- **K**nowledge **FO**r **R**esilient so**C**i**E**ty

Methods and tools for Seismic Risk Assessment and Development of Information System for Emergency Response and Mitigation Plans

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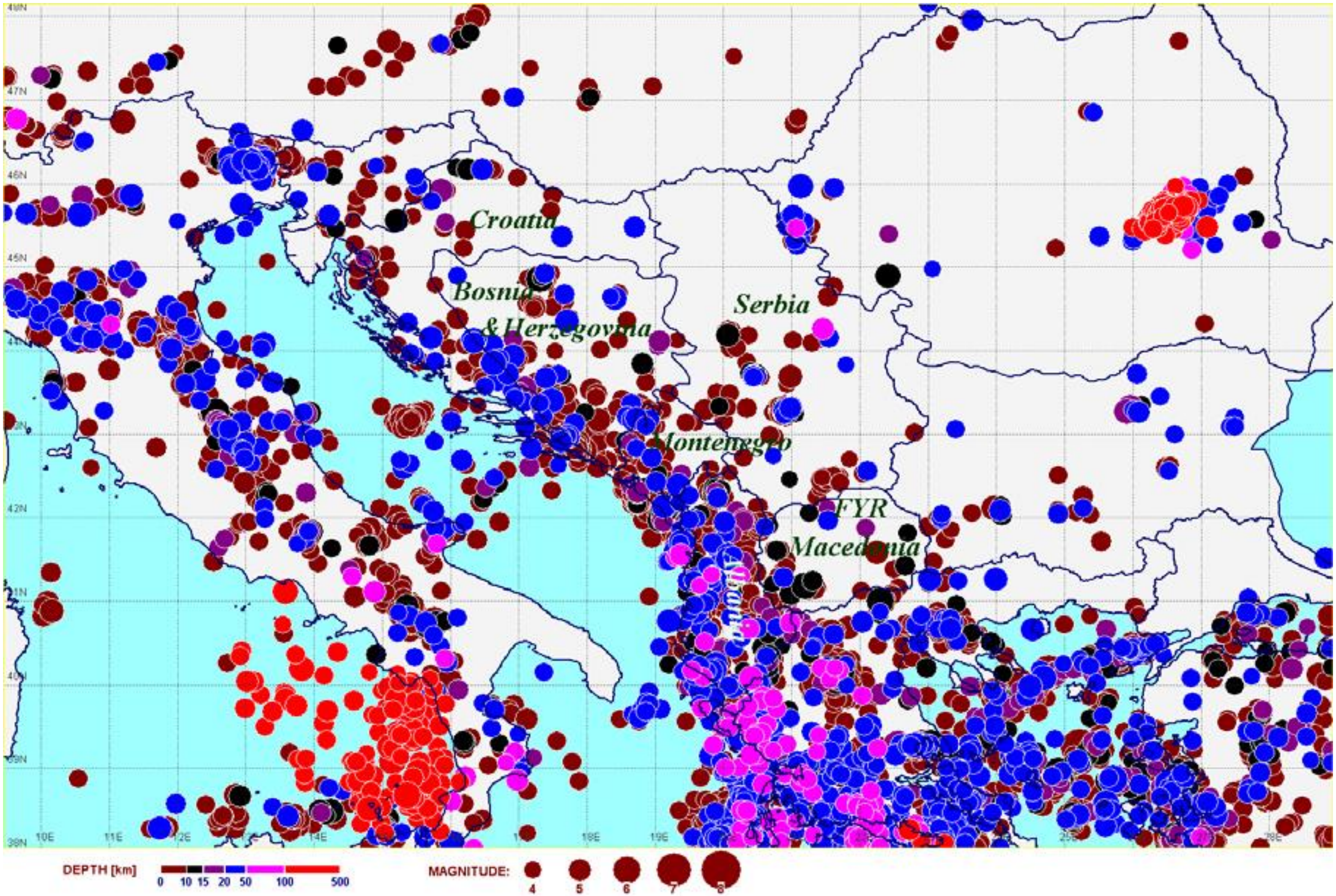
Co-funded by the Erasmus+ Programme of the European Union

Epicentres of earthquakes in the Northern shore of the Mediteranian region and Balkan region with M>6



Seismic map of the region represented by epicenters of stronger earthquakes (Magnitude ≥ 4) occured during the last 33 years (NEIC earthquake catalogue)

Movie 1: Christian Church Earthquake 2011

Public safety community needs

- **Emergency response measures**
- **Mitigation planning**

Movie 2:

SCENARIO: Magnitude=7.0; Depth=10.0; Epicenter: 46.83, -71.26

#Tracts	#Buildings	Total Exposure	Total Loss	Injuries 2am	Fatalities 2am	Injuries 2pm	Fatalities 2pm	Injuries 5pm	Fatalities 5pm
211	213,824	$110,725M	$13,074M	1,920	270	4,646	841	2,442	343

Download Results

Risk assessment process

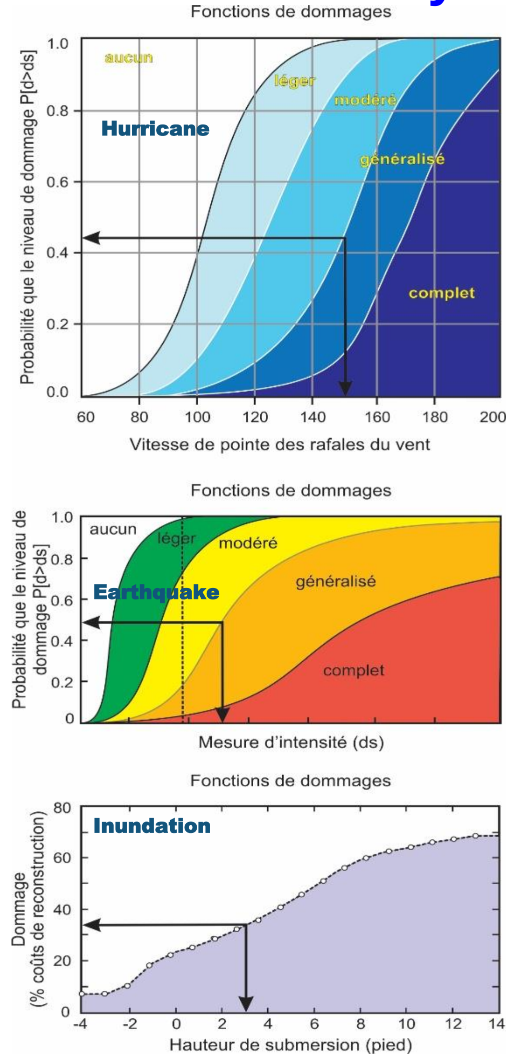
1.Identify hazard

X

2.Inventory assets

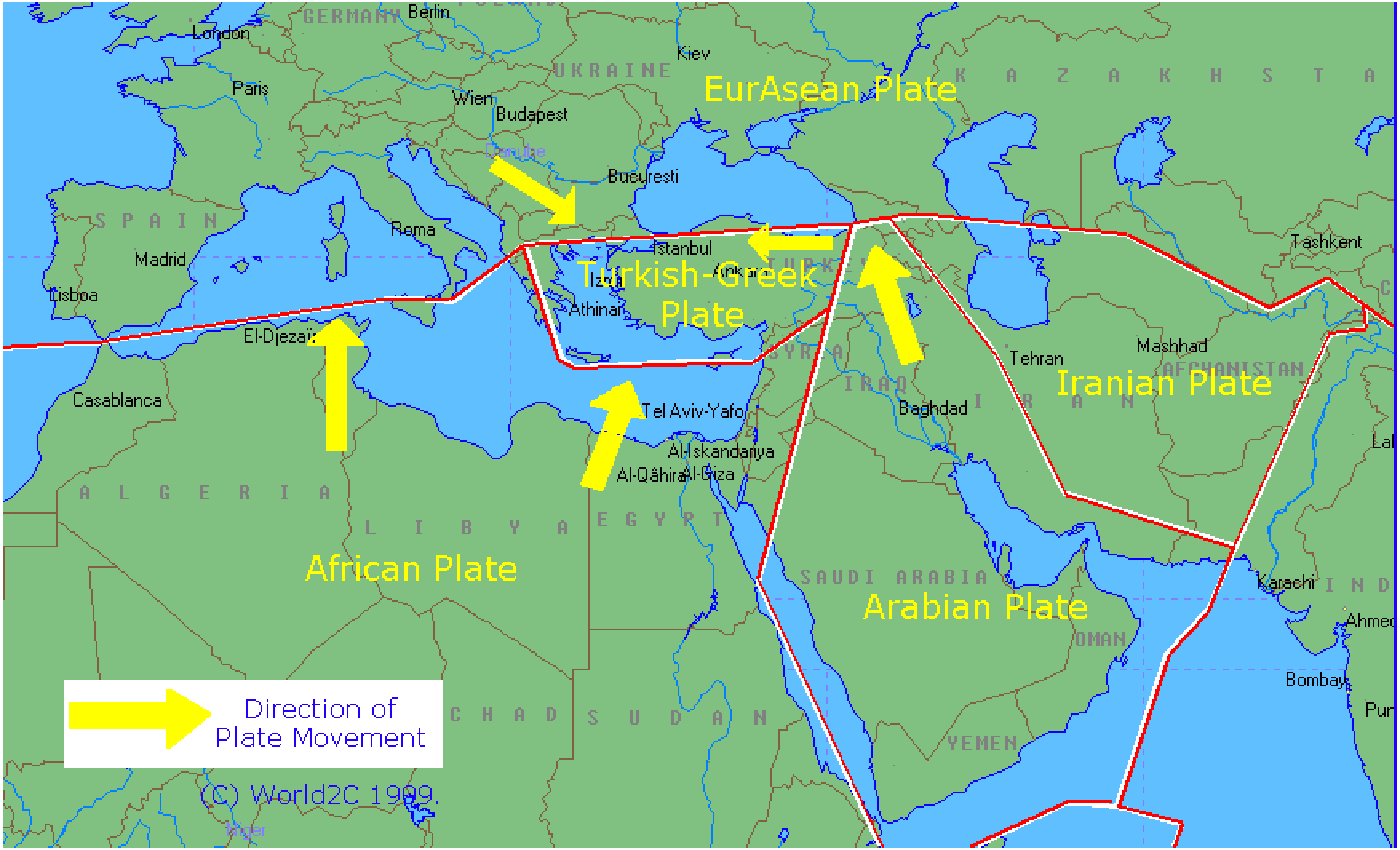
X

3.Assign vulnerability

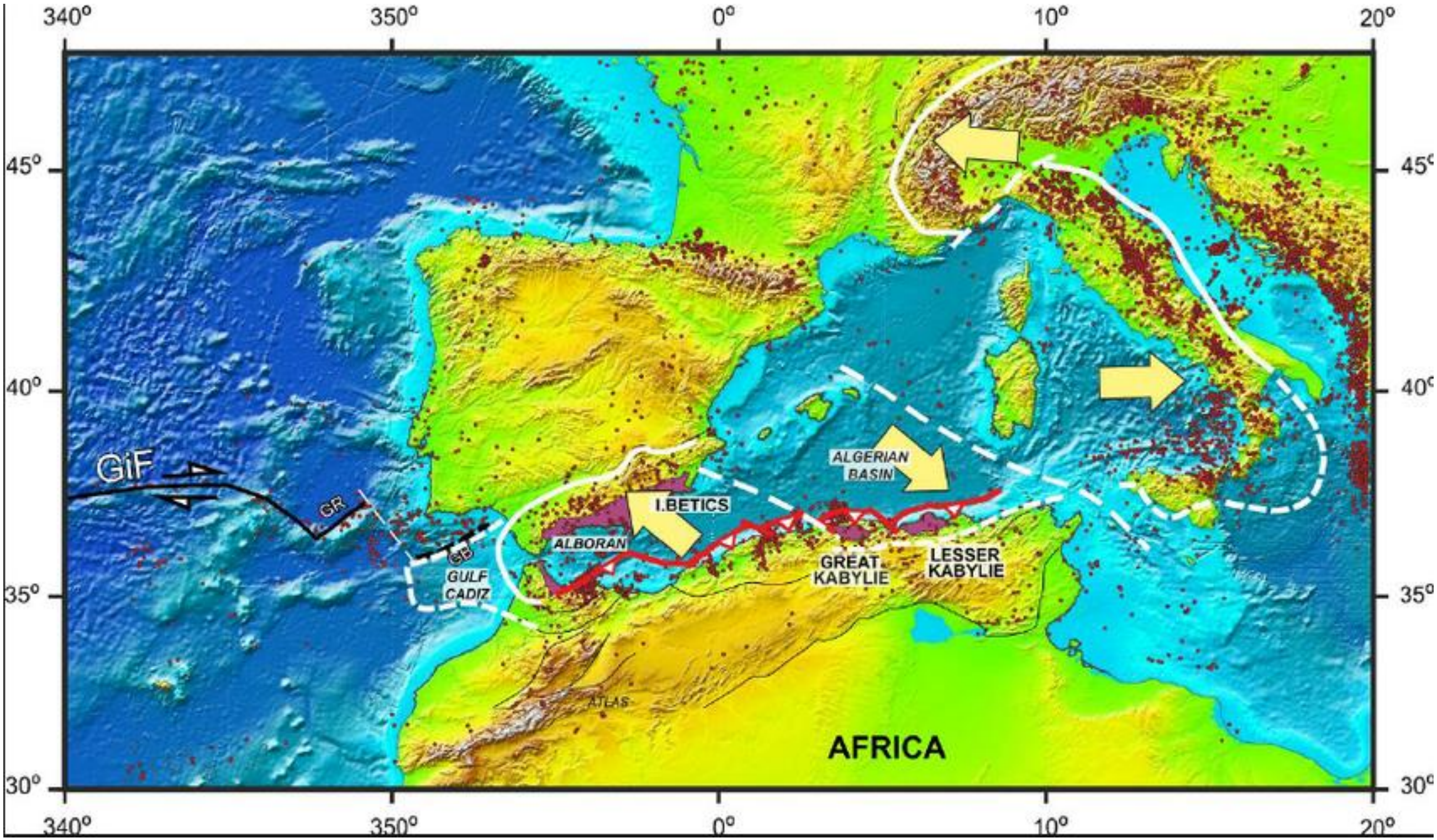


4.Estimate losses

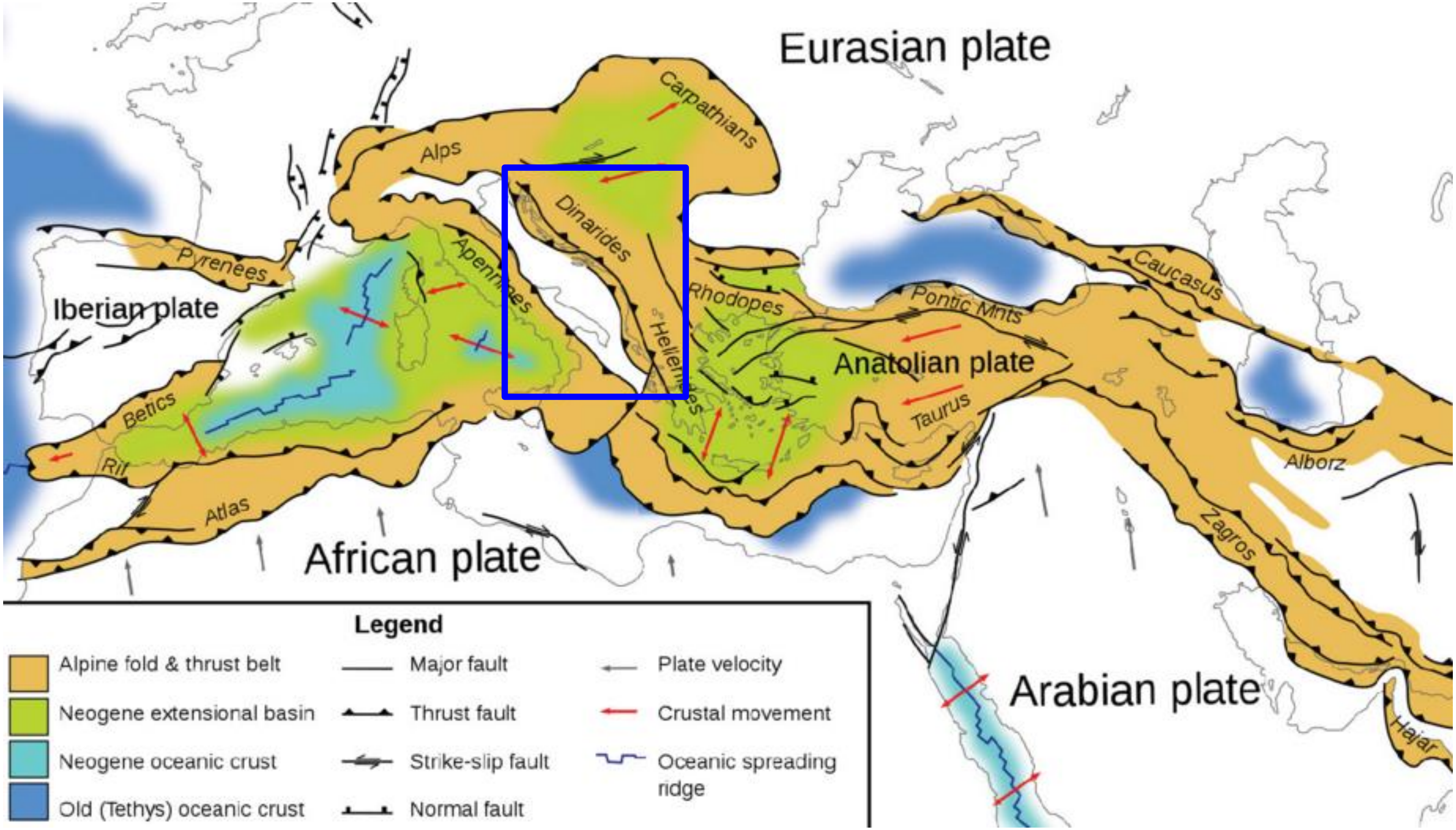
Seismic Hazard- Seismotectonic



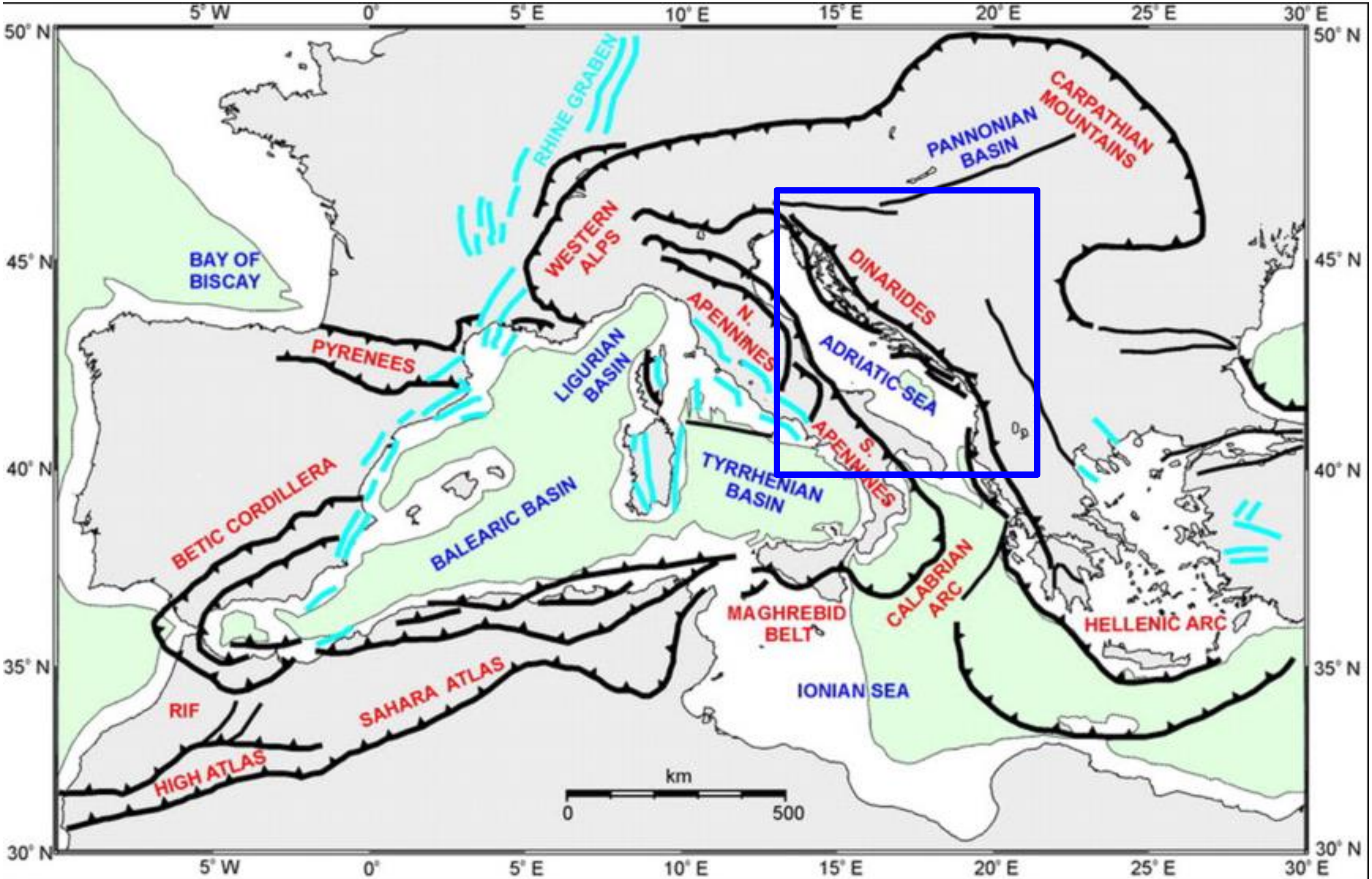
Seismic Hazard- Seismotectonic



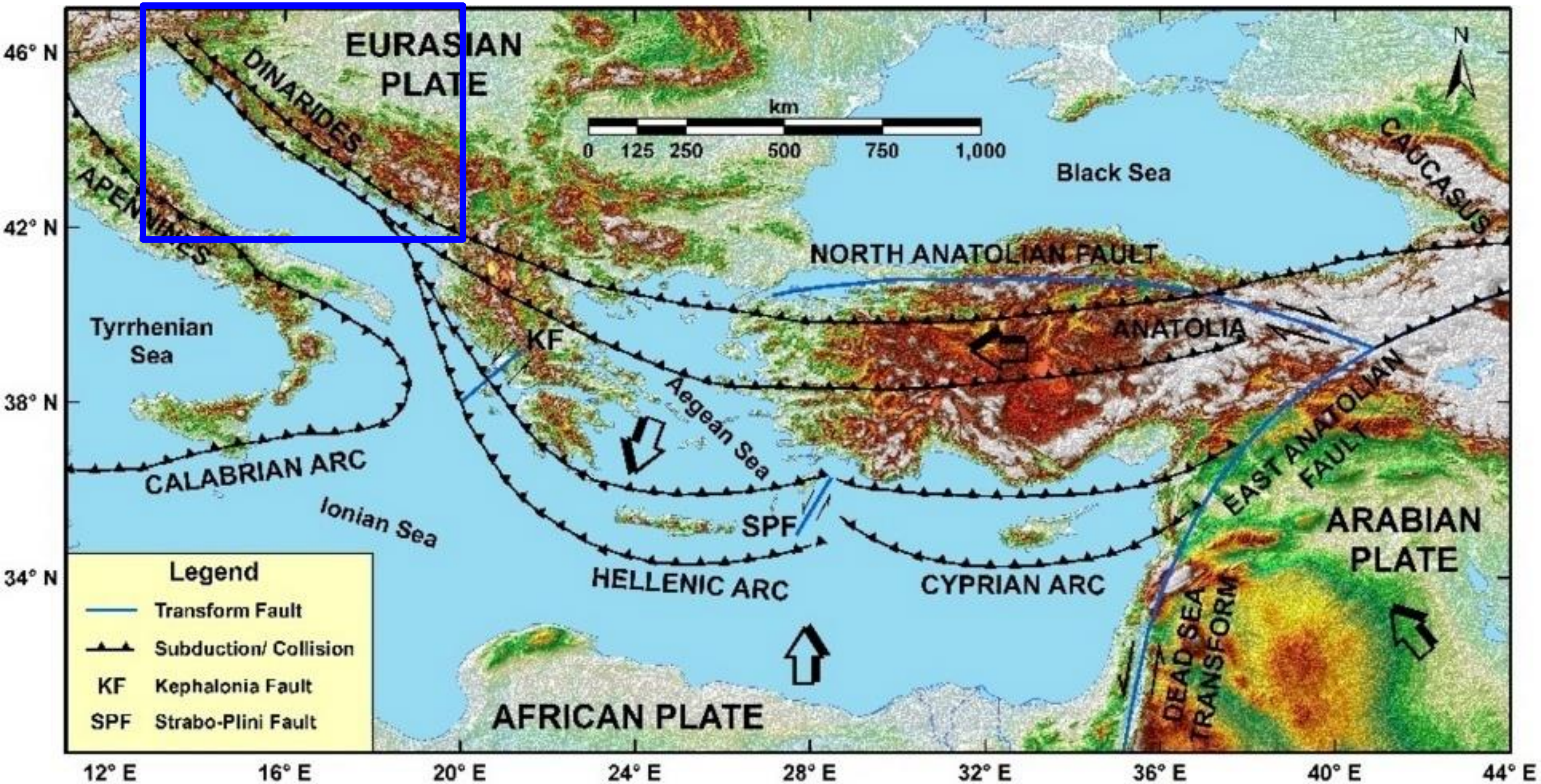
Seismic Hazard- Seismotectonic



Seismic Hazard

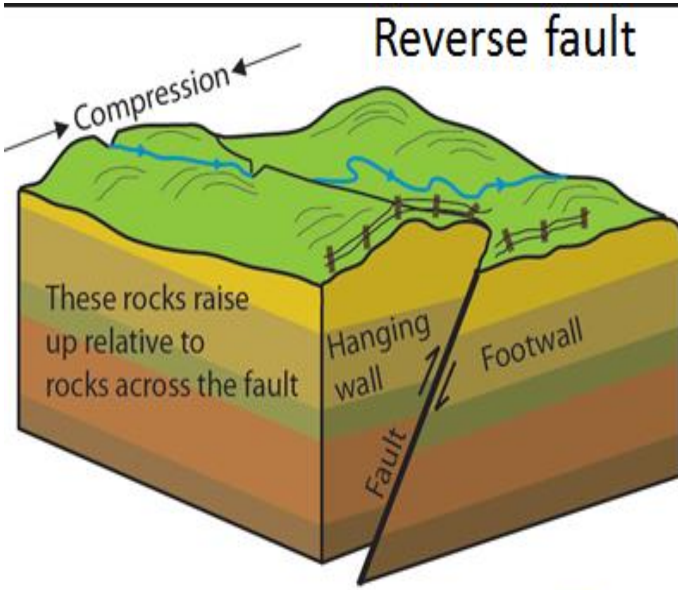


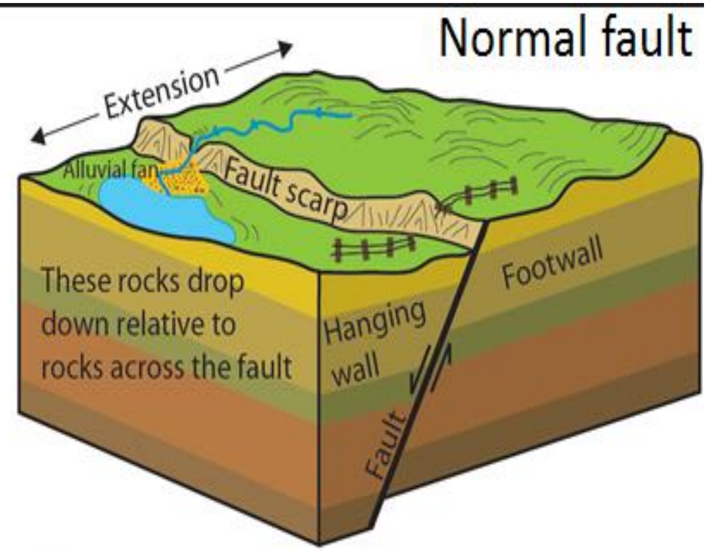
Seismic Hazard- Seismotectonic



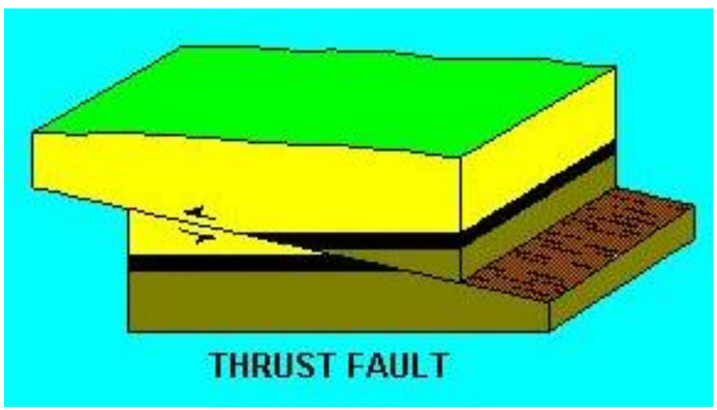
The Adriatic Sea is the largest arm of the Mediterranean Sea incising (in'sajz) deep into its northern coast – Subduction / Collision

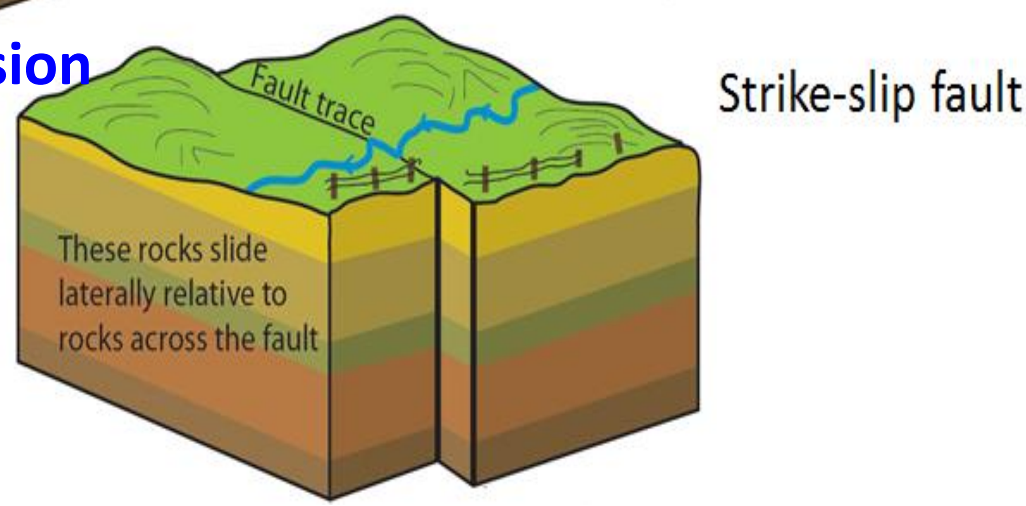
Seismic hazard (fault mechanisms)





