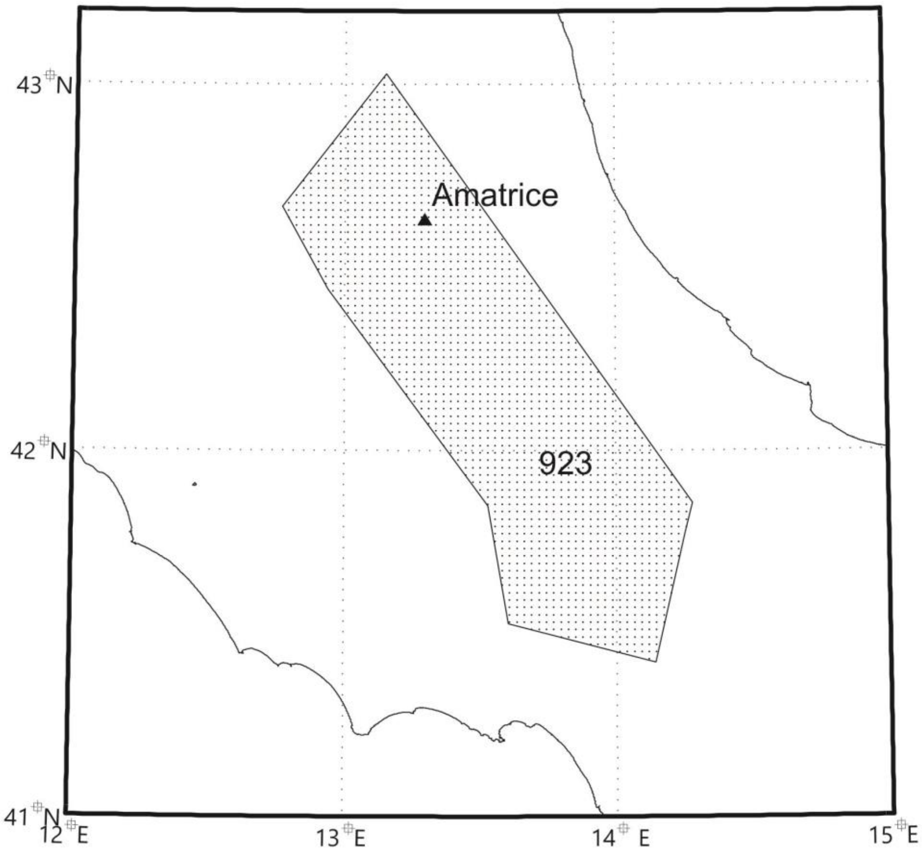
Iunio Iervolino, *professor of earthquake engineering and structural dynamics.*

(Almost) state-of-the-art seismic design





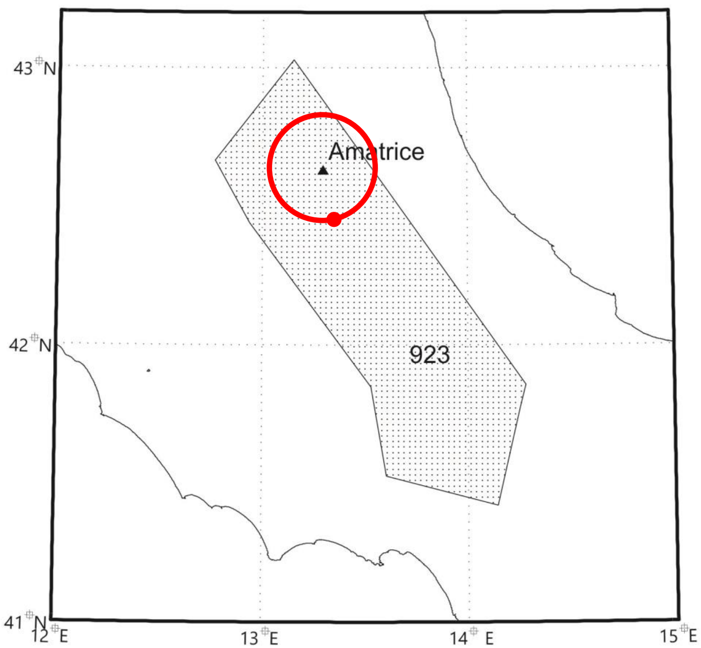
CPTI15 – *Catalogo parametrico dei terremoti Italiani*.

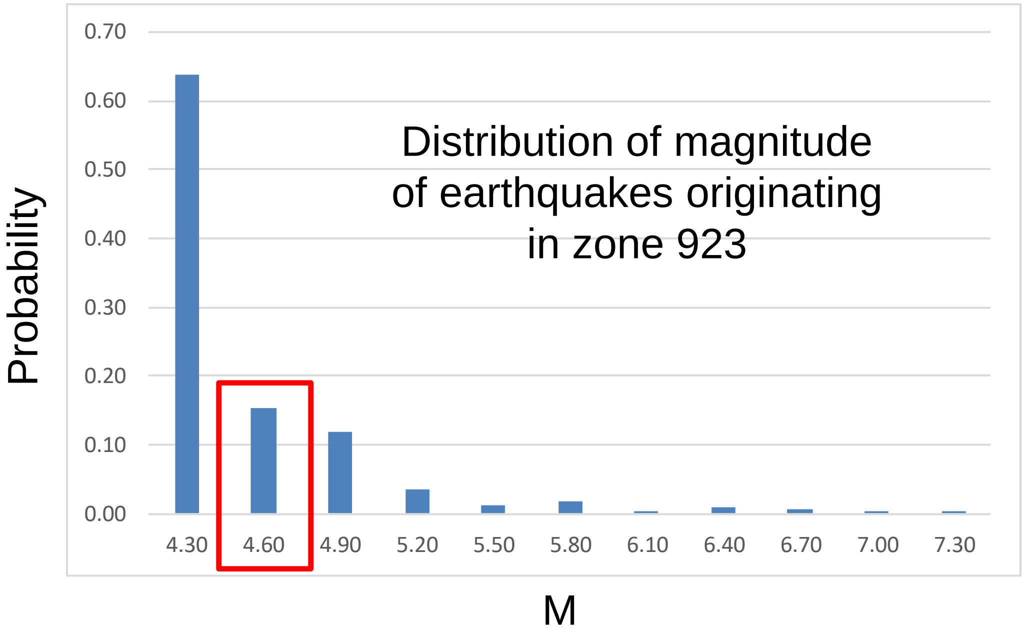


3500+ earthquakes with moment magnitude (Mw) larger than 4 since 1005 D.C.

Zone	ν - rate M>=4 [earthquakes/yr]	Tr – return period [anni]
923 Appennino Abruzzese	0.64	1.6
929 Calabria tirrenica	0.39	2.5
927 Sannio - Irpinia - Basilicata	0.36	2.8
920 Val di Chiana - Ciociaria	0.32	3.2
905 Friuli - Veneto Orientale	0.32	3.2
915 Garfagnana - Mugello	0.31	3.2
921 Etruria	0.30	3.4
919 Appennino Umbro	0.24	4.1
918 Medio-Marchigiana/Abruzzese	0.22	4.6
913 Appennino Emiliano-Romagnolo	0.21	4.9
924 Molise-Gargano	0.19	5.2
914 Forlivese	0.18	5.5
933 Sicilia settentrionale	0.17	5.8
930 Calabria ionica	0.15	6.8
908 Piemonte	0.14	7.2
906 Garda - Veronese	0.13	7.4
917 Rimini - Ancona	0.12	8.2
903 Grigioni - Valtellina	0.12	8.4
932 Eolie - Patti	0.12	8.5
902 Vallese	0.10	9.7
912 Dorsale Ferrarese	0.09	10.9
916 Versilia-Chianti	0.09	11.0
922 Colli Albani	0.09	11.1
935 Iblei	0.09	11.1
910 Nizza - Sanremo	0.09	11.7
925 Ofanto	0.07	14.1
936 Etna (M>=3.5)	0.07	14.3
907 Bergamasco	0.07	15.2
926 Basento	0.06	16.3
909 Alpi Occidentali	0.06	17.6
928 Ischia - Vesuvio	0.06	18.0
911 Tortona - Bobbio	0.05	20.0
904 Trieste - Monte Nevoso	0.05	20.0
901 Savoia	0.05	21.3
931 Canale d'Otranto	0.05	22.1
934 Belice	0.04	23.0