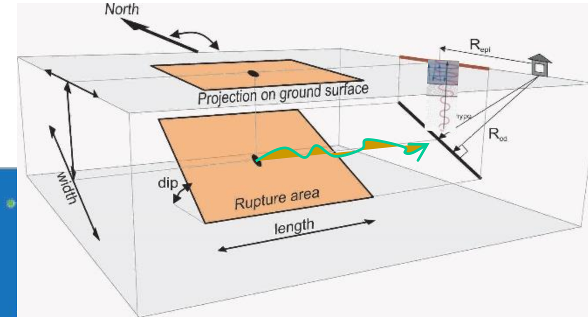
Adriatic Sea–Subduction/Collision

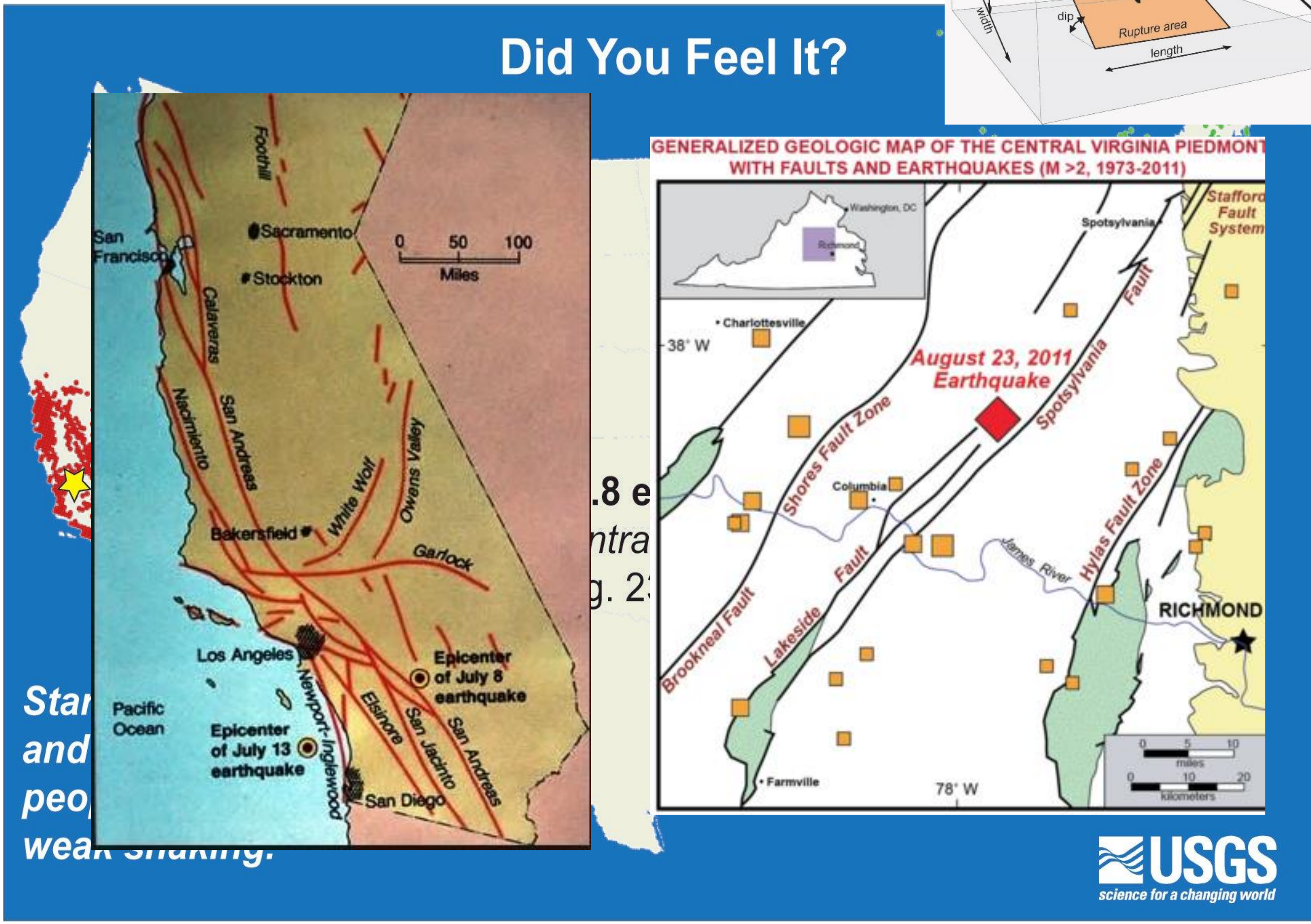




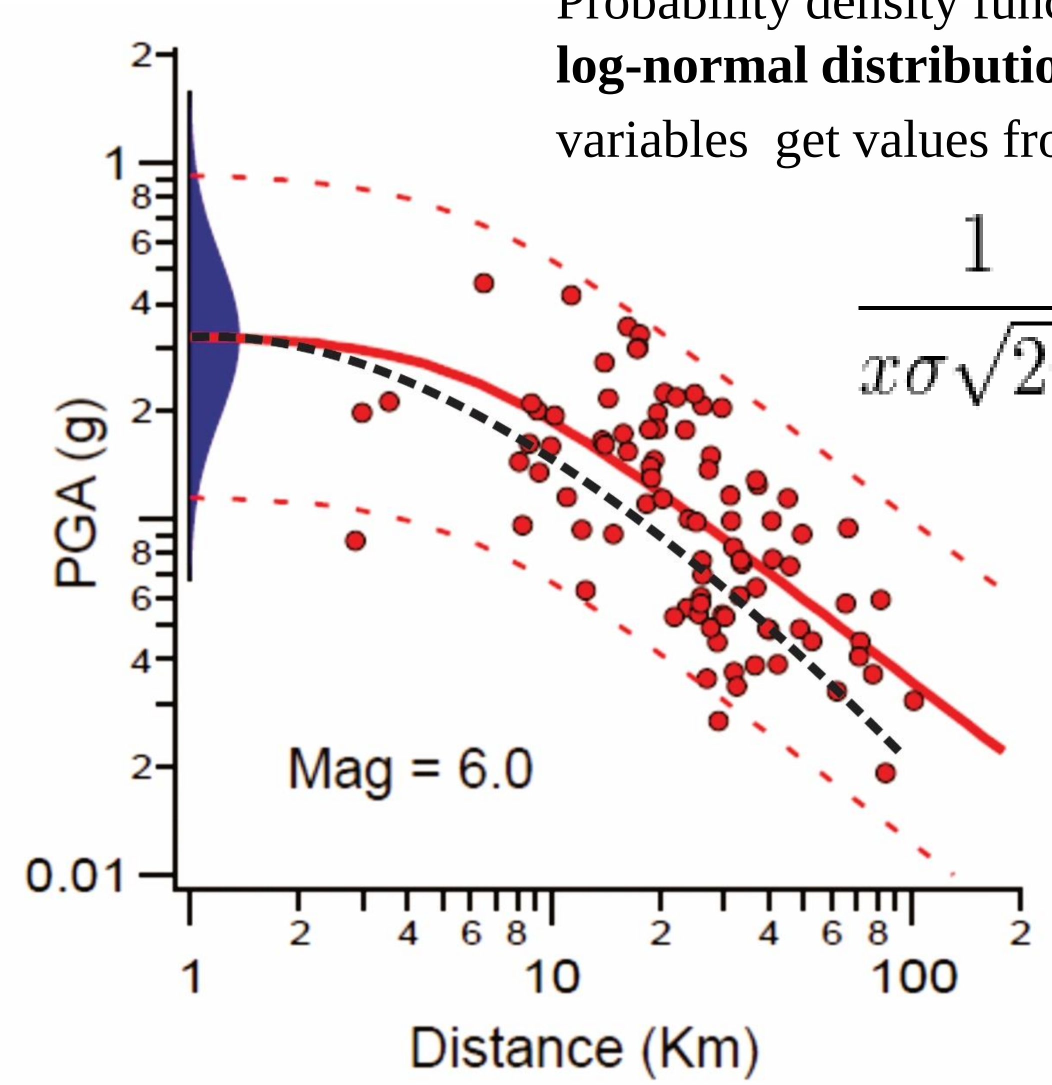
A thrust fault is a break in the Earth's crust, across which younger rocks are pushed above older rocks.

Seismic hazard (attenuation)





Seismic hazard (attenuation)



Probability density function (PDF) of the **log-normal distribution** where the random variables get values from 0 to + ∞ :

$$\frac{1}{x\sigma\sqrt{2\pi}}\, e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$$

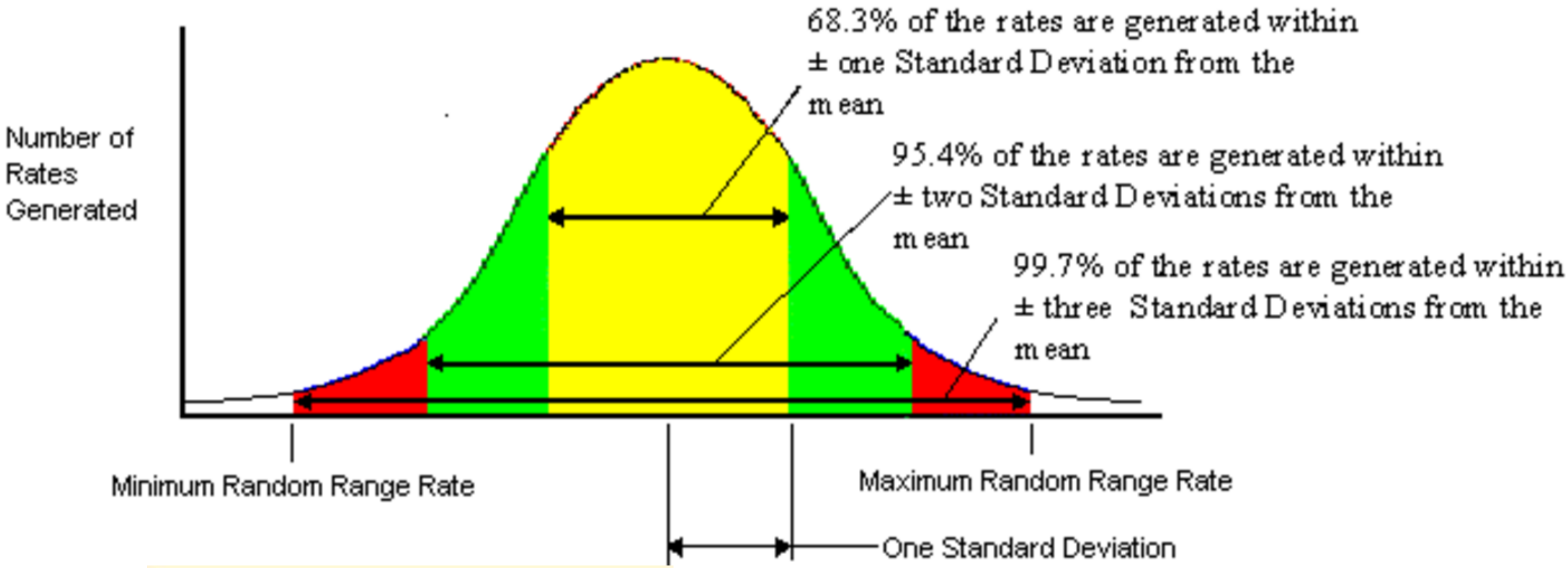
Probability density function (PDF) of the **log-normal distribution** where the random variable get values from 0 to + ∞ :

$$\frac{1}{x\sigma\sqrt{2\pi}}\, e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$$

Probability density function (PDF) of the Gaussian **standard normal** distribution where the random variable get values for **-** ∞ to + ∞ :

$$f(x)=\frac{1}{\sqrt{2\pi}}e^{-\frac{x^2}{2}}$$

Gaussian Distribution



$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

1. **Work out the Mean (the simple average of the numbers)**
2. **Then for each number: subtract the Mean and square the result**
3. **Then work out the mean of those squared differences.**
4. **Take the square root of that and we are done!**

Find the mean, median, and mode of the following set of numbers:

23, 29, 20, 32, 23, 21, 33, 25

Mean: $\dfrac{23+29+20+32+23+21+33+25}{8} = 25.75$

median: 20, 21, 23, 23, 25, 29, 32, 33

$\dfrac{23+25}{2} = \dfrac{48}{2} = 24$

mode: 23

Seismic hazard (attenuation)

The development of a new generation **(NG)** of the attenuation models is an initiative coordinated by PEER (Pacific Earthquake Engineering Research Center) in cooperation with USGS (U.S Geological Survey) and Southern California Earthquake Center (Power et al., 2008).

Ground motion prediction equations mostly used in our region are the following:

- AB2012 (Akkar and Boomer, 2012),
- BA2008(Boore and Atkinson, 2008),
- BINDI2009 (Bindi et al., 2009)
- CF2008 (Cauzzi and Faccioli,2008), recommended within the SHARE project (Segou and Akkar, 2010),
- Additional model,AM2005 (Ambraseys et al, 2005).

AB2012 (Akkar and Boomer, 2012)

$$log(y) = b_1 + b_2 M + b_3 M^2 + (b_4 + b_5 M) log\sqrt{R_{jb}^2 + b_6^2} +$$

$$+ b_7 S_s + b_8 S_A + b_9 F_N + b_{10} F_R + \varepsilon\sigma$$

Where: y (in cm/s^2) denotes intensity M- magnitude

b1,b2.. …b10 regression coefficients

Rjb - distance

The empirical expression comprises three categories of soil:

a)Soft soil Ss=1 ; S_A=0

b)Stiff soil Ss=0 ; S_A=1

c)Rock Ss=0 ; S_A=0

and three types of fault mechanism:

a)Normal fault F_N=1; F_R=0

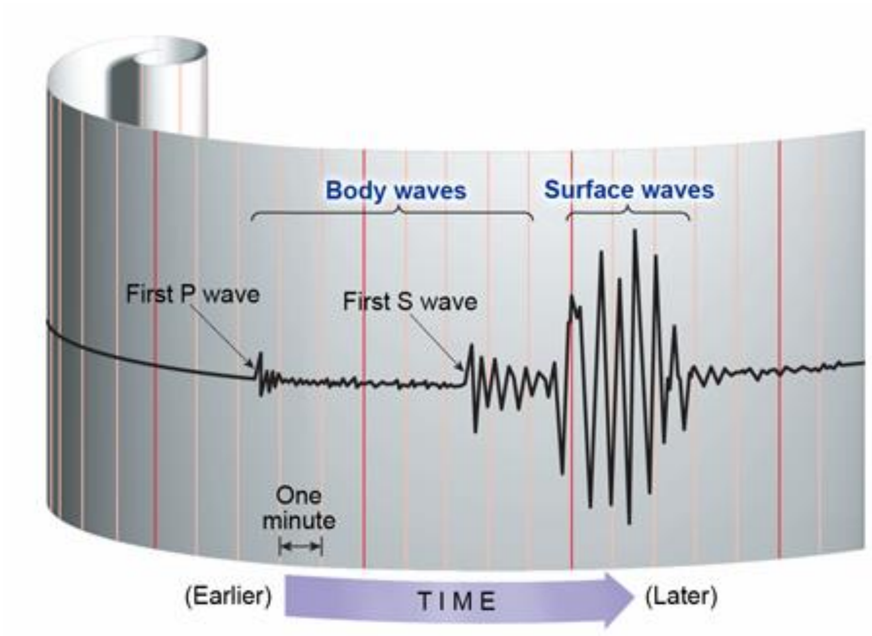
b) Strike slip fault F_N=0; F_R=0

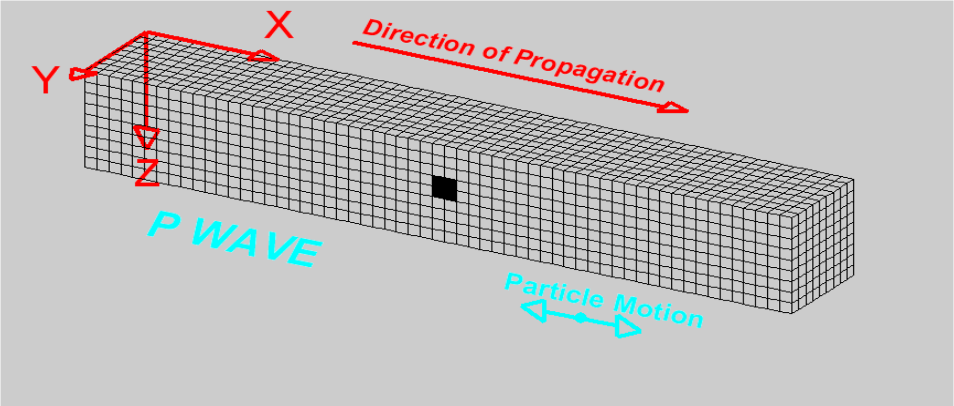
c)Revers fault F_N=0; F_R=1

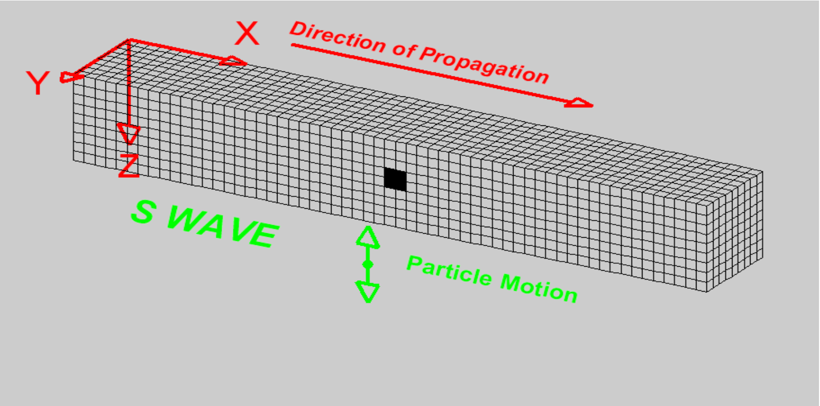
σ - standard deviation

ε - random error at zero mean value and zero standard deviation

Seismic Hazard: EARTHQUAKES

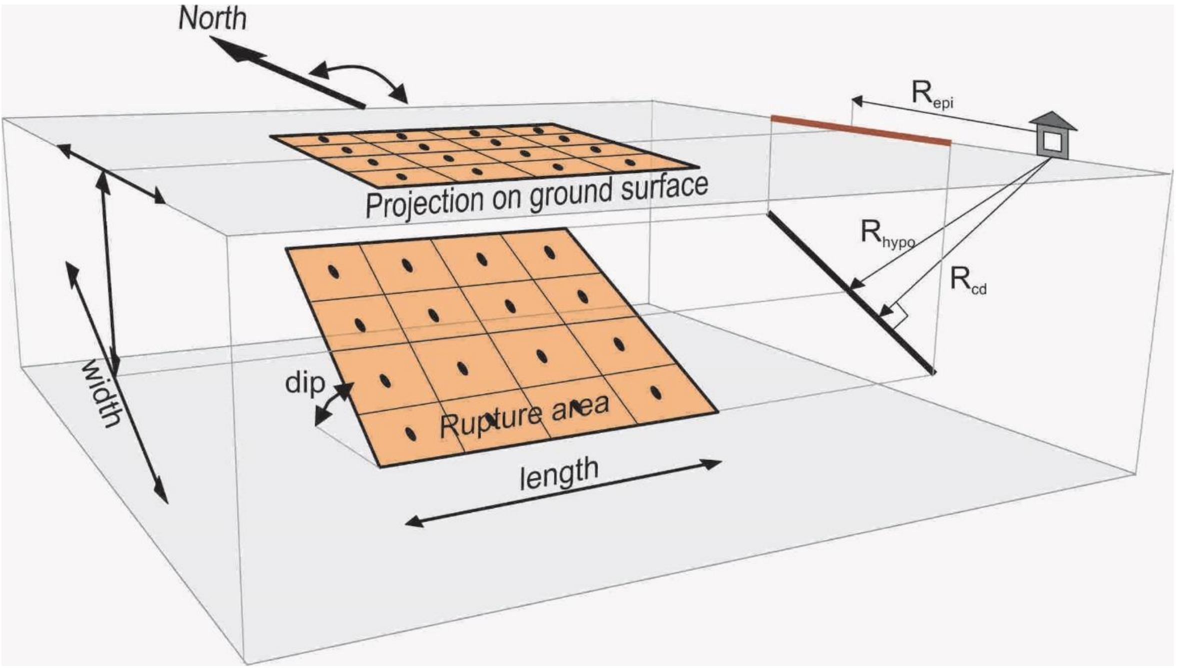






Seismic waves consist of P(compressive) and S(shear, distortional) waves.

Seismic hazard (fault mechanisms)



Johnston 1993, Wells and Coppersmith 1994

Magnitude M	Length (km)	Width (km)
4	0.6	0.9
5	2.6	2.6
6	12.2	7.3
7	57.3	20.3

- **SMSIM — Fortran Programs for Simulating Ground Motions from Earthquakes: Version 2.0 — A Revision of OFR 96–80–A By David M. Boor SMSIM is based on the assumption that the whole seismic energy is concentrated in one point,-point source.**
- **EXSIM takes in consideration the fault dimensions (Motazedian, D., and G. M. Atkinson ,2005)**

Seismic hazard and ground shaking input spectra

1) Probabilistic approach or probalistiacly defined seismic demand.

The mostly used, four distinct exceedance probability levels are :

- 10% in 10 years (return period of 95 years, referred to as RP95),
- 10% in 50 years (RP475),
- 2% in 50 years (RP2475),
- 1% in 100 years (RP10000).

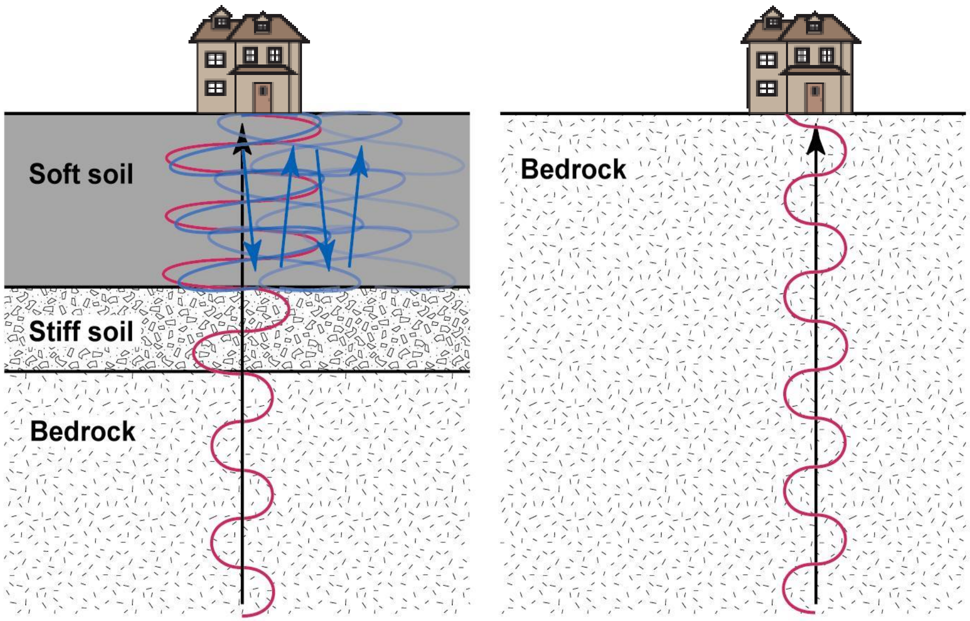
Binomial distribution: $P_n(0) = (1-p)^n$

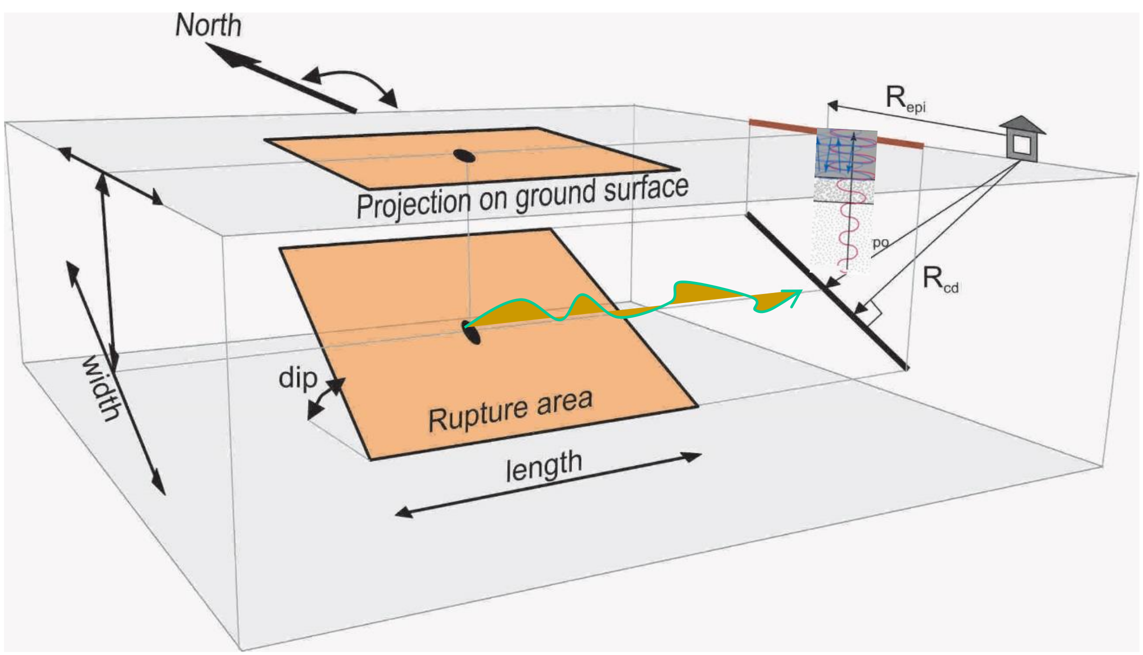
1. Probability of exceedence of a given parameter is 2% in 50 years = Probability of non-exceedence of a given parameter is P=98% in 50 years. What is the return period !?				
P=	years=	0.98=(1-p)^50		
0.98	50	1-p=0.98^(1/	0.99959603	0.9486833
		p=	0.00040397	
return period=		T=1/p=	2475	

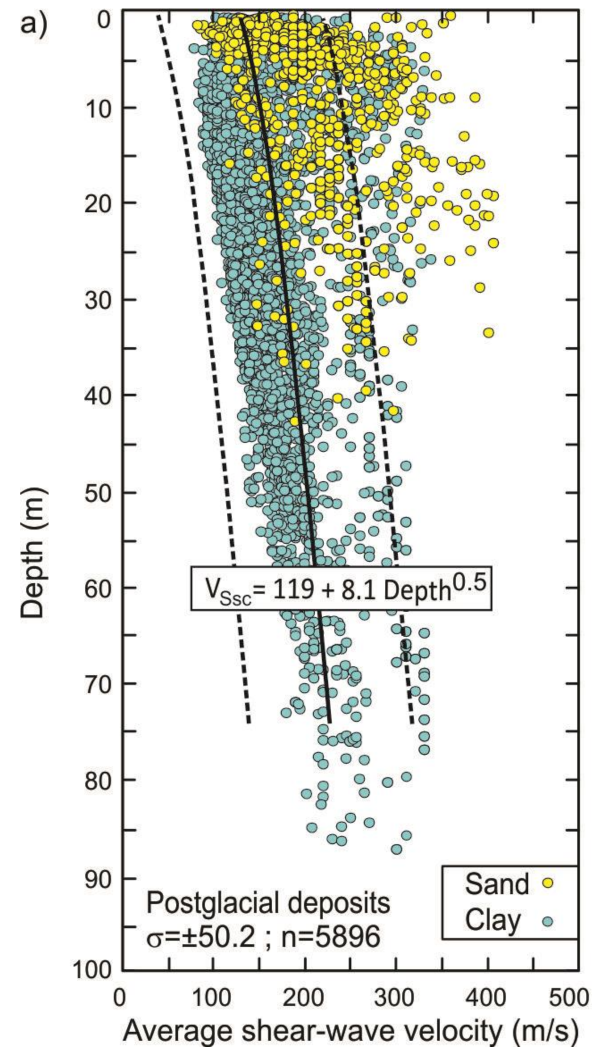
2) Definition of deterministic earthquake scenario (e.g. historical earthquake or used defined event)

3) Use of near –real time data, whereat the spectral amplitudes of recorded ground motion at the considered location are used.

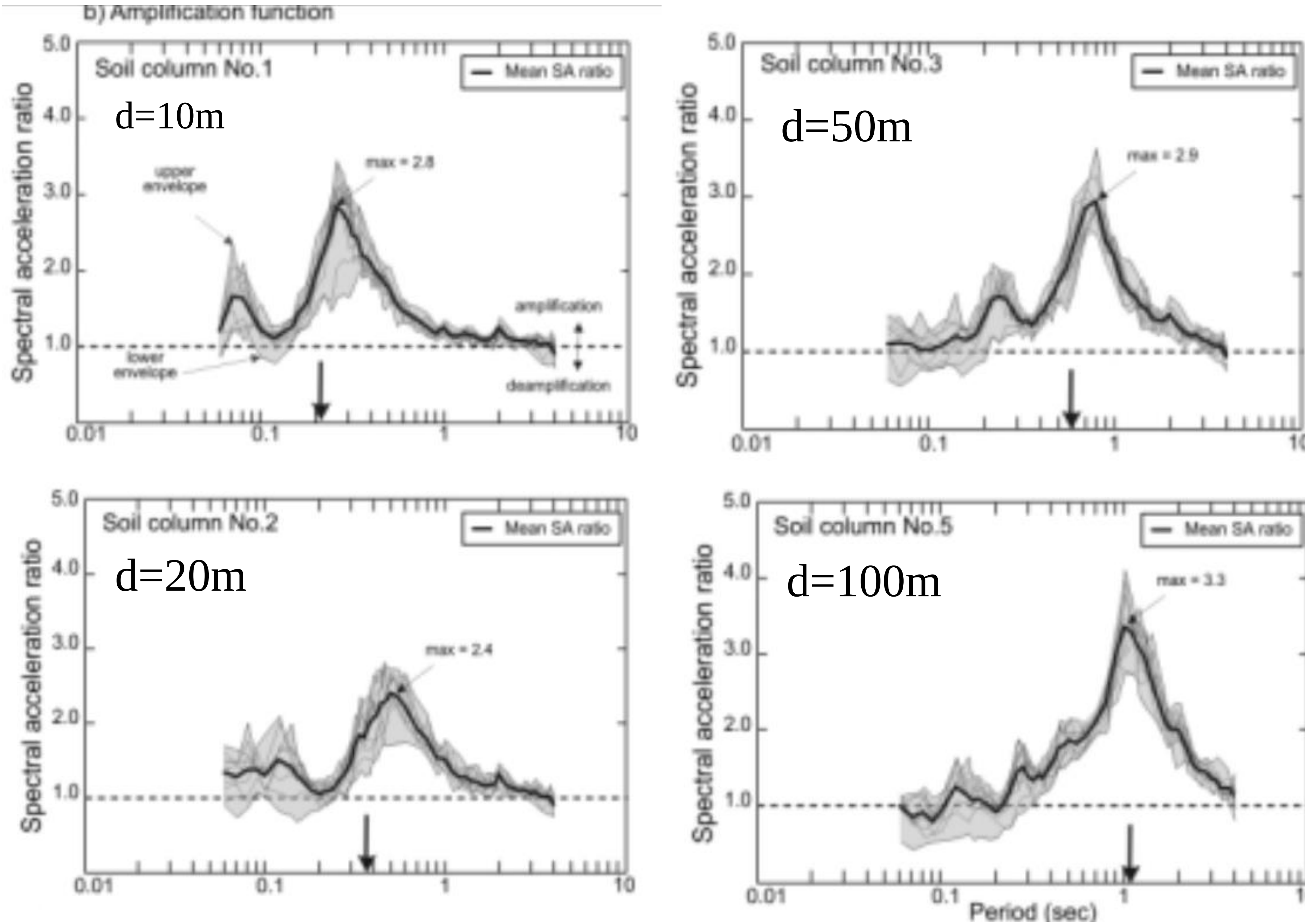
Local Site Effects - Amplification



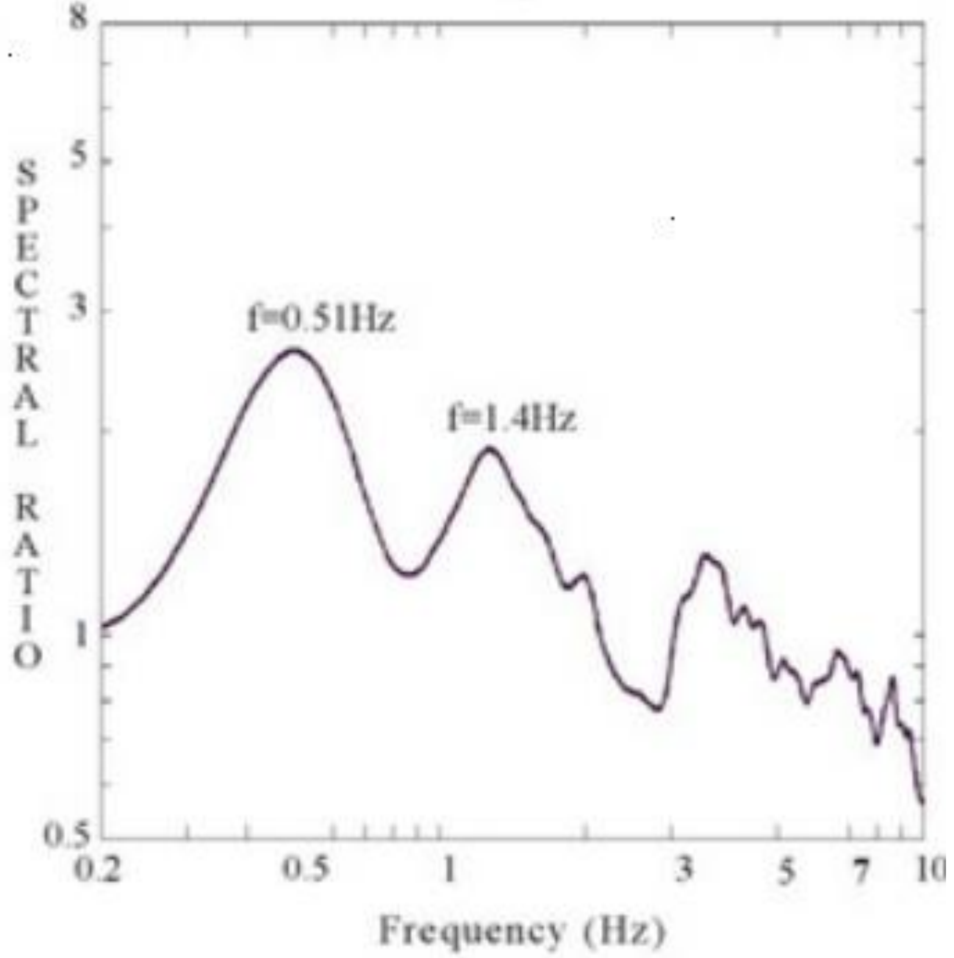


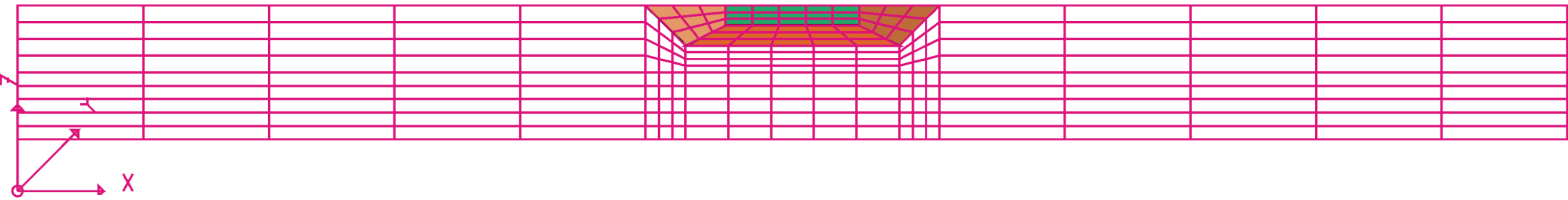


DAF utilizing response spectra



DAF utilizing Fourie spectra





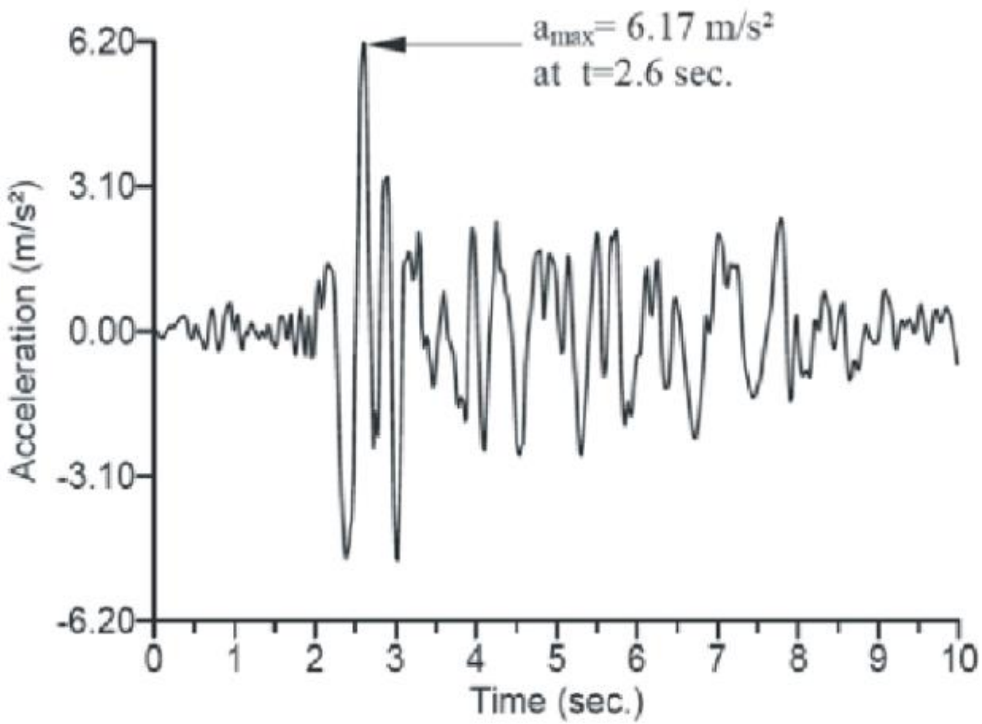
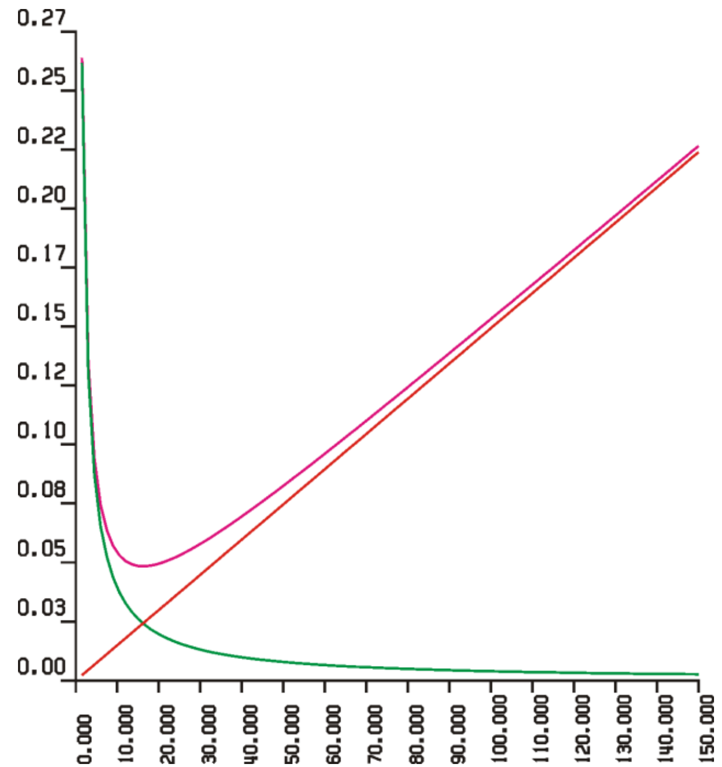
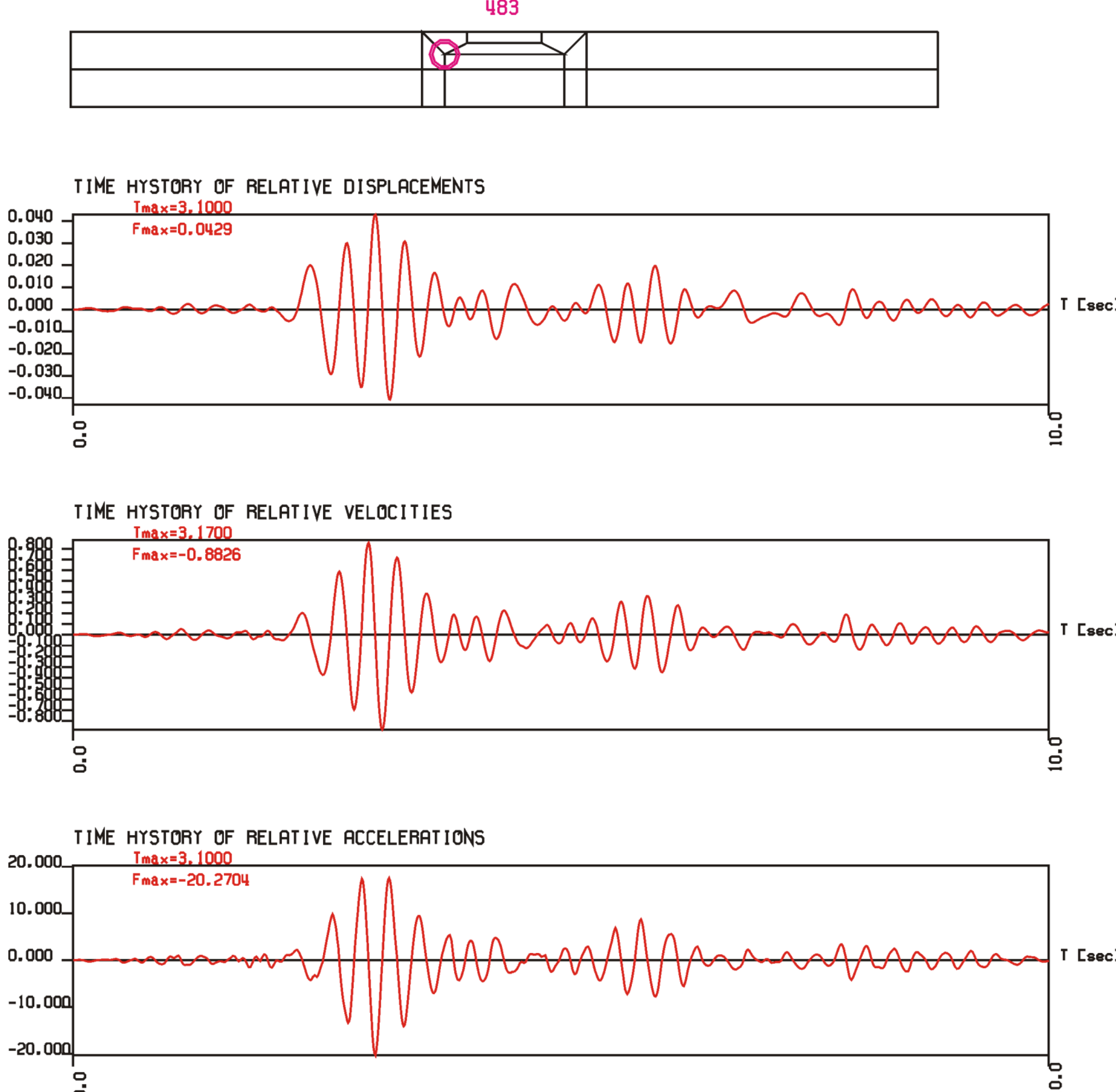
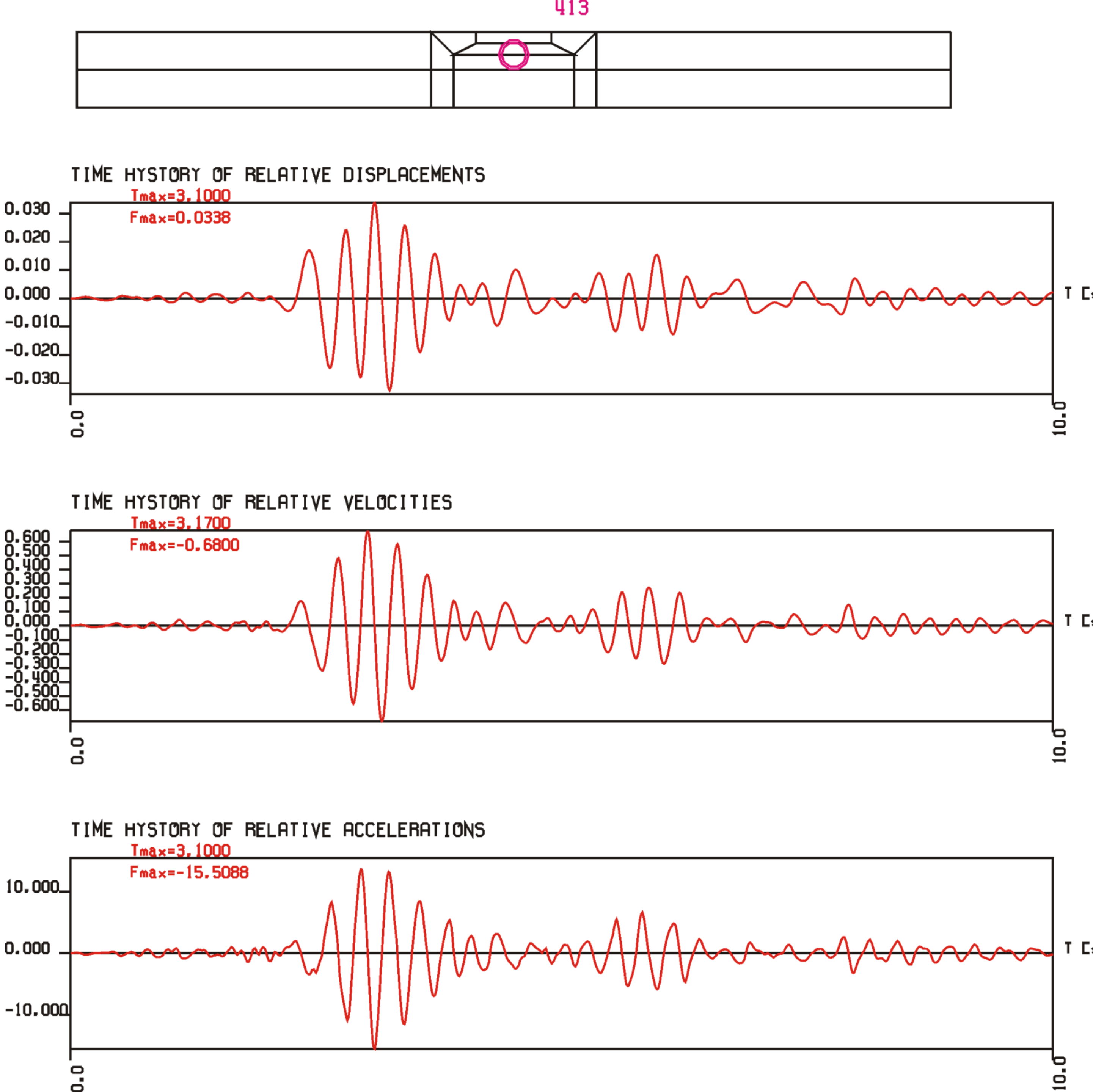
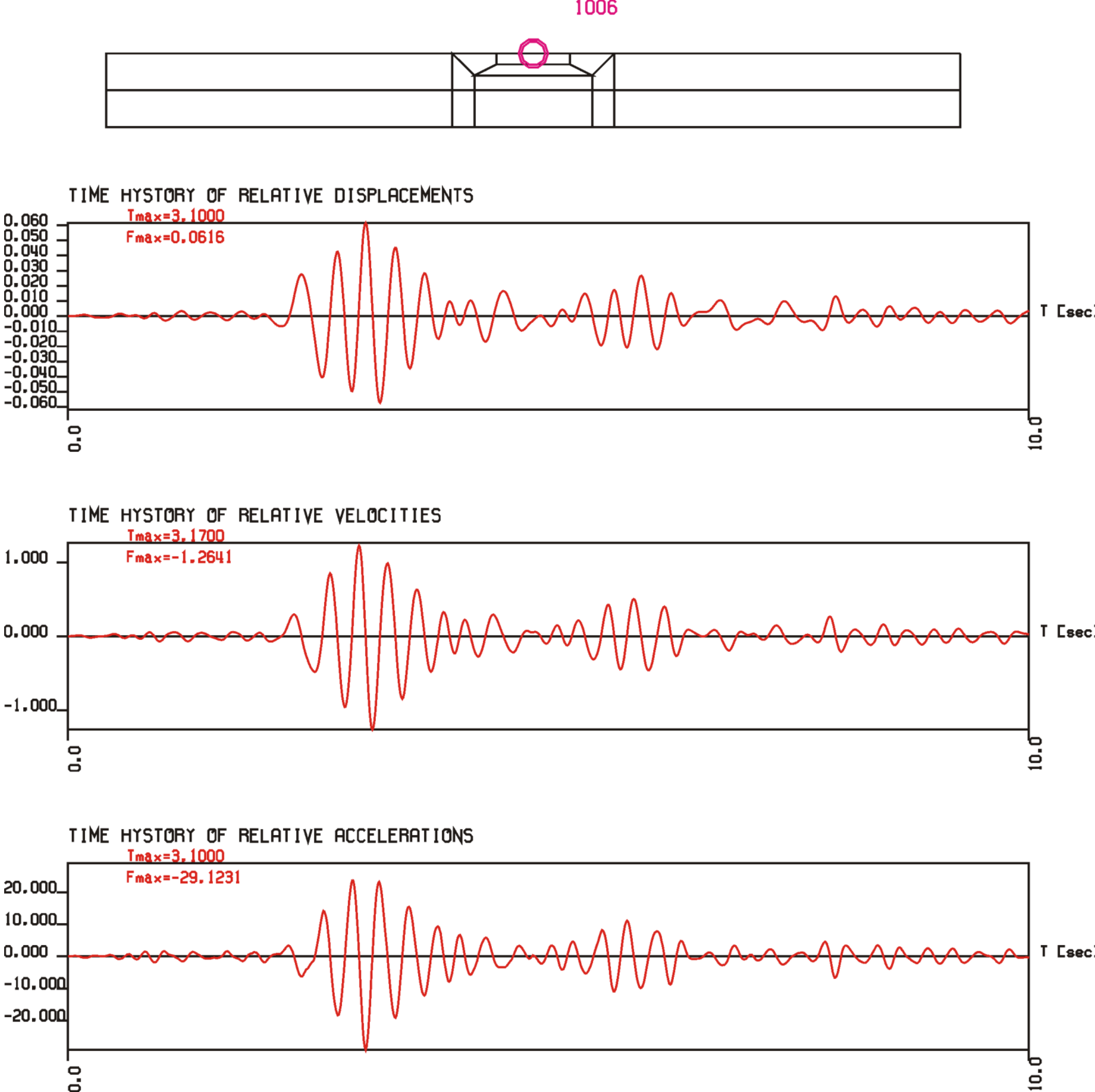


Fig. 3: Main horizontal acceleration component of the 1989 Loma Preita earthquake (first 10 seconds).



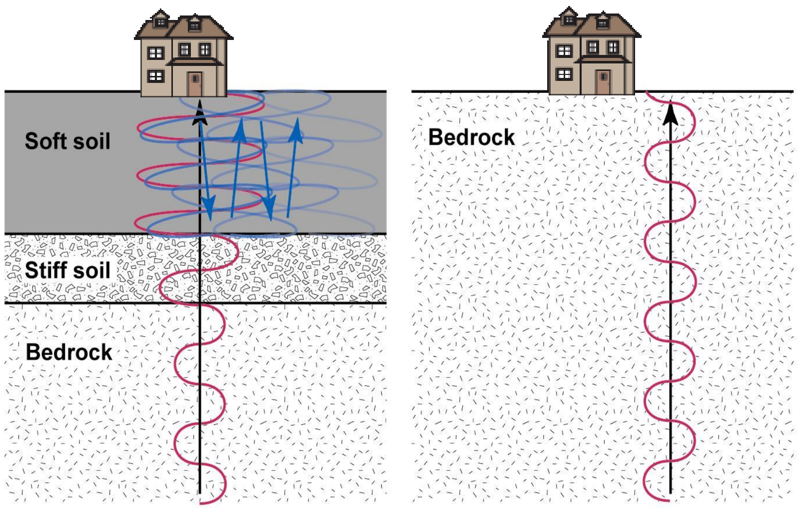

483
TIME HYSTORY OF RELATIVE DISPLACEMENTS
Tmax=3.1000
Fmax=0.0429
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
T [sec]
0.0
10.0
TIME HYSTORY OF RELATIVE VELOCITIES
Tmax=3.1700
Fmax=-0.8826
T [sec]
0.0
10.0
TIME HYSTORY OF RELATIVE ACCELERATIONS
Tmax=3.1000
Fmax=-20.2704
20.000
10.000
0.000
-10.000
-20.000
T [sec]
0.0
10.0

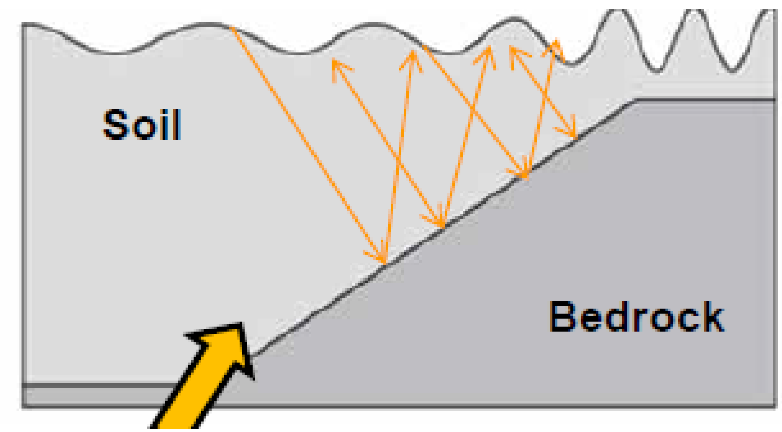

413
TIME HYSTORY OF RELATIVE DISPLACEMENTS
Tmax=3.1000
Fmax=0.0338
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
0.0
10.0
T [s
TIME HYSTORY OF RELATIVE VELOCITIES
Tmax=3.1700
Fmax=-0.6800
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
-0.500
-0.600
0.0
10.0
T [s
TIME HYSTORY OF RELATIVE ACCELERATIONS
Tmax=3.1000
Fmax=-15.5088
10.000
0.000
-10.000
0.0
10.0
T [s

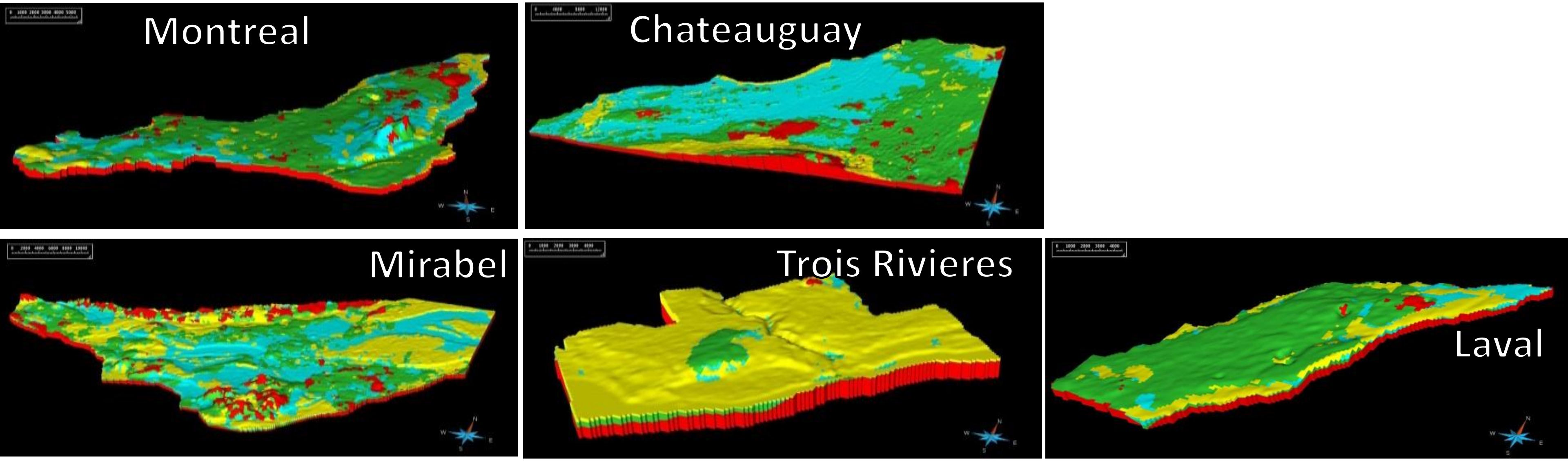


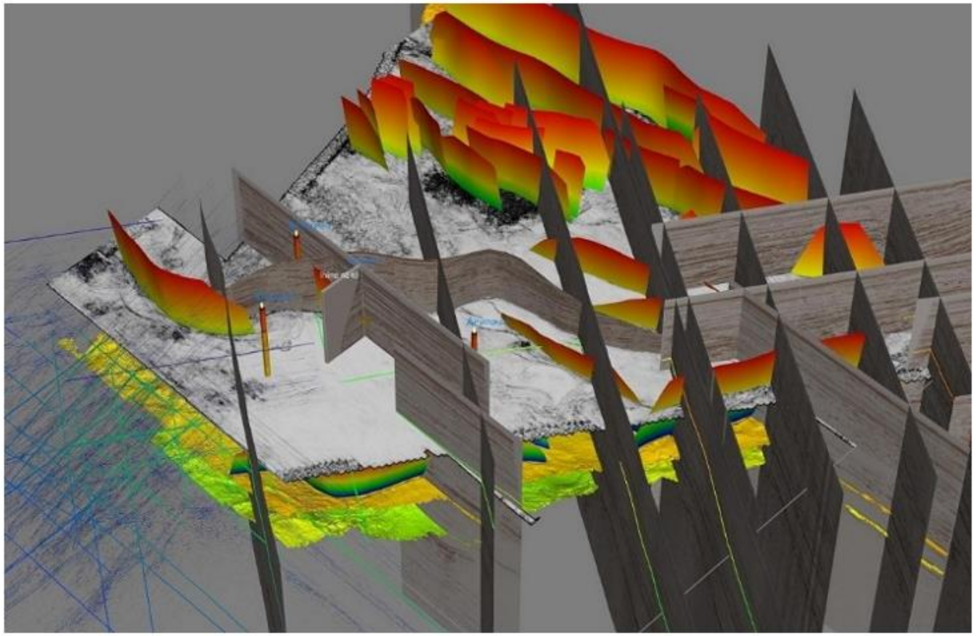
1006
TIME HYSTORY OF RELATIVE DISPLACEMENTS
Tmax=3.1000
Fmax=0.0616
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
T [sec]
0.0
10.0
TIME HYSTORY OF RELATIVE VELOCITIES
Tmax=3.1700
Fmax=-1.2641
1.000
0.000
-1.000
T [sec]
0.0
10.0
TIME HYSTORY OF RELATIVE ACCELERATIONS
Tmax=3.1000
Fmax=-29.1231
20.000
10.000
0.000
-10.000
-20.000
T [sec]
0.0
10.0

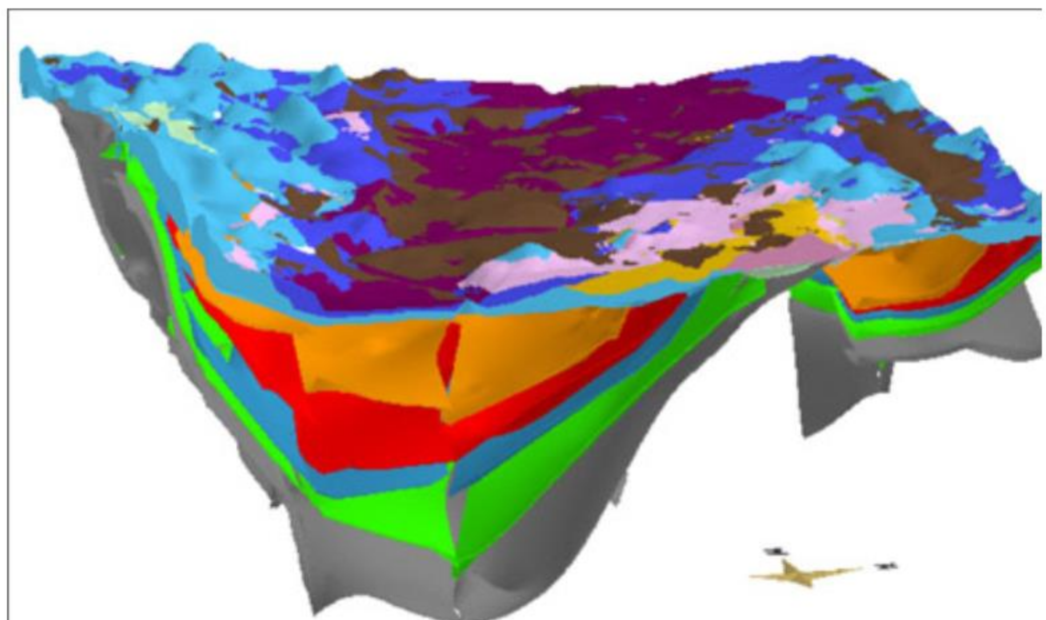
Local Site Effects - Amplification



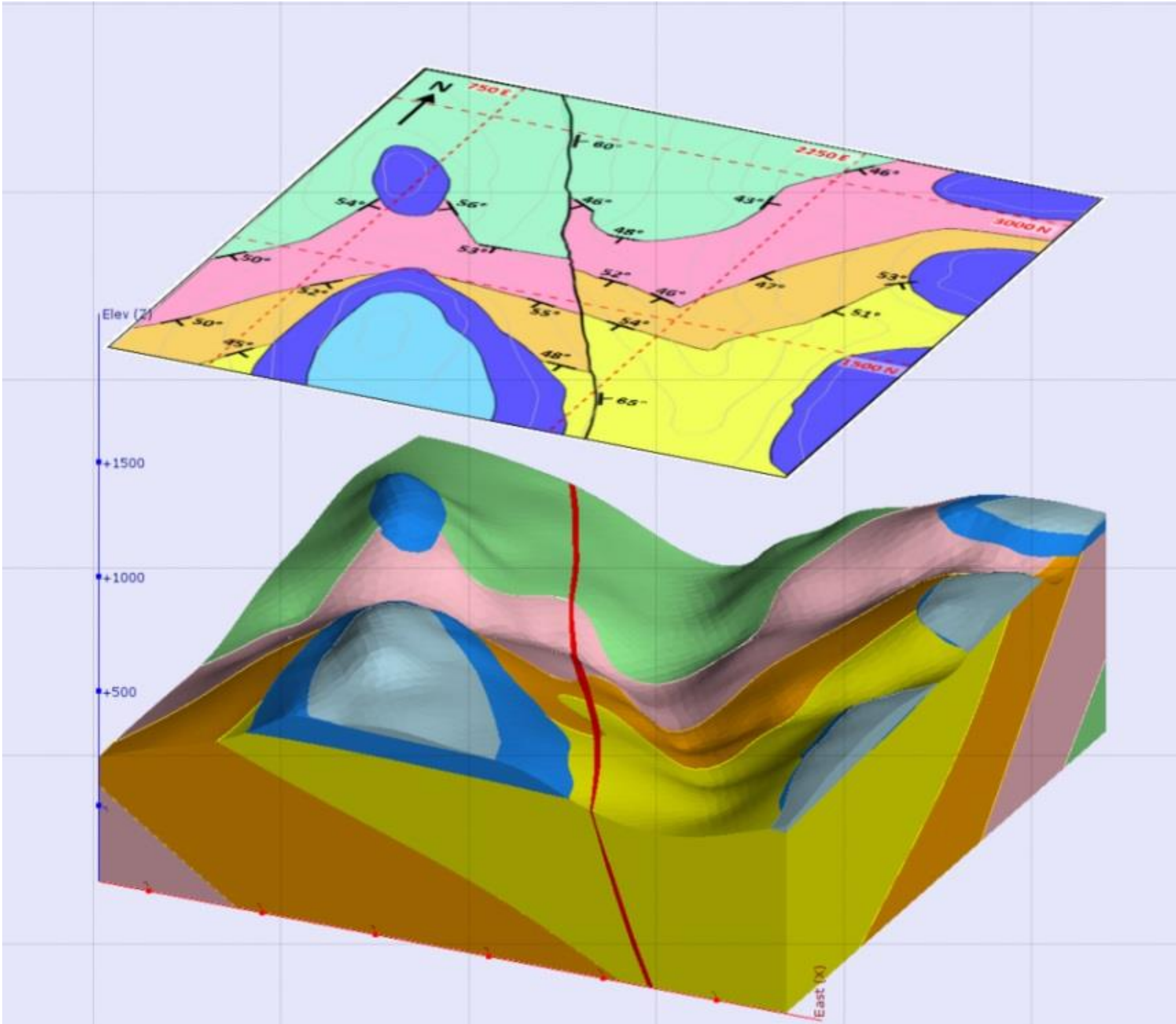




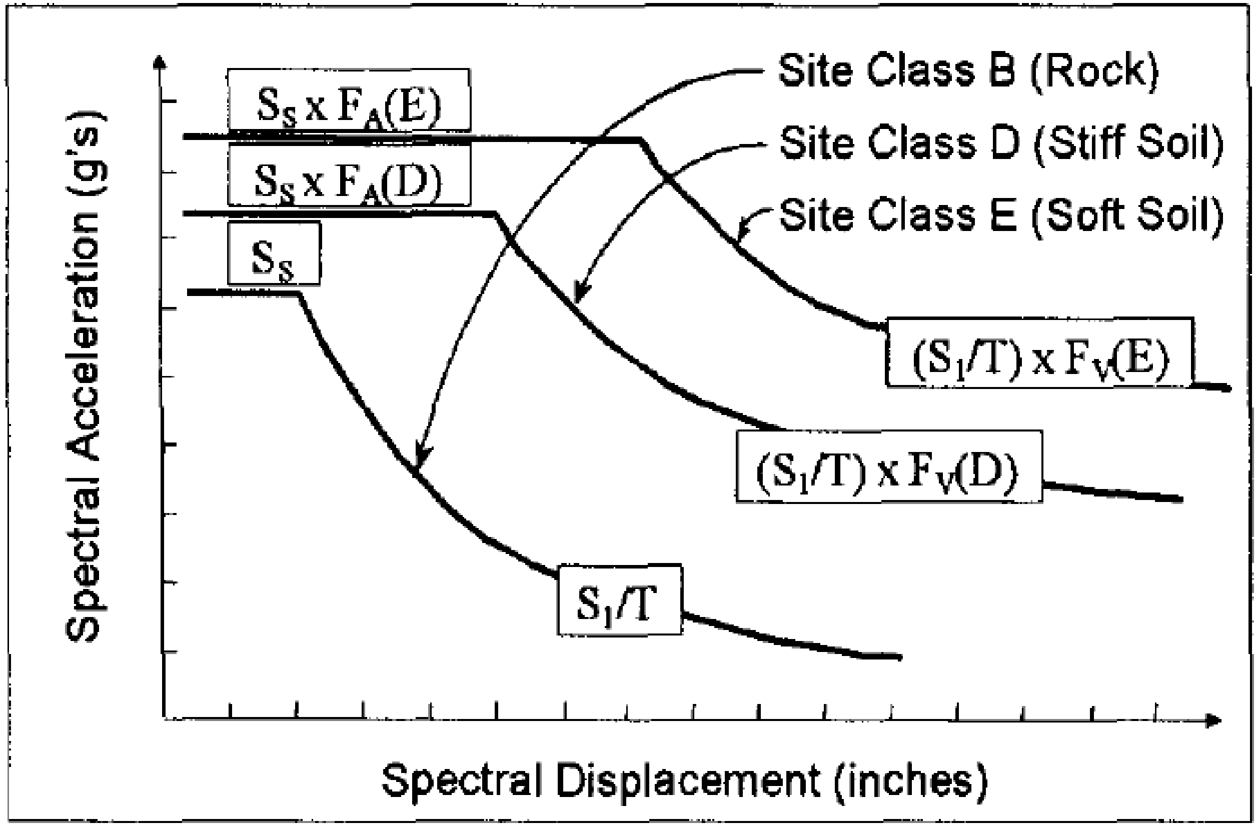




3D modeling using - Leapfrog Geo software



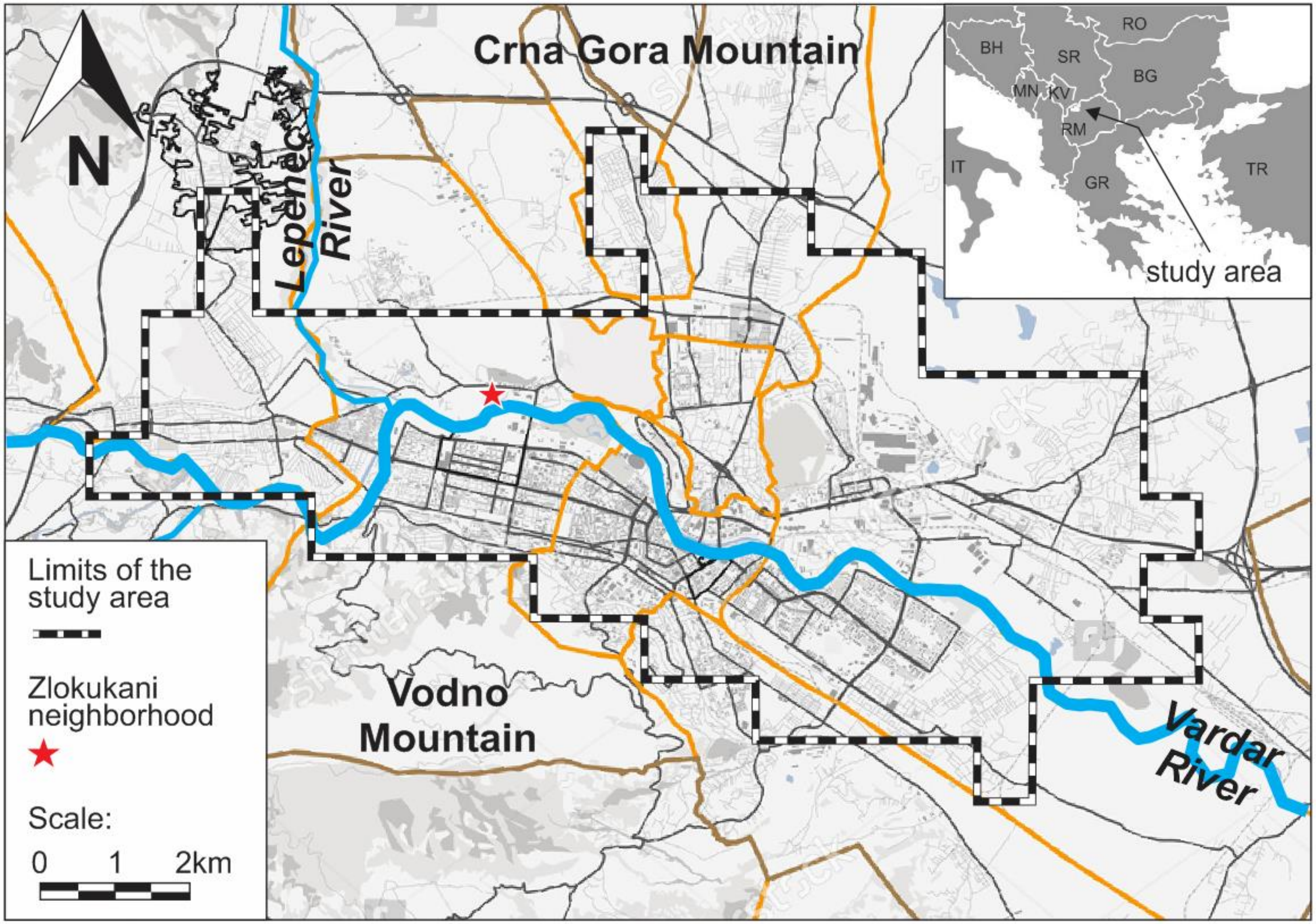
Ground Shaking Input Spectrum- Building Codes