Probabilistic seismic hazard analysis





Annual rate of exceedance of a ground motion intensity threshold

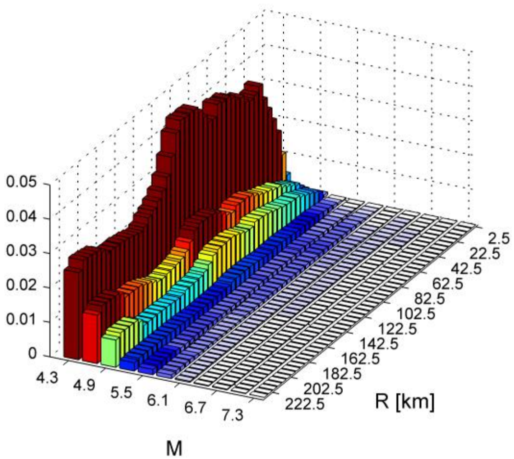
$$\lambda_{Sa(T)>sa} =$$

=

Threshold intensity

$$\sum_{R_{min}}^{R_{max}} \sum_{M_{min}}^{M_{max}} \nu_{M=m,R=r} \cdot P\left[Sa(T) > sa \mid m,r\right] = \sum_{R_{min}}^{R_{max}} \sum_{M_{min}}^{M_{max}} \lambda_{Sa(T)>sa,M=m,R=r} = \lambda_{Sa(T)>sa}$$

$\nu_{M=m,R=r}$



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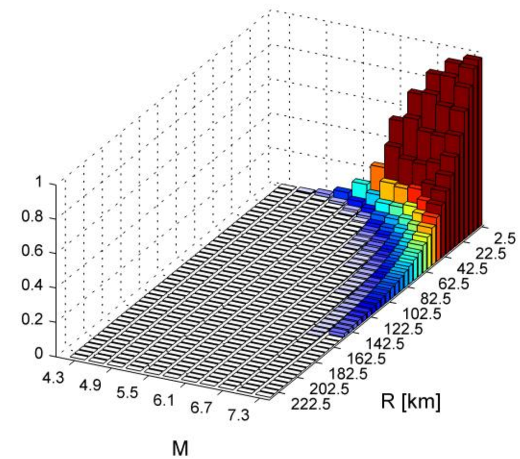
$P[Sa(T=1s) > sa_{Tr=475} \mid M=m, R=r]$



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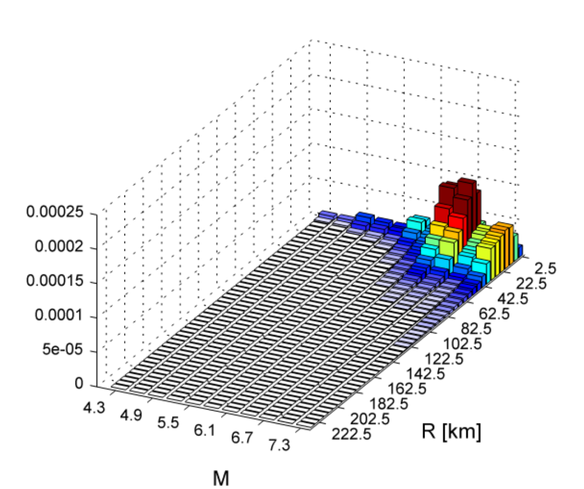
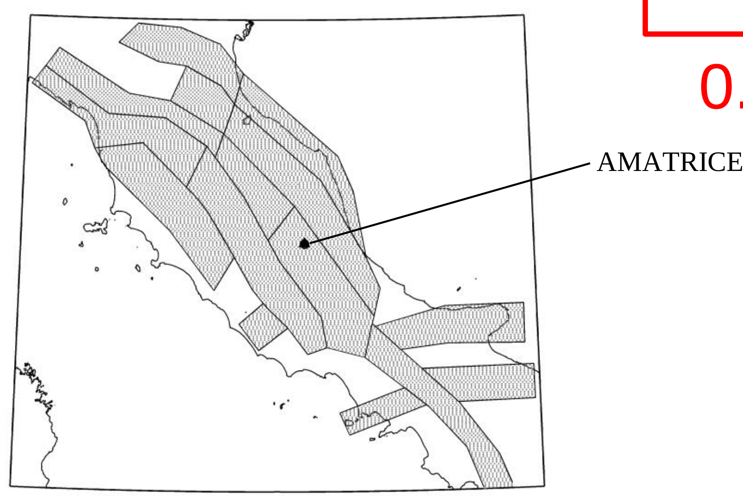
$\lambda_{Sa(T=1s)>sa_{Tr=475},M=m,R=r}$

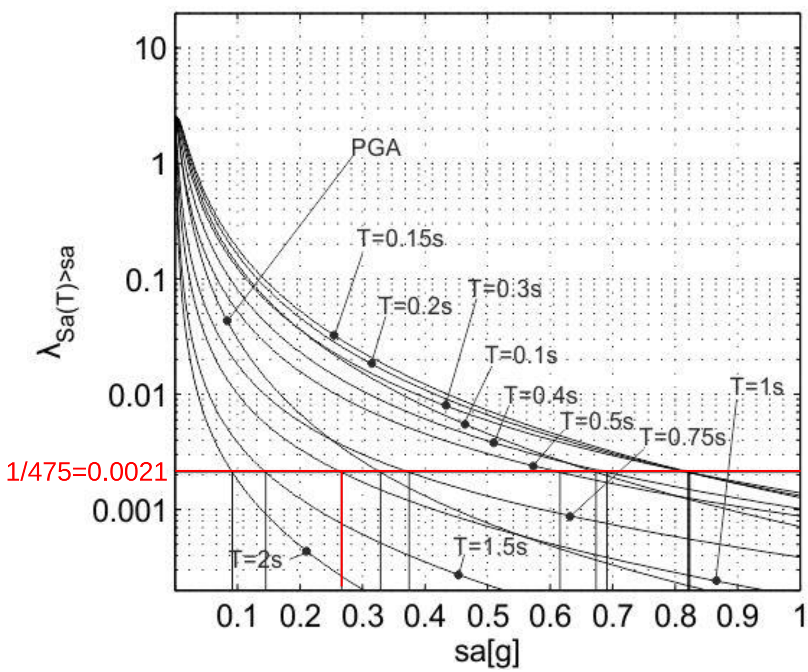


0.0021 = 1/475

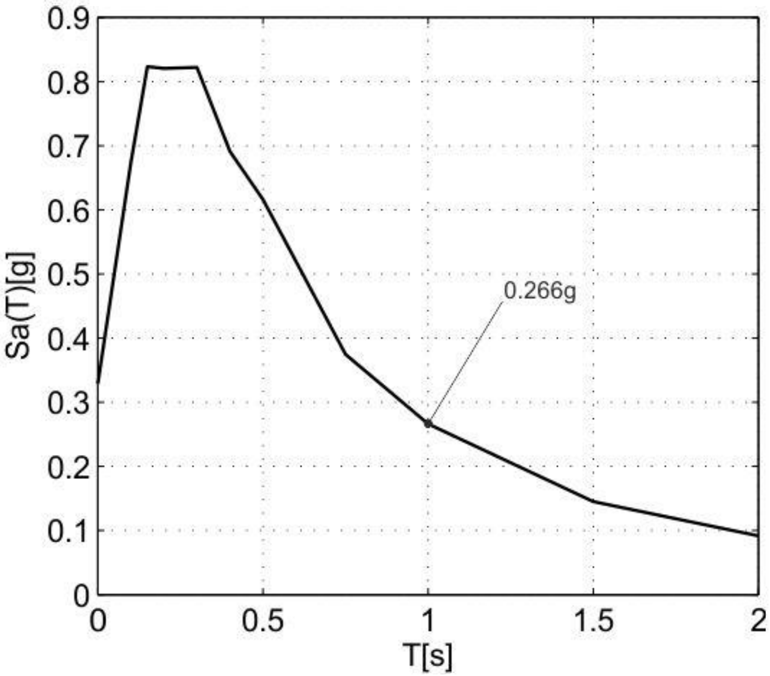


Let's look at the Sa(T=1s) with annual rate 0.0021 or 475 yr return period.

Entering the ordinates of the *hazard curves* the *uniform hazard spectrum* is determined