Example 5%-damped response spectra for three site classes

NEHRP (National Earthquake Hazards Reduction Program) Recommended Seismic Provisions

Seismic Hazard (what –if scenario)



Seismic Hazard (Vs30 distribution in study area)

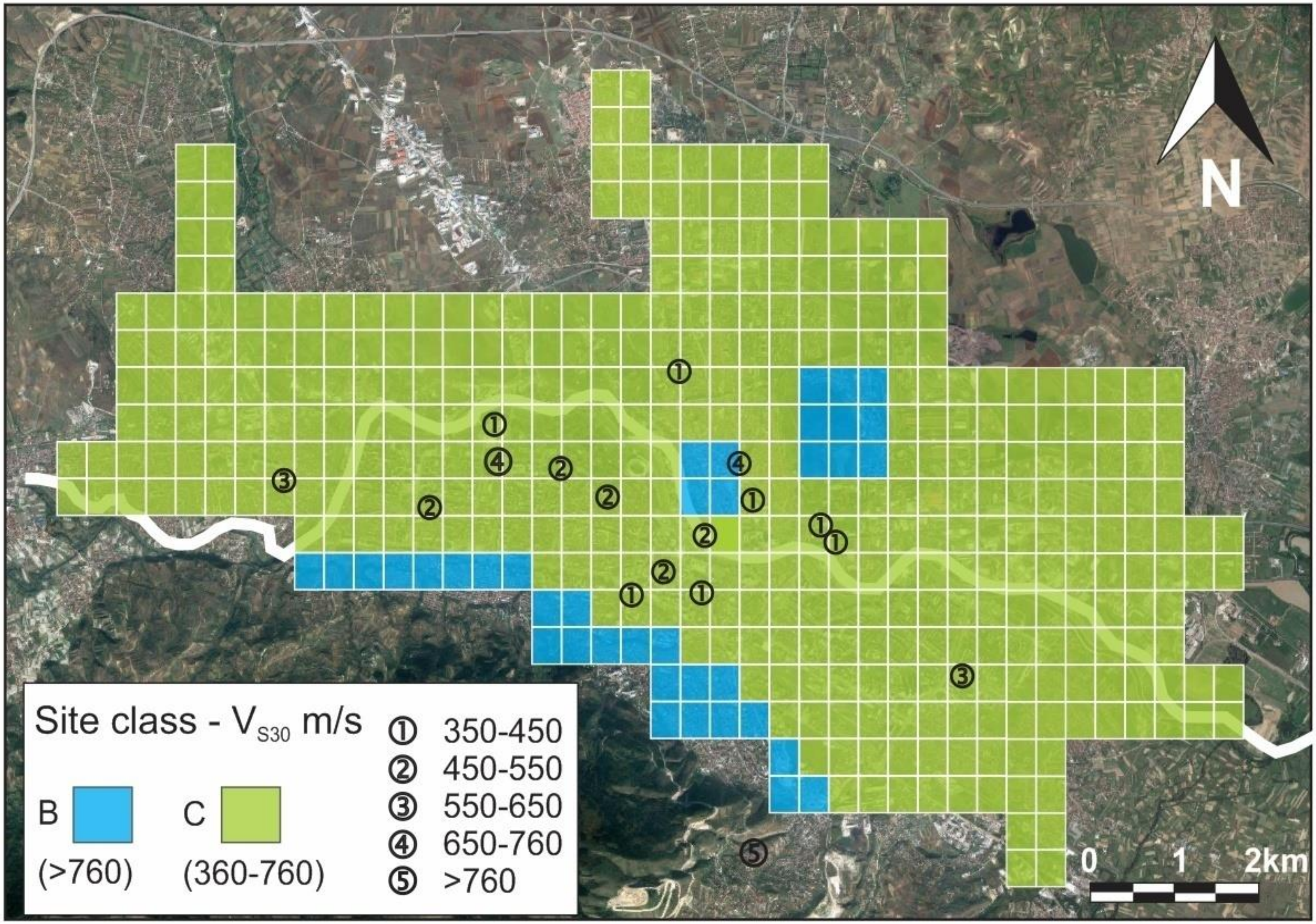


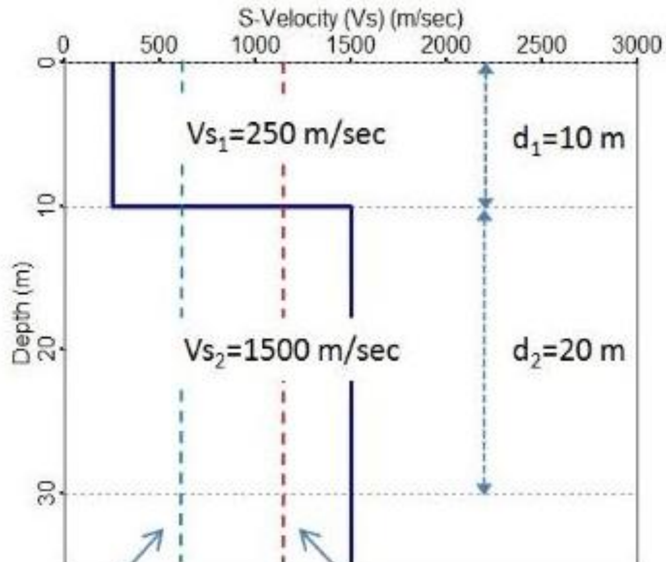
Table 1. Site classifications from the *NEHRP Provisions* [BSSC, 1994].

Soil Profile Type	Description	Geotechnical Properties
A	Hard rock	$V_S30 > 1500$ m/s
B	Rock	760 m/s $< V_S30 \leq 1500$ m/s
C	Very dense soil and soft rock	360 m/s $< V_S30 \leq 760$ m/s or $N > 50$ or $s_u \geq 100$ kPa
D	Stiff soil	180 m/s $< V_S30 \leq 360$ m/s or $15 \leq N \leq 50$, or 50 kPa $\leq s_u \leq 100$ kPa
E	Soil	$V_S30 < 180$ m/s or any profile with more than 3 m of soft clay with PI>20, $w \geq 40\%$, and $s_u < 25$ kPa

Evaluation of Average S-Velocity (Vs^{30})

(for Top 30 m)

Layer Model (Example)



$\overline{Vs_2} \cong \mathbf{563}\ (\boldsymbol{m/sec}) = \boldsymbol{Vs^{30}}$

(Method 2)

$\overline{Vs_1} \cong \mathbf{1083}\ (\boldsymbol{m/sec})$

(Method 1)

<u>**Methods To Calculate Average Shear-Velocity ($\overline{Vs}$)**</u>

(for Top 30 m)

Method 1: $\overline{Vs_1} = \sum \mathrm{Vs_i} \times \left(\frac{\mathrm{d_i}}{30}\right)$

($\mathrm{Vs_i}$ = shear-wave velocity, $\mathrm{d_i}$ = thickness of i-th layer)

Method 2: $\overline{Vs_2} = \frac{\sum d_i}{\sum t_i} = \frac{\sum d_i}{\sum\left(\frac{d_i}{\mathrm{Vs_i}}\right)}$

(t_i= one-way travel time in i-th layer)

$$\overline{Vs_1} = \left(250 \times \frac{10}{30}\right) + \left(1500 \times \frac{20}{30}\right) \cong \mathbf{1083}\ (\boldsymbol{m/sec})$$

$$\overline{Vs_2} = \frac{(10+20)}{\left(\frac{10}{250}+\frac{20}{1500}\right)} \cong \mathbf{563}\ (\boldsymbol{m/sec}) = \boldsymbol{Vs^{30}}$$

$\boldsymbol{Vs^{30}} = \overline{Vs_2}$ **(Method 2!)**

Methods To Calculate Average Shear-Velocity ($\overline{Vs}$)

(for Top 30 m)

Method 1: $\overline{Vs_1} = \sum \mathrm{Vs_i} \times \left(\frac{\mathrm{d_i}}{30}\right)$

($\mathrm{Vs_i}$ = shear-wave velocity, $\mathrm{d_i}$ = thickness of i-th layer)

Method 2: $\overline{Vs_2} = \frac{\sum d_i}{\sum t_i} = \frac{\sum d_i}{\sum\left(\frac{d_i}{\mathrm{Vs_i}}\right)}$

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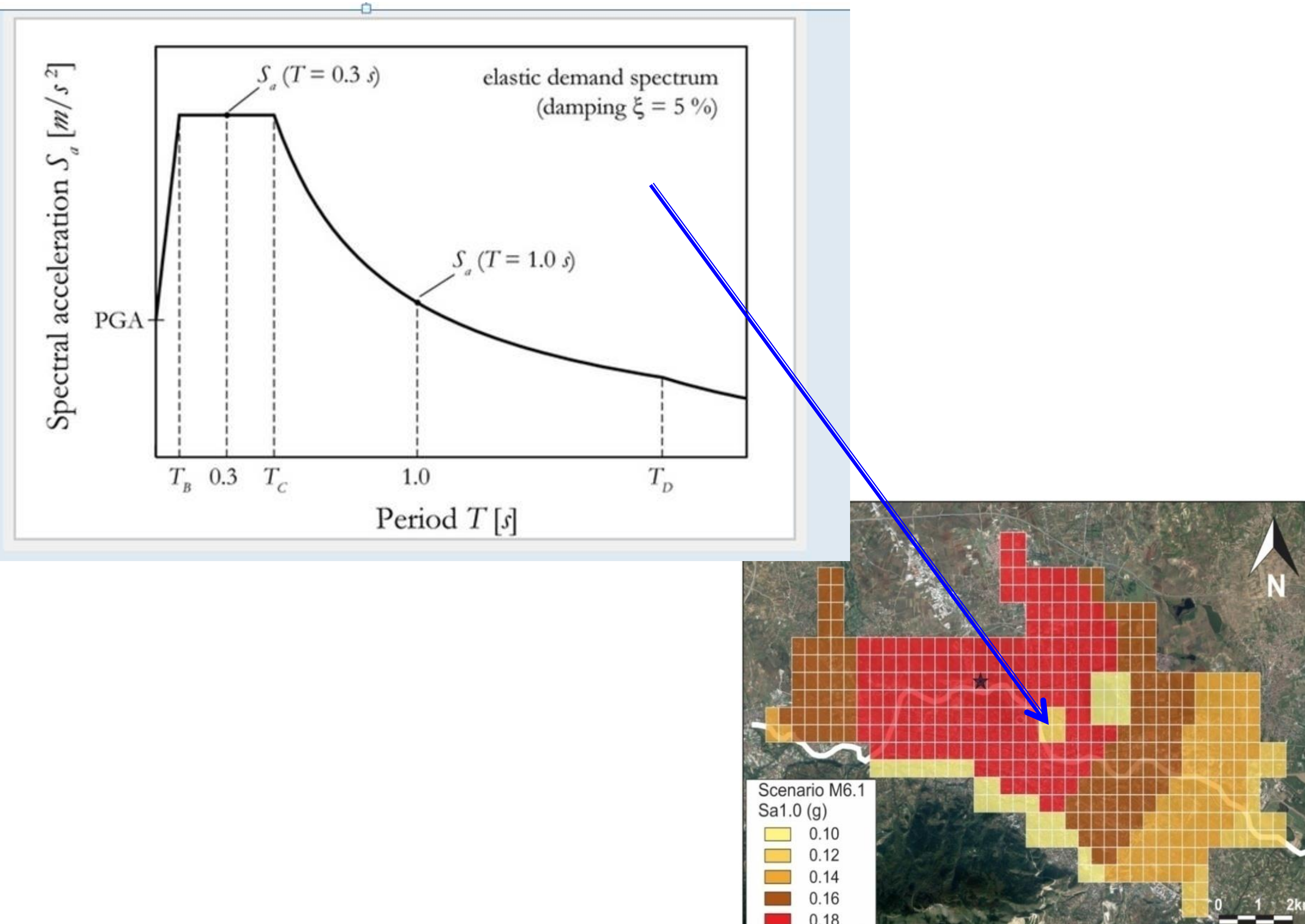
$$\overline{Vs_2} = \frac{(10+20)}{\left(\frac{10}{250}+\frac{20}{1500}\right)} \cong \mathbf{563}\ (\boldsymbol{m/sec}) = \boldsymbol{Vs^{30}}$$

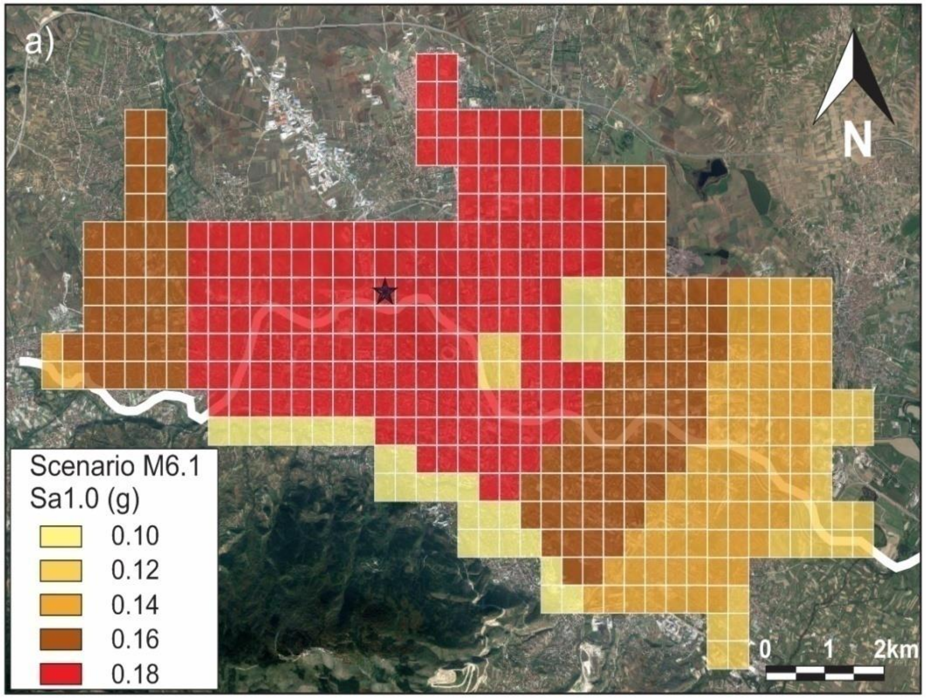
$\boldsymbol{Vs^{30}} = \overline{Vs_2}$ **(Method 2!)**

GROUND SHAKING DEMAND SPECTRUM

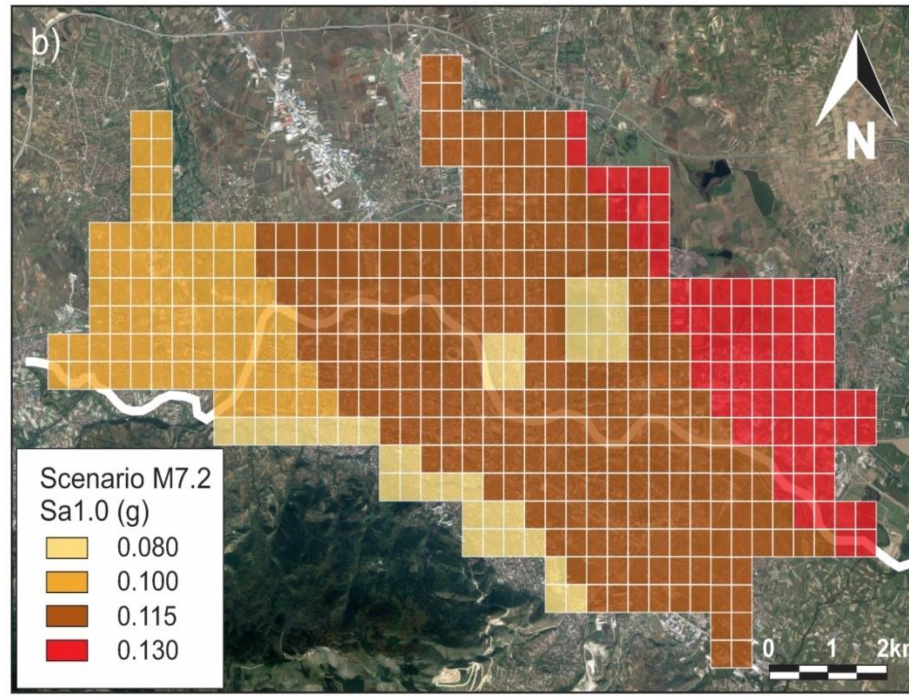


Seismic Hazard (scenario-shakemaps)

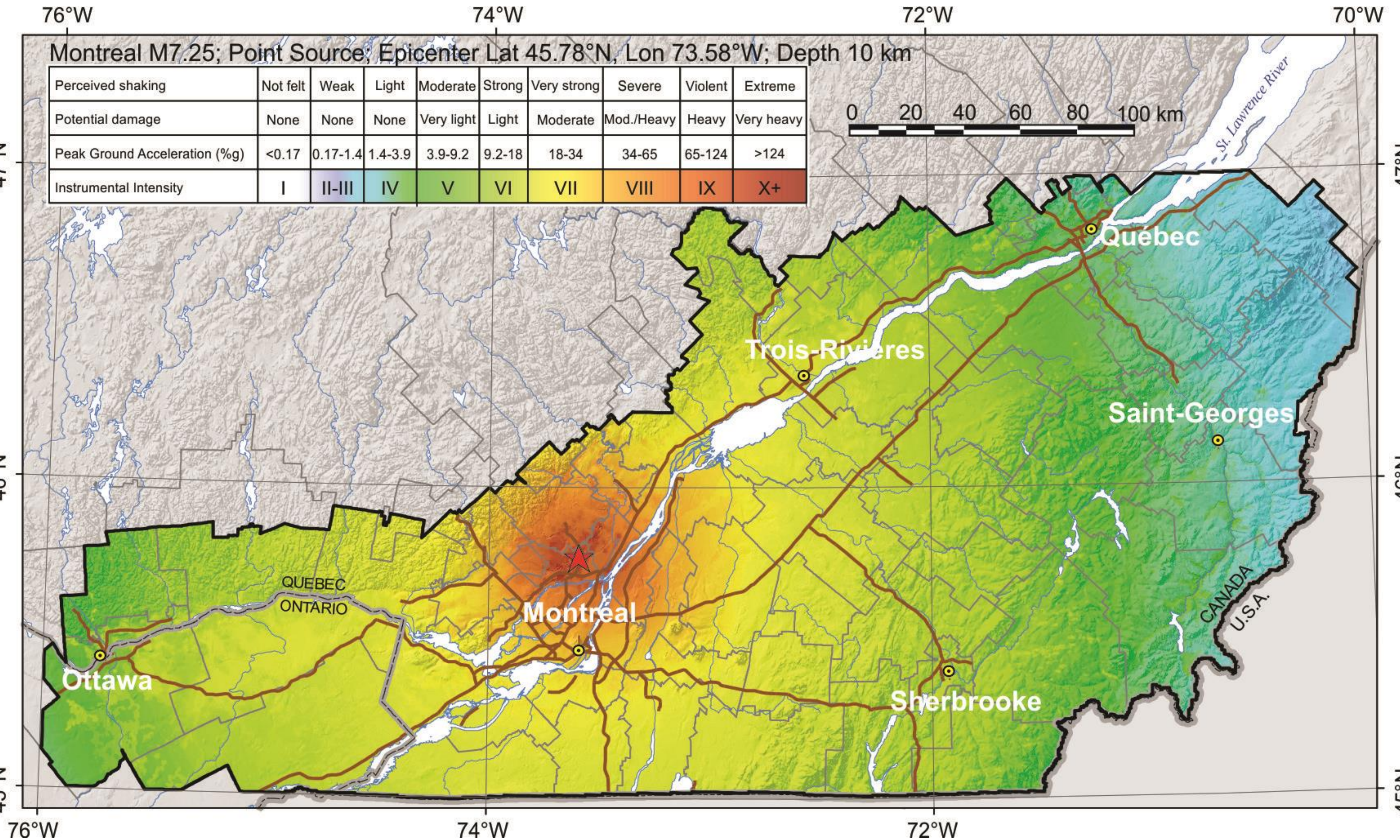
Scenario M6.1 (Zlokukjani)



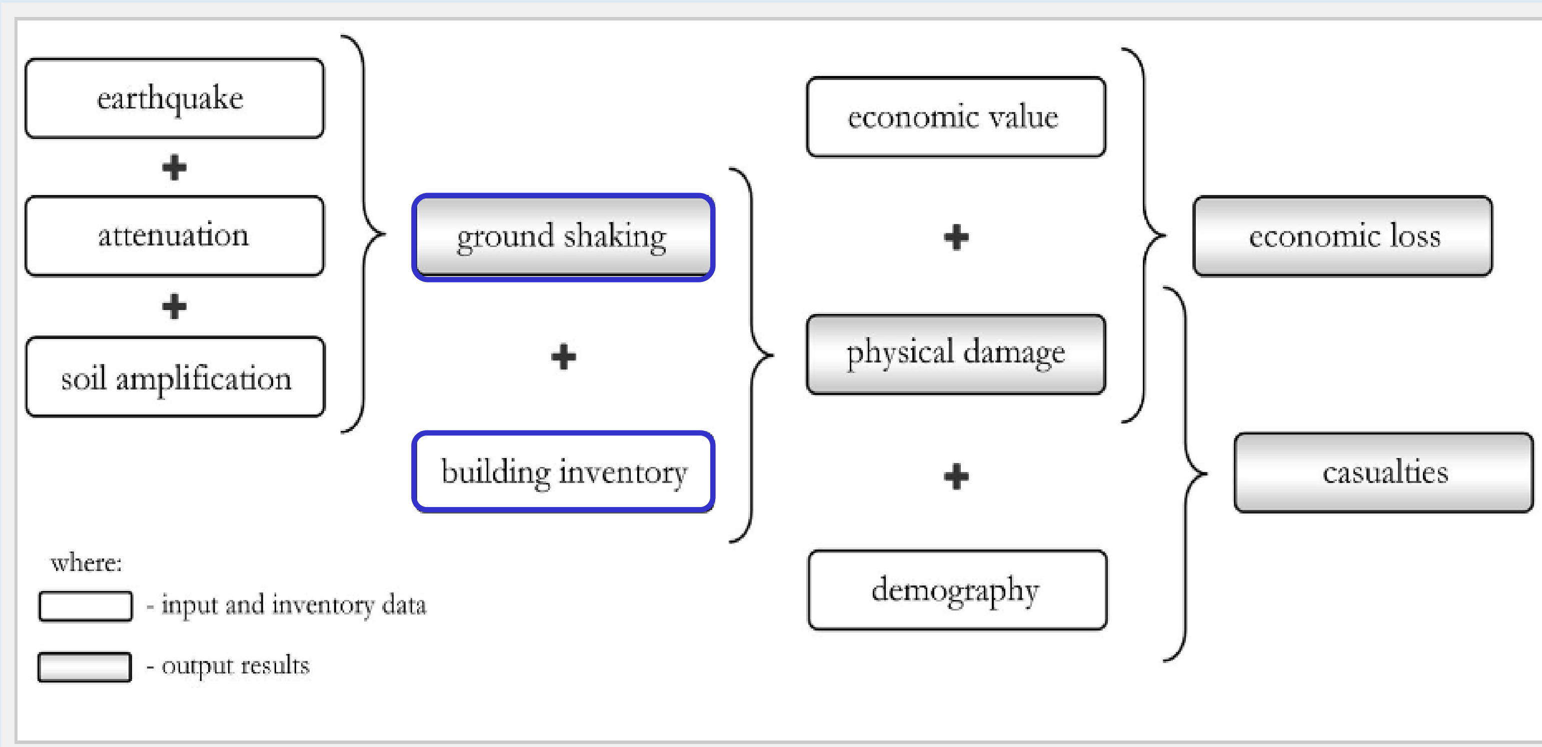
Scenario M7.2 (Kumanovo)



Seismic hazard – shakemap Quebec



So far we can conclude:



Principle flowchart of a deterministic analysis using SELENA. Outputs are provided on the level of geographical units.

Building inventory - UrbanRAT

- Building classification by structural system as a key factor in assessing overall structural performance.