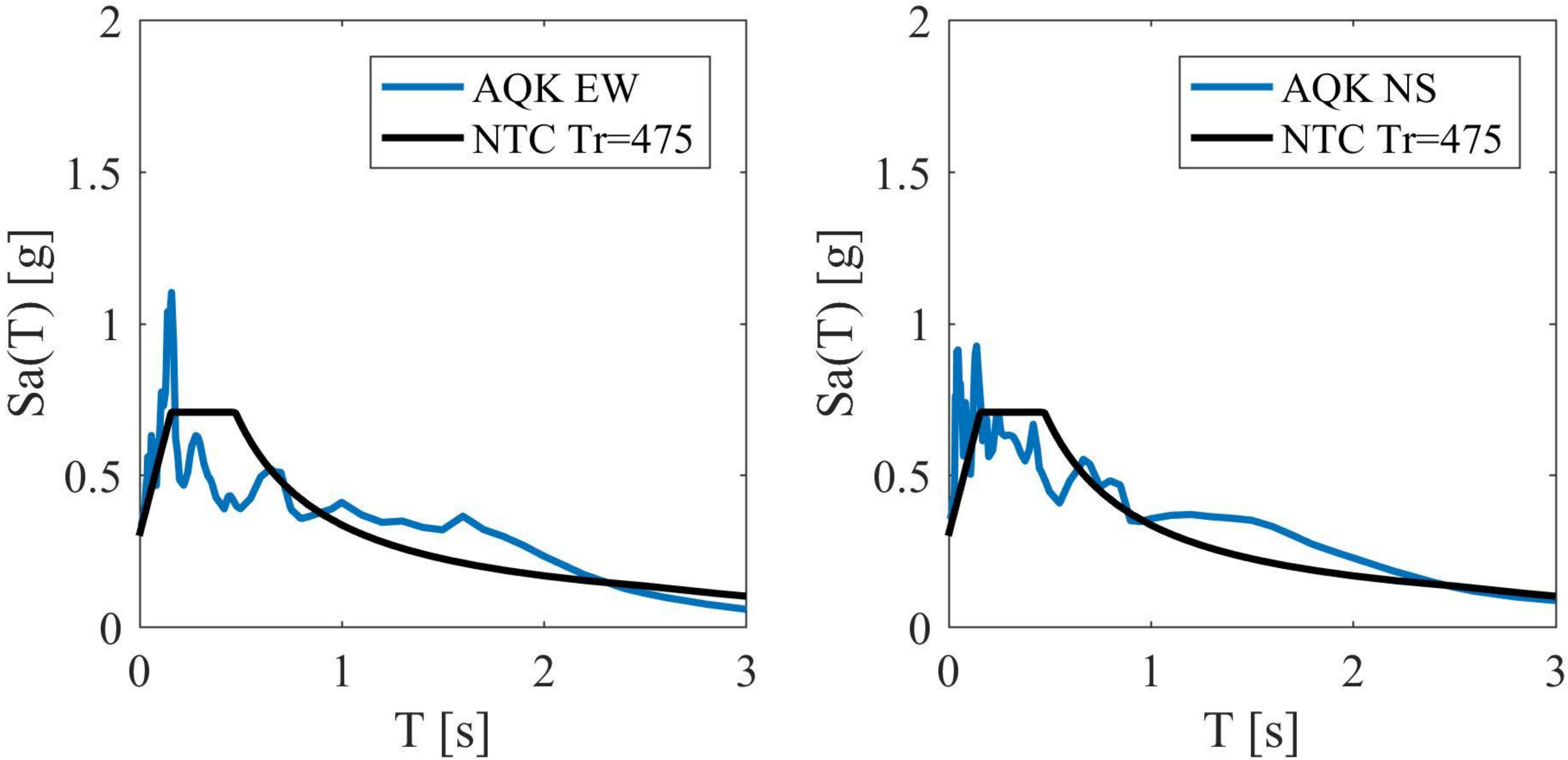


Hazard curves for Amatrice (EC8 site class B)



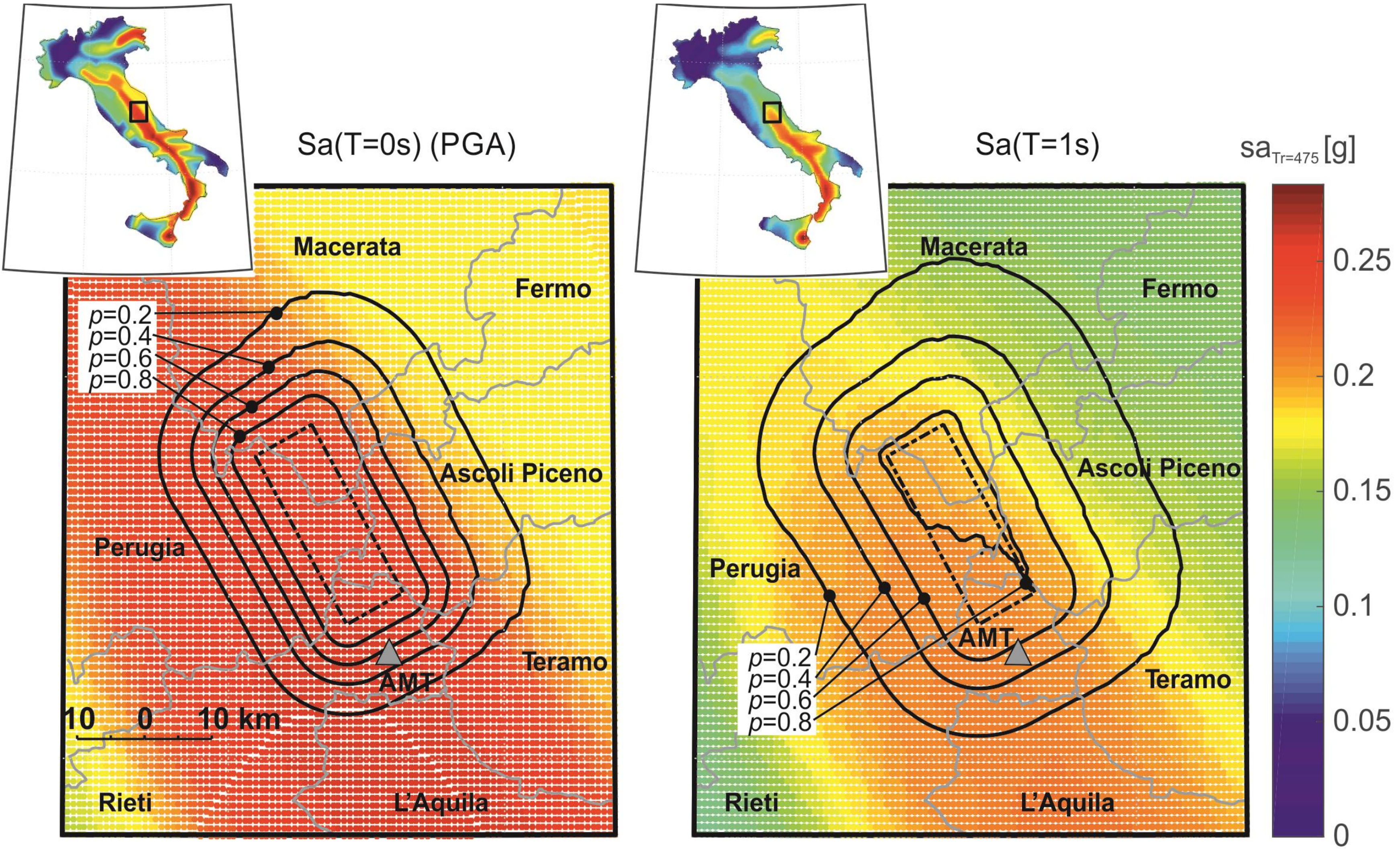
Uniform hazard spectrum (ordinates exceeded on average once in 475 years).

L'Aquila 6.4.2009 (Mw=6.3, R=0km)