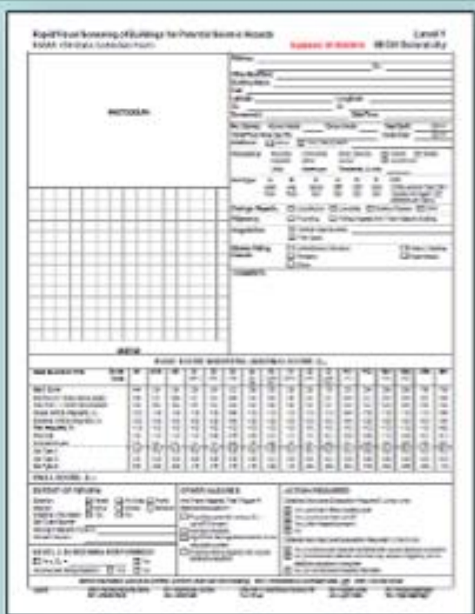
- Building classification by the height (high-rise, mid-rise and low-rise)

- Building classification by design code (date of construction)

- Building classification by occupancy

- Building classification by contents

Building inventory – ROVER

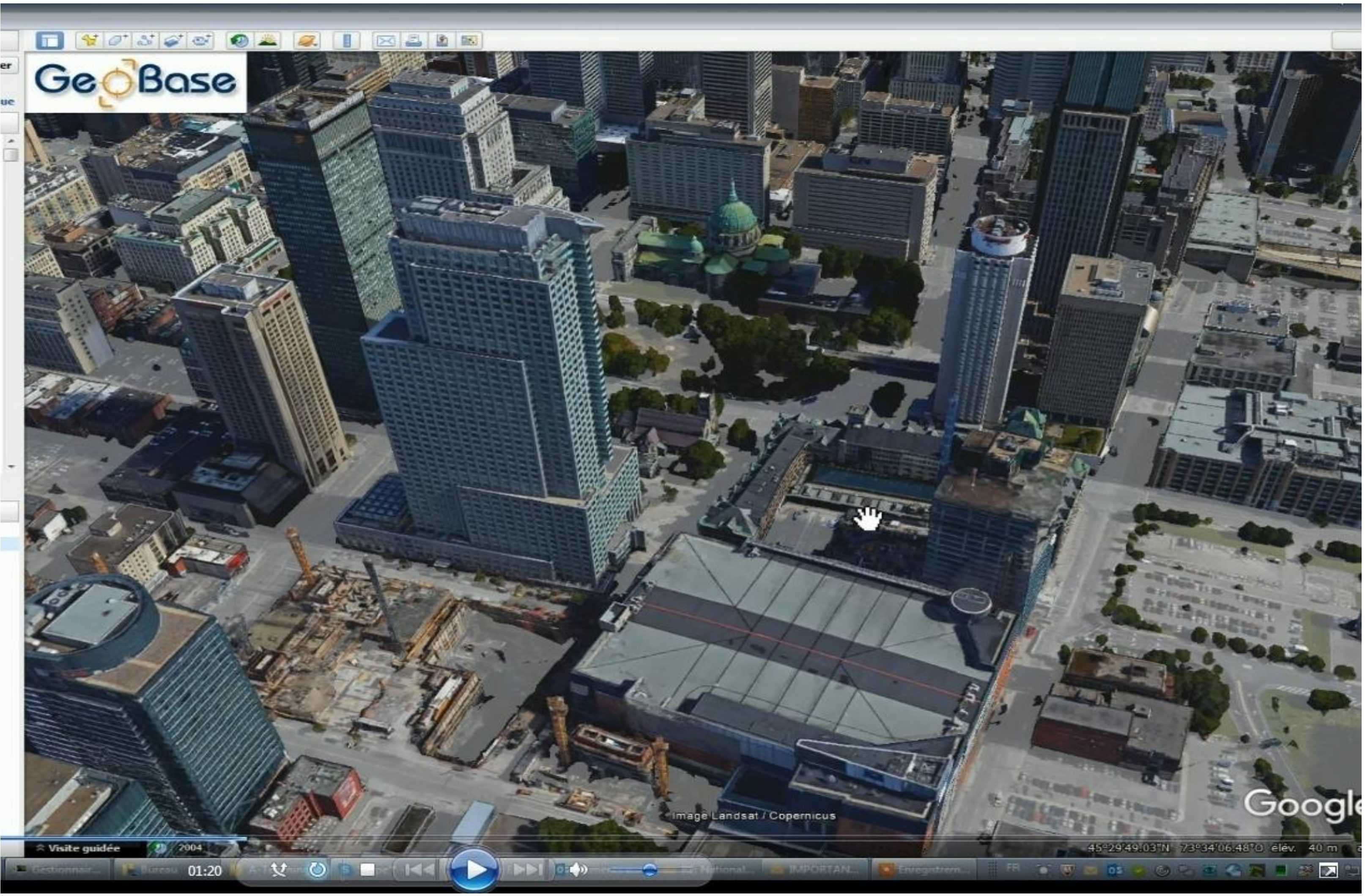


Rapid Observation of Vulnerability and Estimation of Risk

http://www.roverready.org/

https://www.linkedin.com/pulse/cities-can-save-millions-free-fema-atc-20-software-keith-porter

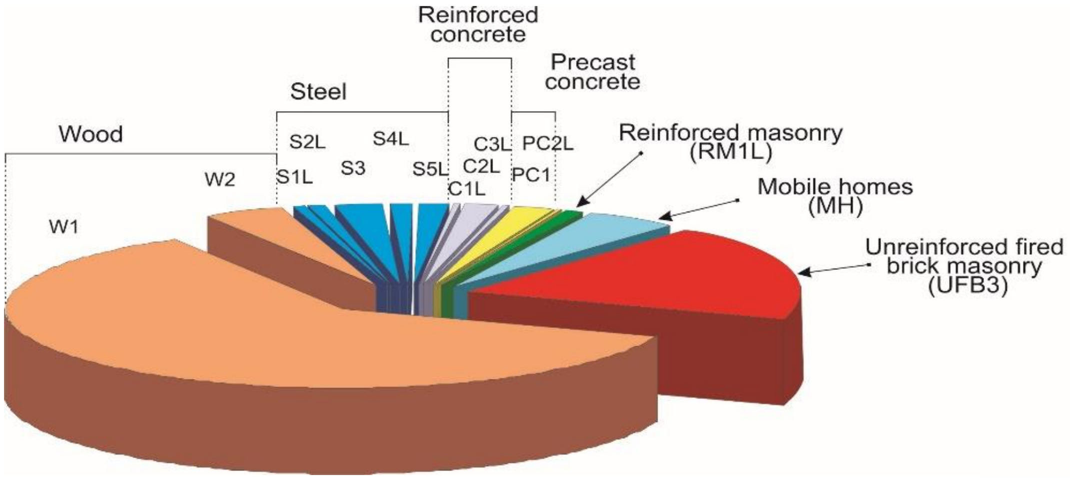
Building inventory



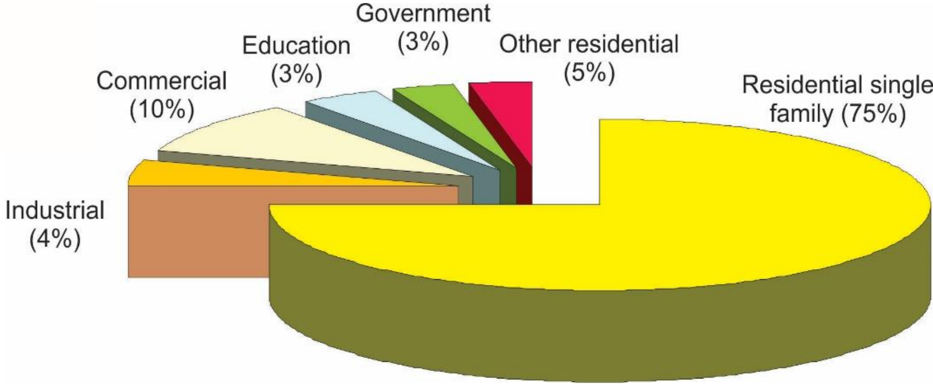
Lidar - Light Detection And Ranging is a remote sensing method used to examine the surface of the Earth

Building inventory (detailed vs. aggregated data)

Structural type

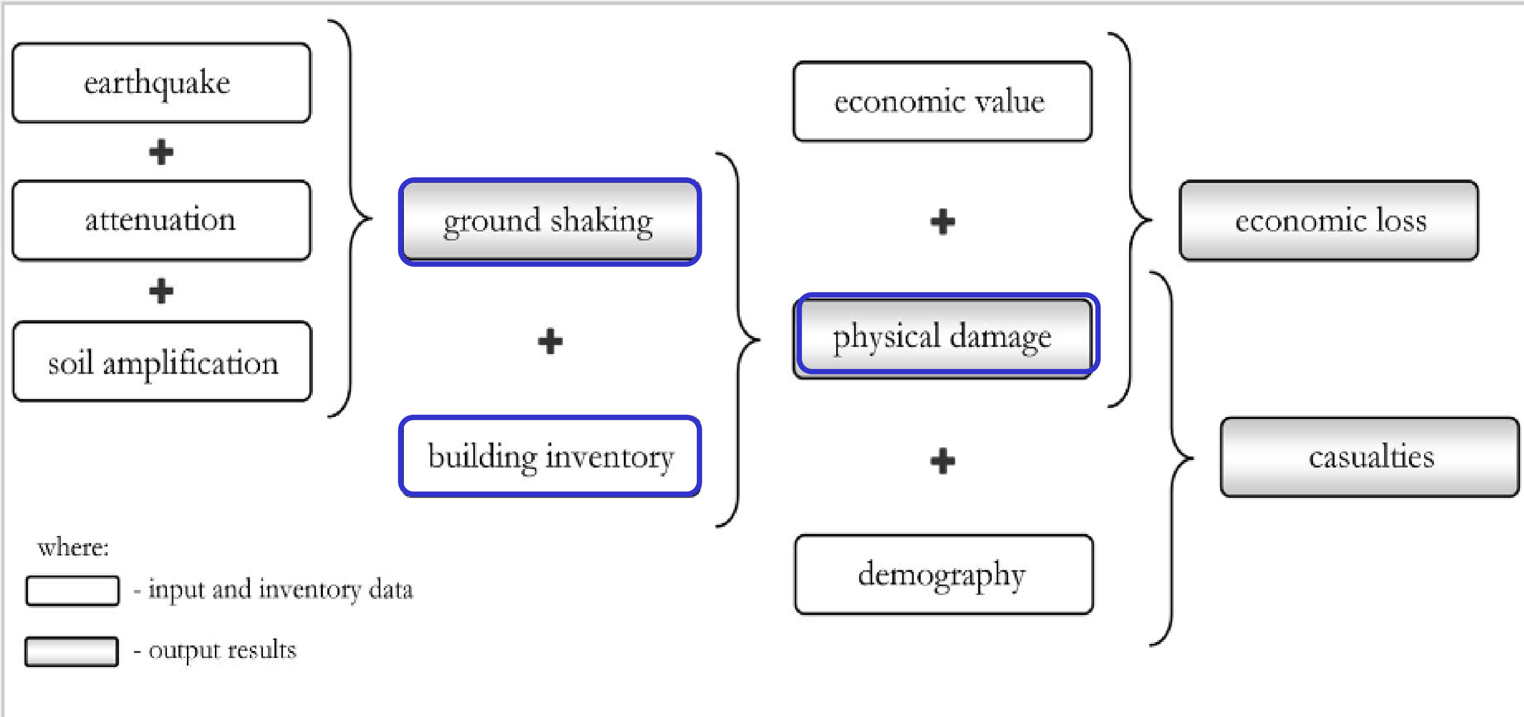


Occupancy



Cost benefit of better capturing losses

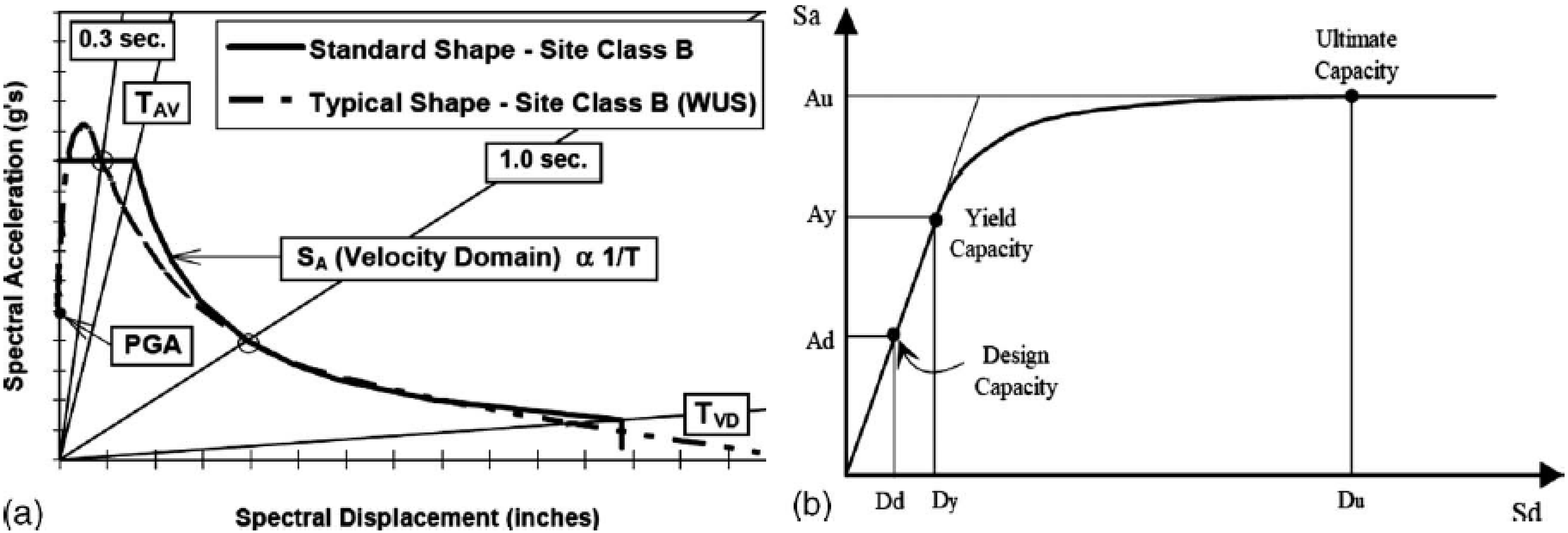
So far we can conclude:



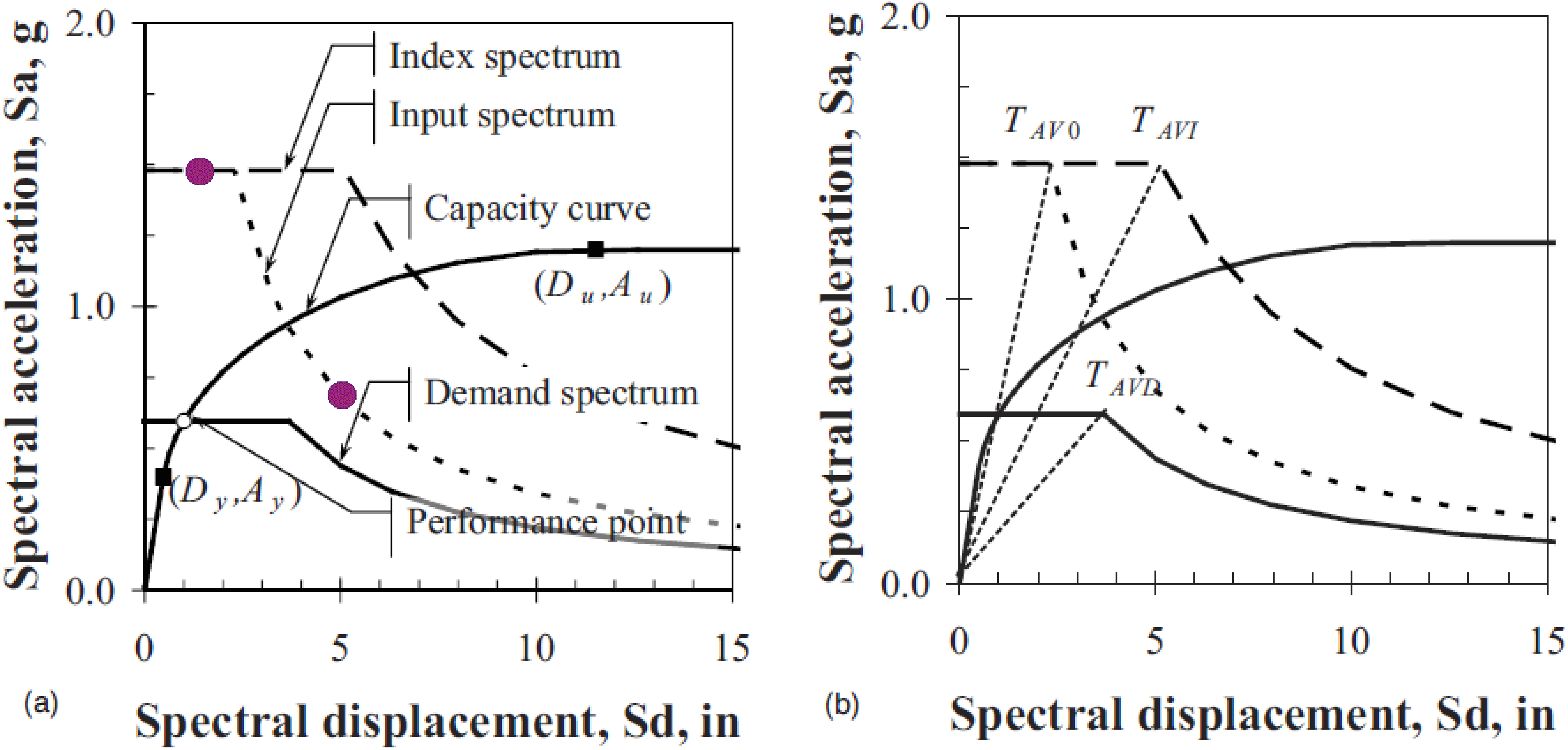
Principle flowchart of a deterministic analysis using SELENA. Outputs are provided on the level of geographical units.

SPECTRA: (NEHPR- National Earthquake Reduction Program)

ADRS format



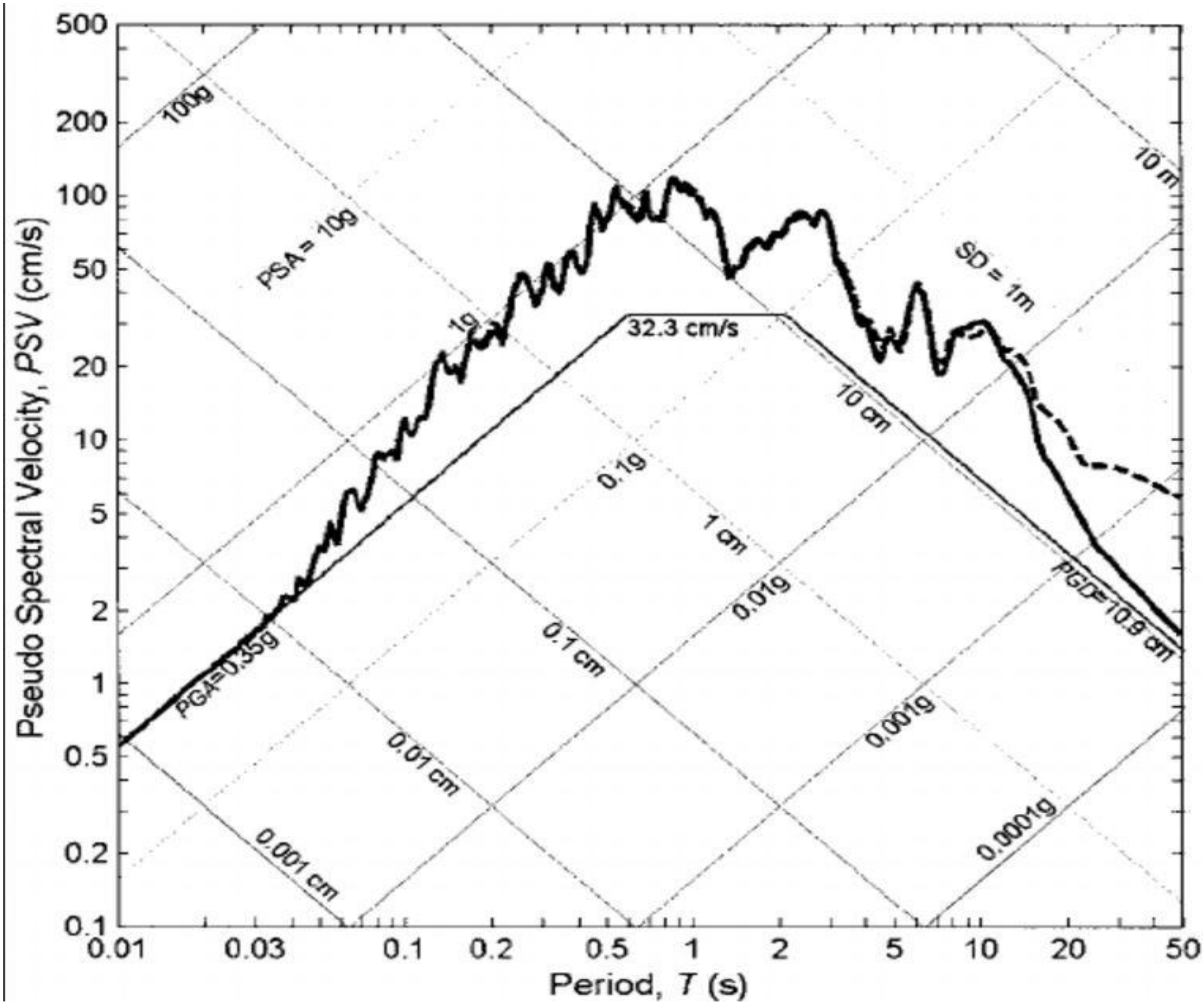
a) HAZUS-MH standardized response spectrum shape b) capacity curve (NIBS and FEMA 2003)



(a) HAZUS-MH various response spectra (b) corner periods

1) The input spectrum

$$
\begin{aligned}
S_a &= PGA & T &= 0 \\
&= S_S & 0 &< T \leqslant T_{AV0} \\
&= S_1/T & T_{AV0} &\leqslant T < T_{VD0} \\
&= (S_1 T_{VD0})/T^2 & T &\geqslant T_{VD0}
\end{aligned} \tag{1}
$$



Tripartite (logarithmic) response spectra

1) The input spectrum

$$\begin{aligned} S_a &= PGA & T &= 0 \\ &= S_S & 0 < T &\leqslant T_{AV0} \\ &= S_1/T & T_{AV0} \leqslant T &< T_{VD0} \\ &= (S_1 T_{VD0})/T^2 & T &\geqslant T_{VD0} \end{aligned} \qquad (1)$$

Using eq. 1b and 1c one can calculate $T_{AV0} = S_1 / S_S$

In general, Sa spectral acceleration and Sd spectral displacement and are related to the period

$$T = 0.32\sqrt{S_d / S_a} \qquad (2)$$

Substituting (2) into 1c and ignoring the constant displacement portion

$$\begin{aligned} S_a &= PGA & S_d &= 0 \\ &= S_S & 0 < S_d &\leqslant S_{dAV0} \\ &= S_1^2/(0.102 S_d) & S_{dAV0} &\leqslant S_d \end{aligned} \qquad (3)$$

S_{dAV0} – indicates the spectral displacement at the intersection of constant acceleration and constant velocity portions. One can calculate it by eq. 3b and 3c, resulting in: $S_{dAV0} = S_1^{\,2} /(0.102 S_S)$

$$T_{AV0} = S_1 / S_S$$

Table 1. Spectral acceleration response factors, WUS rock (Site Class B)

Closest distance to fault rupture	S_S/PGA_B given Magnitude, M:				S_S/S_1 given Magnitude, M:			
	≤5	6	7	≥8	≤5	6	7	≥8
≤10 km	1.4	1.8	2.1	2.1	5.3	3.7	3.1	1.8
20 km	1.5	2.0	2.1	2.0	5.0	3.5	2.5	1.7
40 km	1.6	2.1	2.2	2.0	4.6	3.3	2.3	1.6
≥80 km	1.3	1.8	2.1	2.0	4.1	3.1	2.1	1.5

The inverse of SARF, suggest that for WUS

$$T_{AV0}(M=6) = S_1 / S_S = 1/3.3 \approx 0.3s$$

$$T_{AV0}(M=7) = S_1 / S_S = 1/2.5 \approx 0.4s$$

$$T_{AV0}(M=8) = S_1 / S_S = 1/(6.6/4) \approx 0.6s$$

$$T_{AV0} = S_1 / S_S$$

Table 2. Spectral acceleration response factors, CEUS rock (Site Class B)

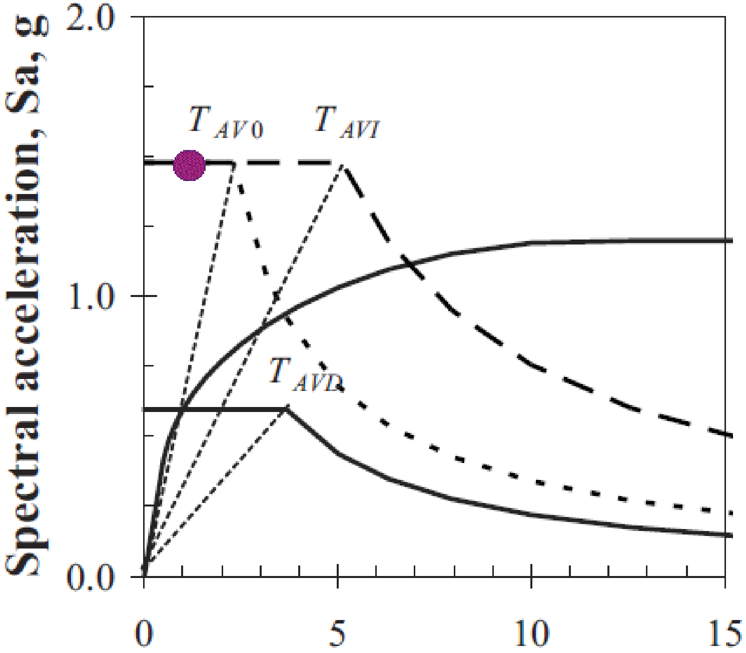
Hypocentral Distance	S_S/PGA_B given Magnitude, M:				S_S/S_1 given Magnitude, M:			
	≤5	6	7	≥8	≤5	6	7	≥8
≤10 km	0.9	1.2	1.5	2.1	8.7	4.2	3.1	2.3
20 km	1.0	1.3	1.4	1.6	8.1	4.0	3.0	2.7
40 km	1.2	1.4	1.6	1.6	7.3	3.7	2.8	2.6
≥80 km	1.5	1.7	1.8	1.9	6.5	3.3	2.5	2.4

ECUS- for central and eastern US,

$$T_{AV0}(M = 6) = S_1 / S_S = 1/(15.2/4) \approx 0.26s < 0.3s$$

$$T_{AV0}(M = 7) = S_1 / S_S = 1/(11.4/4) \approx 0.35s < 0.4s$$

$$T_{AV0}(M = 8) = S_1 / S_S = 1/(10/4) \approx 0.4s < 0.6s$$



Conclusion :

1.The magnitude has a significant influence on (T_{AV0}) and it also has a significant influence on the spectral acceleration intensity Sa(0.3);

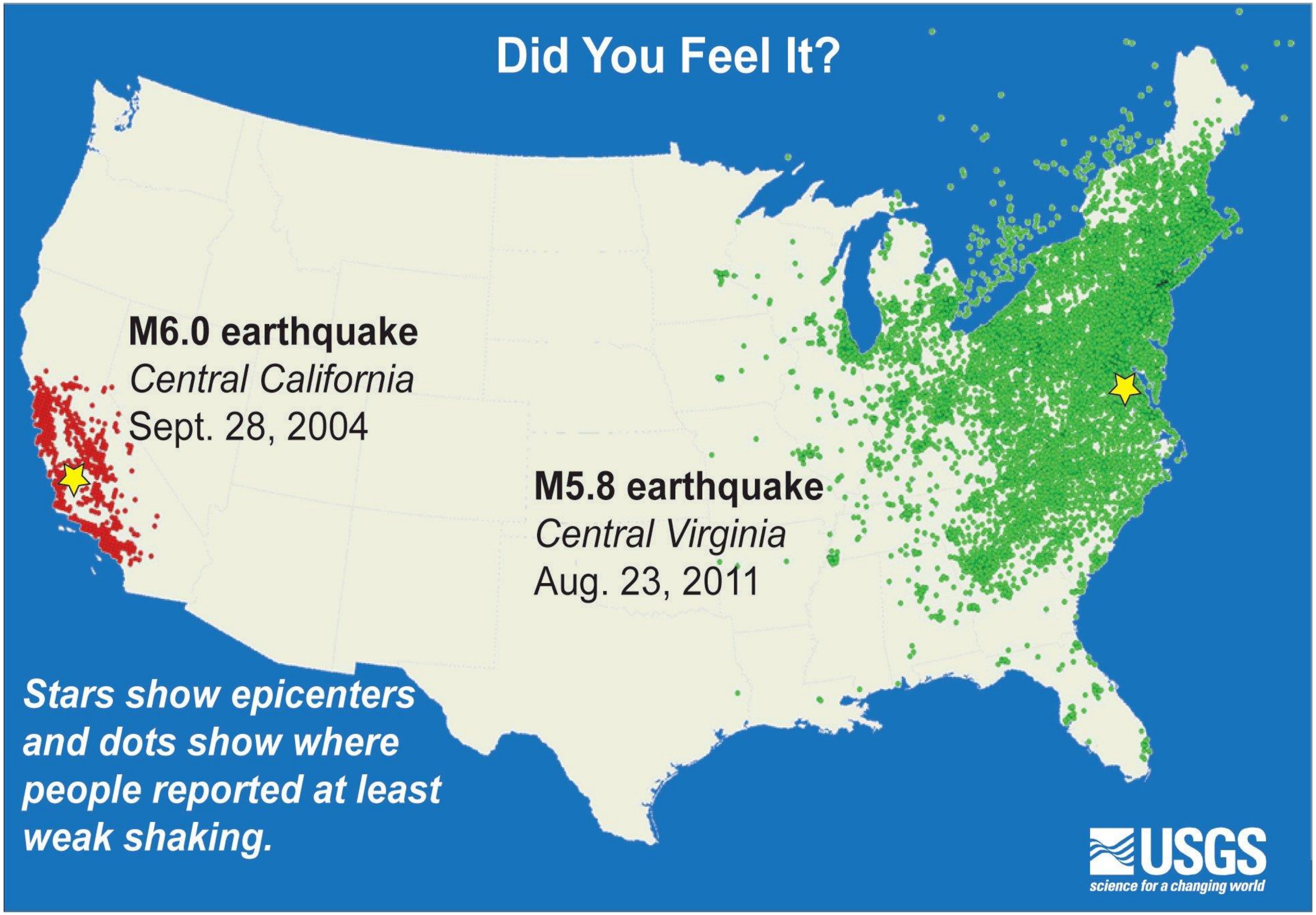
2. T_{AV0} is inversely proportional to distance under the same M;

3. The spectral acceleration Ss(0.3) is inversely proportional to the distance under the same PGA(class B);

4. For the ECUS region, the value of (T_{AV0}) and the magnitude of spectral values(Ss at T=0.3s) are lower than those for the WUS region, considering the same M and distance from the rapture.

Attenuation is stronger in WUS and theseismic energy release is faster and in larger portions in case of the same distance and magnitude.

WUS' spectra are wider and higher in shape



The demand spectrum

$$S_a = PGA_X = PGA \cdot F_a \qquad T = 0$$
$$= S_S F_a / R_A \qquad 0 < T \leqslant T_{AVD} \qquad (6)$$
$$= S_1 F_v / (R_V T) \qquad T_{AVD} \leqslant T$$

Where:

PGAx - site-soil-amplified peak ground acceleration

$\mathbf{T_{AVD}}$ - period at the intersection of constant-acceleration and constant-velocity portions of the demand spectrum.

Fa and **Fv** - reflect site soil amplification (given in ASCE-7 Tables 11.4.-1 and 11.4.-2)

$\mathbf{R_A}$ and $\mathbf{R_V}$ account for damping other than 5%.

$$R_A = 2.12 / (3.12 - 0.68 \ln[100 B_{eff}])$$

$$R_V = 1.65 / (2.31 - 0.41 \ln[100 B_{eff}])$$

$\boldsymbol{B_{eff}}$ **-** denotes the effective damping ratio

Substituting $T = 0.32\sqrt{S_d / S_a}$ into 6c, the demand spectrum becomes:

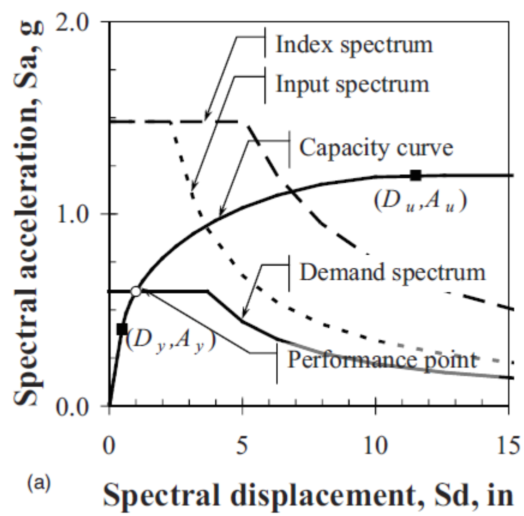
$$
\begin{aligned}
S_a &= PGA_X = PGA \cdot F_a && T = 0 \\
&= S_S F_a / R_A && 0 < T \leqslant T_{AVD} \\
&= S_1 F_v / (R_V T) && T_{AVD} \leqslant T
\end{aligned}
\quad \Rightarrow \quad
\begin{aligned}
S_a &= PGA \cdot F_a = PGA_X && T = 0 \\
&= S_S F_a / R_A && 0 < T \leqslant T_{AVD} \\
&= S_1^2 F_v^2 / (0.102 R_V^2 S_d) && T_{AVD} \leqslant T
\end{aligned}
\qquad (9)
$$

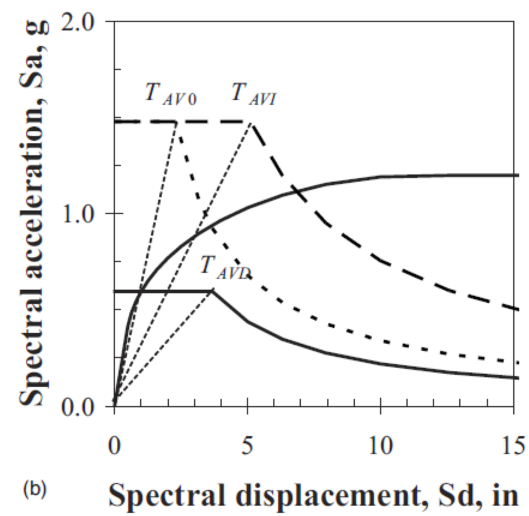
To calculate T_{AVD} equate equations 9b and 9c and solve for Sd

$$
S_S F_a / R_A = S_1^2 F_v^2 / (0.102 R_V^2 S_{dAVD}) \quad \Rightarrow \quad S_{dAVD} = \frac{S_1^2 F_v^2 R_A}{0.102 R_V^2 S_S F_a}
$$

$$
T = 0.32 \sqrt{S_d / S_a} \quad \Rightarrow \quad T_{AVD} = 0.32 \sqrt{S_{dAVD} / S_{aAVD}} \qquad (10)
$$

$$
T_{AVD} = 0.32 \sqrt{\frac{S_1^2 F_v^2 R_A / (0.102 R_V^2 S_S F_a)}{S_S F_a / R_A}} = 0.32 \sqrt{\frac{S_1^2 F_v^2 R_A^2}{0.102 R_V^2 S_S^2 F_a^2}} = \frac{S_1 F_v R_A}{S_S F_a R_V}
$$





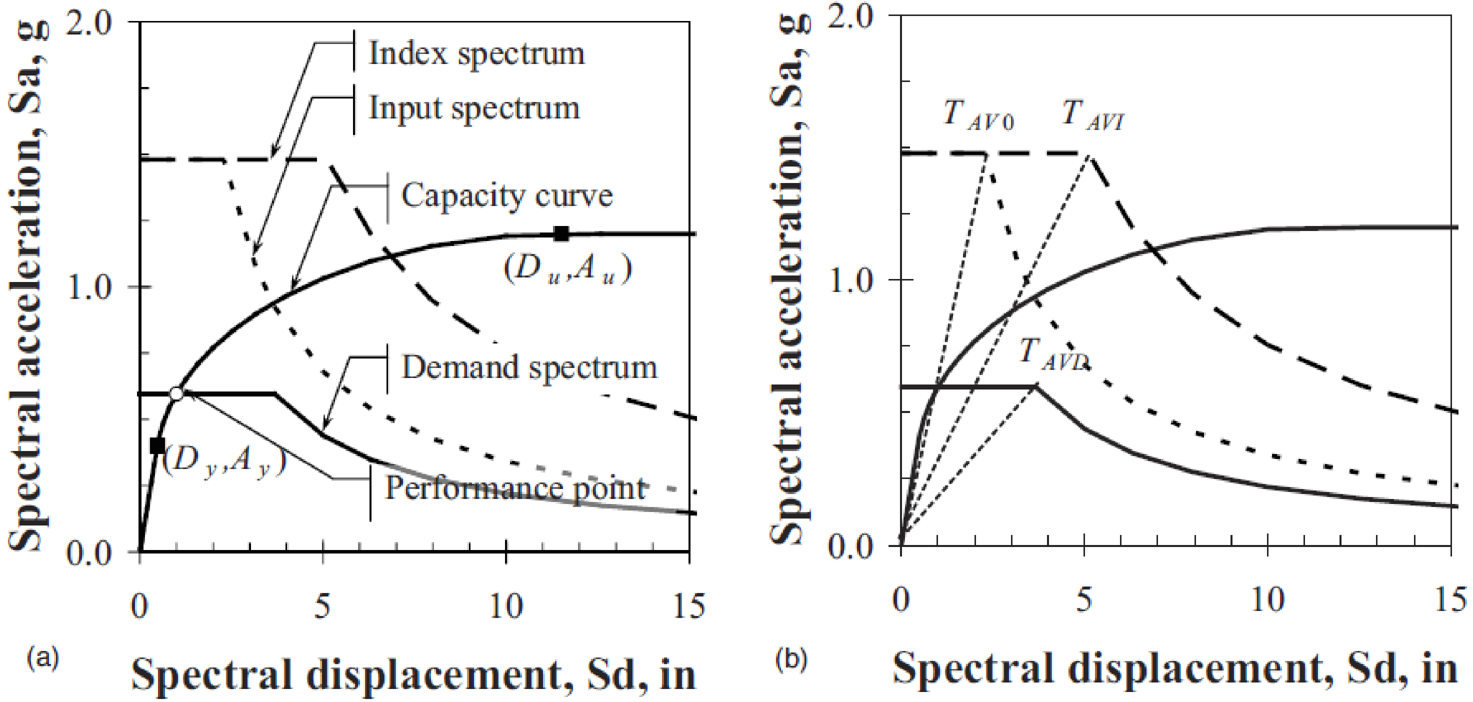
TAVD Values : for WUS on (a) site class B (Vs=750m/s) ;(b) site class D (Vs=250m/s):
CEUS on (c) site class B;(d) site class D.
, The values are calculated for 10% damping.