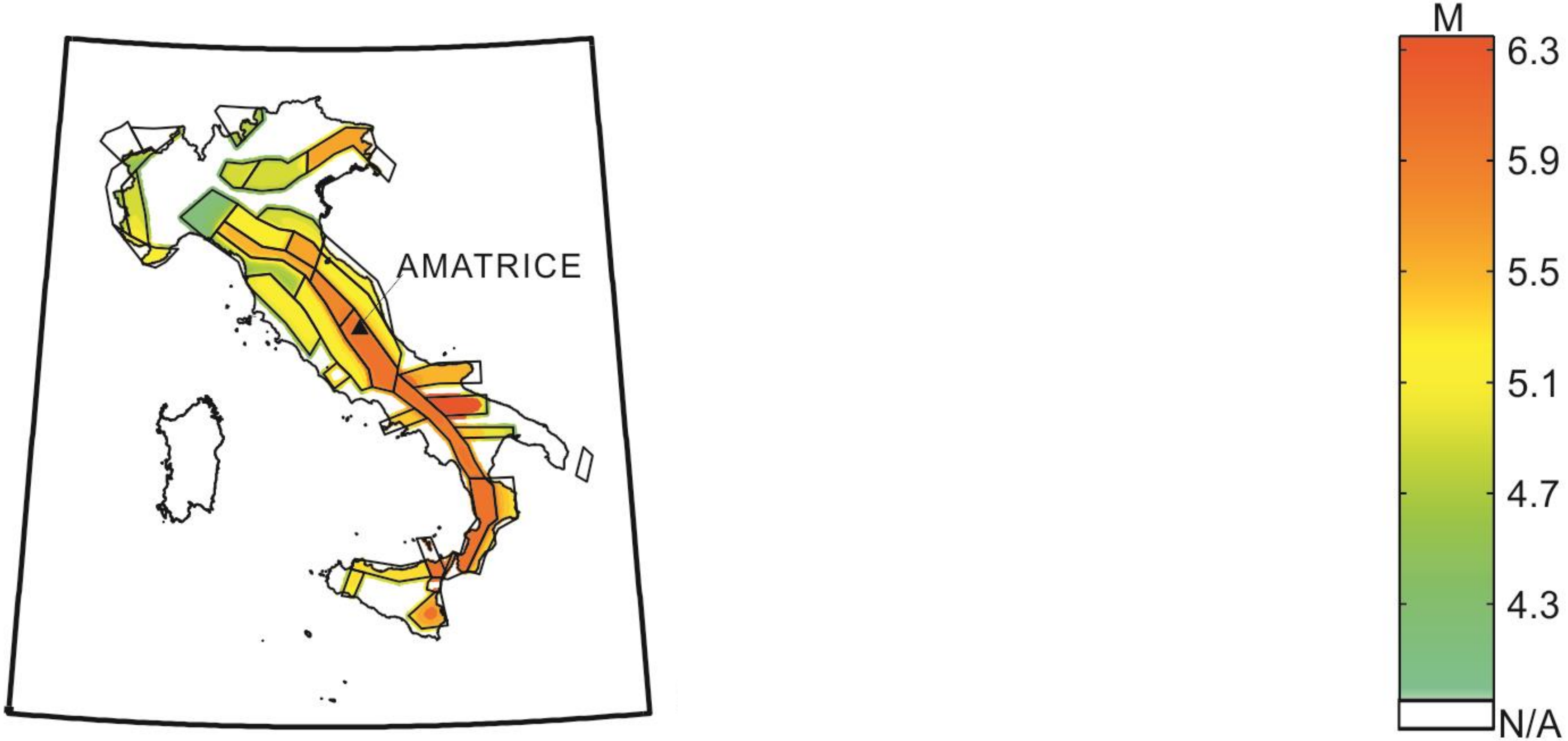


Earthquakes M>6 occur once every 8yr on average in Italy

Amatrice 30.10.2016 (Mw=6.5)



The Italian map of *strong earthquakes**

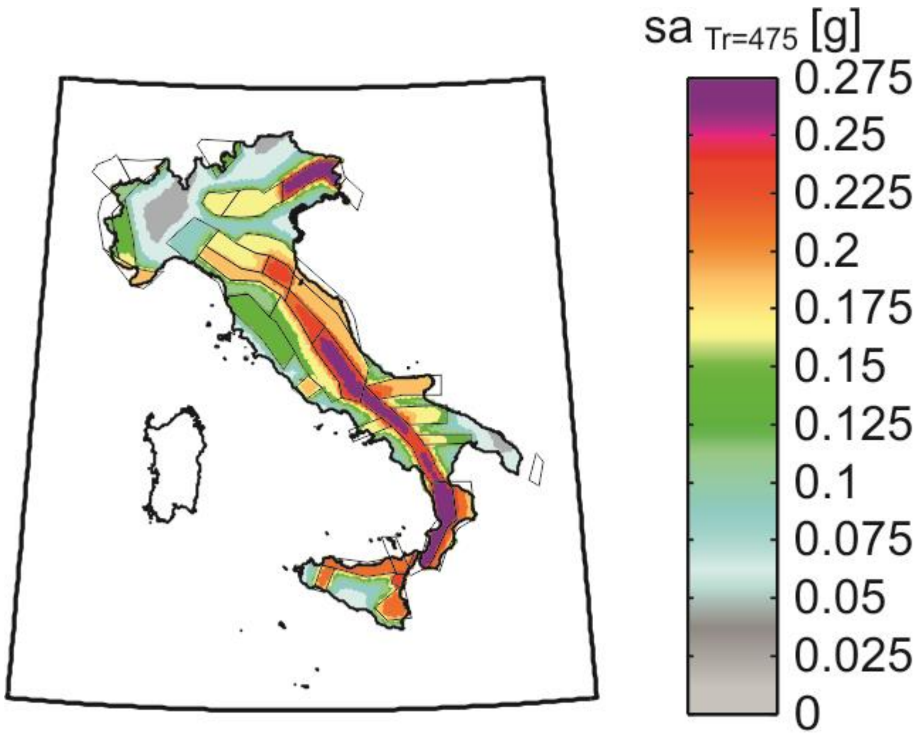


*Minimum magnitude that, if occurring within 5km will cause exceedance of the code spectrum (475 years) with probability larger than 0.5.

How much is exceedance given that the code-spectrum has been exceeded?

$$E\left[Sa(T) \middle| Sa(T) > sa_{T_r=475}\right] = \iint_{M,R} e^{\mu_{m,r}} \cdot \int_{\frac{\log\left(sa_{T_r=475}\right)-\mu_{m,r}}{\sigma}}^{+\infty} e^{\sigma\cdot\varepsilon} \cdot f_{M,R,\varepsilon|Sa(T)>sa_{T_r=475}}(m,r,e)\cdot d\varepsilon \cdot dr \cdot dm$$

Map of PGA of the 475 year uniform hazard (code) spectrum



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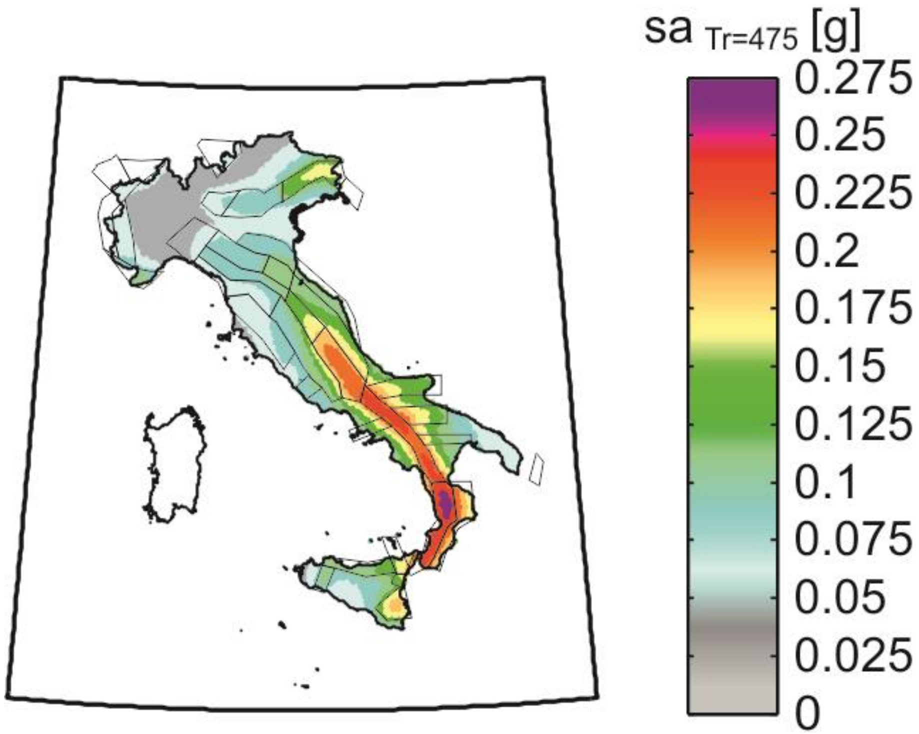
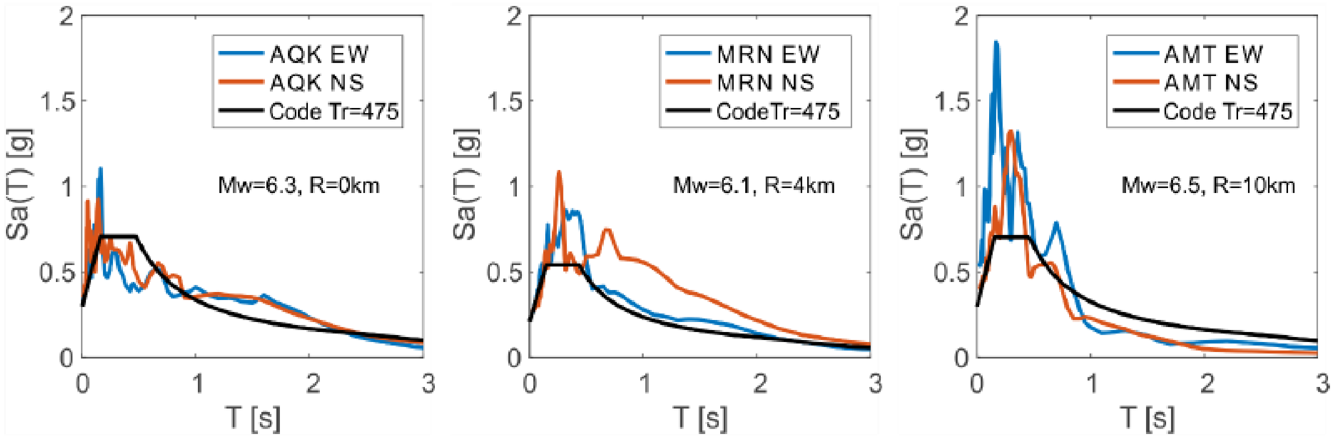
Map of Sa(T=1s) of the 475 year uniform hazard (code) spectrum



Part one - conclusions



1. UHS are hard to be exceeded by any distant earthquakes and by those more frequent to occur near the site of interest; the rarest events to occur close can have probability of exceedance, conditional to occurrence, that approaches one (i.e., exceedance can be relatively certain).

2. Rarity does not necessarily mean very large magnitude; in fact, defining as strong earthquakes those with conditional exceedance probability larger than 50% if occurring close, they can be far from the maximum magnitude considered in the hazard assessment for the site.

3. In case of exceedance is expected to be up to 2.5 times the design spectrum, and occur in the most hazardous sites (around magnitude 6 at the most in Italy).

4. Although exceedance does not necessarily imply violation of the design limit-state, it should be made clear that, in these cases, the seismic structural safety inherent to design will be likely left to further safety margins beyond elastic design actions, which, to date, are generally not explicitly controlled in codes.

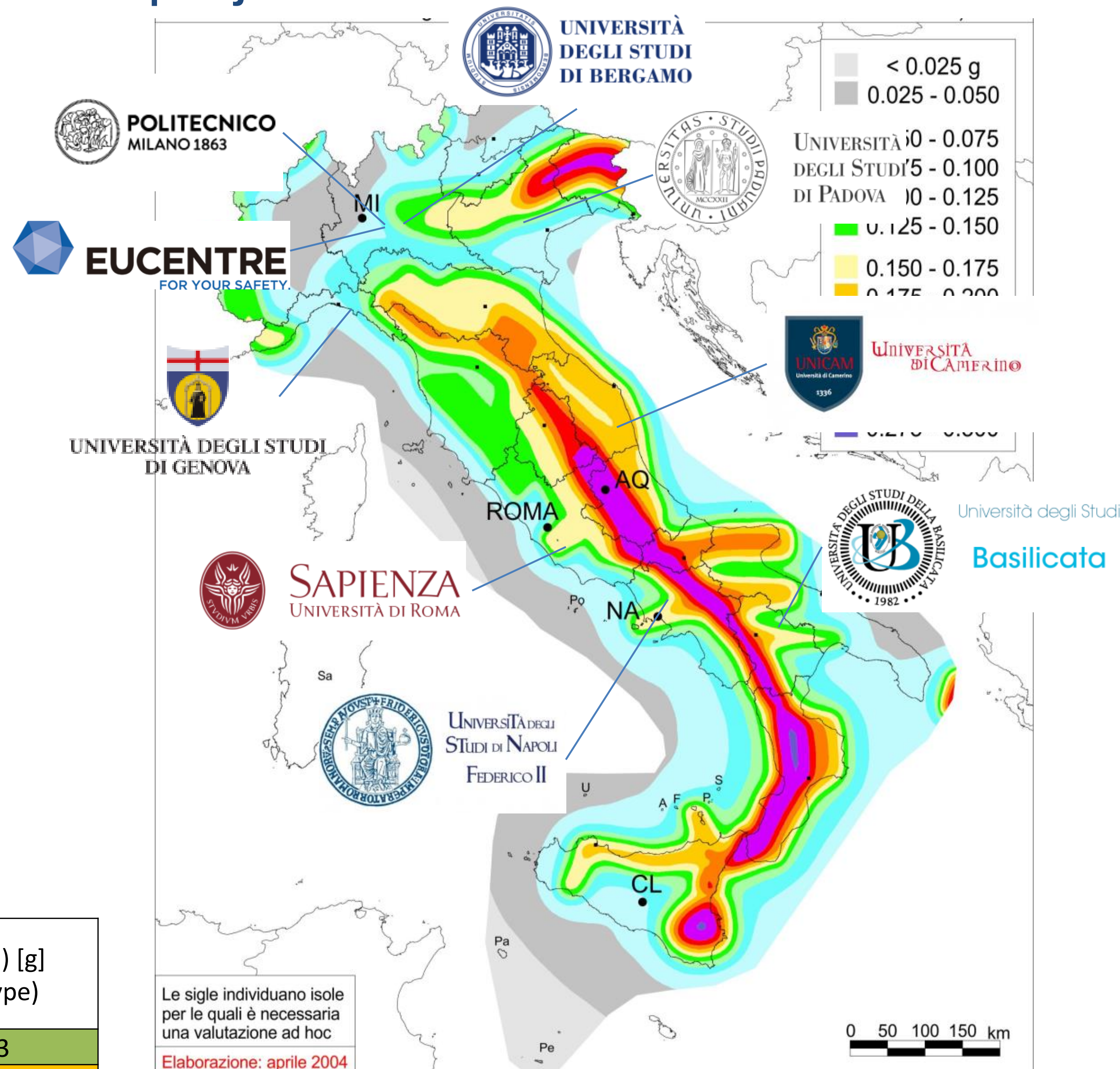
RINTC project 2015-2017

1. Evaluate the failure rate (global collapse and usability-preventing damage) for code-conforming buildings in Italy.

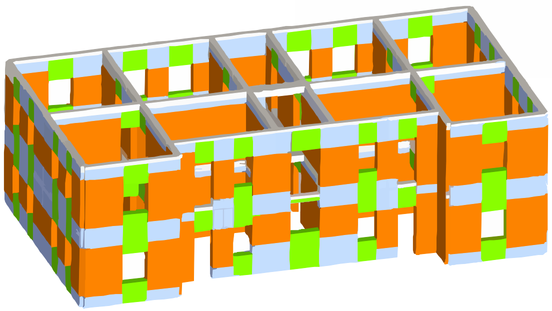
2. Five structural typologies were considered: URM, RC, PRC, Steel, BI.

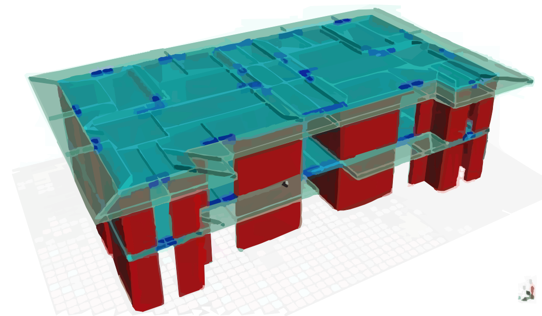
3. Design was for five sites and two EC8 soil classes (A and C).

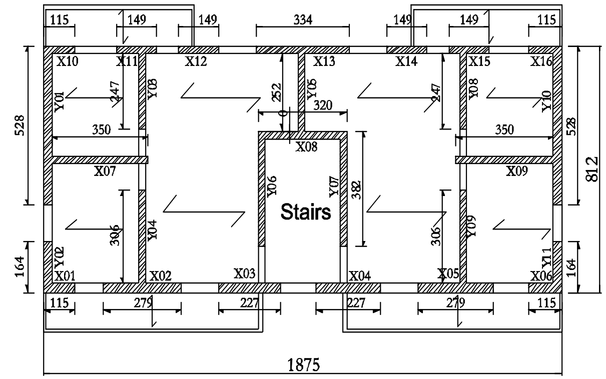
Site	PGA (475) [g] (Soil A-type)	PGA (475) [g] (Soil C-type)
Milano	0.0495	0.0743
Napoli	0.1668	0.24338
L'Aquila	0.2607	0.3451



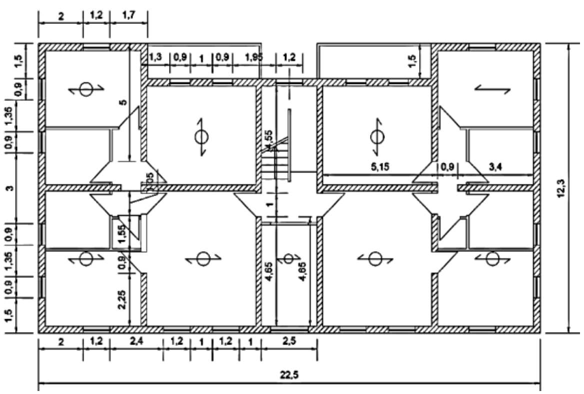
Masonry buildings (50+ structures)


(a)

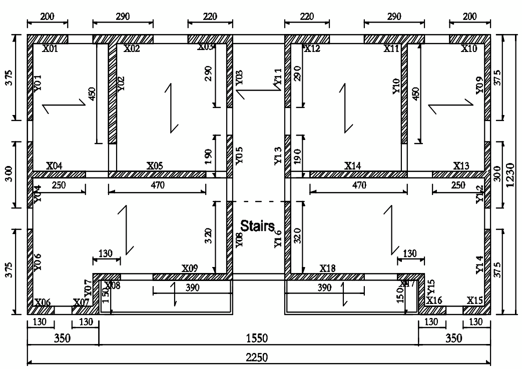

(c)



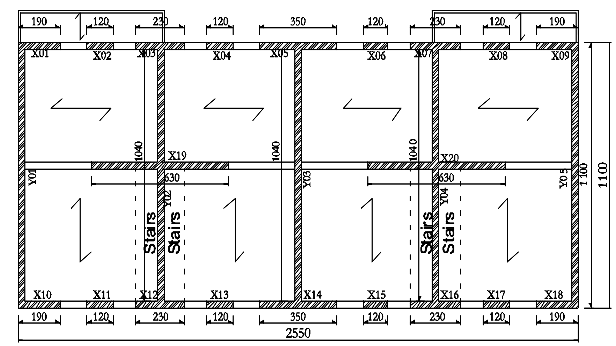
(e)