(a)	Magnitude				(b)	Magnitude			
Dist (km)	5	6	7	8	Dist (km)	5	6	7	8
10	0.20	0.23	0.34	0.65	10	0.46	0.54	0.72	1.5
20	0.20	0.23	0.34	0.65	20	0.45	0.54	0.71	1.2
40	0.21	0.24	0.35	0.68	40	0.48	0.55	0.76	1.1
80	0.22	0.25	0.37	0.72	80	0.50	0.58	0.86	1.3
(c)	Magnitude				(d)	Magnitude			
Dist (km)	5	6	7	8	Dist (km)	5	6	7	8
10	0.14	0.27	0.38	0.40	10	0.22	0.44	0.59	0.59
20	0.15	0.28	0.39	0.41	20	0.22	0.43	0.59	0.62
40	0.16	0.30	0.41	0.43	40	0.24	0.44	0.61	0.64
80	0.17	0.32	0.45	0.47	80	0.26	0.49	0.68	0.68

Conclusion:

1. Magnitude has a significant impact on *TAVD*: higher magnitude is associated with higher *TAVD*,
2. Distance tends to have modest effect of *TAVD*,
3. WUS earthquake events tend to have larger T_{AVD} than CEUS events with similar parameter values.
4. Soil tends to have larger *TAVD* than rock.

The index spectrum



$R_A = R_V = 1$.

$$
\begin{aligned}
S_a &= PGA \cdot F_a && T = 0 \\
&= S_S F_a && 0 < T \leqslant T_{AVI} \\
&= S_1^2 F_v^2 / (0.102 S_d) && T_{AVI} \leqslant T
\end{aligned}
$$

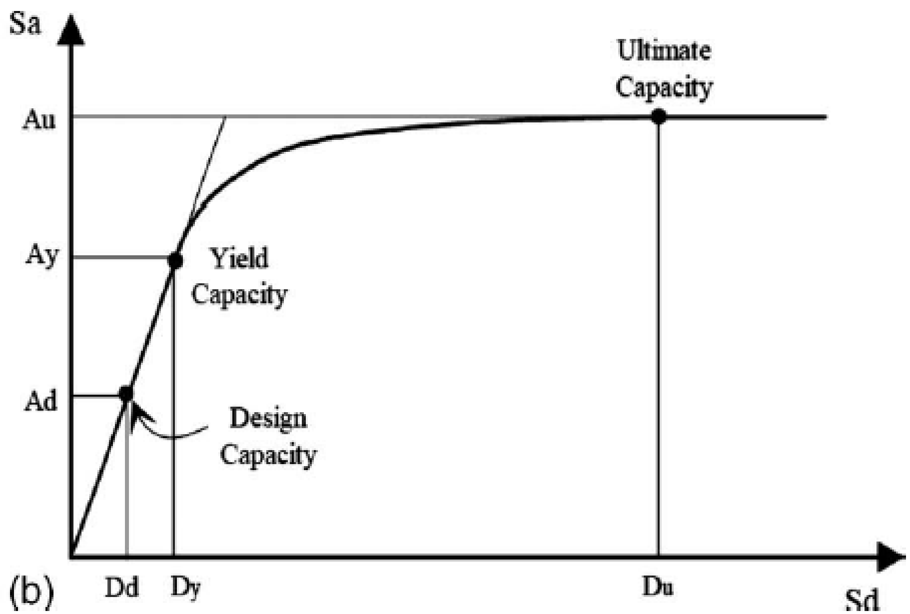
It is usefull to define the third spectrum, so called "index spectrum", the 5% damped and site soil adjusted response spectrum. "Index spectrum" is nothing else than a demand spectrum at 5% damping.

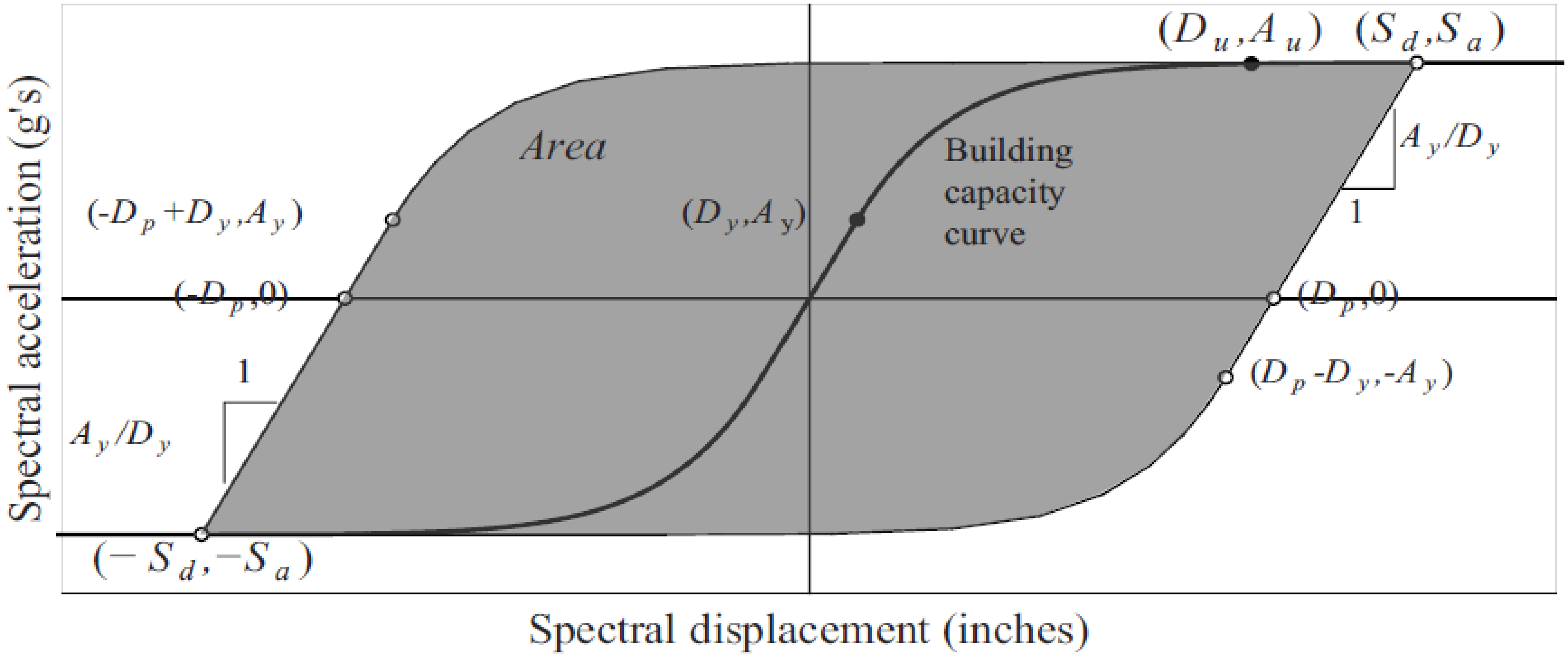
Capacity modelling methods :

a) simulation-based methods

(Rossetto and Elnashai, 2005; Erbrik, 2008; Rota et al. 2010)

b)The mechanics based methods





$$B_{eff} = B_E + k\left(\frac{Area}{2\pi S_d S_a}\right)$$

$$Area \approx 4S_a\left(S_d - \frac{S_a}{A_y / D_y}\right)$$

$$B_{eff} = B_E + k\frac{2}{\pi}\left(1 - \frac{K_s}{K_E}\right)$$

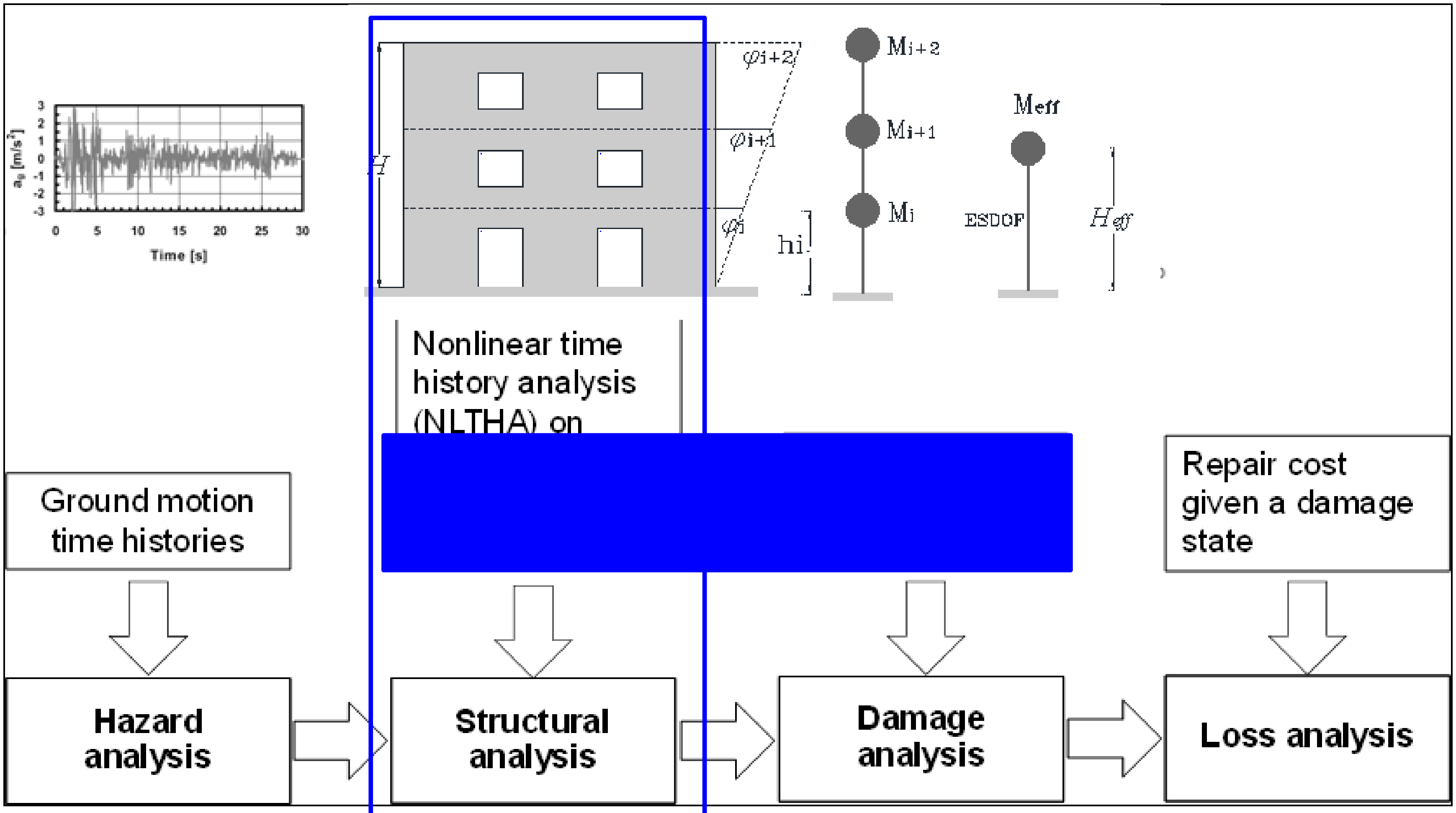
- B_E – is the elastic damping of the model building type
- k – is degradation factor which depends on shaking duration
- $Area$ – is area enclosed by the hysteresis loop

$K_s = S_a / S_d$ – secant stiffness

$K_E = A_y / D_y$ – elastic stiffness

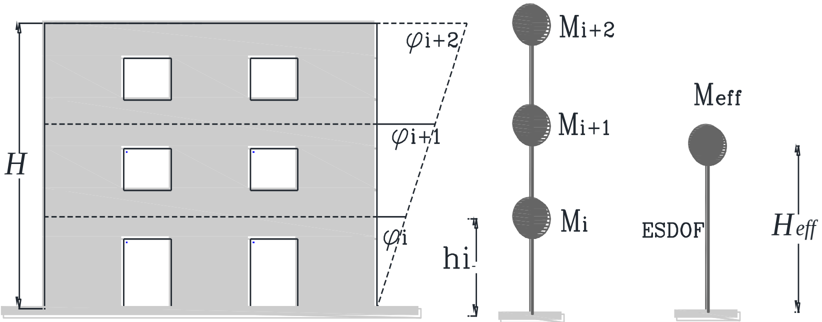
The mechanics based capacity modeling methods

- **(NLTHA) the nonlinear time history dynamic analysis** method applied either on a **MDOF** (Erbrick and Elnashai, 2004; Rota et al, 2010) or on an **ESDOF**(equivalent single degree of freedom) (Akkar et al, 2005; Jeong and Elnashai 2007)



llustration of required input parameters for nonlinear dynamic structural analysis method.

Illustration of the conversion of MDOFs to ESDOFs



- S_d ; S_a - spectral displacement and spectral acceleration of the ESDOF system;
- Δ - top displacement ;
- m^*- equivalent mass of the ESDOF system;
- m_{i-} is the concentrated mass of the i-th floor level;
- φi - is the first mode displacement at the i-th floor level normalized such that the first mode displacement at the top story φ =1.0;
- Γ- is modal participation factor that control the transformation from the MDOF to the ESDOF
- Ki - effective height coefficient
- Ki and φI control the transformation efficiency.

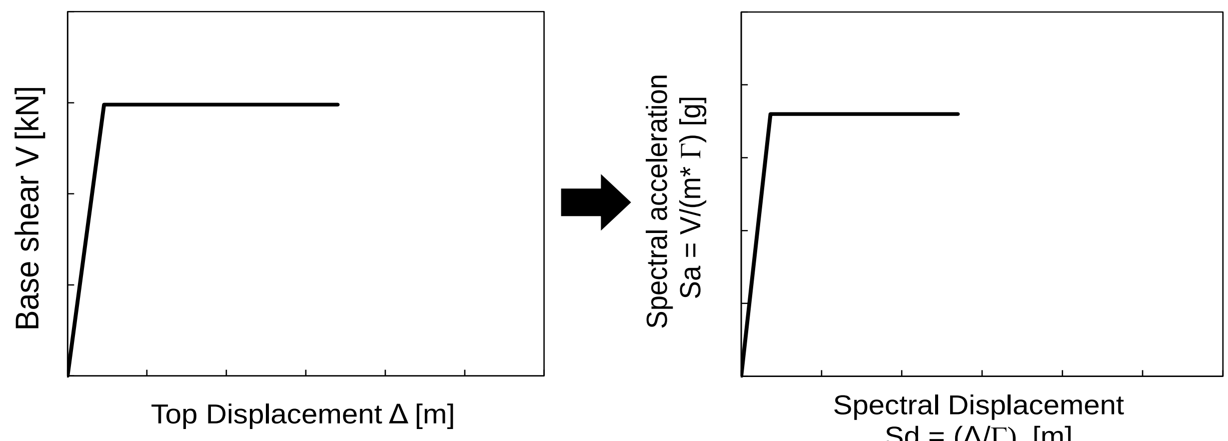
$$m^* = \sum m_i . \varphi_i$$

$$\Gamma = \frac{m^*}{\sum m_i . \varphi^2_i}$$

$$S_d = \frac{\Delta}{\Gamma}$$

$$S_a = \frac{V}{m^* . \Gamma}$$

$$H_{eff} = k_1 H$$



Conversion of the capacity curve to the spectral acceleration-displacement domain.

- **(NLSA) nonlinear static analysis method** (Kircher et al, 1997; Rossetto and Elnashai, 2005; Borzi et al. 2008).

  NLSA : *CSM – capacity spectrum method*

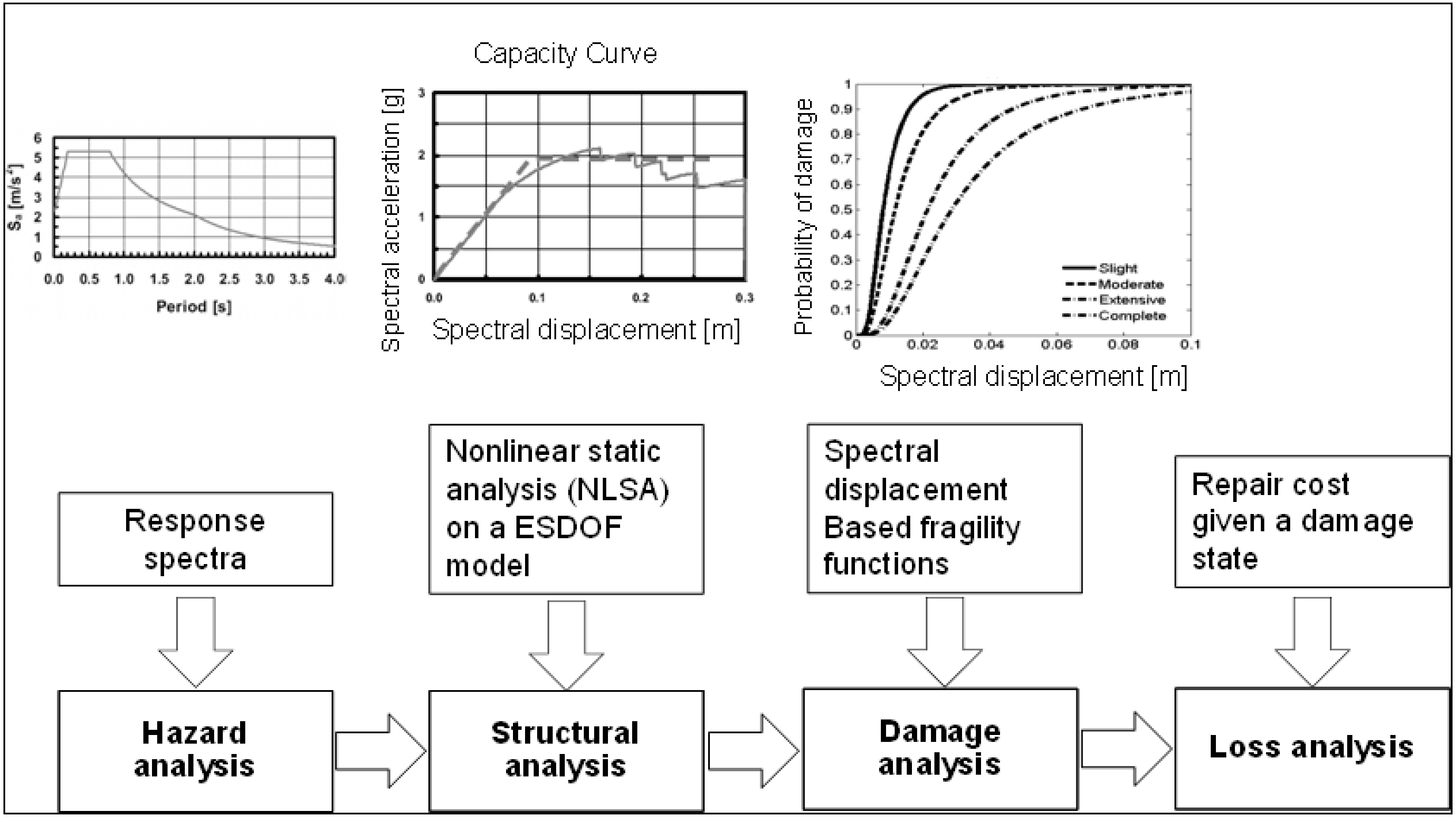
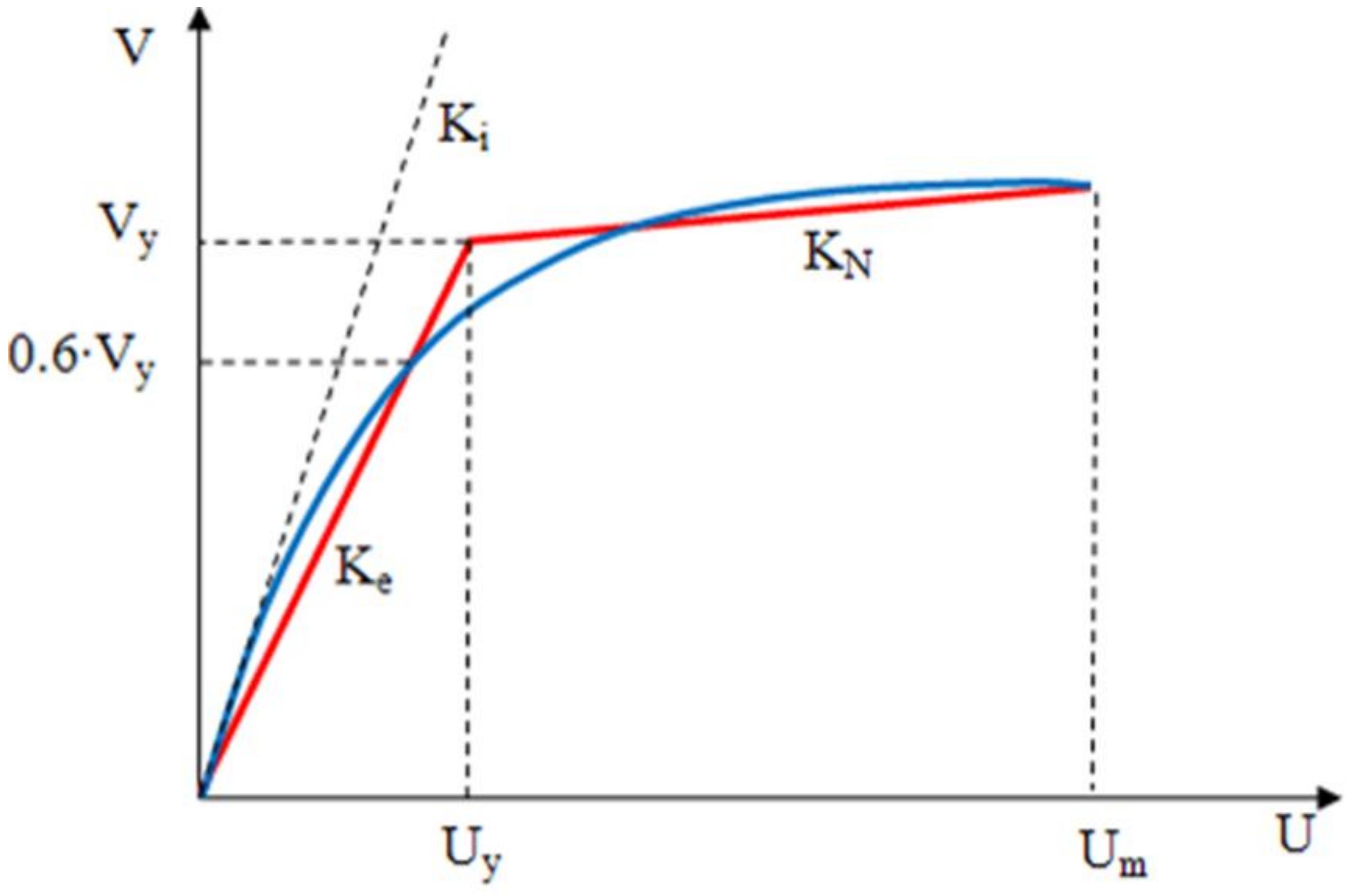
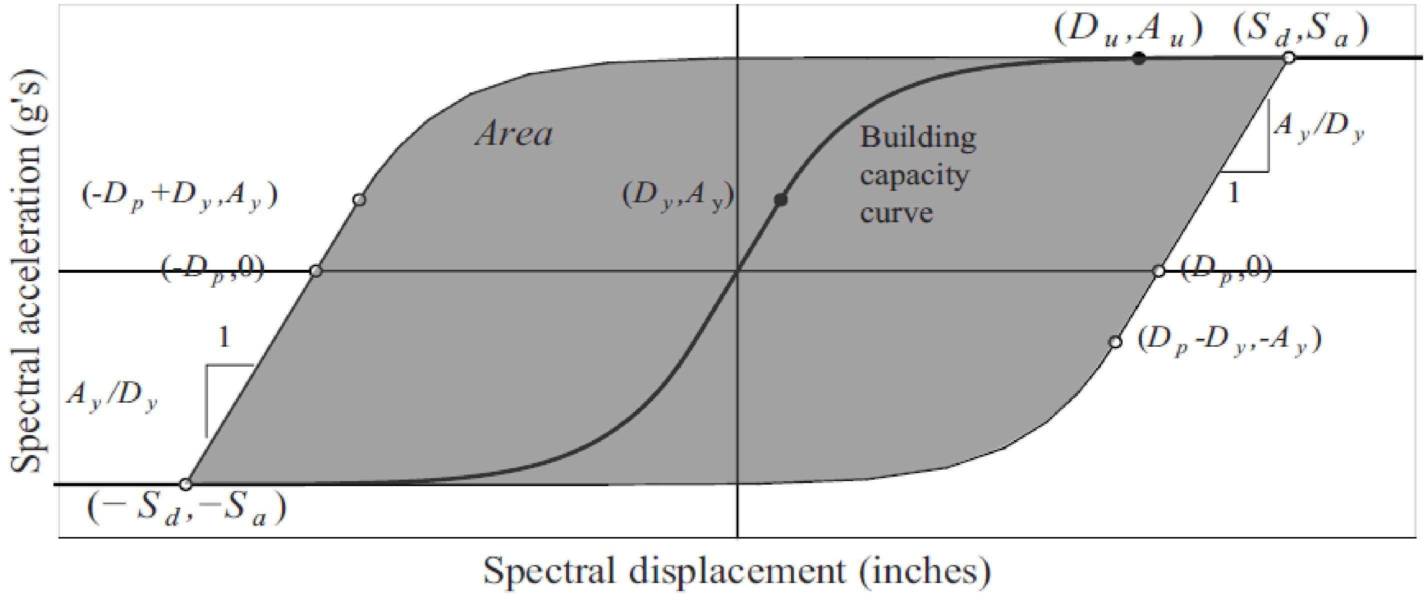


Illustration of the required input parameters for nonlinear static structural analysis method.

CSM- Capacity Spectrum method – Pushover, Capacity Curve





$$
\begin{aligned}
S_a &= S_d A_y / D_y && S_d < D_y \\
&= A_0 + b\sqrt{1 - \frac{(S_d - D_u)^2}{a^2}} && D_y \leqslant S_d < D_u \\
&= A_u && D_u \leqslant S_d
\end{aligned}
$$

where

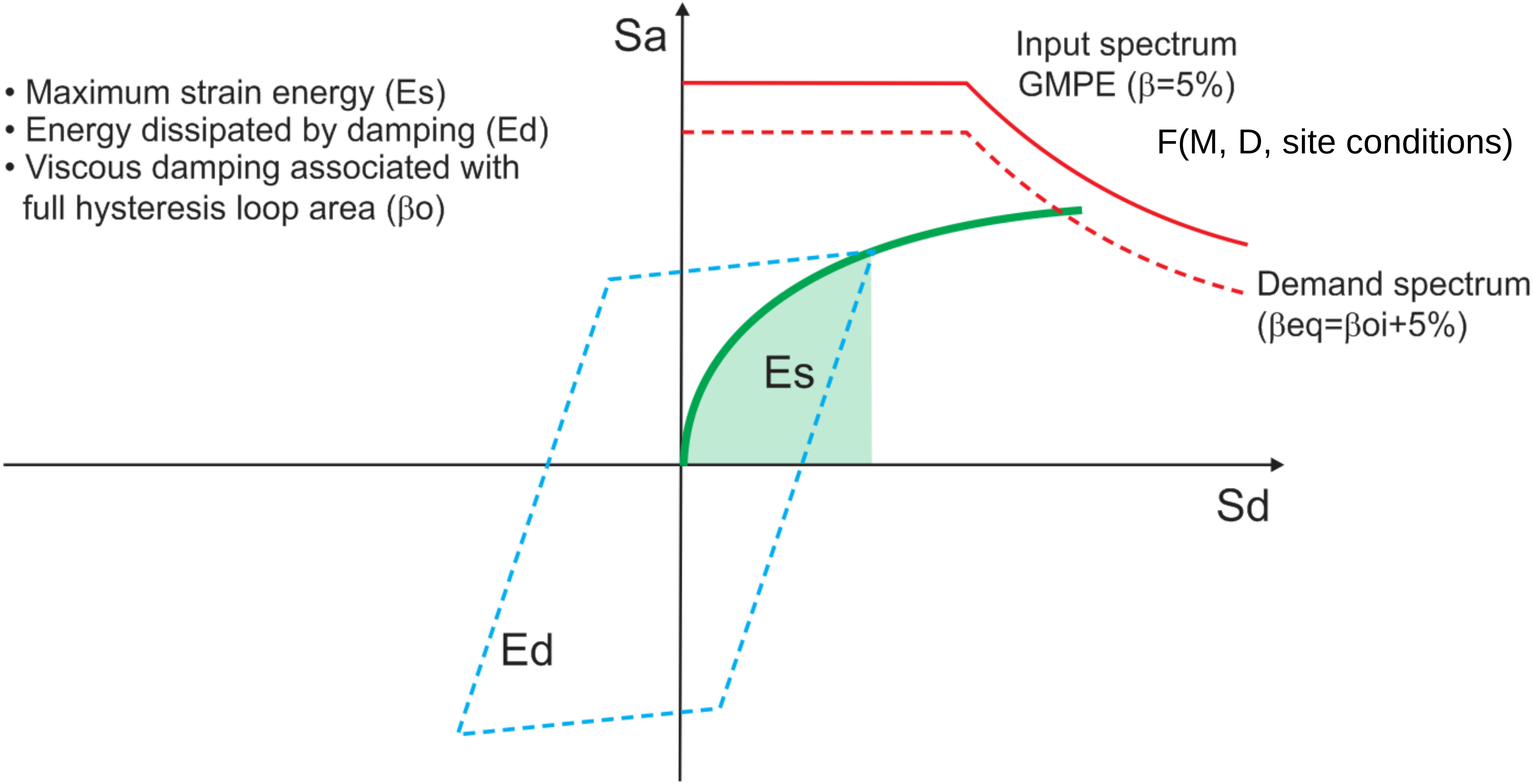
$$
b = \frac{D_y(A_y - A_u)^2 - (D_y - D_u)A_y(A_y - A_u)}{(D_y - D_u)A_y - 2D_y(A_y - A_u)} \qquad A_0 = A_u - b
$$

$$
a = \sqrt{\frac{-D_y(D_y - D_u)b^2}{A_y(A_y - A_u + b)}}
$$

Vulnerability - Capacity spectrum method F

Iterative process repeated until the energy dissipation criterion is respected

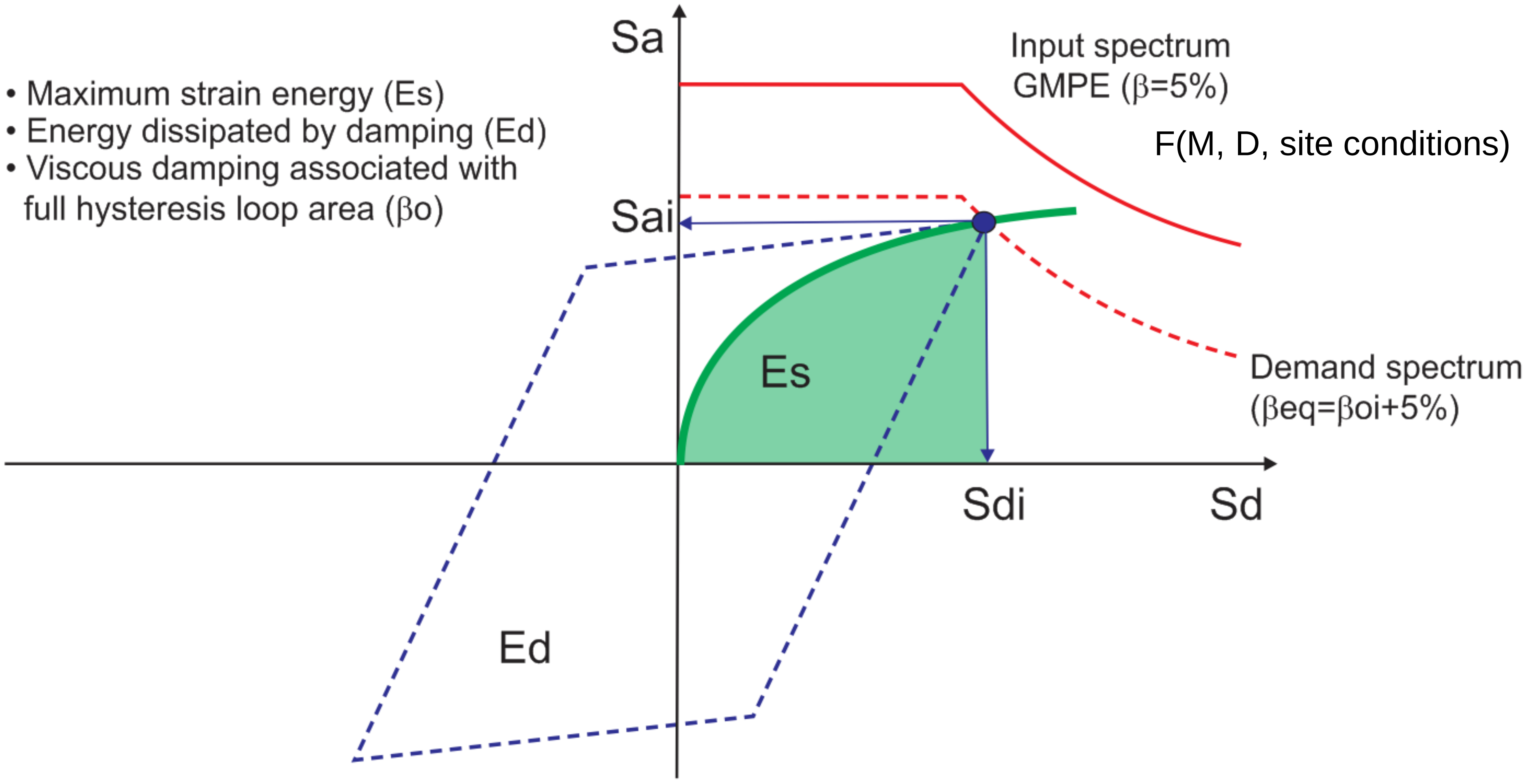
- Maximum strain energy (Es)
- Energy dissipated by damping (Ed)
- Viscous damping associated with full hysteresis loop area (βo)



Vulnerability - Capacity spectrum method F

Iterative process repeated until the energy dissipation criterion is respected

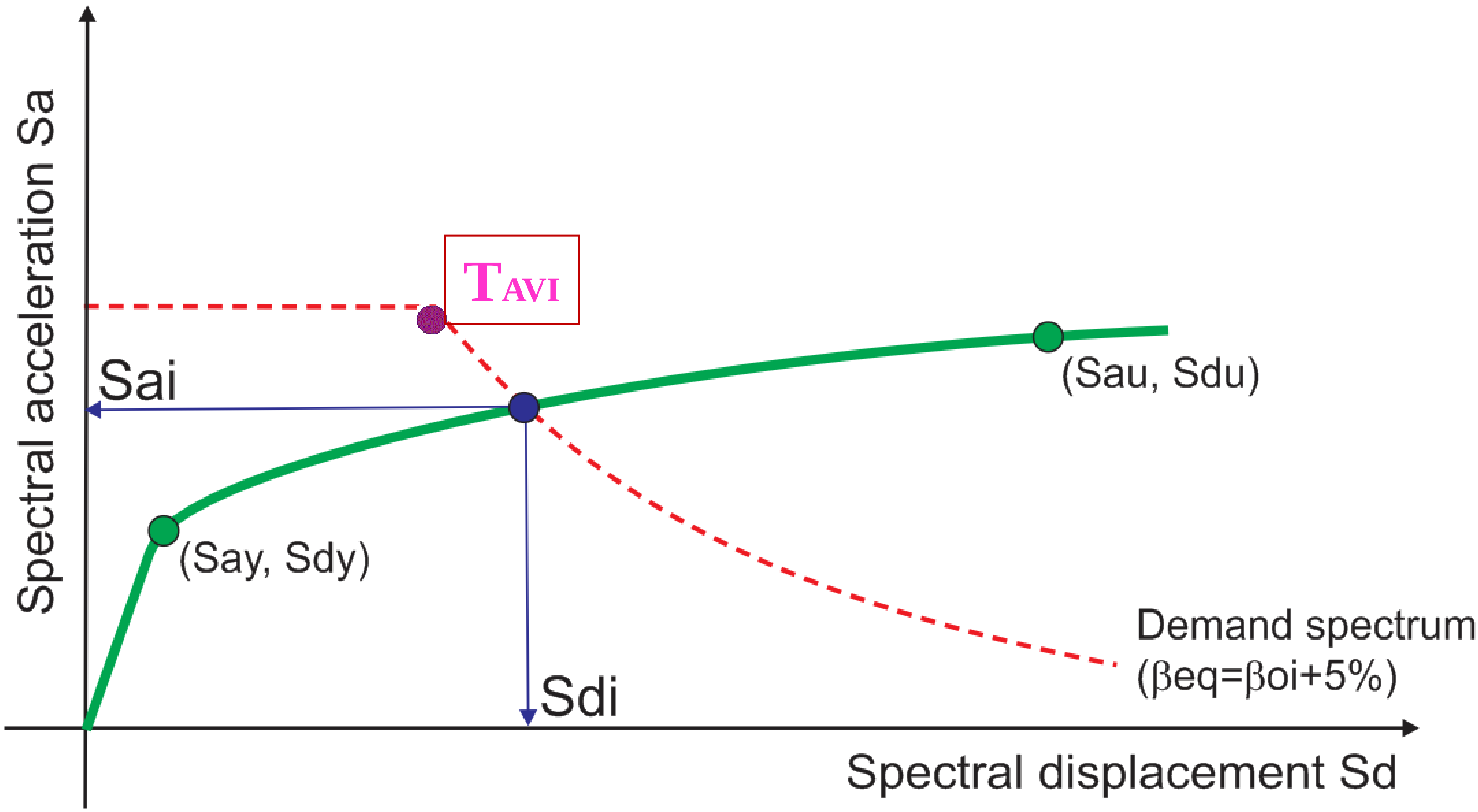
- Maximum strain energy (Es)
- Energy dissipated by damping (Ed)
- Viscous damping associated with full hysteresis loop area (βo)



Performance point gives the structural response to the given earthquake

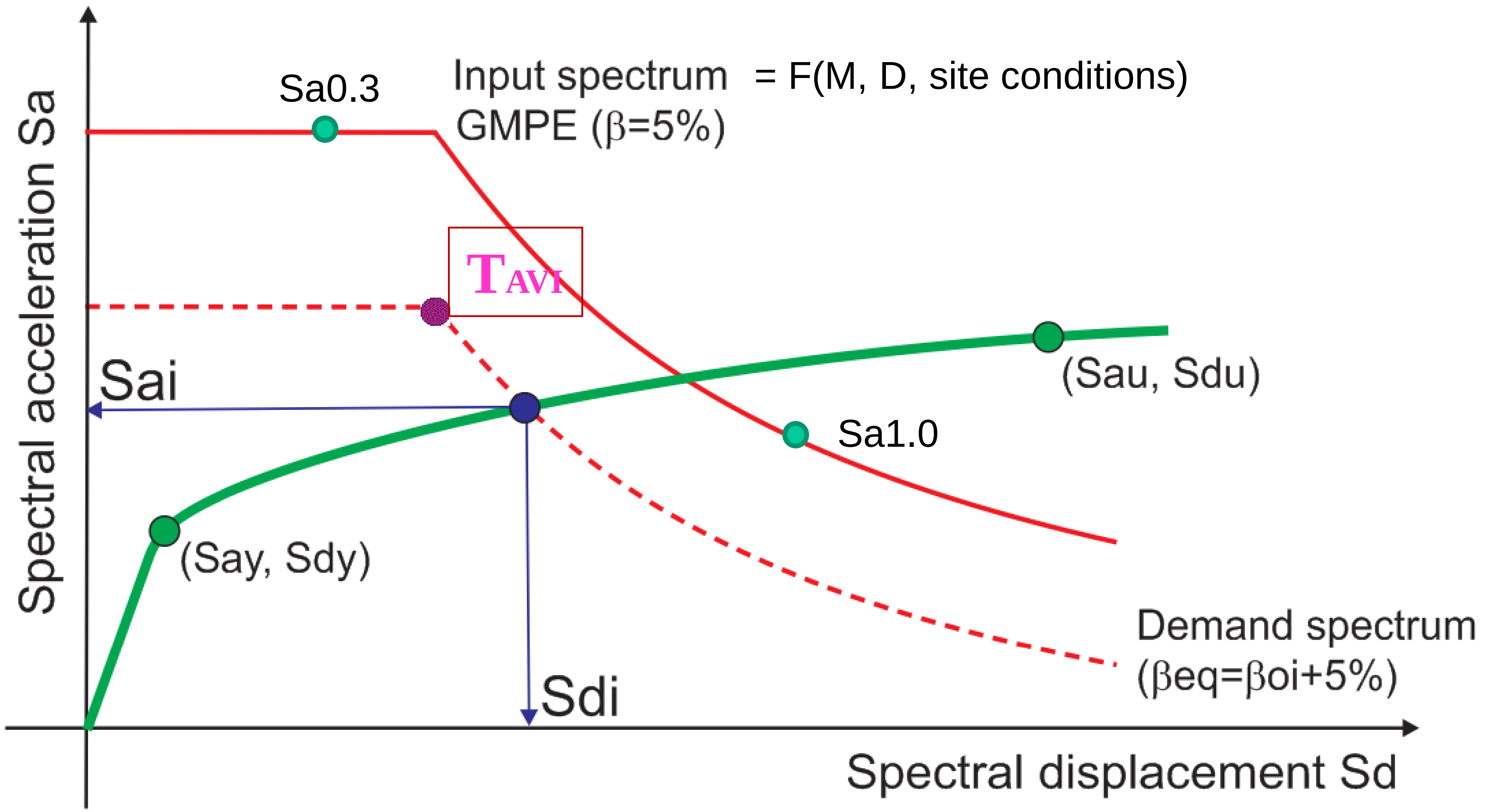
Vulnerability - Capacity spectrum method B

Improved method: from displacement demand to damage assessment



Vulnerability - Capacity spectrum method B

Improved method: from displacement demand to damage assessment



Case 1: $T \leq T_{AVD}$ $T = 0.32\sqrt{S_d / S_a}$

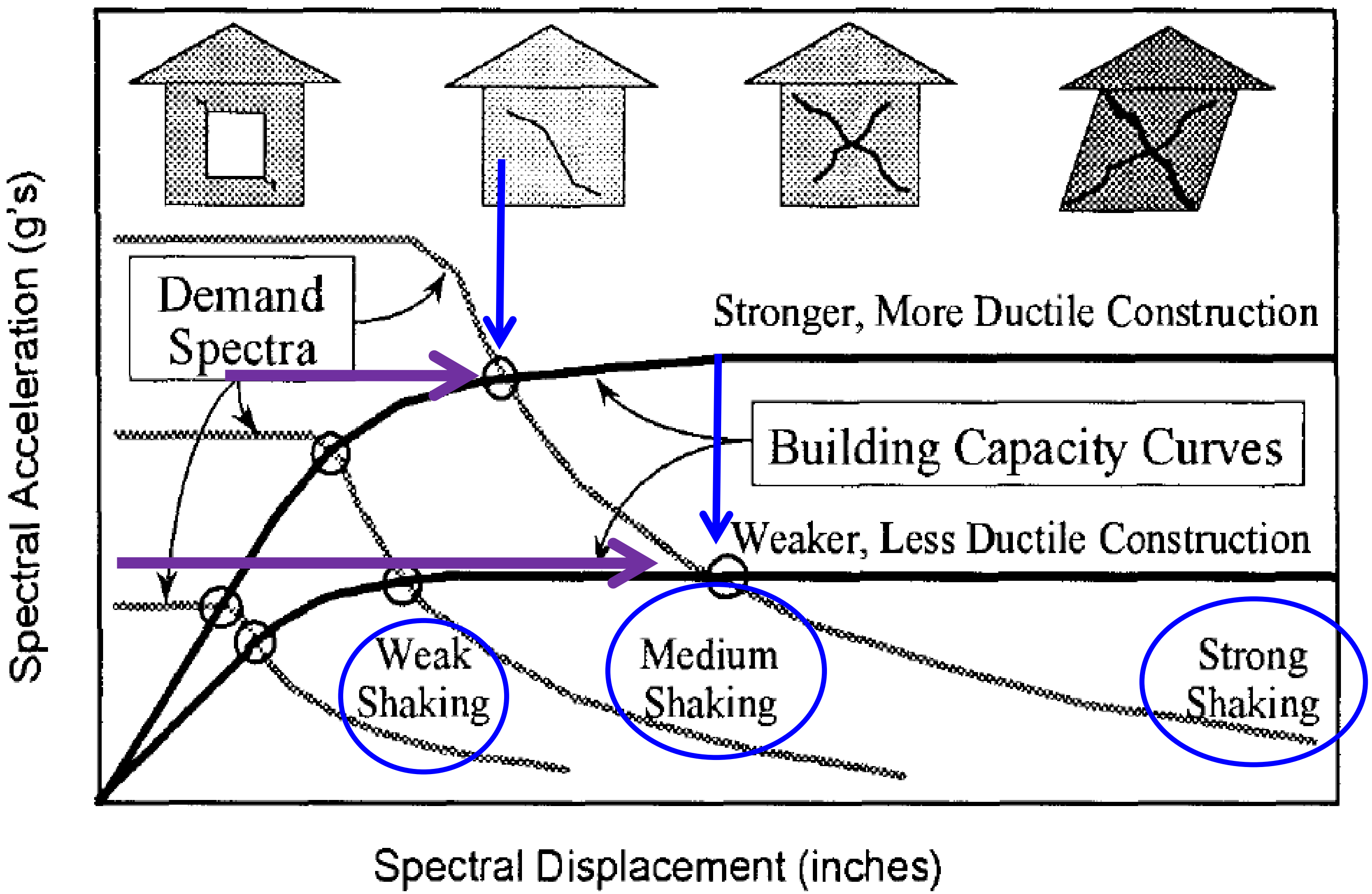
Case 2: $T_{AVD} < T$

$$T_{AVD} = 0.32\sqrt{\frac{S_1^2 F_v^2 R_A / (0.102 R_v^2 S_S F_a)}{S_S F_a / R_A}} = 0.32\sqrt{\frac{S_1^2 F_v^2 R_A}{0.102 R_V^2 S_S^2 F_a^2}} = \frac{S_1 F_v R_A}{R_V S_S F_a}$$

Table 3. Sample T_{AVD} on (a) site class B, western US; (b) site class D, western US, (c) site class B central and eastern US, and (d) site class D, central and eastern US, for 10% damping. Other values apply for different effective damping.

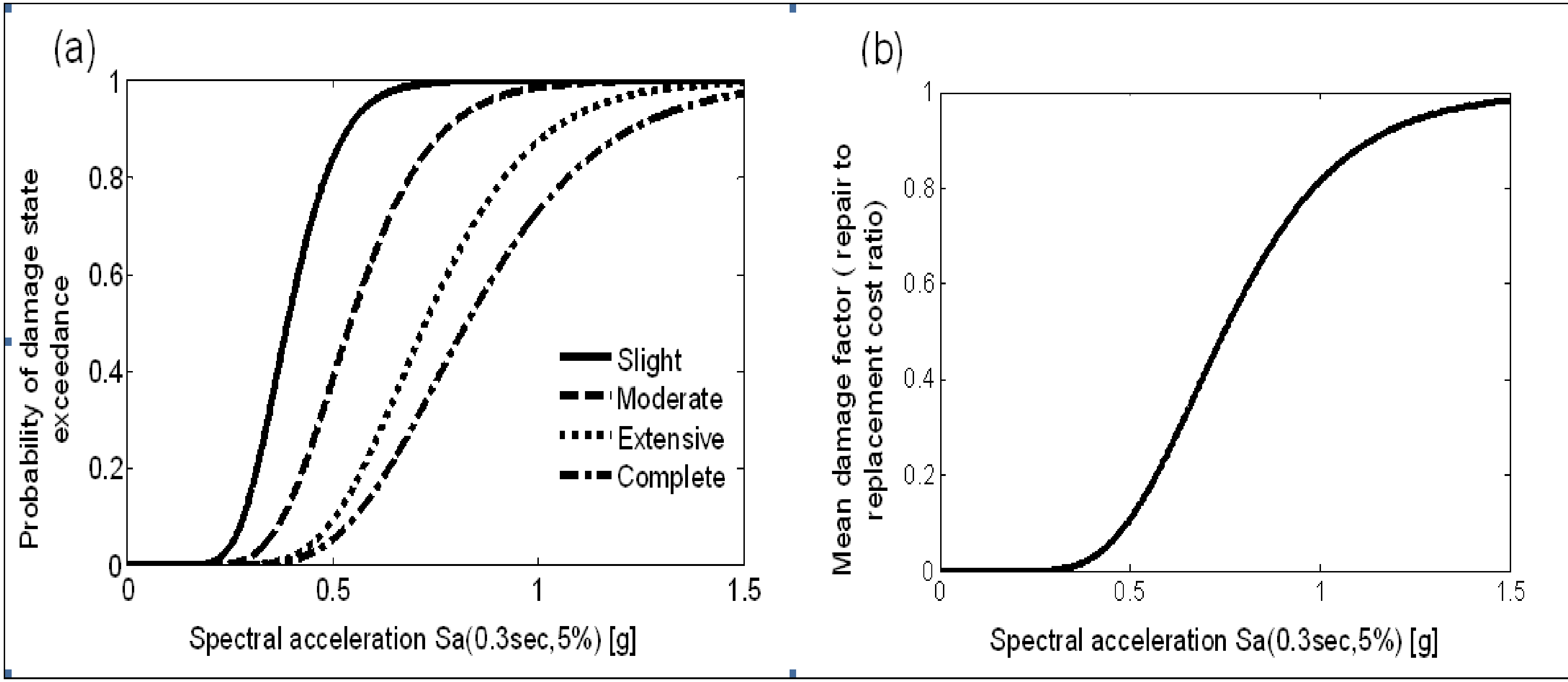
(a)	Magnitude				(b)	Magnitude			
Dist (km)	5	6	7	8	Dist (km)	5	6	7	8
10	0.20	0.23	0.34	0.65	10	0.46	0.54	0.72	1.5
20	0.20	0.23	0.34	0.65	20	0.45	0.54	0.71	1.2
40	0.21	0.24	0.35	0.68	40	0.48	0.55	0.76	1.1
80	0.22	0.25	0.37	0.72	80	0.50	0.58	0.86	1.3
(c)	Magnitude				(d)	Magnitude			
Dist (km)	5	6	7	8	Dist (km)	5	6	7	8
10	0.14	0.27	0.38	0.40	10	0.22	0.44	0.59	0.59
20	0.15	0.28	0.39	0.41	20	0.22	0.43	0.59	0.62
40	0.16	0.30	0.41	0.43	40	0.24	0.44	0.61	0.64
80	0.17	0.32	0.45	0.47	80	0.26	0.49	0.68	0.68

Vulnerability - Capacity spectrum method



Example intersection of demand spectra and building capacity curves

Damageability functions (fragility and vulnrability)



Damageability functions: (a) sample fragility functions and (b) vulnerability function.

Intensity masure:

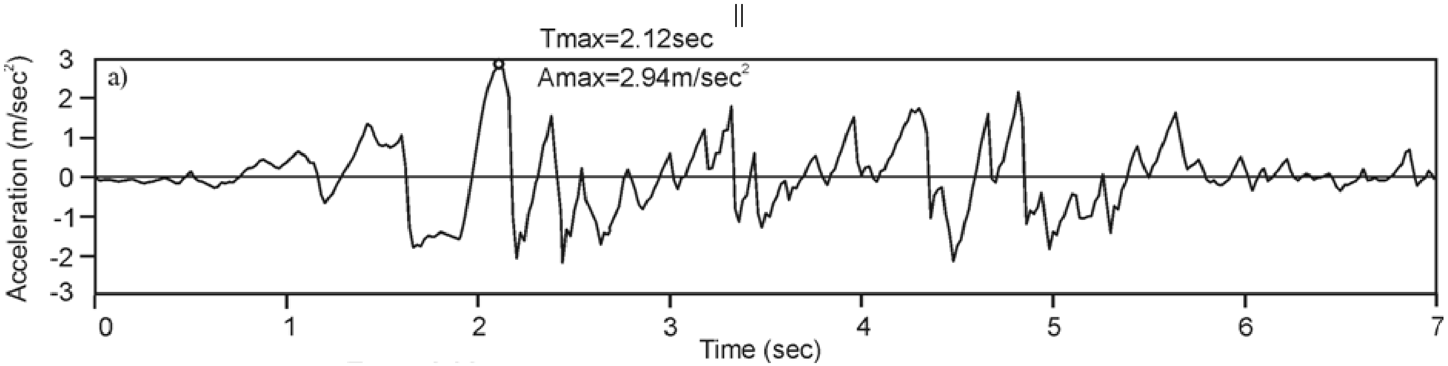
a) Global seismic parametars (PGA ,PGV,PGD)

b) Local seismic parameters (Sa Sd)

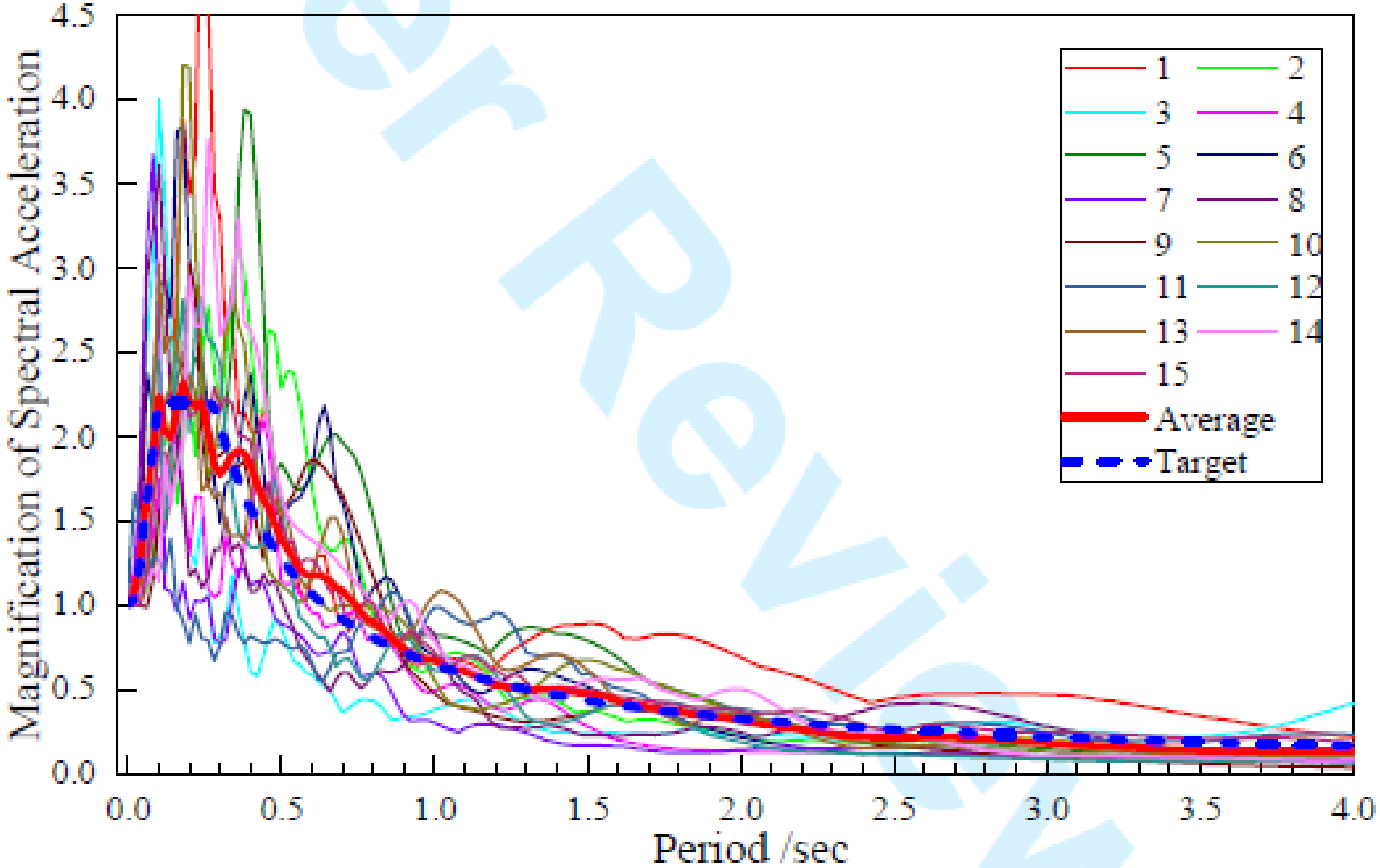
a) Arias intensity

$$I(t) = \sum_{i=1}^{NP} \int_{o}^{t} \left| f_i(t) \right| dt$$

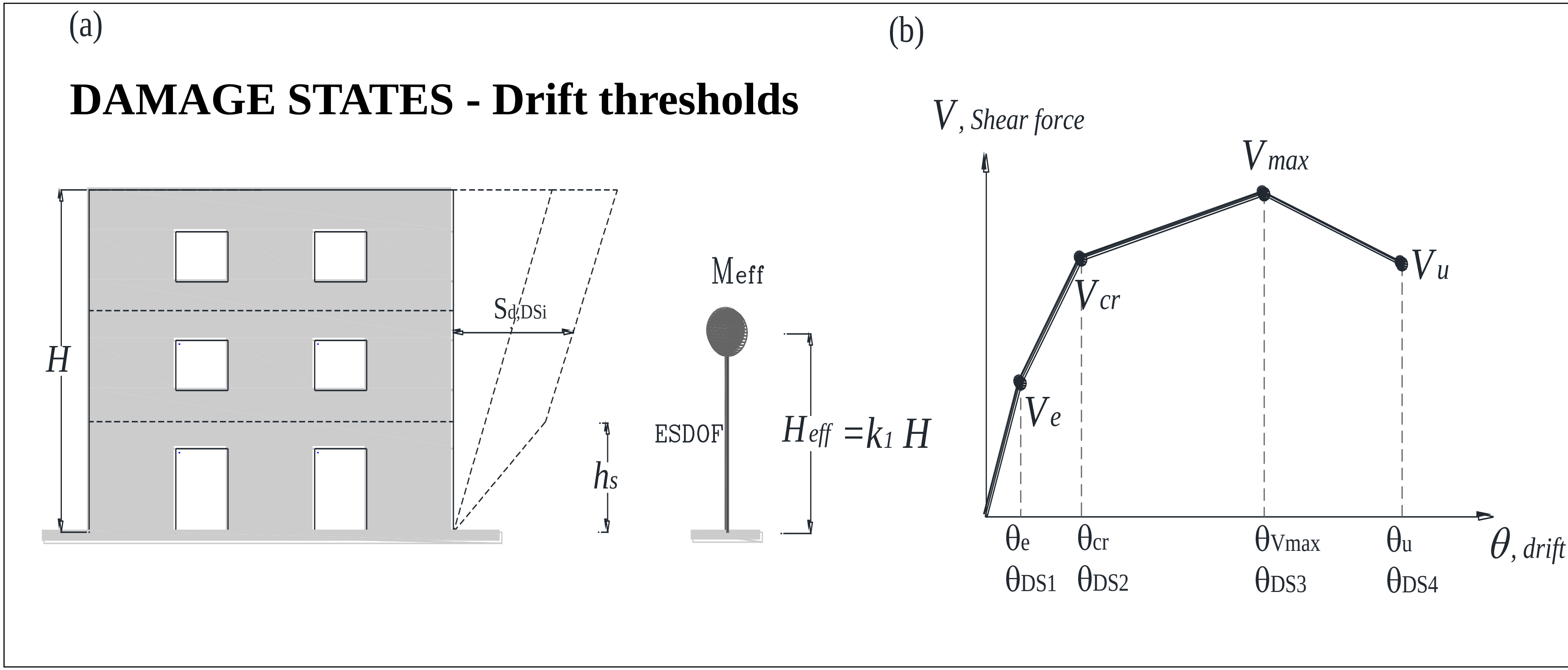
NP = 7000 dt=0.001s



e) or Hausner intensity



The earthquake acceleration response spectrum curves.



Simplified model for computation of damage states: (a) MDOF deformed shape and conversion to ESDOF, and (b) identification of drift thresholds for masonry walls

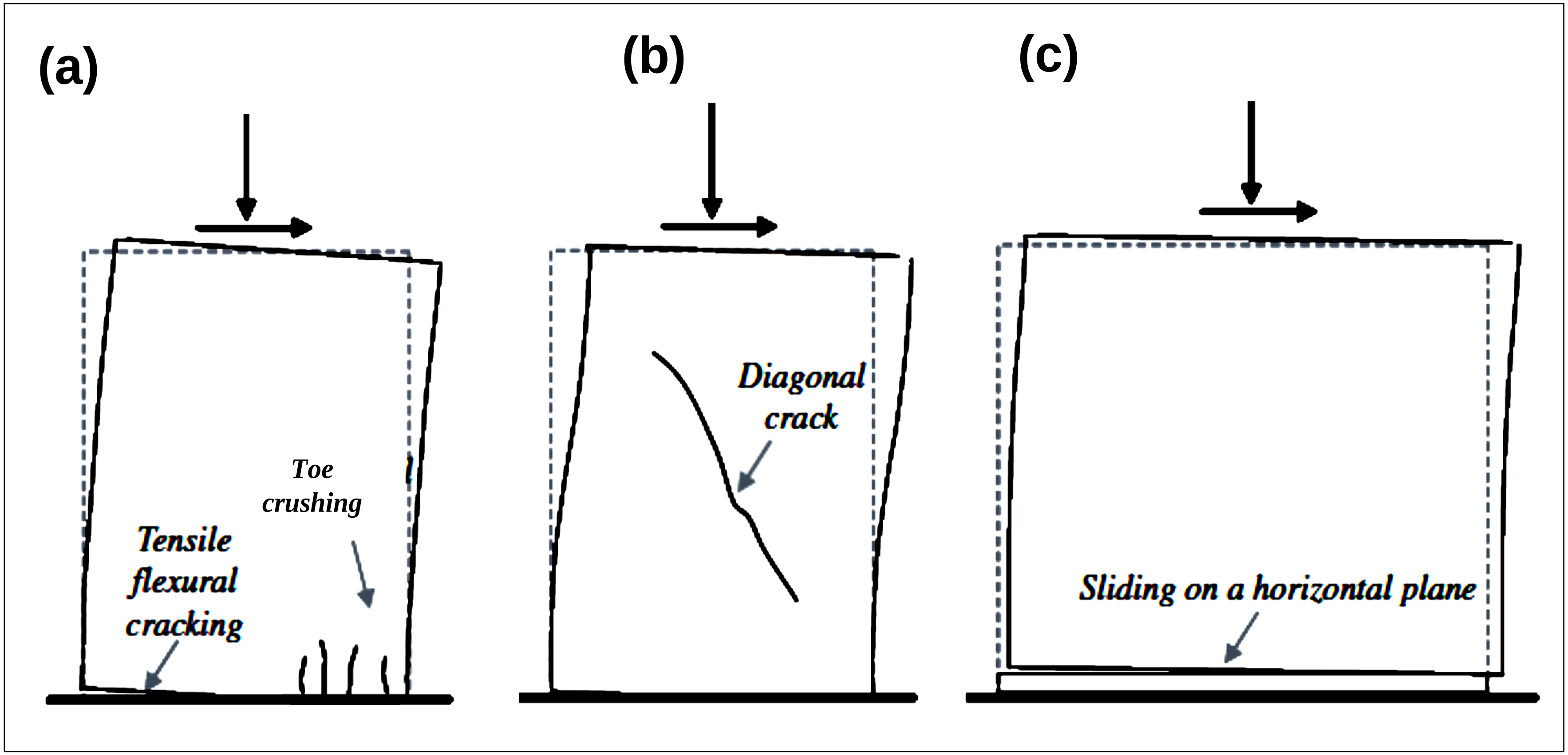
(θ_{DS1}) - flexural cracking;

(θ_{DS2}) - shear cracking maximum;

(θ_{DS3})- shear strength,

(θ_{DS4}) - -ultimate deformation at 20% loss of strength.