(b)



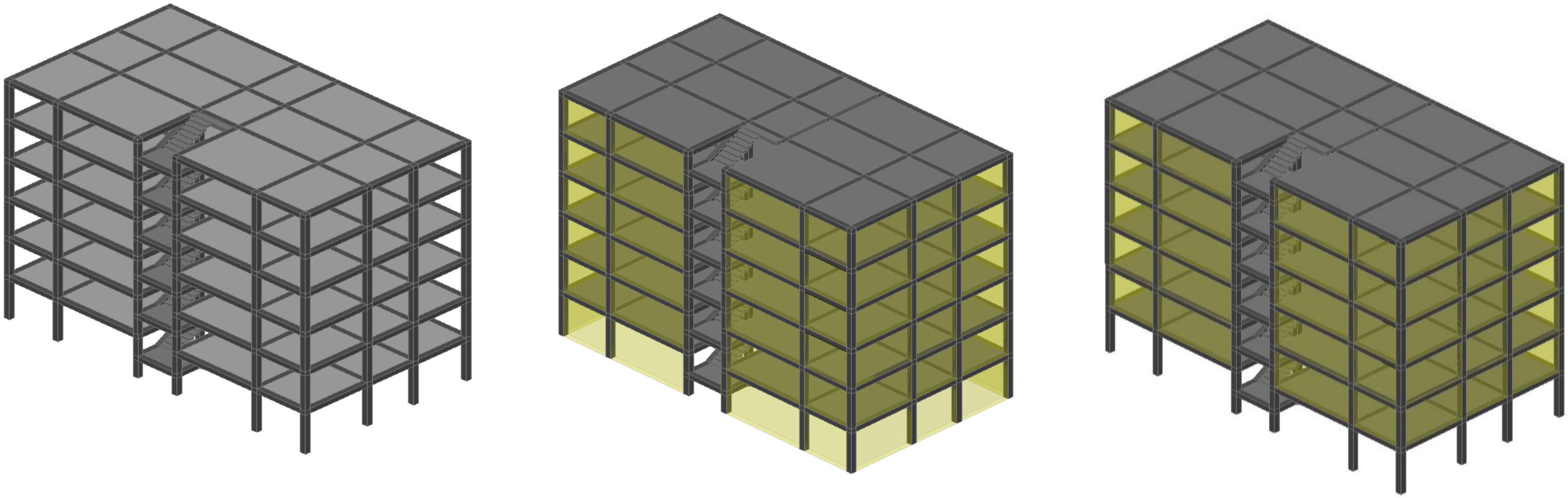
(d)

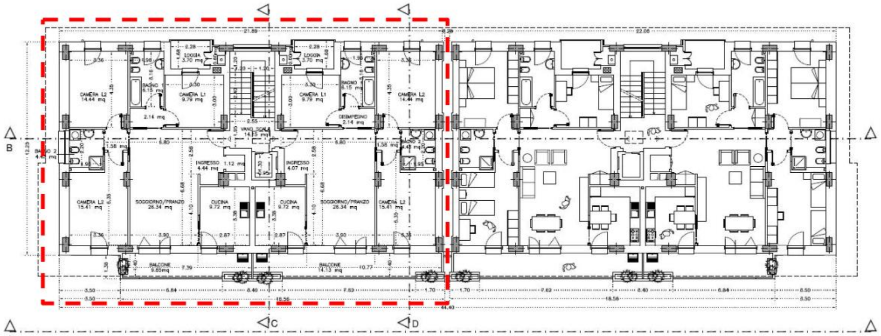


(f)

1. Two and three stories buildings.
2. Regular and irregular.
3. Design with simple building (q=3.6), equivalent frame, and non-linear static approaches.

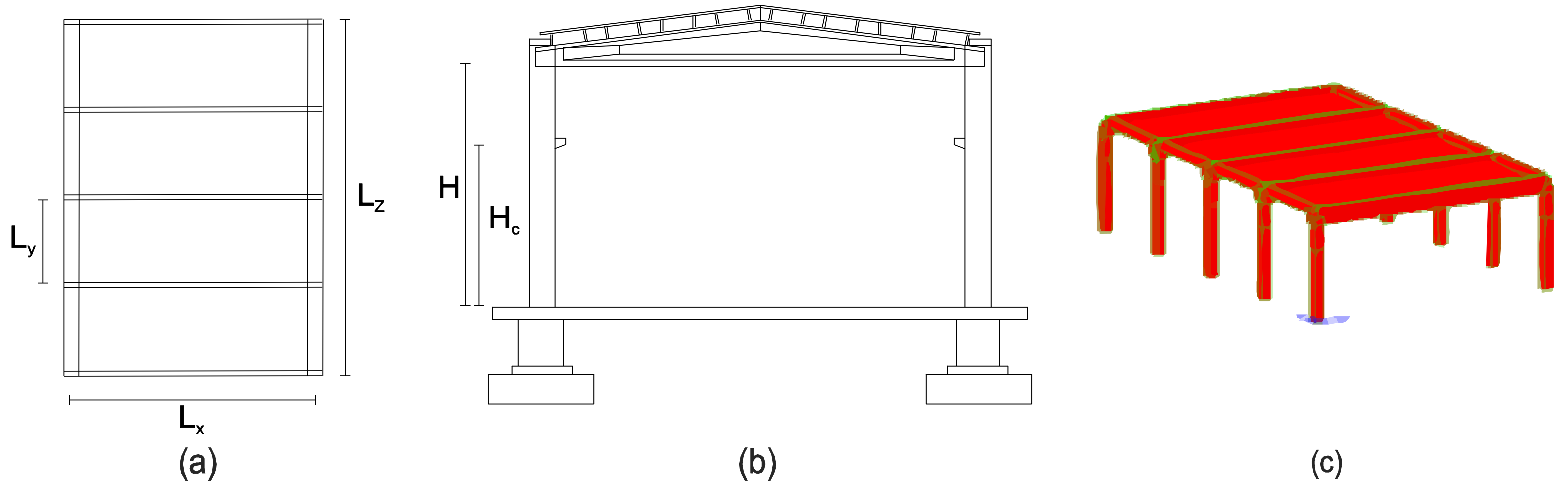
Reinforced concrete buildings (50+ structures)





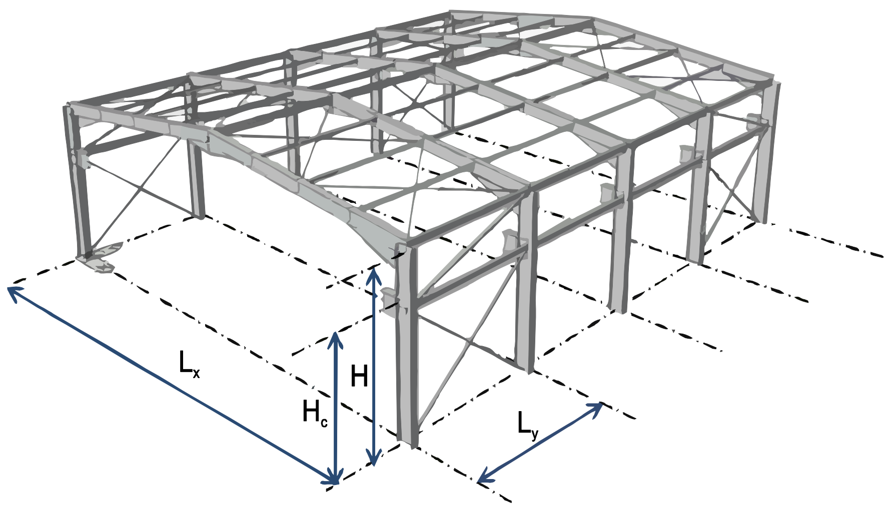
1. Three, six and nine stories.
2. Moment resisting frames and concrete-walls structures.
3. Designed with modal analysis (q=3.9).

Industrial precast reinforced concrete buildings (20+ structures)



Geometry	Lx [m]	Ly [m]	H [m]	Hc [m]
1	15	6	6	4.5
2	20	8	6	4.5
3	15	6	9	7.5
4	20	8	9	7.5

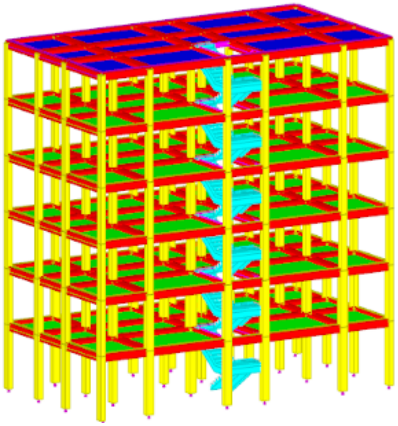
Steel industrial buildings (50+ structures)

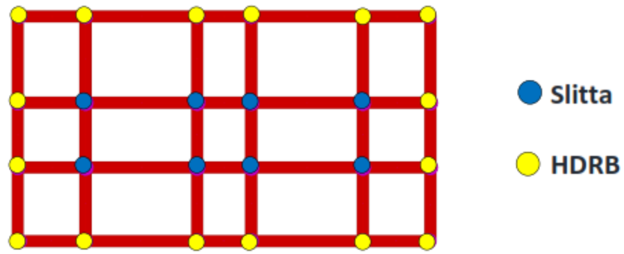


	Snow	Wind	EQ	EQ
Sito	q_s [kN/m²]	q_v [kN/m²]	$a_{g,SLV}$	$a_{g,SLD}$
Milano	1.20	0.39	0.050	0.024
L'Aquila	1.31	0.61	0.261	0.104
Napoli	0.48	0.46	0.168	0.060

Geometry	Lx [m]	Ly [m]	H [m]	Hc [m]
1	20	6	6	4.5
2	20	8	6	4.5
3	30	6	9	6
4	30	8	9	6

Base-isolated buildings (20+ structures)

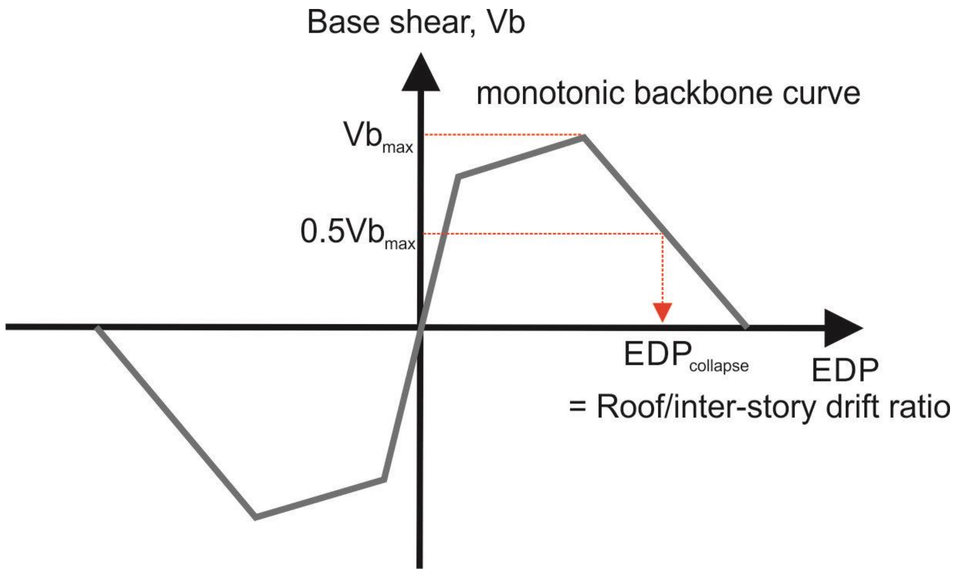




1. High-damping rubber bearings (HDRB).
2. HDRB and sliders (hybrid system).
3. Friction pendulums.

Failure criteria

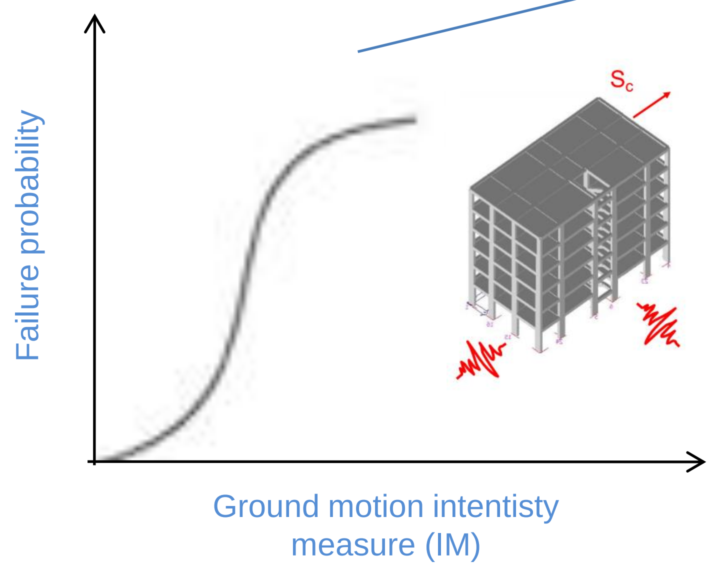
Global collapse

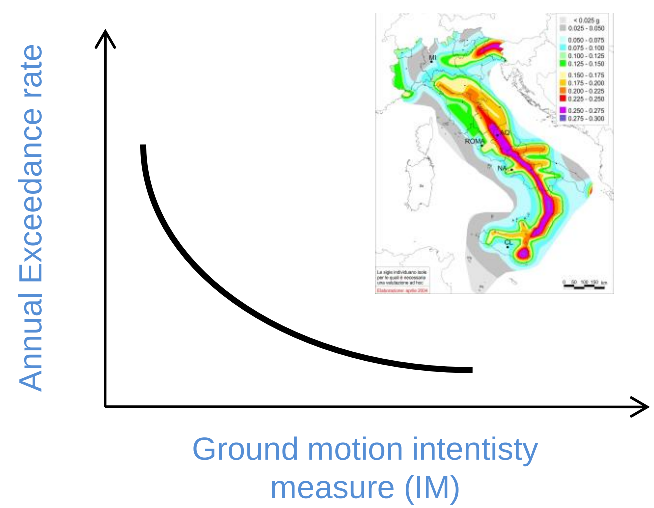


Risk computed in the performance-based earthquake engineering framework

Annual failure rate

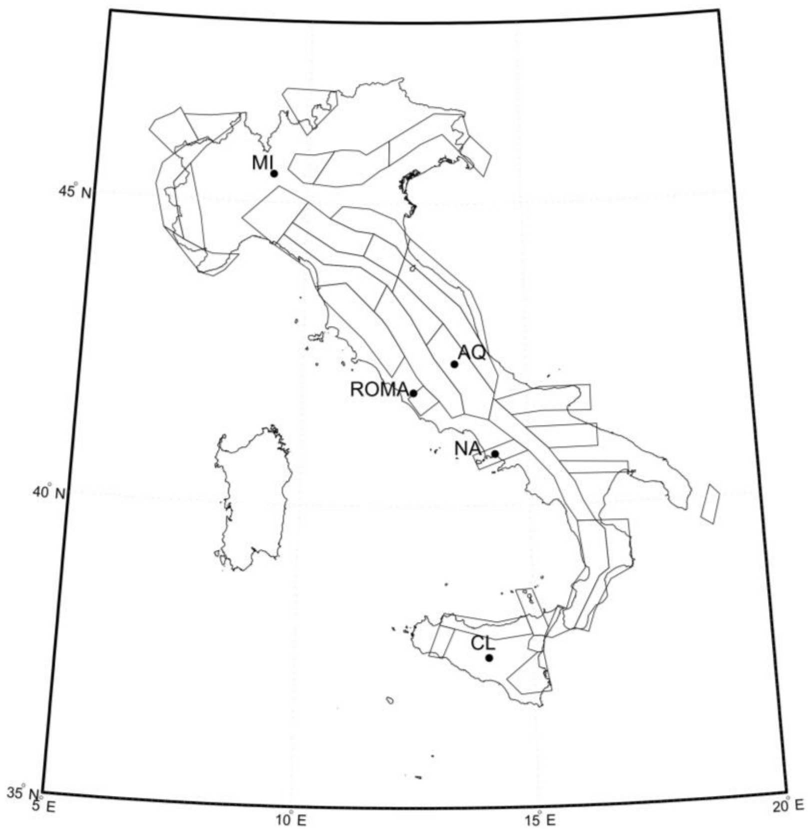
$$\lambda_f = \int_{sa} P\left[f \,\middle|\, Sa(T) = sa \right] \cdot \left| d\lambda_{Sa(T)>sa} \right|$$