Taken from (Calderini et al., 2009)

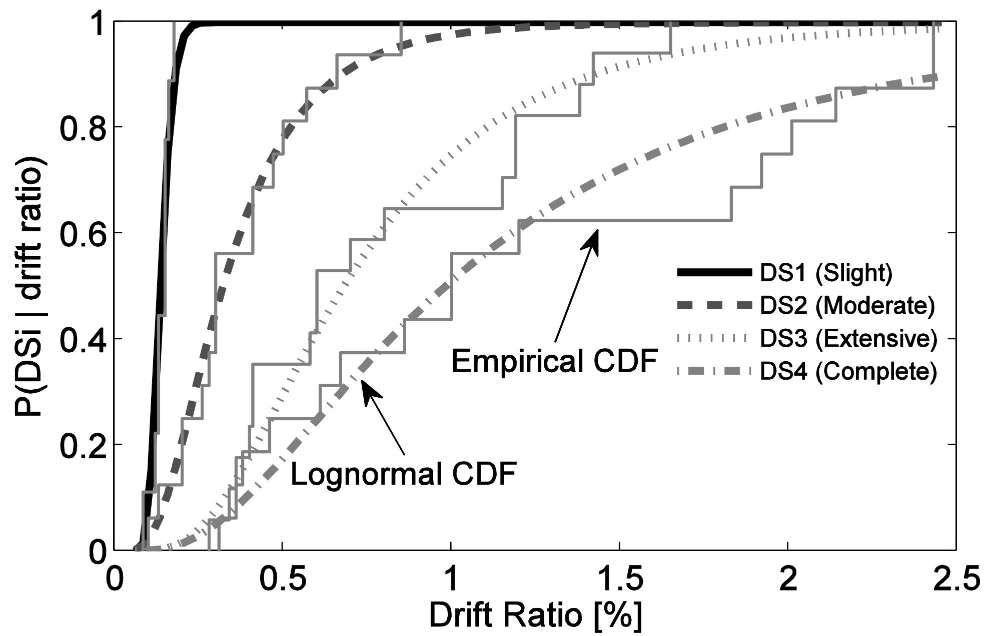


In-plane failure mechanisms

(a) flexural failure, (b) diagonal shear failure (c) sliding shear failure

Drift thresholds for stone masonry walls tested under cyclic loading

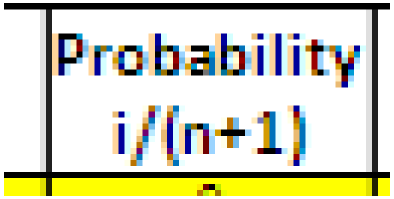
Sample number	θ_{DS1} [%]	θ_{DS2} [%]	θ_{DS3} [%]	θ_{DS4} [%]
1	0.06	0.10	0.28	0.45
2	0.07	0.13	0.34	0.46
3	0.07	0.20	0.36	0.48
4	0.08	0.20	0.40	0.51
5	0.08	0.26	0.41	0.61
6	0.08	0.28	0.41	0.67
7	0.09	0.30	0.58	0.86
8	0.09	0.30	0.60	1.00
9	0.09	0.30	0.70	1.00
10	0.10	0.41	0.80	1.20
11	0.10	0.41	1.15	1.83
12	0.10	0.47	1.19	1.92
13	0.11	0.50	1.19	2.01
14	0.12	0.57	1.38	2.14
15	0.12	0.66	1.42	2.33
16	0.13	0.85	1.65	2.33

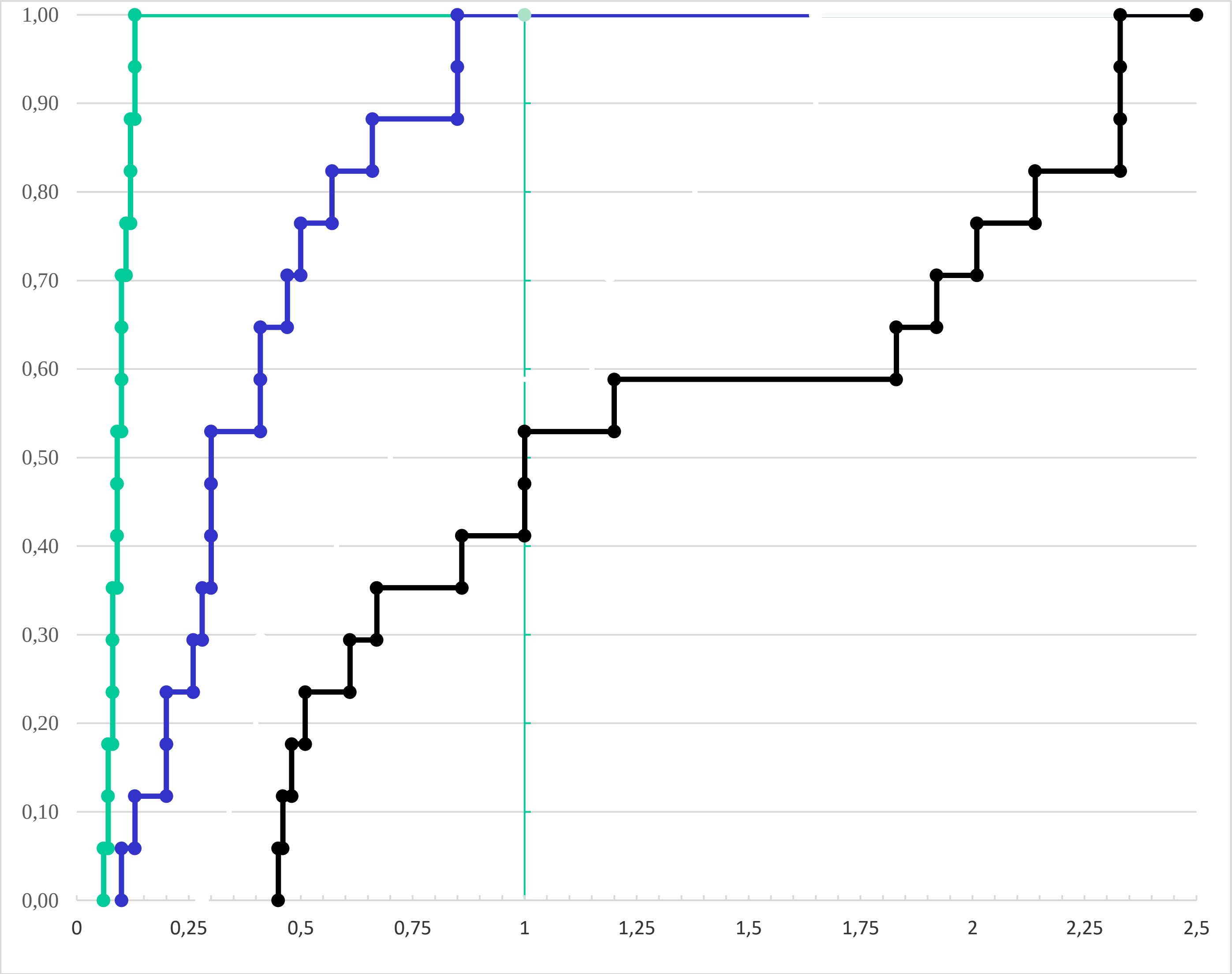


empirical and lognormal CDF- cumulative distribution function

Damage states drift thresholds values were derived from representative literature experimental data (**Tomaževič and Lutman, 2007; Tomaževic and Weiss, 2010; Vasconcelos, 2005; Elmenshawi et al., 2010; Magenes et al., 2010, Rota et al. 2010**).

CENTRAL LIMIT THEOREM





CENTRAL LIMIT THEOREM

	Probability i/(n+1)	Vrednosti od literatura naredeni po golemina .			
	0	0.06	0.1	0.28	0.45
1	0.0588235	0.06	0.1	0.28	0.45
	0.0588235	0.07	0.13	0.34	0.46
2	0.1176471	0.07	0.13	0.34	0.46
	0.1176471	0.07	0.2	0.36	0.48
3	0.1764706	0.07	0.2	0.36	0.48
	0.1764706	0.08	0.2	0.4	0.51
4	0.2352941	0.08	0.2	0.4	0.51
	0.2352941	0.08	0.26	0.41	0.61
5	0.2941176	0.08	0.26	0.41	0.61
	0.2941176	0.08	0.28	0.41	0.67
6	0.3529412	0.08	0.28	0.41	0.67
	0.3529412	0.09	0.3	0.58	0.86
7	0.4117647	0.09	0.3	0.58	0.86
	0.4117647	0.09	0.3	0.6	1
8	0.4705882	0.09	0.3	0.6	1
	0.4705882	0.09	0.3	0.7	1
9	0.5294118	0.09	0.3	0.7	1
	0.5294118	0.1	0.41	0.8	1.2
10	0.5882353	0.1	0.41	0.8	1.2
	0.5882353	0.1	0.41	1.15	1.83
11	0.6470588	0.1	0.41	1.15	1.83
	0.6470588	0.1	0.47	1.19	1.92
12	0.7058824	0.1	0.47	1.19	1.92
	0.7058824	0.11	0.5	1.19	2.01
13	0.7647059	0.11	0.5	1.19	2.01
	0.7647059	0.12	0.57	1.38	2.14
14	0.8235294	0.12	0.57	1.38	2.14
	0.8235294	0.12	0.66	1.42	2.33
15	0.8823529	0.12	0.66	1.42	2.33
	0.8823529	0.13	0.85	1.65	2.33
16	0.9411765	0.13	0.85	1.65	2.33
	1	0.13	0.85	1.65	2.33
	1	2.5	2.5	2.5	2.5

$$i = 0 \rightarrow \frac{i}{n+1} = 0;\ f(i) = 0.45$$

$$i = 1 \rightarrow \frac{1}{16+1} = 0.0588;\ f(i) = 0.45$$

$$i = 1 \rightarrow \frac{1}{16+1} = 0.0588;\ f(i) = 0.46$$

$$i = 2 \rightarrow \frac{2}{16+1} = 0.1176;\ f(i) = 0.46$$

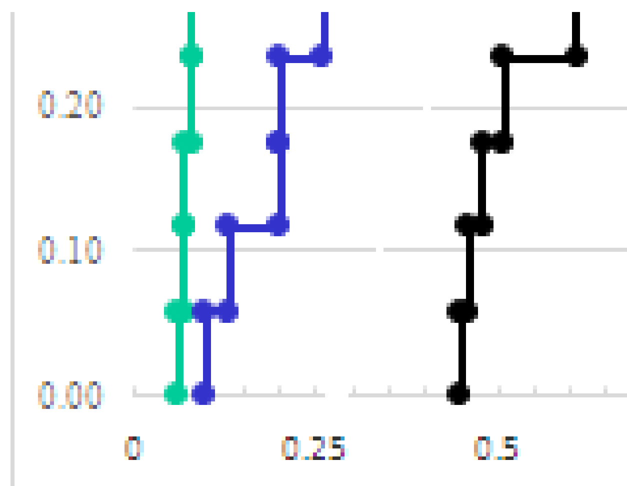
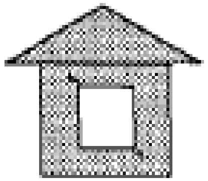
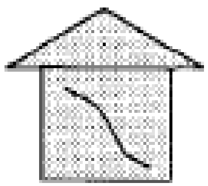
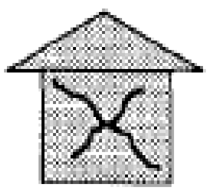
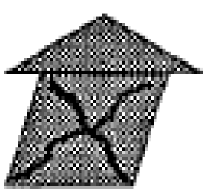
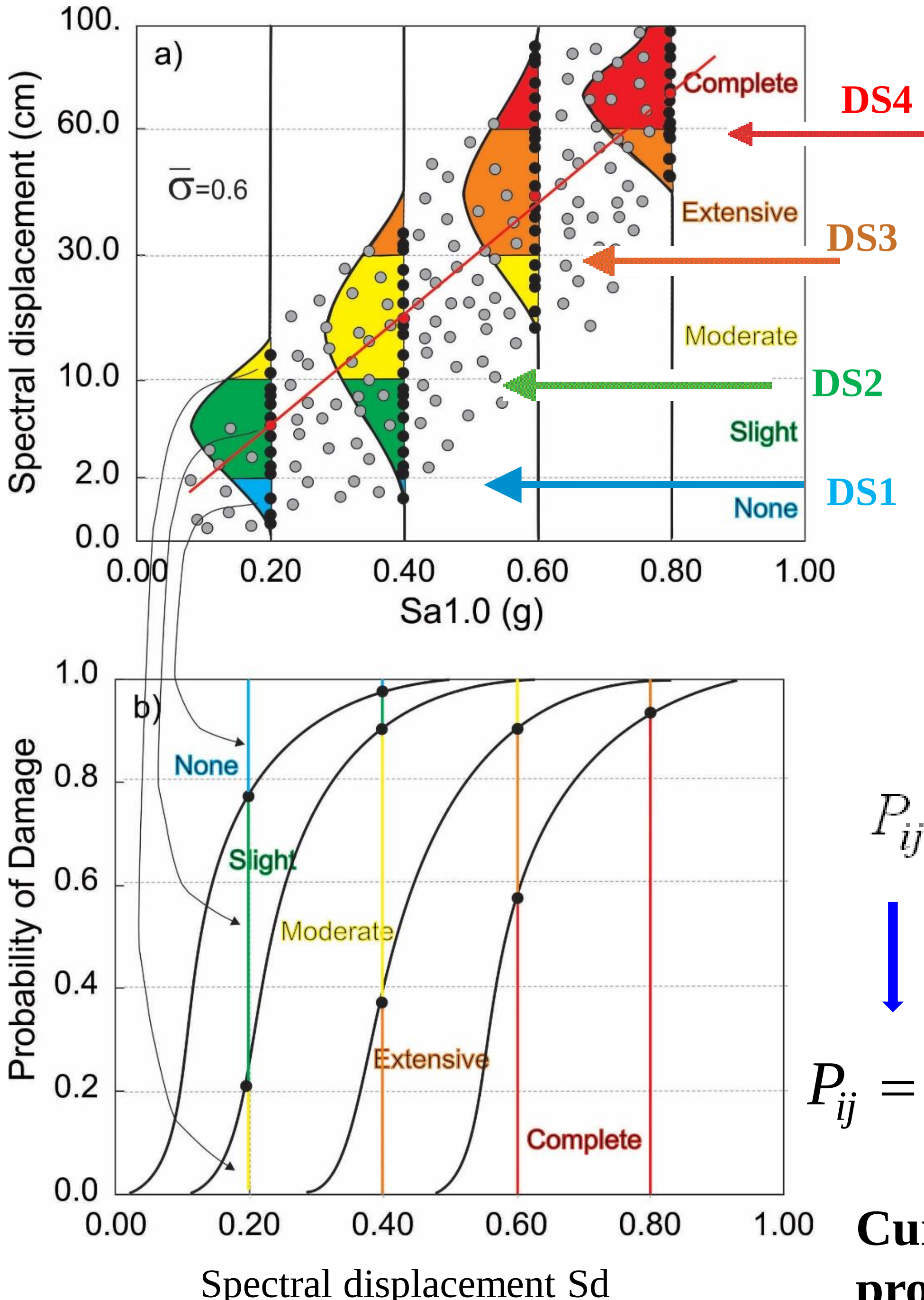
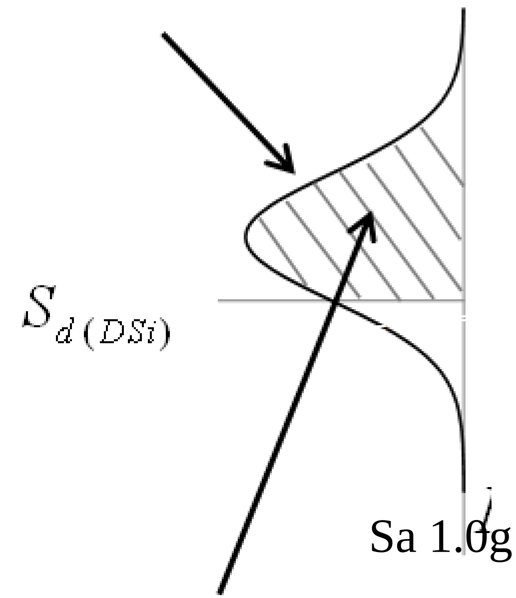


Table 2. Example damage states - light-frame wood buildings (W1)

Damage State		Description
	**Slight**	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as "large" cracks).
	**Moderate**	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	**Extensive**	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	**Complete**	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Five percent of the total area of buildings with Complete damage is expected to be collapsed.



Lognormal distribution of probability of damage



$$P_{ij} = \Pr ob(S_d > S_{d(DSi)} \mid S_{a1.0g})$$

$$P_{ij} = 1 - \Phi\left[\frac{\ln(S_{d(DSi)}) - \lambda_{Sd(Sa,1.0g)}}{\beta_{Sd(Sa,1.0g)}}\right]$$

Cumulative distribution of probability of damage

The cumulative conditional probability of exceedance of a certain damage state DSi for a given the spectral displacement S_d is defined by the following equation :

$$P_{ij} = 1 - \Phi\left[\frac{\ln(S_{d(DSi)}) - \lambda_{Sd(Sa,1.0g)}}{\beta_{Sd(Sa,1.0g)}}\right]$$

$S_{d(DSi)}$ -displacement threshold equal to the median spectral displacement taken form a damage model

$\lambda_{Sd}(S_{a,1.0s}) = \ln(\bar{S}_d)$ - lognormal median

$\beta_{Sd}(S_{a,T=1.0s})$ - lognormal standard deviation

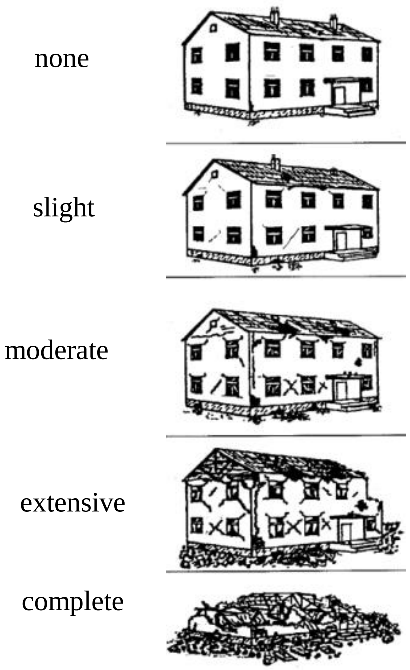
Φ - standard normal cumulative distribution function

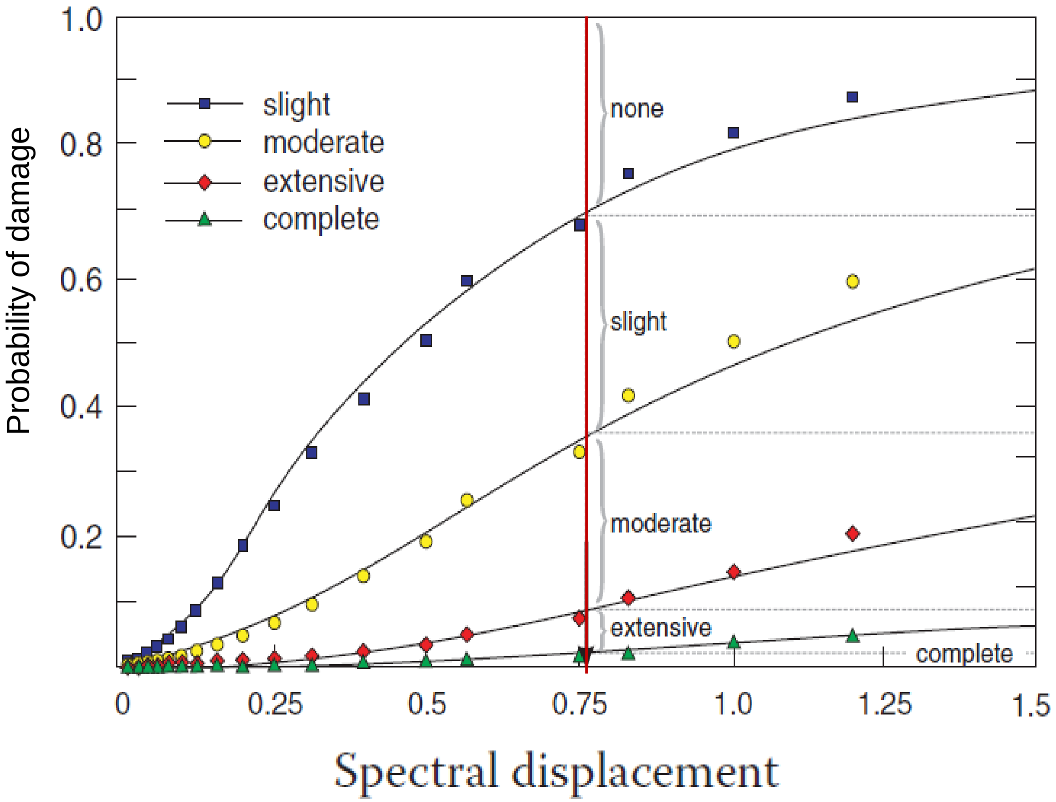
Damage analysis – fragility curves (backward)

Step 1: conduct EQ scenario to obtain intensity measures **(Sa0.3 & Sa1.0)**

Step 2: damage analysis based on fragility functions of input accelerations (Sa0.3&Sa1.0)

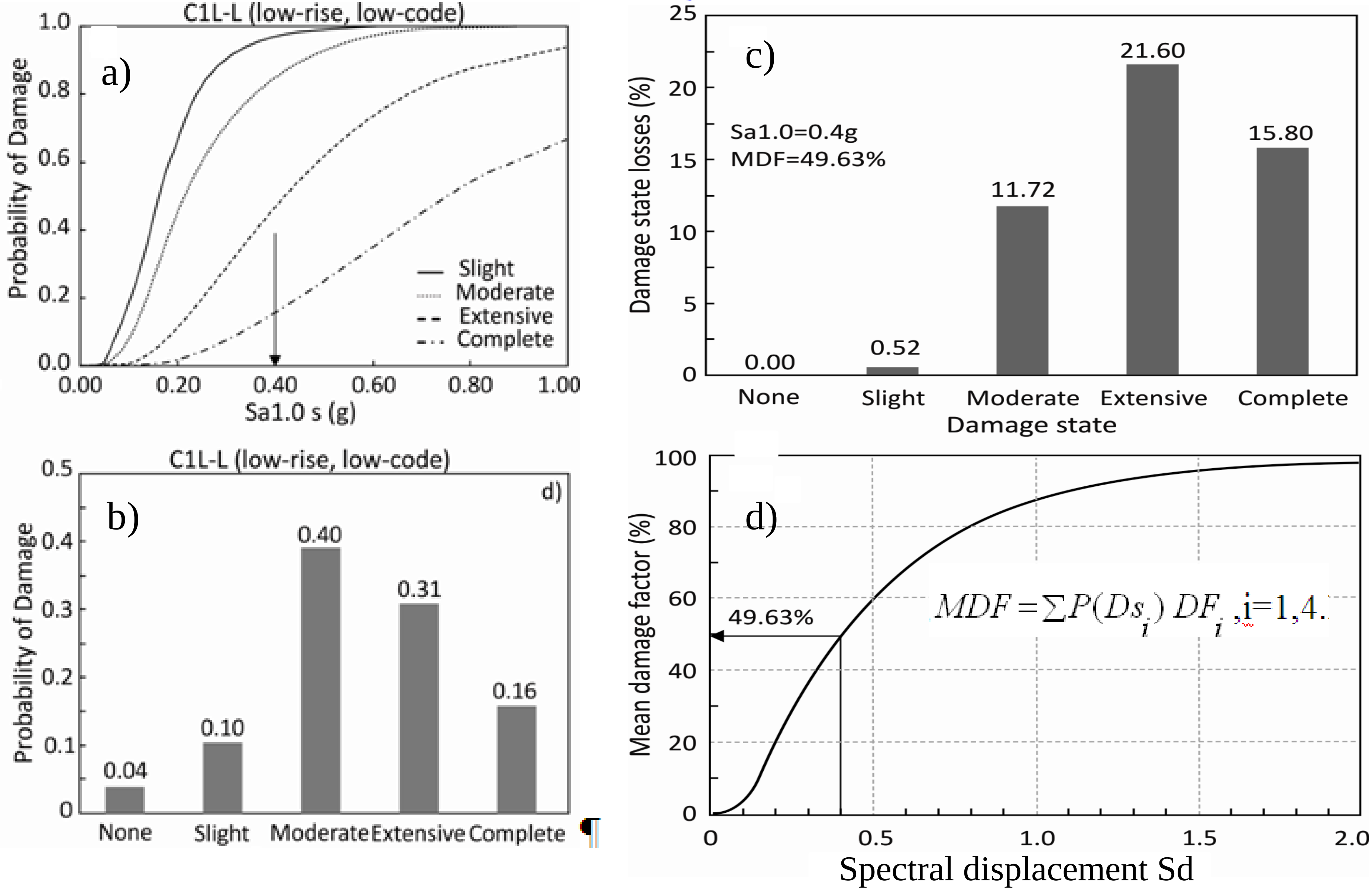
Damage criteria





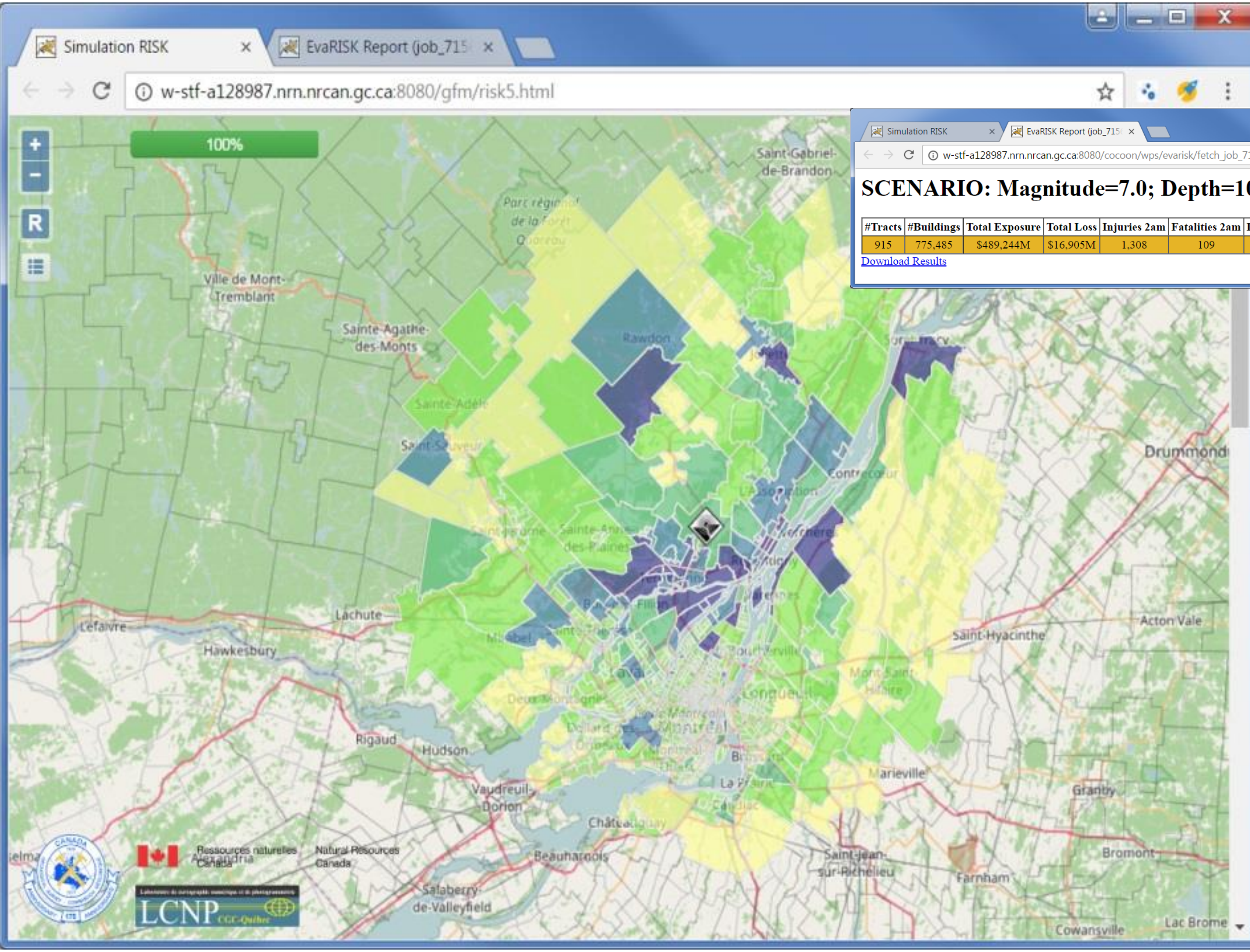
Intensity measure Sa0.3s(g)

Loss analysis



Examples: a) fragility curve IM(Sa1.0) for ductile reinforced concrete moment frame.
b) Probability of respective damage states in (%) c) Damage loss d) Mean damage factor and vulnarebility

Scenario modelling ER2



Simulation RISK | EvaRISK Report (job_715

w-stf-a128987.nrn.nrcan.gc.ca:8080/cocoon/wps/evarisk/fetch_job_715698591_evarisk.html

SCENARIO: Magnitude=7.0; Depth=10.0; Epicenter: 45.78, -73.58

#Tracts	#Buildings	Total Exposure	Total Loss	Injuries 2am	Fatalities 2am	Injuries 2pm	Fatalities 2pm	Injuries 5pm	Fatalities 5pm
915	775,485	$489,244M	$16,905M	1,308	109	3,559	602	1,764	216

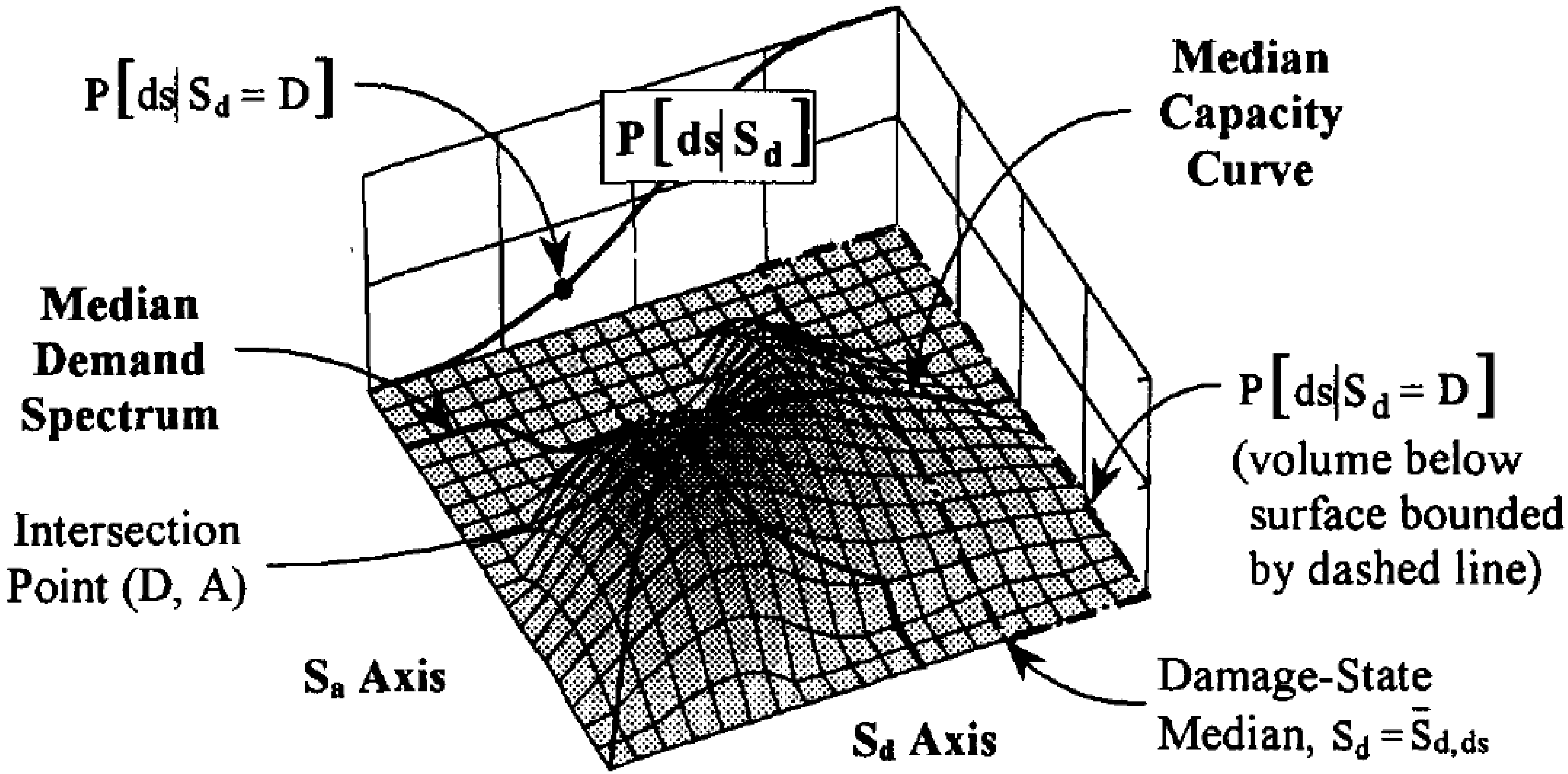
Download Results

Databases

GIS Maps: faults, geology-bedrock, geology-soils, 3D models……

X, Y, Source, Soil1, Thickness1, Depth1, Soil2, Thickness2, Depth2 …

X, Y, Source, Bldg., Age, Height, Stores, Footprint, C.Type, Occupation



. Example joint probability surface of demand and capacity intersection points.

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Thank you for your attention

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