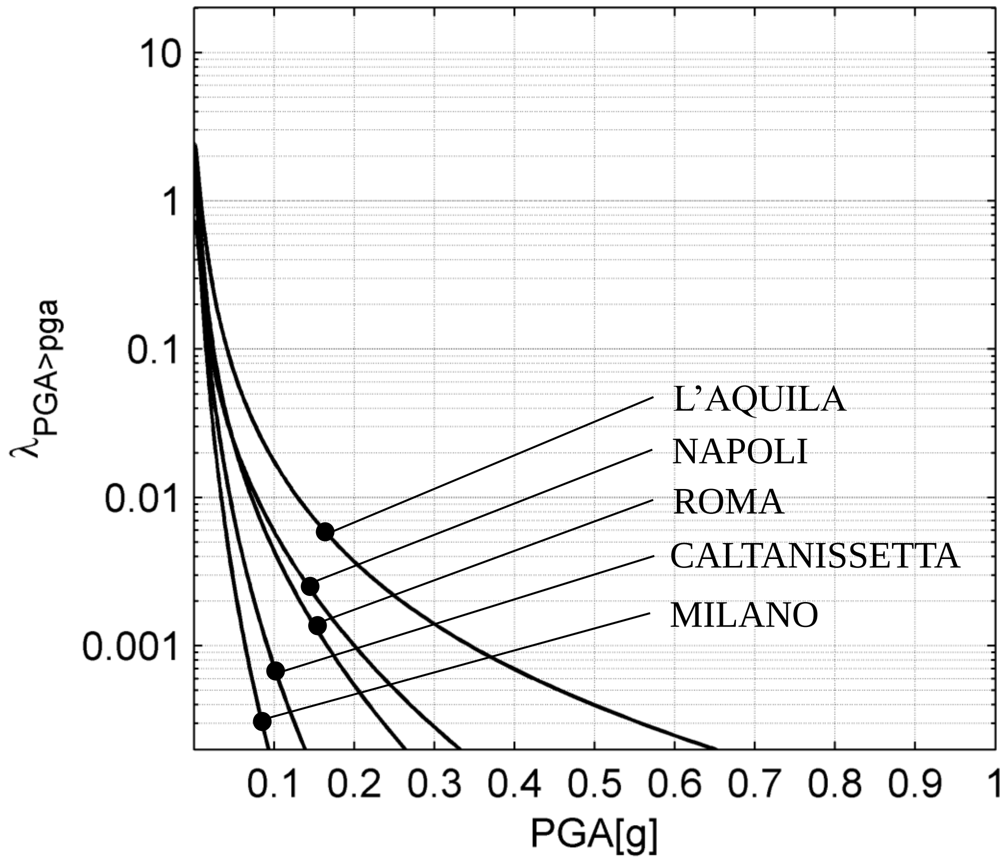




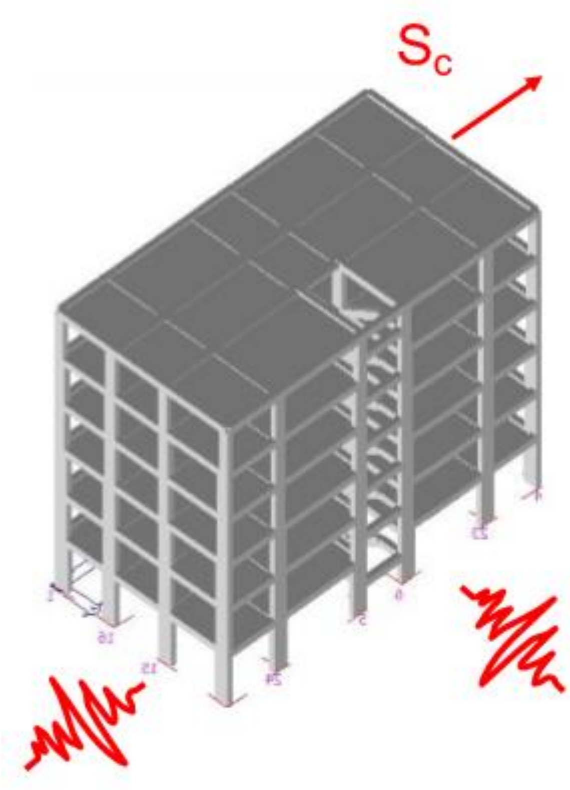
Hazard analysis at all sites (hazard curves stopped at IM with 100,000 years return period)

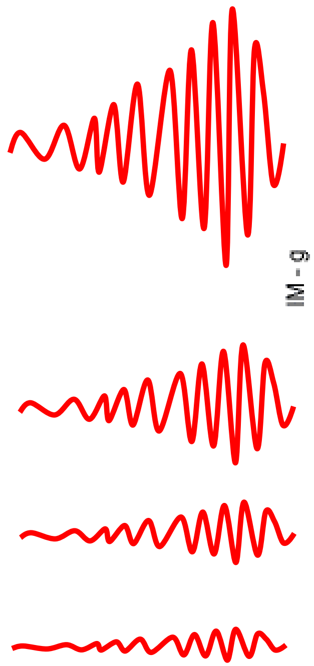
$$\lambda_{Sa(T)>sa} = \sum_{R_{min}}^{R_{max}} \sum_{M_{min}}^{M_{max}} P\left[Sa(T) > sa \mid m,r \right] \cdot \nu_{M=m,R=r}$$

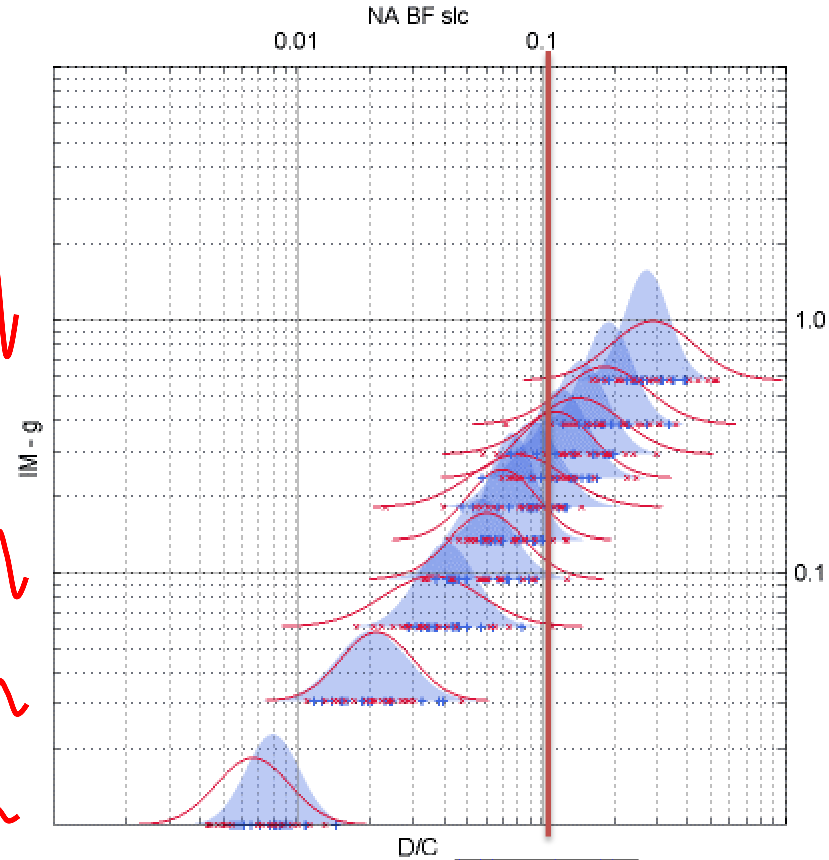


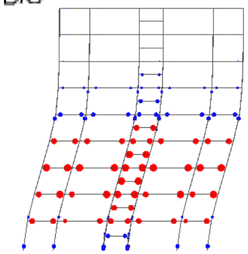


Multi-stripe nonlinear dynamic analysis (recods selected according to the conditional spectrum approach)









$$P\left[f\,|Sa(T)=sa\right]=\left\{1-\Phi\left[\frac{\log\left(edp_f\right)-\mu_{\log\left(EDP|Sa(T)=sa\right)}}{\sigma_{\log\left(EDP|Sa(T)=sa\right)}}\right]\right\}\left(1-\frac{N_{col,Sa(T)=sa}}{N_{tot,Sa(T)=sa}}\right)+\frac{N_{col,Sa(T)=sa}}{N_{tot,Sa(T)=sa}}$$

Global collapse – soil type C results for three sites

	C-type		
	Milan	Naples	L'Aquila
URM	1.02E-05	1.15E-04	8.41E-04
PRC	1.00E-05	2.80E-05	9.98E-05
RC	1.08E-05	1.38E-05	8.56E-05
S	1.00E-05	1.05E-05	1.12E-04
BI	-	8.59E-05	6.93E-04

Usability preventing damage – soil type C results for three sites

	C-type		
	Milan	Naples	L'Aquila
URM	7.20E-05	6.27E-03	9.18E-03
PRC	6.06E-05	2.54E-03	6.01E-03
RC	1.02E-04	3.82E-03	1.03E-02
S	4.29E-05	2.10E-03	5.04E-03
BI	-	1.67E-04	1.35E-03

Part two - conclusions

1. Despite the homogeneity of design seismic actions and engineering choices, the seismic structural reliability tends to decrease with the seismic hazard of the sites.

2. For the less hazardous sites, the failure rates are so low that only an upper bound to the actual failure rate can be provided.

3. On the other hand, the failure rates of buildings at the most hazardous of the sites are, in some cases, comparable to the annual rate of exceedance of the design ground motion intensity.

What seismic risk do we design for when we design new buildings?

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